UNIVERZITET U BEOGRADU
RUDARSKO-GEOLOŠKI FAKULTET

Mr Salahalddin Saeed Ali

GEOLOGIJA I HIDROGEOLOGIJA ŠARAZUR-PIRAMAGRUN BASENA U OBLASTI SULEJMANIJE, SEVEROISTOČNI IRAK

DOKTORSKA DISERTACIJA

Beograd, 2007.

UNIVERZITET U BEOGRADU
RUDARSKO-GEOLOŠKI FAKULTET

AUTOR

Mr Salahalddin S. Ali

GEOLOGIJA I HIDROGEOLOGIJA ŠARAZUR-PIRAMAGRUN BASENA U OBLASTI SULEJMANIJE, SEVEROISTOČNI IRAK

DOKTORSKA DISERTACIJA

Beograd
2007

Mentori:

Dr Zoran Stevanović, redovni profesor
Rudarsko-geološki fakultet
Univerzitet u Beogradu - Srbija

Dr Mikdad H. Al-Džabari, redovni profesor
Fakultet Nauka
Univerzitet u Bagdadu – Irak

Članovi komisije:

Dr Veselin Dragisic, redvoni profesor
Rudarsko-geološki fakultet
Univerzitet u Beogradu - Srbija

Dr Petar Dokmanović, profesor
Rudarsko-geološki fakultet
Univerzitet u Beogradu - Srbija

Dr Dejan Milenić, vanredni profesor
Rudarsko-geološki fakultet
Univerzitet u Beogradu - Srbija

Datum odbrane doktorske disertacije:

____

UNIVERSITY OF BELGRADE
FACULTY OF MINING AND GEOLOGY

UNIVERZITET U BEOGRADU
RUDARSKO-GEOLOŠKI FAKULTET

DOCTORAL THESIS

GEOLOGY AND HYDROGEOLOGY OF SHARAZOOR - PIRAMAGROON BASIN IN SULAIMANI AREA, NORTHEASTERN IRAQ

DOKTORSKA DISERTACIJA

GEOLOGIJA I HIDROGEOLOGIJA ŠARAZUR-PIRAMAGRUN BASENA U OBLASTI SULEJMANIJE, SEVEROISTOČNI IRAK

AUTOR

Mr Salahalddin Saeed Ali

Belgrade
2007

Examination Panel:

Dr Zoran Stevanovic, professor
Faculty of Mining and Geology
University of Belgrade - Serbia

Dr Mikdad H.Al-Jabbary, professor
College of Science
University of Baghdad – Iraq

Dr Veselin Dragisic, professor
Faculty of Mining and Geology
University of Belgrade - Serbia

Dr Petar Dokmanović, professor
Faculty of Mining and Geology
University of Belgrade - Serbia

Dr Dejan Milenić, associate professor
Faculty of Mining and Geology
University of Belgrade - Serbia

DEDICATION

I DEDICATE THIS WORK TO:

THE MEMORY OF THE DEARS WHO HAVE LEFT ME

MY FATHER, MOTHER AND MY BROTHER SORAN

THE FRUIT OF MY LIFE THAT PROVIDES ME WITH LOVE

MY BELOVED WIFE

THE FLOWERS WHO FILL MY LIFE WITH ITS SCENT AND PROVIDE ME WITH COMFORT

MY BELOVED CHILDREN

SALAH

ACKNOWLEDGEMENTS

I am deeply indebted to Professor Dr Zoran Stevanovic for undertaking the task of supervising this thesis, and whose guidance and advice have made this project possible. My gratitude and appreciation are due to my local advisor, Professor Dr Mekdad H. Al-Jabbari, for offering many suggestions and corrections during all stages of the work.

I am also grateful to the Deanery of the College of Science, the Presidency of the University of Sulaimani and the Ministry of higher education of the Kurdistan region for funding part of this study.

Special thanks are due to my friend and the head of the Department of Geology - University of Sulaimani, Dr.Kamal Haji, for his generous help and assistance throughout this work, especially during field work.

My sincere thanks to all the colleagues of the teaching staff, of both the Department of Geology, University of Sulaimani and Salahaddin and the Department of Hydrogeology - Belgrade University, for their help, with particular thanks to Mr.Dyari , Dr.Mariwan and Mr. Sirwan, Dr. Petar Milenic, Mr. Igor Jemcov, Mr. Bojan Hajdin, Mr. Miroslav Krmpotic, Mr. Slavko Spadijer and Mr. Sasha Milanovic for their help, advice and the valuable references they provided.

I wish also to thank the groundwater directory of Sulaimani, and directory of irrigation, particularly Mr. Hoshyar Shali, Mr. Dler and Mr. Baba Rassol, Mr. Aram, Mr. Shadman and all the other geologists who helped me by providing data and guiding me to the location of some wells and piezometers.

Appreciation is extended to Mrs. Beverly Lynch, Mr. Farhad from (Map Com Company), Mr. Vladimir Zivanovic and Branislav Petrovic for their technical help in the preparation of this thesis.

My special thanks are extended to Mrs Aleksandra Maran for her generous logistical sisterhood support during my stay in Belgrade.

My wife’s patience and help are greatly appreciated, and will never be forgotten.

Many thank to all others who gave me their help and whom I have not mentioned.

Abstract

Key words: hydrogeology, groundwater management, water balance and use, hydrochemistry

The Sharazoor-Piramagroon basin is one of the most hydrogeologically important basins of the Iraqi Kurdistan Region. It is located in northeastern Iraq, and comprises a large area of the eastern part of the Sulaimani Governorate. The area, relatively large at 2680 $km^{2,}$ It extends between the latitude 35º 04' 00" and 35" 47' 24" to the north and the longitude 45º 10'12" and 46º 12' 00" to the east. The studied area is a mountain-encircled basin located mainly in the High Folded Zone and partly in the Thrust and Imbricated Zones of the Iraqi side of the Zagros mountain belt.

The entire surface and groundwater of the basin are discharged to the Darbandikhan reservoir through three main and several smaller streams. All the rocks of the basin are sedimentary and range in age from Triassic to Recent.

. The studied area is a part of the region influenced by the Mediterranean climatological system. The mean annual rainfall was 741mm during the period of 1980/1981-2005/2006. Most of the annual rainfall occurs in the eight months from October to May. The four remaining months are regularly dry. During the winter season, snow falls on the upper part of the surrounding mountains.

The stratigraphic units are grouped as karstic for Triassic and Jurassic rocks (TKA and JKA), karstic-fissured aquifers for Cretaceous and Eocene rocks (CKFA and EKFA) respectively, fissured aquifers for Cretaceous Qulqula Fn. (CFA), intergranular aquifers (AIA) and (EIA) for alluvium and Eocene conglomerates respectively, aquitard of Tanjero rocks (TAT) and finally complex aquifers of slide debris (SDA).

Through one and half years of field work and inventory of all water points (springs, deep and shallow wells) geological and hydrogeological maps were prepared. Pumping tests were performed on 22 deep wells distributed throughout the area and covered all types of the existing aquifers. A great variation in the range of 0.2×10^{-4} to 62×10^{-4} m^2/s was found in the transimissivity (T) values.

It is concluded that the relatively thick aquifers of AIA could be considered the most promising area for drilling successful and productive wells, particularly in the eastern and central parts of the basin.

The field observation of the streams and springs in these terrains showed that the surrounding mountainous terrains have a relatively high infiltration coefficient. For

CKFA the percentage of recharge was 56.6% of precipitation, while for TKA and JKA it is estimated to be 69.9%. The estimated recharge percent of intergranular aquifers was variable: from as low as 27.1 % for fine texture sediments to as high as 53.8 % for coarse gravely sediments.

Time series analysis of the five large springs in the basin (Sarchinar, Bestansur, Saraw group, Reshen and Zalim) was found to be a very useful tool for the general characterization of the karst aquifer system. The results of the auto-correlation led to the conclusion that these springs have large storage which drains gradually. The cross-correlation of spring discharge and precipitation data shows that all the springs except Bestansur have the duality of the groundwater flow. The dynamic reserves of all the spring reservoirs are estimated.

Weekly measurements of the static water level in 17 deep wells in the study basin revealed that the decline in head for intergranular aquifers was in the range of 2.7m – 7.7m. A higher decline range of groundwater level in the wells penetrating CKFA was recorded at 5.5m – 12.3m.

The hydrochemical work on 211 water samples collected from different wells, springs and kahrezes during October-2004 shows that calcium and bicarbonates are respectively the most dominant cations and anions. Sulfate and chloride are the second most dominant.

Water samples from 26 deep wells, 25 shallow wells, and 13 large springs were analyzed for the trace elements (Cd, Zn, Cu, Cr, Ni, and Pb). In general, the majority of the water samples are not contaminated with Ni, Pb and Cu, but slight contamination with Cd, Cr and Zn is detected in some water samples.

The main problems regarding the sustainability of the groundwater resources are shown. The current demand for water and that for the next 25 years are determined. Because it has the highest population compared to the other parts, the western part of the basin was found to be under stress. The current exploitation in Sulaimani area is more than the safe yield while in the other parts of the basin it is still below the safe yield. Solutions to get larger amounts of water from the karstic aquifers than those yielded by the springs during the dry season are proposed. Convenient sites for artificial recharge and construction of subsurface dams are also proposed.

For better sustainable groundwater management a number of recommendations are proposed for the decision-makers to introduce in new legislation and regulations to acquire better control of the surface and groundwater resources.

Geologija i hidrogeologija Šarazur-Piramagrun basena u oblasti Sulejmanije, Severoistočni Irak

Ključne reči: higrogeologija, menadžment podzemnih voda, bilans voda i njihova upotreba, hidrohemija voda

Rezime

Šarazur-Piramagrun basen se nalazi u severoistočnom Iraku, u regionu Kurdistana, i obuhvata veliku oblast istočnog dela Guvernata Sulejmanija. Prostire se između 35°04´00“ i 35°41´24“ severne geografske širine i 45°10´12“ i 46°12´00“ istočne geografske dužine. Oblast istraživanja predstavlja basen okružen Iračkim delom Zagros planinskog lanca.

Celokupna površinska i podzemna voda oblasti drenira se u veštačko jezero Darbandikan preko tri veća i nekoliko manjih površinskih tokova. Reljef basena, površine oko 2680 km^2 koji je okružen visokim planinama sa svih strana, odlikuje se blago zatalasanom ravnicom u kojoj se mestimično javljaju brežuljci i brda.

Basen se može posmatrati i kao spoj tri veće doline. Glavna je Tandžero koja ima severozapadni pravac pružanja; druga je Čakan severnog pravca, koja severno od grada Said Sadik nastaje od Galal doline zapadnog pravca pružanja i Čavtan doline istočnog pravaca pružanja. Treću dolinu čine zajedno Zalim i Bijara koje imaju severoistočno odnosno istočno pružanje.

Zbog velike dužine i velike površine oblasti basena, a uz uzimanje u obzir razlike u stratigrafiji i litilogiji, oblast istraživanja je podeljena na četiri podbasena. Nazvani su Sulejmanija (SB1), Arbat-Zarani (SB2), Said Sadk (SB3) i Halabdža-Kurmal podbasen (SB4).

Ova disertacija ima za cilj da doprinese hidrogeološkom poznavanju oblasti i formira podlogu za dalja detaljna istraživanja i analize, uzimajući u obzir značaj podzemnih voda za vodosnabdevanje i navodnjavanje, i fokusirajući se na sledeće ciljeve:

1. Izvođenje regionalnih geoloških i hidrogeoloških istraživanja oblasti.
2. Procena kvantiteta i kvaliteta podzemnih vodnih resurasa.
3. Davanje okvirnih preporuka za najbolju moguću upotrebu podzemnih voda, i izrada predloga i projekata za kontrolu podzemnih voda u istražnoj oblasti.

Oblast Iračkog Kurdistana ima izraženu kontinentalnu klimu Mediteranskog tipa sa toplim letima i hladnim zimama. Najtopliji meseci su jun, jul i avgust, dok su najhladniji decembar, januar i februar. Tokom leta oblast potpada pod uticaj Mediteranskog anticiklona i suptropskog pojasa visokog pritiska. Zimi, oblast je pod, uticajem Mediteranskog ciklona koji se kreće ka istoku i severoistoku. Oblast istraživanja je deo regiona koji je pod

uticajem Mediteranskog klimatskog sistema, tako da su padavine u vidu kiše samo tokom zime i proleća. Maksimalna mesečna suma padavina je izmerena decembra 1991. godine i iznosila je 354 mm. Maksimalne srednje padavine za period 1980-2006 zabeležene su u decembru i iznose 131 mm. Srednja godišnja suma padavina, za period 1980-2006, u oblasti istraživanja je 741 mm. Većina godišnjih padavina se izluči tokom osam meseci od oktobra do maja. Preostala četiri meseca su relativno suva. Za vreme zime snežne padavine su samo u višim delovima planina koje okružuju basen.

Srednja godišnja temperatura iznosi 19.4°C. Maksimalna zabeležena temperatura je iznosila 38.6°C u julu 2000. godine, dok je minimalna iznosila 1.4°C januara 1983. godine.

Srednja godišnja vrednost potencijalne evapotranspiracije, sračunata metodom Torntvajta je iskorišćena za određivanje srednjeg mesečnog bilansa voda. Suficit voda za period 1980-2006 je sračunat na osnovu podataka meteorološke stanice Sulejmanija, za oblast koja se prostire ispod 1200 mnm i iznosi 73.6%, dok je za planinsku oblast (teren iznad 1200 mnm) dobijena vrednost od 77.8%.

Za potrebe morfometrijske analize basena, površina je podeljena na tri manje oblasti dreniranja Tandžero, Čakan i Zalim. Svaki od njih je kasnije podeljen u nekoliko manjih.

Geološki posmatrano, uzimajući u obzir tektonsku klasifikaciju Budaja (1980) i Budaja i Jasima (1987), oblast se većim delom nalazi u Visoko Nabranoj zoni i manjim delom u zoni Navlačenja. Podbaseni SB1 i SB2 se nalaze u Visoko Nabranoj zoni, dok se podbaseni SB3 i SB4 prostiru u okviru zone Navlačenja.

Šarazur-Piramagrun basen se nalazi u okviru zapadnog pojasa nabiranja i rasedanja Zagros koji je kasnije deformisan Laramijskom i postlaramijskom orogenezom.

U ovom basenu antiklinale i sinklinale imaju velike amplitude i male širine; u većini slučajeva su prevrnute ka jugozapadu zahvaljujući pritiscima koji su posledica navlačenja Iranskog platoa. Skoro sve stene u basenu su sedimentnog tipa, a starost se kreće od trijasa do mlađih nastalih tokom kvartara.

U svim podbasenima najveću zastupljenost imaju stene kredne starosti, koje se uglavnom sastoje od krečnjaka organskog porekla (pelaški sedimenti) i klastičnih stena. Klastične stene pripadaju formacijama Tandžero i Kološ (gornja kreda i paleocen) i otkrivene su u sinklinalama, dok je otporniji krečnjak otkriven duž osa i prevoja antilkinala. Ove stene su mestimično pokrivene debelim slojevima u nižim predelima (ravnice i doline reka), nastalim kao posledica rada spoljašnjih sila. Generalno gledano starost stena koje su prekrivene produktima egzogenih procesa se smanjuje prema jugozapadu.

Šarazur-Piramagrun basen ima relativno složenu geološku građu i hidrogeološke odlike, s obzirom da su na odlike basena imali uticaj: 1) geomorfologija, 2) stratigrafija i 3) struktura. Smatra se da je basen jedan od najvažnijih u Iraku posmatrano iz ugla raspoloživosti podzemnih voda i plodnosti tla.

Izdani u basenu su formirane ili u stenama koje su hemijskog porekla (marinska faza taloženja sedimenata) ili u klastičnim stenama (kontinentalna faza deponovanja sedimenata). U ovoj tezi, stratigrafske jedinice su grupisane na sledeći način:

1. karstna izdan – stene trijaske i jurske starosti (TKA i JKA),
2. karstno-pukotinska izdan – stene kredne i eocenske starosti (CFKA i EFKA),
3. pukotinska izdan – stene kredne starosti Kulkula formacije (CFA),
4. zbijena izdan – konglomerati eocenske starosti i aluvijalni nanosi (EIA i AIA),
5. uslovno bezvodni teren – stene Tandžero formacije (TAT),
6. složena izdan – sipari (SDA).

Karta hidroizihipsi formirana je na osnovu merenja statičkog nivoa podzemnih voda u bunarima (prekinuto tokom oktobra 2005. godine). Na karti možemo uočiti da se visoki nivoi podzemnih voda javljaju u oblastima koje okružuju basen, sa većim vrednostima u istočnim, severoistočnim i severozapadnim delovima.

Ravnice Said Sadik, Sirvan i Zarain su potencijalno najvažnije oblasti akumuliranja podzemnih voda, sa najnižim vrednostima hidrauličkog gradijenta i najvišim koeficijentom filtracije.

Regionalna geologija je pokazala da je basen (na osnovu predložene podele izdani) okružen vodonepropusnim stenama, i na osnovu toga je usvojen i nacrtan model nazvan „Oaza“, s obzirom na to da uslovi koji vladaju u oblasti istraživanja podsećaju na pustinjsku oazu koja prikuplja vodu iz okoline, a koja u vreme visokih voda može da istekne kroz jedan kanal.

Za potrebe ove teze, izvršen je test crpenja na 22 produktivna bunara, koji pokrivaju sva četiri podbasena i kaptiraju sve tipove izdani. Velike varijacije u vrednostima su utvrđene za koeficijent vodoprovodnosti (T), a vrednosti se kreću od 0.2×10^{-4} do 62×10^{-4} m^2/s.

Specifična izdašnost izdani pokazuje velike varijacije u vrednostima. Izdan CFKA u podbasenu SB1 ima najveću vrednost specifične izdašnosti izdani kao posledicu male depresije u bunaru (samo 1.1 m) i velike izdašnosti bunara (9.0 l/s), dok u istom podbasenu izdan TAT ima najnižu vrednost.

Uglavnom, možemo da zaključimo da relativno moćni izdanski sloj AIA u podbasenima SB2, SB3 i SB4 predstavlja oblast u kojoj je moguće izbušiti najviše produktivnih bunara, dok izdan AIA u podbasenu SB1 dolazi na drugo mesto zbog relativno male debljine aluvijalnih sedimenata.

Za procenu godišnjeg oticaja sa proučavanog basena iskorišćena je metoda SCS (Soil Conservation Service).

Basen je podeljen prema poreklu površinskog materija na osnovu tabele Američke službe za zaštitu tla (USDA) iz 2004. godine. Usled nedostatka odgovarajućih karata površine terena, urađena je detaljna studija za podelu basena u različite oblasti sa različitim brojem krivih. Ovo je obavljeno upoređivanjem osobina svake teorijske krive sa krivom sa istim osobinama u basenu koji je istraživan.

Terenska merenja tokova i izvora ovih terena pokazala su da stene koje čine građu okolnih planina imaju visok koeficijent infiltracije (mali koeficijent površinskog oticaja).

Za podbasen SB1 godišnja direktna infiltracija u izdan CFKA je procenjena na 82.9 x 10^6 m^3, sa infiltracijom iz povremenog toka Čakčak u iznosu od 7.5 x 10^6 m^3. Godišnja infiltracija u sistem podzemnih voda izdani AIA kao suma direktne infiltracije i infiltracije iz površinskih tokova je procenjena na 52.2 x 10^6 m^3. Procenjeno je da formacija Tandžero, koja pokriva veći deo podbasena SB1, dobija 15.9 x 10^6 m^3 vode.

U okviru podbasena SB2 procenjeno je da se u izdan CFKA infiltrira 76.5 x 10^6 m^3, u izdan AIA 74 x 10^6 m^3 i u izdan TAT 15 x 10^6 m^3 vode.

Što se tiče podbasena SB3, oblast prihranjivanja se nalazi u planinskom regionu, i sastoji se ne samo od krednih već i od jurskih i trijaskih sedimenata, od kojih se ovi drugi pružaju i na teritoriju susednog Irana. Procena godišnje infiltracije za ovaj podbasen je bila otežana, posebno za izdan TKA čiji je veći deo izdanka u Iranu. Ukupna godišnja infiltracija za sve tri izdani je preliminarno procenjena na 187.6 x 10^6 m^3. Godišnja infiltracija izdani AIA je procenjena na 89.3 x 10^6 m^3 od čega 18.5 x 10^6 m^3 dolazi od infiltriranje iz Čakan doline, a 8.7 x 10^6 m^3 od podzemne infiltracije iz jurskih karstnih kanala.

Oblast prihranjivanja podbasena SB4, slično podbasenu SB3, čine stene trijaske starosti od kojih je samo trećina površine u okviru granica Iraka. Bilo je teško proceniti godišnji priliv vode kojom se prihranjuje izdan TKA. U skladu sa procenom da površina prihranjivanja u Iranu iznosi oko 100 km^2, došlo se do veličine od 89.9 x 10^6 m^3 za izdan TKA i 61.8 x 10^6 m^3 za CFKA. Godišnja infiltracija za izdan AIA je procenjena na 57 x 10^6 m^3.

Mehanizam isticanja vode iz pet velikih karstnih vrela je analiziran na osnovu analize vremenskih serija i Furijeove spektralne analize. Vrela su Sarčinar, Sarav, Rešen, Zalim i Bestansur. Dinamičke rezerve ovih vrela određene su na osnovu Mailetove formule za recesioni period hidrograma vrela. Za ovu analizu upotrebljene su dnevne vrednosti isticanja vrela za period oktobar 2004 – oktobar 2006.

Auto-korelogram svih analiziranih vrela pokazuje njihovu sličnost u hidrauličkim osobinama. Auto-korelogram isticanja prevazilazi granice poverenja od 79-88 dana, što potvrđuje postepeno oslobađanje vode iz izdani prilično velikog kapaciteta. Sličnosti su u određenom obimu nađene, takođe, i na kros-korelogramu padavina i isticanja za sva vrela osim Bestansura, kod koga je primećen vrlo mali nivo korelacije od 2 do 15 dana, dok je posle toga korelacija beznačajna. Niske vrednosti kros-korelacije pokazuju da je uticaj infiltrirane vode značajno prigušen dužinom karstnih kanala. Kros-korelogram za vrelo Bestansur, nasuprot drugim vrelima ne pokazuje brz odziv niti bilo kakvu međusobnu povezanost sa dnevnim kišnim događajima. Ovakvo ponašanje vrela Bestansur ukazuje na pukotinski tip (sekundarne poroznosti) izdani iz koje se prihranjuje. Takođe, nije nađena otvorena veza između površine i mesta isticanja vode iz sistema.

Spektralna gustina funkcije isticanja vrela pokazuje velike pikove pri niskim frekvencijama od 0.003135 (319 dana), što potvrđuje postojanje godišnjeg ciklusa događaja.

Korišćenjem Mailetove recesione krive, određena su dva recesiona koeficijenta za vrela Sarčinar, Sarav i Zalim, dok su za vrelo Rešen utvrđena tri i samo jedan za vrelo Bestansur.

Vrednosti dinamičkih rezervi za izdani svih posmatranih vrela su očekivano visoke. Za Sarčinar su procenjene na oko 37.58 x 10^6 m^3 (1.19 m^3/s), za Sarav 22.1 x 106 m^3 (0.92 m^3/s), za Rešen 40.96 x 10^6 m^3 (1.7 m^3/s), za Zalim 62,73 x 10^6 m^3 (2.62 m^3/s) i za Bestansur 13.93 x 10^6 m^3 (0.59 m^3/s). Ove vrednosti teoretski znače da se za period od dve do šest godina može vršiti crpenje vode iz izdani bez bilo kakvog dodatnog prihranjivanja.

Za sva istraživana vrela procenjene vrednosti godišnjeg prihranjivanja izdani pomoću metode CSC krivih upoređene su sa onima koje su dobijene procenom na osnovu merenja isticanja svakog vrela u periodu istraživanja. Jedino su za izvor Sarčinar pronađene određene podudarnosti između dobijenih vrednosti. Vrednosti za ostala vrela pokazuju određene kontradikcije što može biti posledica pogrešne procene površine prihranjivanja izdani koja se nalazi izvan basena ili čak i izvan države.

Nedeljna merenja statičkog nivoa vode u 17 dubokih bunara u okviru basena su vršena u periodu od decembra 2004 godine do februara 2006 godine.

Nivo podzemnih voda u zbijenim izdanima je varirao od 2.7 m do 7.7 m, sa maksimalnim promenama zabeleženim u podbasenu SB1, a minimalnim u podbasenu SB2. Veće promene nivoa podzemnih voda su zabeležene u bunarima koji kaptiraju izdan CFKA i iznosile su od 5.5 m do 12.3 m. Očigledno, veće promene nivoa podzemnih voda uzrokovane su intenzivnim prihranjivanjem uzvodnih delova terena aluvijalnih izdani. Verovatno se prihranjivanje izdani vrši pomoću proceđene vode kroz rečno dno površinskih tokova kao što su Čakan i Surajo Zamaki, Hasanava i Darašeš.

U sklopu hemijskih analiza određeni su makro, mikro i elementi u tragovima za podzemne vode u basenu. Takođe, određena je ukupna mineralizacija utvrđivanjem ukupno rastvorenih minerala (TDS), električne provodljivosti (Ec) i reaktivnosti vode u smislu njene pH. Merenja su urađena i na terenu i u laboratoriji.

Na terenu je uzeto 211 uzoraka iz različitih bunara, vrela i kareza (ručno kopane galerije u stenama) tokom oktobra 2004. godine.

Vrednost pH u uzorcima vode varira od 6.6 do 8.4, a srednja vrednost pH iznosi 7.4. Vrednost mineralizacije se kreće od maksimalno zabeleženih 1300 ppm do minimalno izmerenih na izvoru Kleja (EIA) na jugu SB2.

Voda svih izvora se može svrstati u malomineralizovane (TDS<1000 ppm), osim vode iz kiselog izvora Kurmal u podbasenu SB4, koja je blago mineralizovana.

U istraživanoj oblasti joni Ca preovlađuju u katjonskom sastavu u svim uzorcima vode. U izvorima koncentracija jona Ca varira između 32 ppm i 215 ppm. Generalno gledano koncentracija ovog jona raste ka jugu prema gradovima Sulejmanija, Said Sadik, Zarain i Arbat.

Koncentracija bikarbonatnog anjona u uzorcima varira od 55 ppm do 380 ppm.

Najveća pozitivna anomalija bikarbonatnog jona zabeležena je južno od grada Sulejmanija i u okolini Arbata, Zaraina i Said Sadka. Ove visoke vrednosti su grupisane u blizini glavnih odvodnih kanalizacionih kanala; takođe, koncentracija bikarbonata se uvećava u smeru kretanja podzemnih voda što ukazuje na uticaj urbanizacije na kvalitet vode.

Koncentracija sulfata u izvorskoj vodi se kreće u intervalu od 10 ppm do 110 ppm. Za duboke bunare izmerena koncentracija sulfata se kreće od 2 do 180 ppm; najveća zabeležena koncentracija je na dva bunara i najverovatnije potiče od infiltracije vode sa poljoprivrednih površina i kanalizacije. Bunari se nalaze južno od grada Sulejmanija gde se nalaze kanalizacioni kanali grada, koji se ulivaju u reku Tandžero, kak i kanali koji služe za navodnjavanje.

Koncentracija nitrata u istraživanoj oblasti nalazi se u opsegu od 0 do 70 ppm. Većina izvora, duboki ali i plitki bunari uglavnom su bez nitrata u vodi (ili ih nije bilo moguće detektovati).

Uzorci vode iz 26 bunara, 25 plitkih bunara i 13 velikih izvora i vrela je analizirana za potrebe utvrđivanja mikroelemenata (Cd, Zn, Cu, Cr, Ni i Pb).

Koncentracije kadmijuma u većini ispitivanih uzoraka pokazuju blago povećane vrednosti u odnosu na dozvoljenu vrednost od 0.003 ppm (koja je u skladu sa pravilnikom Svetske Zdravstvene Organizacije iz 2006. godine i Iračkog standarda kvaliteta vode iz 1996. godine).

U većini uzoraka nisu konstantovane značajne koncentracije Ni, Pb i Cu.

Zagađenje koje potiče od kanalizacije je uticalo na prisustvo jona Zn u nekoliko uzoraka uzetih iz bunara. Korišćenje otpadnih voda iz kanalizacionih kanala za navodnjavanje razlog je za prisustvo ovog jona i u uzorcima uzetim na lokacijama van gradskog područja.

U 15 plitkih bunara (od ukupno 25), čije su vode uzete za hemijsku analizu, zabeleženo je prisustvo hroma. Primećeno je da ovi bunari pokazuju slično zagađenje kada su u pitanju i ostali zagađujući elementi. Lokacija ovih zagađenih plitkih bunara potvrđuje da je uzrok ili korišćenje veštačkih đubriva ili otpadne vode iz domaćinstava i industrije.

Prosečna vrednost TH (ukupne tvrdoće) u uzorcima koji su analizirani kreće se u opsegu od 83 ppm do 480 ppm. Visoke vrednosti TH u južnim delovima grada Sulejmanija mogu biti posledica procurivanja vode iz kanalizacije u podzemne vode, kao što je i detektovano u Vulubi. Čista voda je ograničena na onu koja potiče iz izvora koji dreniraju TAT izdan i vodu iz dubokih bunara koji kaptiraju TAT i CFKA izdan u ruralnim regionima, u blizini oblasti prihranjivanja severno i severoistočno od grada Sulejmanija.

Uzorci iz 11 dubokih bunara, 11 plitkih bunara i svih 5 karstnih vrela (Zalim, Kalabo, Sarčavi Sarav, Bestansur i Sarčinar) su uzeti za određivanje biloške potrošnje kiseonika – BOD_5. U svim uzorcima vrednost se kreće u relativno malom opsegu od 0-1 mg/l.

Što se tiče hemijske potrošnje kiseonika – COD, zagađenje je prisutno u nekoliko uzoraka iz plitkih bunara koji zahvataju vodu iz AIA izdani.

Bakteriološka istraživanja su pokazala da je bakteriološko zagađenje prisutno u različitoj meri i od strane različitih vrsta bakterija. Plitki bunari imaju veće koncentracije bakterija što je verovatno uslovljeno i njihovom nekvalitetnom izradom (prilikom bušenja i završne pripreme za upotrebu), kao i nemara prilikom izrade betonskog zaštitnog bloka.

Kalcijum i bikarbonat su preovlađujući joni u vodama basena. Sulfati i hloridi su sledeći po zastupljenosti. Više od 97% uzoraka je kalcijum bikarbonatnog tipa sa varijacijama: 25.5% je $Ca\text{-}Mg\text{-}HCO_3$ tipa, 30% je $Ca\text{-}Mg\text{-}SO_4$ tipa i 15% je $Ca\text{-}HCO_3$ tipa.

Na osnovu glavnih koeficijenta (rNa+rK)/rCl, zaključeno je da većina voda uzetih iz dubokih bunara u okviru oblasti istraživanja pripada meteorskom tipu.

U okviru poglavlja šest ove teze, analizirano je korišćenje podzemnih voda u skladu sa održivim razvojem. Utvrđene su trenutne potrebe i potrebe stanovništva u narednih 25 godina za sva četiri podbasena. Utvrđeno je i da se najveći pritisak na izdan vrši u podbasenu SB1, zahvaljujući najvećem broju stanovnika tog dela oblasti.

Ceo region ima veliko povećanje broja stanovnika, bez pravih rešenja sistema za vodosnabdevanje i odvod otpadnih voda. Ovo je uzrokovalo da stanovništvo buši bunare dubine 60-100 m u svojim dvorištima, bez ikakve kontrole od strane lokalne uprave. To je bio samo početak postojanja problema nadeksploatacije izdani i rizika od zagađivanja u okviru velikih gradova i njihovom okruženju. Od 2003. godine do danas 8000-12000 dubokih bunara izbušeno je bez ikakve dozvole. Veliki broj ovih bunara je izrađen bez bilo kakve zaštite i jako je podložan zagađenju koje potiče od otpadnih voda sa površine.

Na sreću, 85% ovih bunara se u potpunosti nalazi u okviru TAT formacije koja ne predstavlja važnu regionalnu izdan u okviru basena i koja se ne može smatratati potencijalnom za buduća tehnička rešenja. Ako se uporede količine vode projektovane za 25 godina i trenutna potrošnja za grad Sulejmanija i okolinu, dolazi se do toga je potrošnja 173,83 x 10^6 m^3 (5.5 m^3/s), dok postojeći sistem vodosnabdevanja zasnovan na vrelu Sarčinar i reci Mali Zab raspolaže sa 3 m^3/s. To znači da postoji deficit od 2.5 m^3/s vode, bez uzimanja u obzir mogućeg sušnog ciklusa i daljeg povećanog korišćenja podzemnih voda. Novi projekat vodosnabdevanja, koji je trenutno u fazi izrade za grad Sulejmanija iz veštačkog jezera Dokan treba da uveća rezerve za 2.2 m^3/s.

Jasno je da i ove dodatne rezerve ne mogu izaći u susret stvarnim potrebama stanovništva u narednih 30 godina. Stoga je pronalaženje dodatnih alternativnih izvora vodosnabdevanja pomoću zajedničke upotrebe podzemnih i površinskih voda, u skladu sa održivim razvojem, veliki izazov, ali i nužnost za ovu oblast

Sa druge strane, raspoložive rezerve vode u preostala tri podbasena su sasvim dorasle lokalnim zahtevima, ali je i tu prisutan loš način upravljanja rezervama podzemnih voda.

Stepen iskorišćavanja podzemnih voda u podbasenu SB2 je nizak u poređenju sa onim u podbasenu SB1. Glavni izvor vodosnabdevanja je vrelo Bestansur. Za vreme vlažnog perioda velika količina istekle vode se ne koristi, dok za vreme sušnog perioda, kada je potreba za vodom najveća, količine istekle vode jedva da pokrivaju samo deo potreba. Trenutna eksploatacija podzemnih voda pomoću postojećih bunara je ograničena. Ako se količina od 45% godišnjeg prihranjivanja smatra kapacitetom izvorišta sigurnim za eksploataciju, onda je trenutna količina vode koja se eksploatiše tek 30% od te vrednosti. U skladu sa tim, ova se oblast može smatrati oblašću niskog pritiska na izdan od strane populacije.

U okviru podbasena SB3 eksploatacija podzemnih voda iz AIA izdani predstavlja 40% osiguranog kapaciteta svih izvorišta za eksploataciju.

U podbasenu SB4 pritisak na izdan je relativno veći nego u podbasenima SB2 i SB3. Eksploatacija voda iz izdani AIA se može još povećati bušenjem novih bunara bez većeg uticaja na rezerve izdani.

Predložena su dva rešenja za iskorišćavanje podzemnih voda iz karstne izdani, osim onog putem kaptaže prirodno isteklih voda putem vrela:

- Regulacijom karstne izdani na samim vrelima ubacivanjem pumpi ispod nivoa podzemnih voda (korišćenjem statičkih rezervi),
- Bušenjem bunara kojima bi se kaptirale vode dubljih delova izdani i crpenje podzemnih voda u granicama koje ne bi naškodilo održivosti izdani.

U oba slučaja bi se koristile statičke rezerve u toku sušnog perioda godine, koje bi bile obnoviljene u kišnom periodu godine.

Kod vrela Sarčinar i Sarav se očekuje povećanje izdašnosti kao posledica ispumpavanja i snižavanja nivoa podzemnih voda, sa ozirom na to da su statičke rezerve njihovih izdani značajne.

Sa ekonomske tačke gledišta, praktičnije rešenje je ispumpavanje vode na samim izvorima i vrelima. Razlog za izvođenje ovog zaključka je visoka cena izrade bunara u karstu i rizik da se bunarom ne uđe u odgovarajući karstni kanal usled velike heterogenosti karstne mreže kanala. Pravilan raspored mreže kanala koji dovode vodu do karstnih vrela, može da omogući ispumpavanje vode bez nekih većih tehničkih problema i značajnih sniženja nivoa podzemnih voda. Ukoliko to ne bi bio slučaj, izradili bi se specijalni kaptažni objekti npr. vertikalno okno sa horizontalnom galerijom.

Postoji nekoliko mogućih lokacija u okviru basena gde bi bilo moguće izvršiti veštačko prihranjivanje izdani AIA. Značajne zapremine vode otiču povremenim tokovima u kišnom periodu bez ikakve dobrobiti za stanovništvo. U reljefu terena postoji nekoliko lokacija gde se može omogućiti direktna infiltracija u podzemlje ili sprovođenje vode u manje kanale za postepenu infiltraciju.

Neke od tih lokacija su sledeće: Kamartl i Surtka u SB1 podbasenu, Merade i Kleja u SB2 podbasenu, Čakan i Surajo u SB3 podbasenu, i na kraju Kazena, Zamaki, Biara i Darašeš u SB4 podbasenu.

Predložena je i izrada podzemnih brana kao jednog od rešenja za veštačko prihranjivanje izdani i čuvanje vode. Branu je moguće izraditi na jednom od tokova u podbasenu SB1 Jakian ili Dole Nader.

U radu su, takođe, razmatrani rizici i problemi koji trenutno pogađaju ovo područje, a koji se u budućnosti mogu povećati, a koji su vezani za podzemnu vodu kao resurs. Glavni problem je nadeksploatacija, moguća suša, presušivanje karstnih izvora i vrela kao i bunara koji kaptiraju tu izdan, zatim značajano degradiranje životne sredine i njeno zagađivanje. Zbog toga su predložena rešenja za racionalniju upotrebu podzemnih voda u skladu sa održivim razvojem. Rešenja za poboljšanje upravljanja podzemnim vodama predložena su i donosiocima odluka, kao kombinacija različitih mogućnosti. Sledi nekoliko predloga:

- Uprava Iračkog Kurdistana treba da razmisli o tome da prekine sa upotrebom čistih podzemnih voda za stanovništvo, osim vode za piće i održavanje zelenih gradskih površina. U budućim planovima treba razmotriti recikliranje otpadnih voda i njihovu upotrebu u domaćinstvima, navodnjavanju i održavanju gradskog zelenila. Očekuje se i da bi se izgradnjom malih brana u odgovarajućim dolinama prikupile površinske vode tokom kišnog perioda godine i njihovom upotrebom još više poboljša raspoloživi resurs. Ovaj prilaz ne samo da poboljšava upravljanje resursima nego omogućava i bolje reagovanje u slučaju ekstremnih situacija kao što su suša i incidenti povezani sa zagađivanjem. Zajednička upotreba podzemnih i površinskih voda omogućava mnogo fleksibilniji prilaz upravljanju vodnim resursima.
- Prekršajne ili krivične kazne za zloupotrebu podzemnih voda, za neodgovarajući tretman otpadnih voda i slične sankcije, mogu

znatno da poboljšaju kontrolu upotrebe podzemnih voda. Naravno ove sankcije treba i primenjivati na pravi način da bi imale efekat. Puno kazni, ali koje ne dotiču glavne zagađivače prirodne sredine postoji u sadašnjim zakonima. Neke od potreba za čistom vodom mogu biti smanjene upotrebom prečišćene vode ili vode nižeg stepena kvaliteta.

- Instalacija opreme za uštedu vode koja je jasno uočljiva u građevinskim projektima i pravilnicima (npr. prečišćena voda za ispiranje toaleta) treba da bude jedan od poteza koji se očekuje od lokalne uprave.
- Prevođenje voda iz drugih slivnih područja je još jedan predlog koji treba razmotriti u okviru plana strateškog razvoja. Predložena je izgradnja 60 m visoke brane na vodotoku Kevata (Čvarta-Pendžuin basen) severno od podbasena SB1. Ova brana bi omogućila prikupljanje više od 250 miliona m^3 vode i snabdevanje više od 900 000 stanovnika grada Sulejmanija i okolnih sela, a sve na osnovu procenjene potrošnje od 200 l/st/dan uz navodnjavanje 1000 ha zemljišta. Severozapadno od grada Sulejmanija, trebalo bi da bude formiran park pod imenom Havari Šar. Ova voda bi trebalo da bude prebačena u SB1 podbasen dizanjem na visinu od 1250 mnm, pomoću 4 km dugog tunela, odakle bi lako mogla da se gravitaciono distribuira u sistem vodosnabdevanja grada Sulejmanija posle prečišćavanja.
- Pravo na eksploataciju podzemnih voda treba jasno naglasiti u svim zakonskim aktima i jedino bi javna uprava trebala da ima pravo na upravljanje vodnim resursima.
- Grupa sastavljena od specijalista za upravljanje podzemnim vodama i korisnika bi trebala da bude oformljena sa zadatkom nadgledanja procesa vezanih za korišćenje voda, jer je vlada nekoliko puta dozvoljavala veću eksploataciju voda određenim lokalnim upravama uz povećanje taksi (IGES, 2006). Značajniji od toga, je dijalog između relevantnih korisnika podzemnih voda i njegovo uvođenje u kreiranje politike upravljanja i očuvanja podzemnih voda.
- Da bi se smanjila koncentracija nitrata u podzemnim vodama korišćenje veštačkih đubriva bi trebalo ograničiti. Veoma je važno da zemljoradnici postanu svesni da određena količina đubriva može biti iskorišćena za poboljšanje prinosa, ali da se ne sme sa njom preterivati. Podizanje javne svesti najznačajniji je deo ovog zadatka.
- Naučna istraživanja i osmatranja još jedan su od načina da se pomogne u donošenju pravih odluka, pa kao takva treba da budu podržana od strane lokalne i nacionalne uprave.

- Obrazovanje stanovništva i stvaranje slike o tome da je voda koja se nalazi u podzemlju i koju ne mogu uvek da vide, najdragoceniji resurs. Na taj način javnost bi postala svesna da svakodnevne aktivnosti mogu imati uticaja na stanje podzemnih voda i njihovo potencijalno zagađenje. Teško je utvrditi i otkriti uzrok zagađenja onda kada do njega već dođe.

LIST OF CONTENTS

Chapter Four

Chapter Five

Chapter Six

List of Annexes

SADRŽAJ

Poglavlje četiri

Poglavlje pet

Poglavlje šest

Spisak priloga

Chapter One

Introduction

1.1 Preface

The population of the Iraqi Kurdistan Region is more than five million; nearly all inhabitants are ethnically Kurdish and speak the Kurdish language. In the past, the main activities of this population were agricultural cropping and livestock production. Now this economic activity has changed dramatically, as most of the population is engaged in education, government, trade, and industrial businesses.

The modern political situation in the Iraqi Kurdistan region has been complicated. Since the late 1930s several revolutions have taken place against the Government of Iraq (GoI) for the rights to self-governance of the Kurdish population. All the Kurdish demands were answered by violence, with grave military operations destroying villages, disturbing both nature and demography. Moreover, the Iraq-Iran war (1980-1988) had the greatest impact on a large part of the Kurdistan region particularly that located along the frontal border between the two countries. The cease-fire between Iraq and Iran was signed in 1988, but soon after, another regional conflict started when Iraqi forces invaded Kuwait in August 1990.

The UN Security Council passed Resolutions 660 and 661, condemning the invasion and demanding unconditional Iraqi withdrawal, as well as imposing economic sanctions against Iraq, including a wide-ranging trade embargo. The first Gulf War which began in January 1991 opened the long period of sanctions imposed under a US-led initiative at the UN Security Council which resulted in many Iraqis dying due to nutritional and medical shortages.

“By 1991, the UN Security Council passed Resolution 688 which called upon the formation of a “safe haven” in the north of Iraq for the Kurds. The Kurdish safe-haven was delimited with borders similar to those of the three northern Governorates (Sulaimani, Erbil and Dohuk). Although predominantly Kurdish, Kirkuk was kept by the GOI, primarily because of the extensive oil reserves in its vicinity. Many Kurds escaped from the city, and a significant number, including many women and children, were rounded up and ordered to leave by the GoI forces".[1]

When the GoI compulsory withdrew its administration from Iraqi Kurdistan and enforced an embargo on the area, a decision was made by the Kurdistan Liberation Movement to hold elections and form a parliament. A general election held in May 1992 resulted in the formation of the first Iraqi Kurdistan National Assembly and the establishment of the Kurdistan Regional Government. This de facto situation continued under drastic economic and social conditions until the last war, which ended with the regime change, started in 2003. These complicated political problems resulted in a halt to development in the Kurdistan region and a scarcity of the simplest principal services. Except for the main roads which are badly paved, there were no paved roads to the villages. An inefficient and old water distribution system remained as it had been 50 years earlier. Natural resources have not been managed properly.

After a long period of isolation from the outside world, the Kurdistan Region started to reopen to the world after April 2003. Directly after the regime change, the city of Sulaimani and the surrounding towns started to experience rapid urbanization phenomena, growth in industries and, to a lesser extent, growth in agricultural activities.

The population of the Sulaimani area is now estimated to be about 1.7 million. The growth has caused great stresses on water resources in the area and is expected to continue even more vigorously in the future. Moreover, life style has improved which accordingly has increased the demand for potable water. The water needs of the area are expected to rise to about 0.7 Million m^3/day by the year 2020. This volume of water is to be supplied conjointly by the existing water resources, mainly from two existing reservoirs (Dokan and Darbandikhan), and the ground water system.

The seasonal over-exploitation of the aquifers and the occasional decrease in annual precipitation have heightened the decline of the ground water supply. Although this region has 600-1000mm of rainfall per year, virtually no rainfall occurs during five months of the year. This also contributes to the increasing problem of water shortages in the dry seasons. Moreover, the absence of groundwater management and aquifer controlling regulations could add to negative future impact.

[1] *Maran and Stevanovic, 2007," Iraqi Kurdistan Environment" (in press)*

Therefore, in order to meet water requirements, a sustainable use of ground water to a maximum possible extent is necessary.

This implies a more comprehensive study of ground water resources.

In addition to the facts clarified above, the main motives for selecting the Sharazoor- Piramagroon basin for study and hydrogeological assessment are:-

1- Geologically, this area could be considered typical as it represents the complex geology of all Iraqi Kurdistan regions. Part of the study area is located in the thrust, part in the imbricated, and the rest extends from the high folded zone to the border with the low folded zone. In addition, the different types of aquifers, from karstic limestone aquifers of the Triassic age to recent intergranular aquifers, exist.

2- As the center of the second largest governorate in the region (Sulaimani Governorate), this area is the most heavily populated area of Kurdistan Region.

3- The most promising fertile plain in Iraq and in Kurdistan (Sharazoor plain) comprises about 50% of the study basin. It is an area of great importance for future development in the fields of agriculture, industry and environment.

4- In spite of all these features, the area has not yet been studied in detail geologically or hydrogeologically.

1.2 Location and definition of the basin

The Sharazoor-Piramagroon basin is located in northeastern Iraq (Kurdistan Region), and comprises a large area of the eastern part of the Sulaimani Governorate. It extends between the latitude 35º 04' 00" and 35" 47' 24" to the north and the longitude 45º 10'12" and 46º 12' 00" to the east.

The name of the basin is originally attributed to Stevanovic and Markovic (2004) who took it from the name of the two local plains that form the western and eastern low lands of the basin respectively. The studied area is a mountain-encircled basin and located in the Iraqi side of the Zagros mountain belt which includes mainly the area located between Sulaimani city in the west, and Biara and Zarain towns in the northeast and south respectively. The entire surface and groundwater of the basin is discharged to the Darbandikhan reservoir through three main and several smaller streams (Fig.1.1).

The area, relatively large at 2680 km^{2}, is surrounded on all sides by high mountains while the central part of the basin consists of gently dipping flat plains with sporadic hills.

The entire basin can be recognized as three large branched valleys. Each branch is divided again into smaller branches forming a dendritic pattern. The main branch is the Tanjero stream that stretches from the Darbandikhan reservoir toward the northwest for more than 70km and ends near the Qizlar village at the head of Chachaq valley. This branch includes Sulaimani city and both Arbat and Zarain towns. The second branch stretches from the reservoir toward the north and splits into two smaller valleys, one, called Galal valley, directed toward the northwest, the other, which climbs Suren mountain, is called Chawtan valley. This second branch includes Said Sadiq and Shenedari towns and is drained by Chaqan stream. The third branch is directed from the reservoir toward the northeast and climbs the Avroman mountain as two smaller branches named Zalim and Biara valleys and is drained by streams with the same names.

1.3 Economy, industry and development of the basin

In general, due to the instability of the political situation of Iraq and the whole region, the economy of the area is not good yet. As mentioned previously, due to a reduction in the life activities, the economy is still in bad condition. With the political changes in Iraq since 2003, and because the Kurdistan Region has become much safer compared to the rest of Iraq, economic activities have upgraded and improved. Reconstructions and rehabilitations have created good opportunities for jobs, trading etc. The salary levels of the governmental employees have also improved relatively. Foreign companies have started to come to the area for investment which has created an environment for re-activation of currency mobility and banking opportunity. In spite of everything, however, unfortunately no infrastructural projects have been included among these activities. Industry is still limited, and no large industrial projects have been achieved. It is restricted to the private small factories for building construction materials or small food industries etc.

The studied basin includes one of the most fertile plains in Iraq with guaranteed annual rainfall for cropping. The fertility of the basin can be attributed to the existence of all types of rock around the plain, such as many types of sedimentary and igneous rocks.

Fig. 1.1 Location map of the Sharazoor–Piramagroon basin

The principal cultivated crops are wheat, sunflower, cotton, and different types of vegetable and orchard activity. Orchards in the basin grow grapes and apricots. The increase of both human and livestock population in the basin has caused increased pressure on the existing trees and the grazing grass and soil of the basin. No regulation has been established for the organization and management of the uses of the natural ranges in the basin. Another source of pressure on the natural environment of the basin is human urbanization in the basin, represented by the expansion of the cities and towns and the increase in industrial waste and harmful smoke, as well as house and factory sewage.

All of this affects the quality and quantity of the ground water and surface water, as evident in the increased pollution in the stream and groundwater which can be observed in the summer and autumn. Mustafa (2006) mentioned such pollution and effects on Tanjero and Kani Pan Streams and groundwater south of Sulaimani.

At 2003 and during end of the spring, most of the fish in the Darbandikhan and Dokan dams died due to unknown factors. However, these deaths were attributed by some researchers to the depletion of oxygen as a result of pollution caused by high turbidity and the increase of organic matter as a result of rapid erosion of soil with grass.

1.3.1 Soil

The soils of Iraqi Kurdistan and the study area are the result of weathering, erosion and sedimentation, and soil-forming processes during the Quaternary period, for more than 1 million years.

The soils of the plains and the outer parts of the depressions are generally permeable and well - to moderately well drained (Berding, 2002). The total available moisture (TAM) is rather high and typically varies between 110 and 130 mm (per meter of soil), while the readily available moisture (RAM) is about 70 % of the TAM value. Bulk densities (g/cm^3) may vary between 1.3 (topsoil) and 1.45 (subsoil).

According to Berding (2003), the soils in the plains and foothills zone are generally deep and, regarding texture, remarkably homogeneous. The sand, silt and clay contents vary within rather narrow limits and the vast majority of soils have silty clay loam over silty clay. The silt content is typically higher than the clay content with 50-65% silt, 30-45% clay and 5-10% sand being representative. Only on more recent alluvial deposits (lower terraces) close to the rivers, is the texture more variable and includes sandy and loamy soils. Where the aeolian/fluviatile cover is thin or has been eroded the underlying gravel (and cobble) beds are exposed. The gravel and cobble content of the soils may then change over short distances from nil to more than 40%. Gravelly/cobbly soils are estimated to occupy less than 10% of the plains (Berding, 2003).

In general, the soils of the basin are rich in lime (20 to 40 % $CaCO_3$ are commonly found values) and very often have a pH between 7.5 and 8.2. The high lime content and the associated mild alkalinity of the soils reflect the geological pattern and overwhelming presence of limestone rocks in the various sedimentary formations which form the parent materials. In the basin no gypsum is found in the soil and the generally very low electrical conductivity (usually EC of saturation extract < 1 ds/m) indicates, in combination with usually deep groundwater tables, a very low salinization hazard (Berding, 2003).

Based on results of over 100 soil analyses done within FAO Programs in northern Iraq (2001-2002), the cation exchange capacity (CEC) of the soils is generally high with typical values being 30-45 cmolc/kg soil in the plains of the mountain zone and 20-35 cmolc/kg soil in the plains and foothills. These values reflect the presence of Smectitic clays which are responsible for the swelling and shrinking phenomena. According to Berding (2003), the high $CaCO_3$ content of most soils may, however, affect the swelling behavior of the clay. Firstly, it can act as inorganic cement, binding adjacent clay particles together and thus preventing them from swelling. Secondly, it can act as a source of calcium ions, the presence of which will tend to suppress the formation of diffuse double layers on the clay. The exchangeable cations (calcium, magnesium, sodium and potassium), usually represented on the exchange complex of the soils, are dominated by calcium which occupies 70 to 80% of the exchange complex in the plain zone. Ca/Mg ratios between 7 and 12 are common. Sodium usually occupies between 5-15% of the exchange complex while potassium is least represented with percentages often between 2 and 8 (Berding, 2003).

Available phosphorus (determined by extraction with sodium bicarbonate) is usually low in the soils because of their generally high lime content. Soluble phosphate tends to react with calcium carbonate to form calcium phosphates of varying solubility. Values in the upper 50 cm in most soils are typically between 3 and 15 ppm.

Organic matter content as the main source of naturally available nitrogen in the mountain region is higher (roughly double) than in the soils of the plains and foothills. This is a direct consequence of higher rainfall (biomass production) and lower temperatures (lower rate of mineralization) in the mountain areas than in the plains and foothills. The contents of organic matter in the upper 30 cm rank between 1.0 and 2.5 %.

Following the World Reference Base for Soil Resources (WRB) (IUSS/ISRIC/FAO, 1998), Berding (2002) classified the soils in northern Iraq, including the project area, and stated:

"In the plains and foothills leaching and accumulation of lime and swelling and shrinking of the clay are the main soil forming processes. Rather than accumulating, it seems that organic matter tends to decrease in the present land use conditions of the plains and foothills (including grazing and burning of crop residues). Surface horizons therefore seldom qualify for a mollic horizon (colours are not dark enough) but rather for an ochric horizon which means that Mollisols are an exception rather than the rule in the plains and foothills. The swelling and shrinking of the clays manifests itself through surface cracks in the dry season and the build-up of internal pressures in the soil… Many of the soils are also self-mulching (develop a crumb structure in the uppermost layer)… The vertic properties are mostly not sufficiently developed for a true Vertisol. This may be due to the high CaCO3 content which tends to suppress the swelling behavior of the clay. The accumulation of lime in the form of nodules and/or pockets of white soft powdery lime starts at depths of 25 to 40 cm… These soils are therefore classified as Calcisols. The "Vertic" qualifier is added to account for the vertic properties described above. Because of the high silt content the qualifier "Siltic" (meaning that at least part of upper meter contains more than 40 % silt) may very often be added. Furthermore, the qualifier "Skeletic" applies when the gravel and pebble content of the soil exceeds 40%.

Barzinji (2003) mentioned that the dominant soils of the bottom land of the sub-basins and in the plains are Chromoxererts and Calcixerolls, while Rendolls is dominant on the northern facing slopes of the mountains. On the other hand, Xerorthents is the dominant group on the southern facing slopes. The land capability class ranges from I to III for the main plains and the bottomlands and from V to VIII for the hilly area and mountain slopes, (Mam Rassol 2000, Barzinji 2003).

In the alluvial valleys fluvic soil material (stratification visible, irregular decrease of organic matter content) is often present and the soils are classified as Fluvisols in that case. Sometimes the surface horizon is sufficiently dark for a mollic horizon and the "Mollic" qualifier is then applied while the often high content of pebbles will be reflected by the "Skeletic" qualifier"[2].

[2] Berding F: Agro-ecological zoning of the three northern governorates of Iraq, p.15,16

- Vegetation cover

The total area of Iraqi Kurdistan is estimated at 4,017,905 ha, while the arable part, depending on fertilization level, is assumed to be between 1,4 x 10^6 ha (34 %) to 3,2 x 10^6 ha. Orchards occupy 81,023 ha. Almost half of the arable land is rain-fed. Forest area covers 1.9 million hectares in Iraqi Kurdistan. Most forests are oaks, followed by hawthorns, maples, chestnuts and poplars. They are still a major source of income for small farmers in the mountains.

The deterioration in plant cover has probably been going on for centuries and is still a problem in Iraqi Kurdistan, having a strong effect on the general climate. The Kurdistan Regional Government has made great efforts to develop plantation programs in areas with adequate rainfall and in irrigated areas. Large sustain in field was done by the FAO Agricultural Program through nursery establishment and management (e.g. Dokan village). This programme has focused mainly on relatively fast-growing species (Pinus spp., Cupressus spp. and Eucalyptus spp.). However, the lack of forest is typical of the entire reservoir and adjacent areas, and much of the zone is intensively used for grazing, as evident in the dense network of anastomosing narrow livestock tracks on the hill slopes. Overgrazing becomes especially apparent near villages with an almost complete disappearance of vegetation cover. Grazing of stubbles after harvest is a common practice in the cropland areas (Berding, 2003).

The growing period for most crops continues beyond the rainy season and, to a large extent, crops mature on moisture stored in the soil profile. The capacity of a soil to store moisture which is available to a crop depends mainly on soil texture, effective soil depth and on the percentage of coarse elements. Very limited data, however, suggest that silty clay loam to silty clay soils (no coarse elements) may store between 110 and 140 mm of available moisture per meter of soil. According to Berding (2003), the texture of the majority of the soils tends to be in the “silty clay loam over silty clay” class, while the texture of “lighter” soils varies mainly between sandy loam, loam and sandy clay loam and only exceptionally becomes as light as loamy sand.

-Land Use

The agricultural potential of the upland of the entire basin is limited. The limiting factors are soil depth, slope steepness, and stoniness and rockiness. By contrast, the nearly level lands in the lower parts of most of the basin, such as the area south west of Sulaimani (part of Piramagroon plain), Zalm, Halabja, and SaidSadiq sub-basins, are more important for agriculture. Most parts of the basin are barren of trees; only 20% is sparsely covered with oak tree. The dominant tree species is *Quercus aegilops*; *Quercus infectoria* and *Quercus libani* can be found with *Quercus aegilops.*(Barzinji,2003). These trees exist along steep slopes and the summit of Avroman, Suren, Kura Kazhaw, Shinrawe and Balambo Mountain.

Dry farming is practised over most of the area, while summer cropping is practised in most plain areas of Sharazoor and Halabja.

The authors of Polservice (1980) classified most of Sharazoor and Halabja area into different classes based on suitability for irrigation land. The table below shows land use capability for the present case and potential lands for future development.

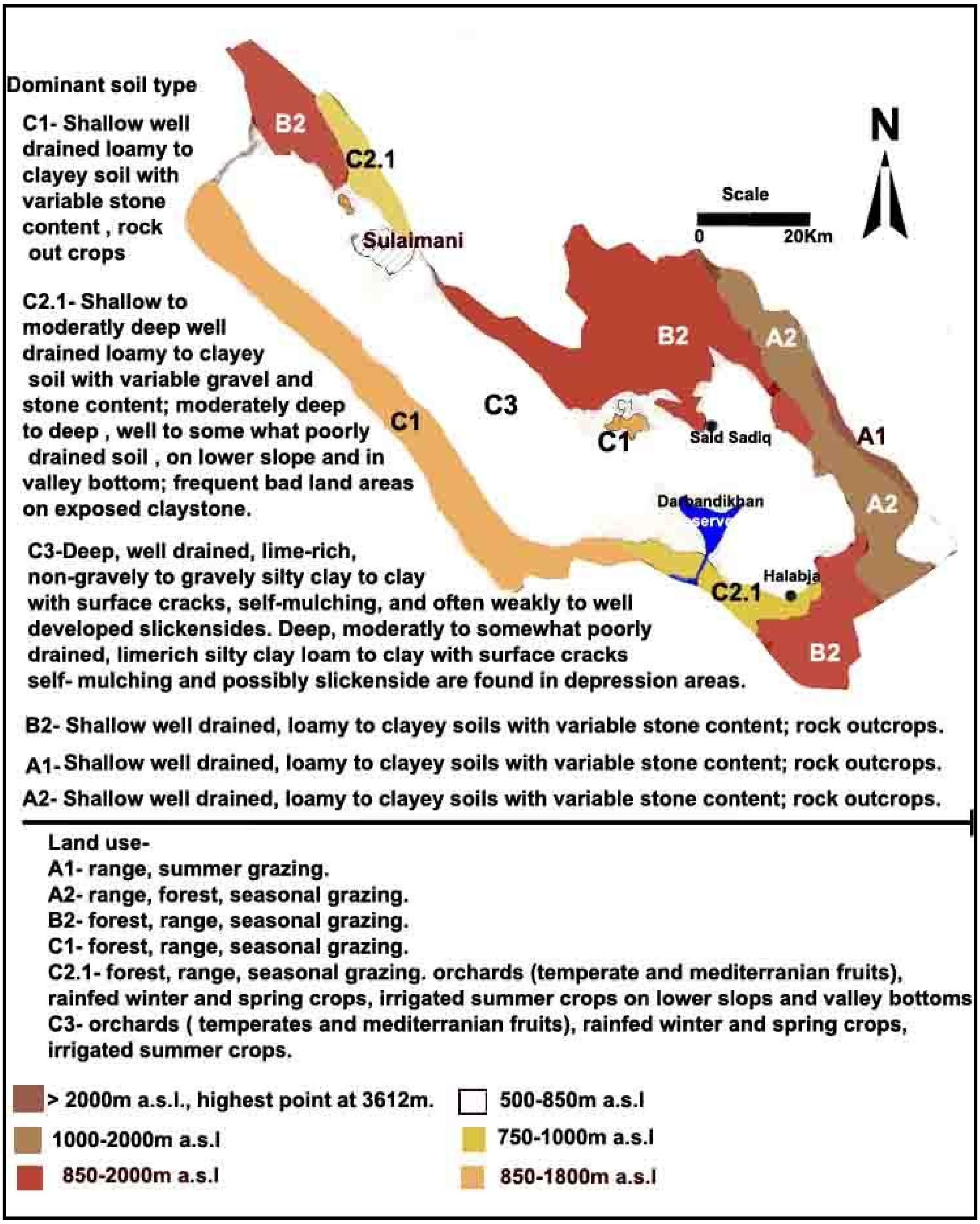

Fig.1.2 Dominant soil type and land use of Sharazoor-Piramagroon basin (Berding, 2003)

1.4 Division of the basin into four sub-basins

Because of the great length and extensive surface area of the basin, in addition to differences in stratigraphy and lithology, it was found that subdivision of the basin into four sub-basins would simplify the discussion and graphical presentation on suitable scales. Division also allows for some sub-basins to be described more precisely than the others according to important and accessible data and factors.

The four sub-basins are named according to the main town, village or plain that is included in the basin. These sub-basins are shown in figure 1.3.

Generally the Sharazoor-Piramagroon basin has a long and irregular shape, but it more or less resembles a scoop where the two eastern sub-basins make up the head of the scoop while the two western ones make up its handle. The names (as proposed in this study) and locations of the sub-basins are as follows:1 - Sulaimani sub-basin, 2 - Arbat-Zarain sub-basin, 3 - Said Sadiq sub-basin, 4 - Halabja-Khurmal sub-basin. From this point on, each sub-basin is referred to by the numbers 1-4 above.

Sulaimani sub-basin (SB1)

This sub-basin is located at the extreme northwest of the studied basin which includes the Sulaimani city which is the center of Governorate and the second main city of northeast Iraq. It has a surface area of more than 582 km^2 and a maximum width and length of 15 and 32 km respectively. All the surface runoff and most of the groundwater discharge of this sub-basin are drained exclusively to the Darbandikhan reservoir by Tanjero stream which collects water from tens of tributaries.

- Most of the valley surface consists of gently sloping plain to the west and south of Sulaimani City. The rest consists of the rock-covered mountains of Piramagroon, Azmir and Goizha in addition to Chachaq valley, which is located in the northwest of the sub-basin. The basin boundary at the north, northeast, and northwest, west, south and southwest consists of flow divide on the summit of Azmir, Goizha, Piramagroon, Tasluja and Baranan mountains (or anticlines) respectively. The south and southeastern boundary consists of an arbitrary straight line that connects one point on the northern boundary at latitude (35º 30´ 36˝) and longitude (45˚ 30́ 0˝) and other point on the southern boundary at latitude (35˚ 26́ 24˝) and longitude (45˚ 25́ 24). This line passes through Weladar village and Tanjero Bridge on the road between Sulaimani city and Qaradagh town (Fig.1.3).

Table1.1 Land Use Capability Classification (present-Potential, after Polservice, 1980)

Soil Series	Land-Use Capability Class		Description Of Terms
	Present	Potential	
1	2	3	
Plain Soils			
Grdi Naze-Malawais	3s 3s 3s	2s 2s 2	Classes 1,2,3,4,5,6 1-Arable land areas 2-Arable with moderate suitability 2s –Arable lands with some soil limitation(fissures, texture) 2sg-same as above with some soil limitations, such as (fissures, stony surface, fine grained soil). 2sw-As above, but with soil limitations (fissures) and texture(s) and water logging. 2g-As above with gravely or stony surface (g). 3-Arable capable for cultivation ,but with clear limitations(topography(t) ,water logging(w),soil depth, fissures), Texture(s),and gravely or stony surface(g) 3stg-As above but with soil limitation (gravely and stony surface) with moderate slopes. 3s, 3g, 3sg, 3w- As above with limitations of (g, w, s). 4- Area of reduced capability which can be utilized only after introduction of special farming methods, with serious limitations. 4g, 4s, 4sw, 4stg-with limitations regarding (g,s,w,t). 5-Non-arable areas, with serious limitations such as frequent flooding and poor drainage as well as textures. 6-Non-arable areas in the present in future. 4/6-Now unsuitable for agriculture cultivation, but potentially (after land reclamation measures)could be classified in class 4 with soil limitations and gravely surfaces.
Sharazoor	2s 2s 2s 2s 2s 2sg 2sg	1 1 2 1 2 2 2g	
Sirwan	3sw 3sw 3sw	2s 2s 2s	
Malawais-Gerdi Nazy	3s 3s 3s 2s 2s 3sg 3sg	2 2 2 1 1 2sg 2sg	
Basharati	4sw	2s	
Cone Soil			
Zamaki	3sg 3sg 3sg 3sg	2s 2s 2s 2s	
Halabja	4sg 3sg 3sg 3sg 3s	3sg 2sg 2sg 2s 2s	
Arbat	3st	3s	
Foothill Soils			
Mwan	4stg 4stg 4stg 4stg 4stg	3sg 3sg 3s 3g 3sg	
Khurmal	3stg 3tg	2sg 2g	
Hilly Soils			
Saraw	6stg 6stg 6stg	4/6sg 4/6sg 6sg	
Tanjero-saraw	6stg	6gs	

- Arbat-Zarain sub-basin (SB2)

This sub-basin is located nearly at the center of the Sharazoor-Piramagroon basin which contains the famous town of Arbat and Bestansur, Kani Panka, and Greza springs. It has a surface area of more than 789.4 km^2 and a maximum width and length of 19 km and 35 km respectively. The sub-basin has an irregular and elongated shape. Like the previous sub-basin, all the surface runoff and the groundwater discharge of this sub-basin are drained exclusively to the Darbandikhan reservoir by Tanjero stream. Nearly all (80%) of this Sub-basin surface consists of gently sloping plain which now makes up the main cultivation land in the sub-basin.

The basin boundary at the north, northeast, south and southwest are bounded by the summits of Goizha, Barda Kar, Baranan and Bakir Agha mountains (or anticline) respectively. The northwest boundary coincides with that of the southeastern boundary of SB1. The eastern boundary is indicated by the water divide line that is located along the Kani Panka and Mowan hills (anticline).

- Said Sadiq sub-basin (SB3)

This sub-basin is located nearly at the northwest of the Sharazoor-Piramagroon basin which contains the town of Said Sadiq and most of the large karstic springs such as Reshen, Saraw, and Mowan springs. It has a surface area of more than 706 km^2 and is semi-circular in shape. All the surface runoff and the groundwater discharge of this sub-basin are drained to the Darbandikhan reservoir by the Chaqan and Surajo streams. The basin boundary at the north, northeast is indicated by the runoff divide line at the summit of Kura Kazhaw and Suren mountains (or anticline) respectively. The western boundary is 2 km to the west of Khurmal town.

- Halabja- Khurmal sub-basin (SB4)

This sub-basin is located at the extreme east of the Sharazoor-Piramagroon basin and named in reference to its two largest towns, Halabja and Khurmal (Fig.1.3). The basin is nearly rectangular with equal sides. It has a surface area of more than 534 km^2 which contains many large springs such as Zalim, Chawg, and Biara springs. All the surface runoff and the groundwater discharge of this sub-basin are drained to the Darbandikhan reservoir by Zalim and Biara streams. The basin boundary at the north, northeast, and east coincides with the summits of Avroman, Shinrwe and Balambo mountains.

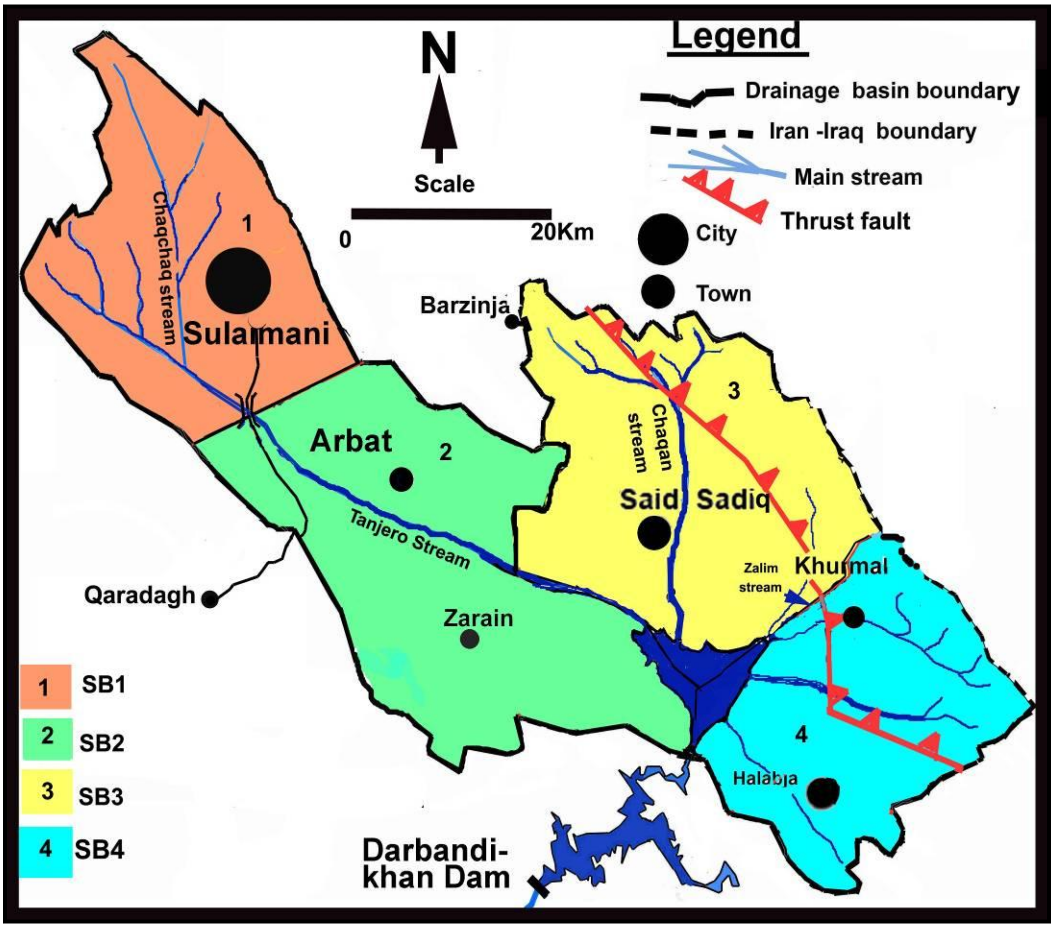

Fig. 1.3 Sub-division of the Sharazoor-Piramagroon basin into four smaller sub- basins

1.5 Previous Studies

As cited in the study of Stevanovic & Iurkiewicz (2004), the first mention of the hydrogeology of Sulaimani area was by Mac Fadyen (1938; *Water supply of Iraq)* who discussed the water supply problem in the town of Sulaimani and elsewhere in the district. During the 1950s, investigations of groundwater resources were intensified by Parsons Company (1957) who started investigations throughout Iraq and included collection, evaluation, and correlation of geological and hydrogeological information of groundwater in the area available at that time.

The study of Sulaimanyia Liwa was completed in 1957. A rough preliminary assessment of safe yield was considered and all the available drilled and hand dug wells, Kahrezes and springs were inventoried. Most of the studies performed on the scale of Iraq and Northern Iraq predominantly covered the area of Erbil basin (200 km west of Sulaimani City); unfortunately, the share of Sulaimani area from these studies was brief. Many other studies exist but most of them relate only indirectly to either hydrology or hydrogeology and are concerned only with a small part of the area. Among these was the Polservice Hydrological Co. (1980) that studied the Hydrological condition of Sharazoor plain.

Cwiertniewski (1961) prepared a report on the water supply of Sulaimani city. He was the first who believed that Sarchinar spring is fed by solution channels in limestone.

El-Yossif and Al-Najim (1977) studied the hydrology and water quality of Sarchinar spring. They estimated the average annual flow rate of Sarchinar spring for the period 1962-1973.

The Hydrogeological assessment performed by Energoprojekt, Belgrade (1981) on the Kaolos Dam site and Shanadari area could be considered the most detailed one achieved until the commencement of the comprehensive and systematic regional study by FAO in 2000.

Mam Rassol (2000) studied the influence of groundwater quality and the chemical constituents in Sulaimani area on the corn crops.

Al-Manmi (2002) studied the hydrogeology and hydrochemistry of Sulaimani city and its outskirts. His Msc thesis was more focused on the environmental and hydrochemical assessments than on quantitative assessments.

Ali and Ameen (2005) studied the hydrogeology and hydrochemistry of Zalim Spring at the Northeast of the studied basin.

Al-Rawi et al (1990) studied the main geological, structural, and stratigraphical settings of the Sarchinar Spring without any explanation of the regime and mechanism of the spring flow, but, as a result of the detection by geoelectrical survey of some underground openings near the spring, they referred to some karstic nature of the aquifer.

Karim and Ali (2004) discussed through detailed field geological investigations the development of the western part of Sharazoor plain and they presented a conceptual model explaining the stages of this development plain. They attributed the development to the vertical and lateral erosion of Tanjero stream which activated the sliding of huge limestone masses during Holocene. The results of this study motivated the second author (Ali, 2005) to conduct a study on the groundwater occurrence along the frontal area of these huge slide masses, and to explain how these slide masses caused the diversion of some groundwater flow direction toward the northeast and, consequently, the formation of local shallow aquifers.

The hydrological study of Barzinji (2003) covered some parts of the Piramagroon-Sharazoor basin. He achieved morphometrical and a few hydrological analyses for Zalim, Chaqchaq, Chaqan and Goizha Dabashan watersheds.

Stevanovic and Markovic (2004) and Stevanovic and Iurkiewicz (2004) studied, through a comprehensive program of FAO, the regional geology and hydrogeology of the three northern governorates (Sulaimani, Erbil and Dohuk), which could be considered the first regional and systematic hydrogeological study conducted up to the present time. Other studies in the area are mentioned but the related reports are not available.

Ali et al (2007) studied the mechanism of the flow of Sarchinar spring through the application of auto and cross- regression analysis to demonstrate the nature of the karstic system of the aquifers feeding this large spring.

More recently, Al-Tamimi (2007) achieved regional assessments of the surface and groundwater resources of the middle part of Diala river basin. Part of this study covered the Piramagroon-Sharazoor basin as the upper sub-basin of Diala basin. He demonstrated the possible conjunctive use of both surface and groundwater resources.

Few ecological studies have been performed on water resources in certain parts of the basin individually; among these, Maulood and Hinton (1978) studied the ecology of Sarchinar spring water, taking into consideration physical and chemical aspects .Two years later the same two authors published their paper on the pollution ecology of Kiliasan River in the Northwestern part of the basin resulting from both domestic and industrial sources.

Mohammed et al. (1980) studied the influence of the Sulaimani Sugar factory on the levels of some trace heavy metals in the same river.

Ibrahim in his MSc Thesis (1981) studied the ecology of some selected springs in Sulaimani province, among which some springs in this basin, such as Sarchinar, Khurmal, Greza, Zalum, Saraw, Biara and Kani Panka springs, were incorporated.

Recently, an ecological study on the aquatic life of Sarchinar, Chaqchaq and Kiliasan streams in the Sulaimani area was conducted by Muhammad (2004). This study was followed by the latest attempt of Mustafa (2006), who investigated the impact of sewage wastewater on Tanjero River, Kiliasan Stream, groundwater, sediment and soil of the area west and south of Sulaimani City.

Due to the unstable political situation, no systematic hydrogeological investigation was conducted in the area between 1990 until 2000. Moreover, only part of the detailed topographical or geological maps, aerial photos, studies and reports were saved and are available at the local universities, in other local governmental institutions or in private libraries. Limited availability or, in some cases, a total lack of technical equipment (hydrogeological, hydrological and geophysical) resulted in the use of inadequate methodology in the selection of drilling sites, well-developments and field measurements in general. Until the last few years, no accurate and adequate hydrogeological maps, essential for planning any groundwater exploration and exploitation, were available for northern Iraq or some targeted areas. Also, crucial data regarding well exploitation capacity, major springs discharge and groundwater level fluctuations have not been collected in a systematic manner. Recently, FAO GW programme (since 2000), which the author of this thesis also participated in as a consultant, has started to fill these gaps and provide a base for better groundwater management in the region.

In conclusion, there is still no detailed and systematic study of the hydrogeology of the Iraqi Kurdistan region including Sulaimani area. This dissertation intends to contribute to framing a relevant hydrogeological base for more detailed analysis, considering the importance of groundwater use for water supply and irrigation.

1.6 Aim of the study

This thesis focuses on the following goals:

1- Performance of regional geological and hydrogeological investigation of the basin. This includes preparation of geological and hydrogeological maps, cross-sections and columns to show the relation of the available groundwater to the topography, lithology, stratigraphy, and structural geology.

2- Assessment of groundwater resources, including the assessment of the aquifers' characteristics (geometry, recharge, discharge, hydraulic parameters and groundwater circulation).

3- Groundwater quantity (the balance and estimation of the total reserve of the main aquifers and available resources/safe yield for exploitation in selected promising areas);
4- Groundwater quality (hydrochemical zoning, water validity for drinking and irrigation).
5- Analysis of groundwater regime (groundwater table and spring yield versus time, amplitude and parameters, estimation of minimum yield in recession period).
6- Provision of recommendation of the best possible groundwater practice and proposals for groundwater control projects in the area.
7- Consideration of water resource conservation, watershed managements, and proper planning for drilling deep and shallow wells in a way to optimize the balance between yield and annual recharge of the aquifers.

1.7 Methodology

The first step included the collection, systemization and analyses of all available documentation in the hydrology, geomorphology, geology and hydrogeology of the basin and wider area of north-east Iraq.

Field work started in September 2004, lasted two years, and covered the following systematic activities:

1. Detailed geological survey, mapping all geological formations, structures, and geomorphological features for the entire basin and some surrounding areas.
2. Inventory of the most remarkable and representative water points: deep and shallow wells, hand dugs wells, springs, kahrezes, streams. Checking their exact positions and measuring their discharge (as much as possible).
3. Sampling of water from 101 deep wells, 67 shallow wells and 43 springs for chemical analyses and some biological analyses, besides *in situ* measuring of temperature, pH, electrical conductivity and total dissolved solids (TDS). Multi-parameter portable device type (90-FLT TPS) was used for this purpose. This was carried out during the least recharge period of October 2005.
4. Installation of gauging stations in five major springs for discharge measurements and flow measurements by gauging staff, existing bridges, and weirs and occasionally by home-made v-notch. Digital current meter

type (SIAP/BOLOGNA-Denominazione; CE 9615) was used for measuring the flow rate. Daily measurement was followed for each station. In addition, some rough discharges measurements were achieved for some main streams and valleys at different sections and during different periods of the year (as much as time permitted).

5. Weekly and monthly monitoring of seventeen deep wells (with piezometers installed). This was carried out by using an electrical sounder for measuring static water levels.
6. For the determination of some of the hydraulic parameters of the aquifers, short duration (180-500 min) pumping tests on 22 production wells covering the majority of and the dominant aquifers of the basin. These tests were performed during October 2005.

Laboratory work focused on the chemical and biological analysis of water samples, for major cations and anions and some trace elements. All the samples were analyzed in the Laboratory of Chemistry department of College of Science, Sulaimani. Some samples were analyzed twice and some were analyzed in the department of Geology / University of Sulaimani for accuracy checking. The techniques used for water analysis are the standard methods of water analysis as specified by the APHA (1975, 1995) and other approved procedures. A summary of the laboratory works are shown in table 1.2.

Bacteriological analysis was performed by using most probable number (MPN), as followed by Sharma (1998). Total Coli form and Faecal Coli form were surveyed.

Desk study – parallel to the continuous field and lab work, all the documents and data obtained were elaborated on and prepared with the results of field data and laboratory results data for analysis. Preparation of different maps and diagrams was an important part of the desk work.

Different software and programs were used in this study for analysis and mapping, among them, Aquitest version 3 for pumping test data analysis, Statistica 6.0 for statistical analysis, particularly for time series analysis of daily spring discharge –rainfall data analysis. Rock ware (RW2002-2004) was used for some geological calculations.. For some mapping, sketches, cross-sections, Grapher 4.0, Photoshop 8.0 and Surfer 8.0 were used. Finally, Arc view 9.0 MapInfo version 9.0, and Autocad 2004 were also used for maps belonging to the basic data base and morphometrical analysis. For hydrochemical data presentation, Piper, stiff diagrams AqQA software was used.

Table 1.2 Summary of Chemical and biochemical analysis methods used for this study

Analysis	Method	Instruments	Reference
Ca^{+2}, Mg^{+2}	titrimetric method	-------------------	Bartram and Ballance, (1996)
Na^{+} , K^{+}	Flame Photometry	Flame photometer	APHA (1998)
HCO_3^{-2}	Titration	Normal Instruments for wet analysis	Abawi and Hassan (1990)
SO_4^{-2}	Titration	Normal Instruments	APHA,(1995)
NO_3^{-}	Spectrophotometric	Spectrophotometer	APHA, (1998)
Cl^{-}	Titration	Normal Instrument	Bartram and Ballance, (1996), APHA, (1998)
Cr,Pb,Cu, Cd,Zn ,Ni	Spectrophotometric	Atomic Absorption	APHA (1998) Bartram and Ballance, (1996)
Total Hardness	Evaporation	Normal Instrument	Abawi and Hasan (1990)
TDS	Evaporation	Normal Instrument	APHA (1975)
BOD	Titration with Sodium thiosulfate	Normal instrument	Winkler Method APHA (1998)
COD	Reactor type Hatch DR2010	Normal instrument	Health protection method

Chapter Two

Climate and Hydrology

2.1 Climate

- General Climate of the Region

The Iraqi Kurdistan Region has a distinct continental interior climate with hot summers and cold winters of the Mediterranean type. The hottest months are June, July and August while the coldest months are December, January and February. During summer, the region falls under the influence of Mediterranean anticyclones and sub-tropical high pressure belts. In winter, the region is invaded by Mediterranean cyclones moving east to north-east through the region. In addition, the Arabian Sea cyclones move northward in this season pass over the Gulf carrying a high amount of moisture which causes a lot of precipitation in the region. The region is also exposed to the influence of very cold polar air masses migrating with the polar jet streams downward to the Gulf, (Aziz, 2001: cited in Stevanovic and Markovic, 2004). The autumn and spring are very short with mild temperatures.

The climate of northern Iraq is characterized by clear seasonal differences, caused mainly by the change in the type of atmospheric circulation during the year, and by the intensity of the insulation.

In the cold season, this part of southeastern Asia is influenced more by the Mediterranean front. As a result of the contrast between the cold European air and warmer masses of air from northern Africa, a frontal zone of high pressure develops over the Mediterranean area; disturbances of cyclonic character occur frequently along this zone. Some barometric depressions stray to the east and break through these high-pressure areas, reaching Iraq. This does not occur frequently, however, and the precipitation on the cold front is short and boisterous. In summer, the thermal differences between the air masses are much less, and also the circulation systems, which support them, are weaker (Polservice, 1980; Stevanovic and Markovic, 2003).

The mean annual air temperature in the northern part of Iraq is high (approximately 20 ºC), although slightly lower than in the south and middle parts (23ºC in Baghdad). January is the coldest month of the year but generally the mean temperature does not drop below 5 ºC. However, the temperature can drop to minus 15ºC, but only on days when northern and northeastern air masses rush in. The mean temperature in July and August in this part of Iraq exceeds 30ºC; in fact, temperatures exceeding 45ºC are often recorded. Because of the high frequency of days with sun radiation the 24-hour temperature amplitude often reaches high value. Concerning the number of so-called the thermally characteristic dates, the mean number of days with a temperature exceeding 40ºC is 80-100 annually.

In winter, in northern Iraq winds from the northern sector prevail, while in summer, western and southwestern winds occur most frequently. Generally, the average wind velocity in the individual months of the year does not exceed 5 m/s. In summer, the total cloud cover is limited and clear weather predominates. The average annual air humidity is 40-45%, and it exhibits a high seasonal diversity. In January, humidity approaches approximately 70% while it drops to below 20% in July and August. Moreover, the relative humidity in this zone exhibits large 24-hour fluctuations, understandable in view of the high 24-hour air temperature amplitude. In the climatic zone under discussion, fog occurs rarely, depending on the distance from the hydrographic network and water-logged areas. Foggy days usually occur in December and January, and their total number throughout the year does not exceed 20.

In addition, the basin is located at the boundary of major deserts of the Middle East; therefore both the weather and climate are variable. The climate is greatly affected by the dusty and warm wind that blows from the southern and western desert of Iraq, Jordan and Saudi Arabia. Dust storms raise the daily temperature to a maximum value of more than 45º C (Polservice, 1980).

- Precipitation

The annual rainfall in the region is not much less than that in most European countries, but its distribution is different: it is exceptional to have rainfall between June and September. The topography also has a great influence on the rainfall distribution. The precipitation increases from SW to NE, reaching its maximum at the highest altitudes of the Avroman and Suren mountains ranges on the wind sides (the southwestern side) near the Iranian border.

The three stations in Sulaimani (1941-2006), Dokan dam (1958-2002) and Darbandikhan dam (1962-2002) have made observations over long periods, while other smaller surrounding stations (Chwarta, Penjween, Halabja, Arbat, Sharazoor Said Sadiq, Kani Panka, Ahmed Awa) do not have accurate and complete data covering more than two or three years.

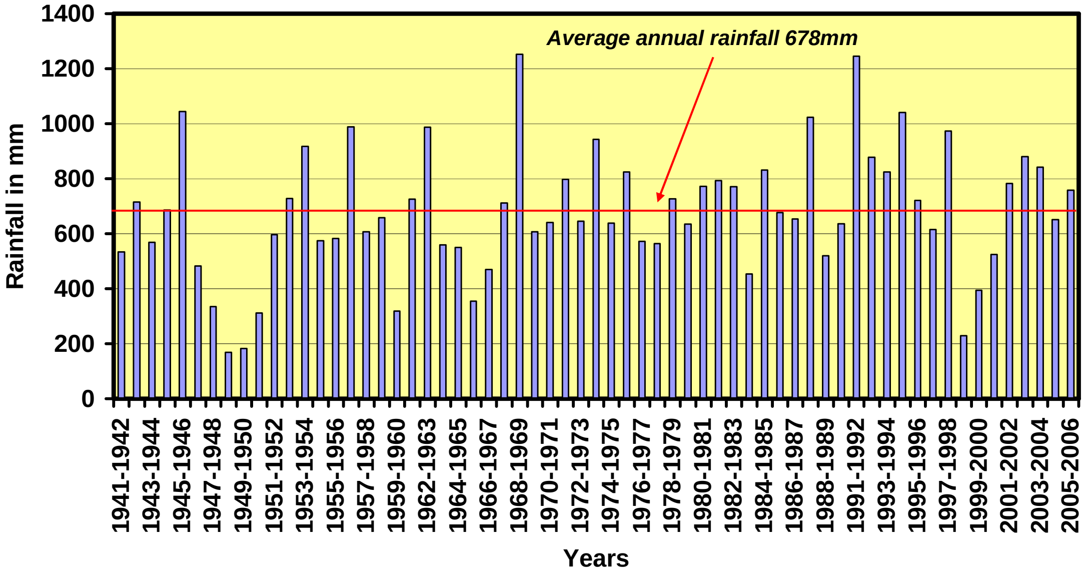

Fig.2.1. Annual rainfall in Sulaimani station 1941-2006.

The longest period of recorded data observed at the Sulaimani rainfall station showing an annual average precipitation of 678mm is for the years1941-2006 (Fig.2.1). The total seasonal minimal rainfall registered at this station is 169mm in 1948 -1949. The most severe drought years are from 1947-1951, the most recent, from 1998-2001. The maximum seasonal annual sum, which occurred after two consequent drought seasons, was registered in 1968-1969 (1252.3mm). Similar values have been registered at two stations located close to the Dokan and Darbandikhan dams. Average annual rainfall is 682mm and 772mm at Darbandikhan and Dokan dams respectively. The absolute minimal sums for the two stations were 326mm and 392mm, registered in 1999.

Typical characteristics of the climate of Northern Iraq are the cycles of dry and wet years. The existence of short and longer-term duration cycles has also been detected. For example, the Darbandikhan and Sulaimani stations registered a cycle of 4 successive years of drought (1964-1967) followed by two very wet and rainy years. Similar cycles occurred by the end of 1970s, as well as in the mid 1980s, but with a shorter dry period of two years and only one compensatory rainy year. The last recorded drought cycle started in 1999. The data collected by FAO throughout the Iraqi Kurdistan Governorate for October 1999 - April 2000 show a reduction of about 50% compared to the average rainfall for this period of the year. During the previous wet season (1998/1999) the recorded rainfall was only 30-35% more than the average rainfall for the area. At Darbandikhan, the recorded sum of 1005 mm represents the third maximal rates in the last 40 years (Stevanovic and Markovic, 2004).

In principle, the main recharge of ground water derives from the infiltration of rainfall and percolation of surface waters from perennial rivers or ephemeral streams. Thus, analyses of climatic elements such as rainfall, evapotranspiration and runoff are essential for balancing the ground water. In addition to rainfall data from some nearby stations recently established by FAO and operational since April 2000, such as Halabja, Said Sadiq, Penjween, Arbat, Chwarta and Barzinja stations, various historical data have been collected from Sulaimani and from Dokan and Darbandikhan dam stations,. The former have the only regularly recorded data for the years 2001-2003. The variation of annual rainfall at some of these stations is shown in fig.2.2. The average monthly rainfall variation at the same stations is shown in fig.2.3. Apart from Penjween and Barzinja stations which show higher monthly rainfall, the data from the other stations are more similar to that of Sulaimani station; hence it can be said that data from the Sulaimani station represent an average of the wider area.

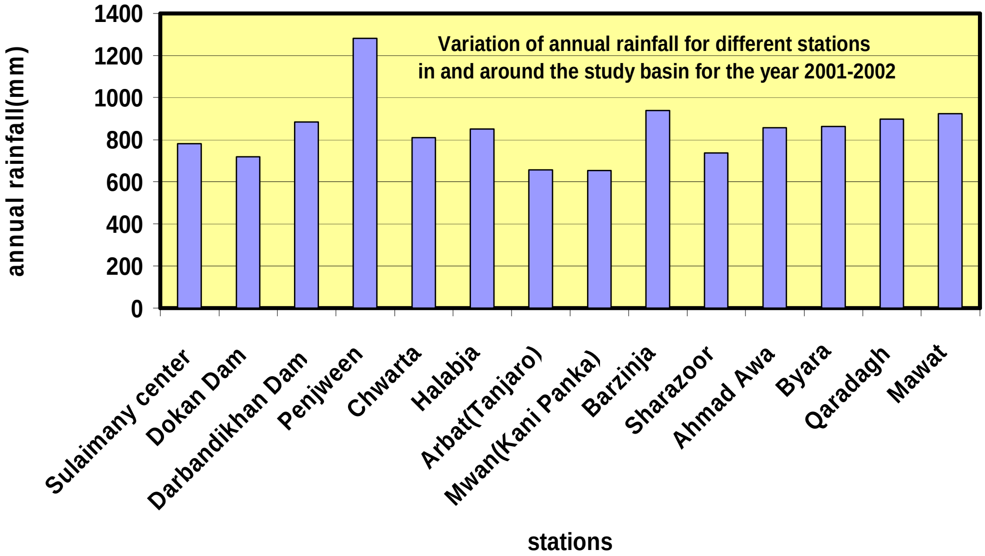

Fig.2.2 Variation of annual rainfall for the stations in and around Sharazoor-Piramagroon basin, for the year 2001-2002.

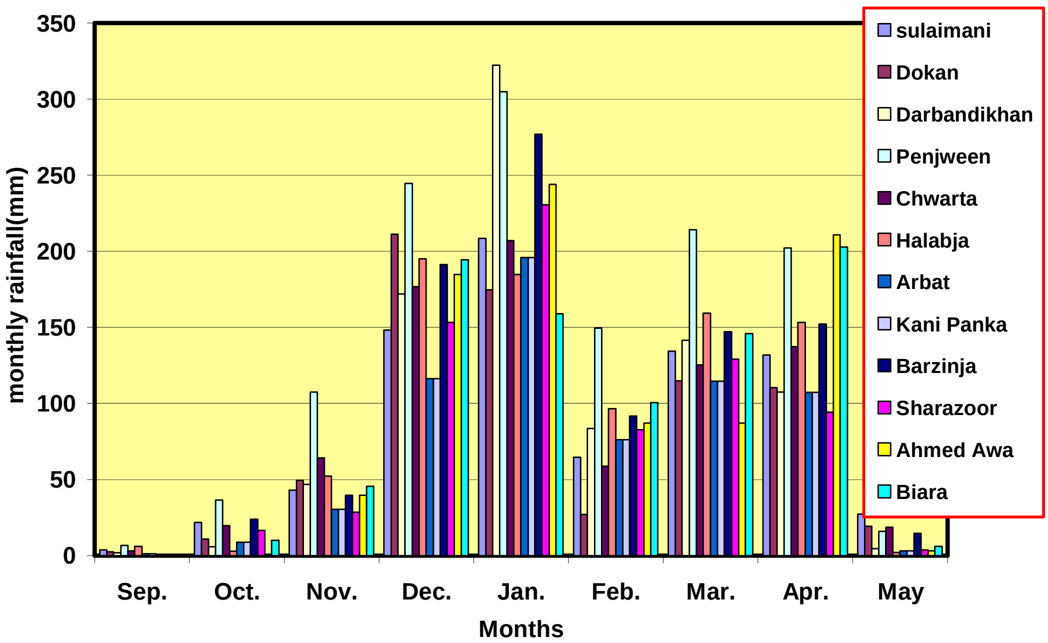

Fig.2.3 Monthly rainfall variation of the metrological stations in and around the study basin for the year 2002-2003.

Due to the lack of metrological data for the surrounding and other metrological stations in and outside the basin, rainfall and temperature data for the years 1980/1981-2005/2006 in Sulaimani station are used for water balance analysis. This station could be considered relatively representative of most of the entire basin because, as shown in figs 2.6 and 2.7, the orientation of all the isohytal lines are essentially parallel with the orientation of the longest dimension of the studied basin. This means that there is no significant variation along this dimension which passes nearly through the center of all the four sub-basins. However, to estimate the annual recharge amount for the mountainous areas on the transverse direction and located in the north, northeastern and northwestern parts of the catchment of the main karstic springs, some empirical estimation of precipitation was applied. These empirical data were derived from the available data of Chwarta station. Excellent correlation coefficient (0.99 for rainfall and 0.97 for temperature) is found between both stations and Sulaimani station for the year 2002-2003 (Figs.2.8 and 2.9), and the extrapolated equations were used to calculate the expected monthly rainfall and temperature for those high elevated areas located inside the basin.

To a certain extent the data of Penjween station could be representative of the high mountainous belt comprising the north, northeastern and eastern parts of SB3 and SB4 i.e. Suren and Avroman mountains with elevations around 1800-2500m a.s.l. and an average annual rainfall of 1000mm. Initially, in order to avoid any misleading results, it was preferable to avoid the optimistic data to estimate water balance, particularly according to the 38-year rainfall data of 1941/1942 to the end of 1978/1979 mentioned in Polservice (1980), where more than 60% of the data are above 1000mm annual rainfall.

For rainfall: $P1 = 1.042\ P2 + 1.0845$

P1 =precipitation (at elevation 1200m) (mm)

P2 = Precipitation (average monthly of Sulaimani station) (mm)

For average monthly temperature (t): $t1 = 1.0\ t2 - 3.34$,

t1= average monthly temp. (at elevations 1200m)(C^0)

t2= average monthly temp. (at Sulaimani station)(C^0).

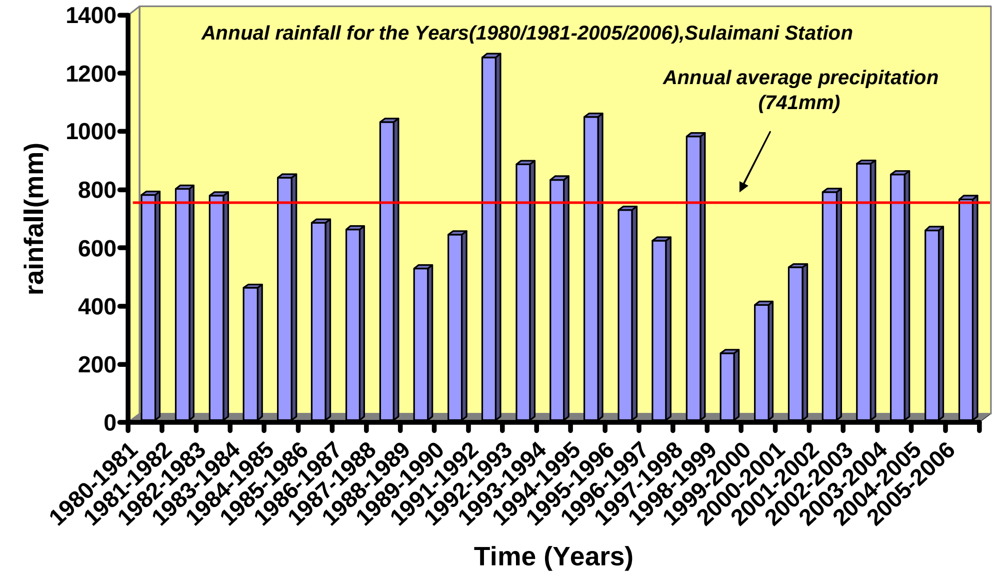

Fig. 2.4 Average annual rainfall at Sulaimani station for the years 1980-2006

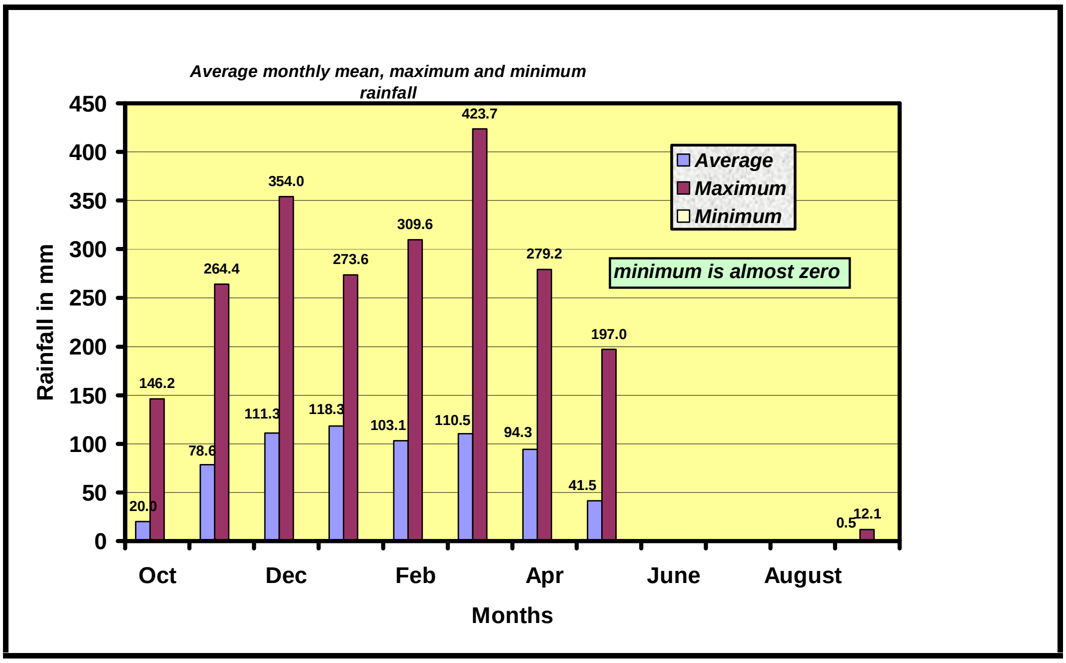

Fig.2.5 Average, maximum and minimum monthly rainfall at Sulaimani Station 1942-2006.

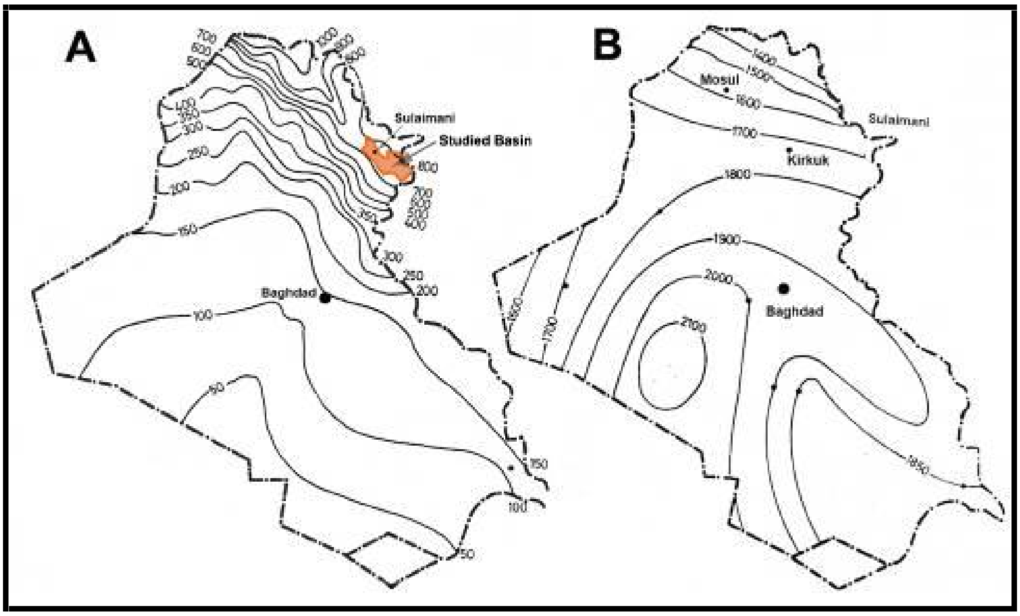

Fig.2.6 A -Isohytal map of annual mean precipitation of Iraq (Hassan et al, 1978, cited in: Al-Sayab et al, 1982). B- Isohytal map of annual evapotranspiration of Iraq. (Kinana et al, 1974, cited in: Al-Sayab et al, 1982).

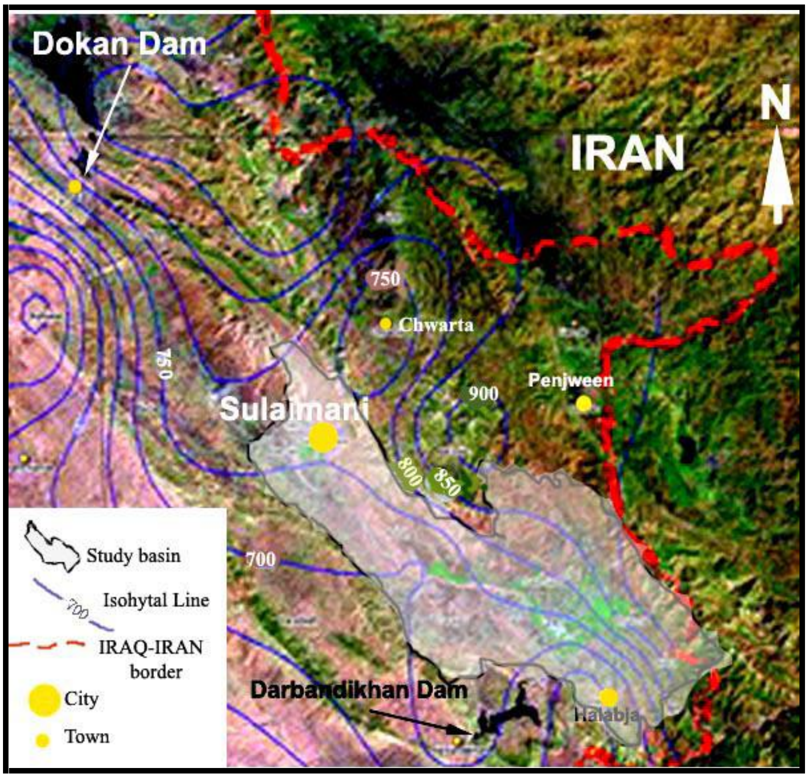

Fig.2.7 Isohytal line of the study area, based on the average data of metrological stations of north Iraq (FAO - Agrometerology-Iraq, 2003)

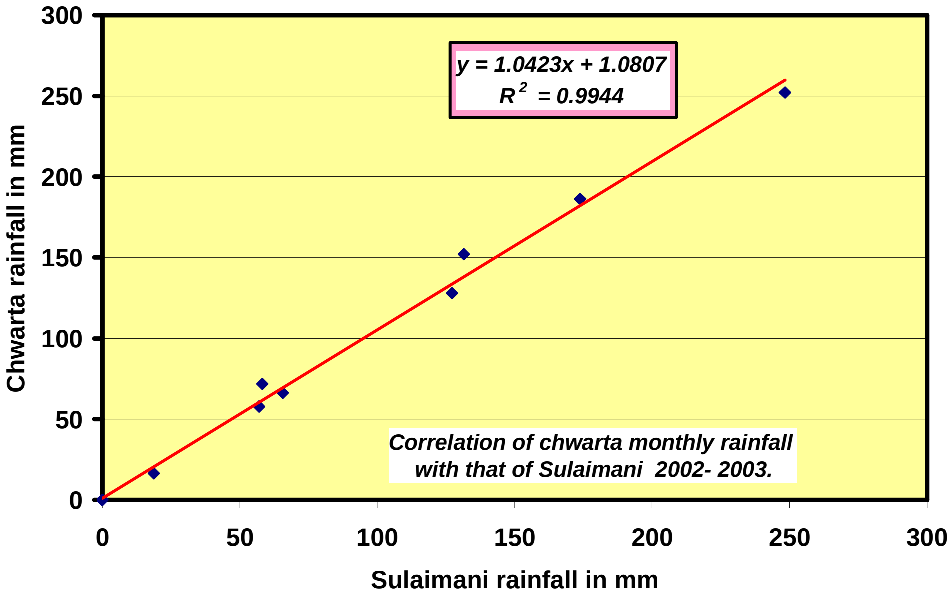

Fig.2.8 Correlation between average monthly precipitations at Chwarta station with that of Sulaimani station for the year 2002-2003.

- Daily rainfall and intensity

Due to the political instability of the region since the beginning of the 1960s, important daily rainfall data are missing either because there were no records made or because these data have been handled carelessly. It is important to note that the daily mean precipitation in mountainous areas during the wet season is usually above 5mm/day, which is estimated as the required minimum for aquifer recharge (in case of low intensity rain). In the plains (southern part), the daily amount is often lower and, due to high soil moisture and air humidity deficit, produces the absorption of all predictable water by the soil and vegetation. Thus, deeper percolation and aquifer rechargeable potential in such cases is reduced (Stevanovic and Markovic, 2004).

The warm and arid continental climate is negatively affected by the availability of both surface and groundwater as the precipitation is limited to less than 750mm--while in some years it diminishes to less than 300mm. During summer, the warm climate puts pressure on both the ground and surface water for irrigation, drinking, livestock and industrial uses. Another effect of the warm climate is high evapotranspiration in the area which is aided by low humidity in the summer.

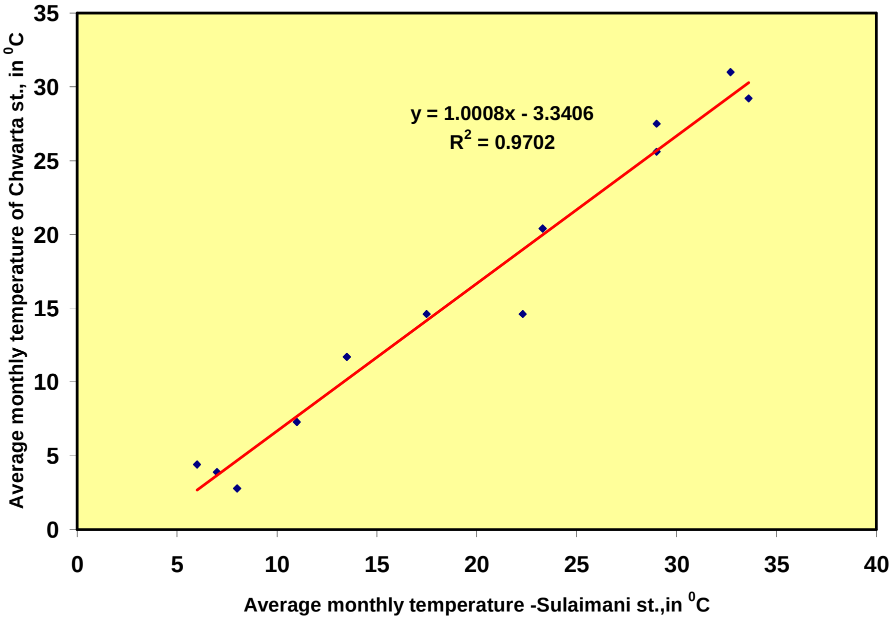

Fig.2.9 Correlation between monthly temperatures at Chwarta station with that of Sulaimani station for the years 2002-2003.

2.2 Water availability and water losses estimation

When water balance for a certain area is used and the output data are not available, empirical approaches are usually considered based on hydrometrological data. Thus the input parameters for such water balance are used to clarify a possible period of water surplus and deficit. These parameters are mainly of two groups. The first group represents the elements of water availability, while the second includes elements of water losses. The water balance technique can provide useful insight into both ground water recharge and aquifer characteristics. The significance of this balance over a period of many years in a catchment area can be simplified in two assumptions. The first is that the values of soil moisture storage and surface water storage are almost the same at the beginning and at the end of the balance period. The second is that the groundwater levels are the same at the beginning and end of the balance period. Thus, the water balance equation can be written in the following simplified form:

$$P = Rs + I + AET \pm R \pm E$$

Where:

P = Precipitation, Rs = Surface runoff, I = *Infiltration,* AET =Evapotranspiration, R = annual variation of water reserves, E = possible error in calculations.

As an aforementioned $\pm R$, $\pm E$ could be neglected temporarily, in case the balance equation is considered the longer period.

The input parameters of the water balance equation can be used to clarify possible periods of water surplus and deficit (Hasan, 1998). These parameters represent the water availability and water losses elements.

- Rainfall

Rainfall is the most important parameter in the water balance and aquifer recharge. The study area is a part of the region influenced by the Mediterranean climatological system, so rainfall occurs exclusively during winter and spring season. The maximum monthly rainfall recorded was 354 mm in December of 1991-1992. The maximum average monthly rainfall for the years 1980-2006 is 131mm in December. The mean annual rainfall was 741mm during the period of 1980/1981-2005/2006. About 52% of the annual rainfall was more than the annual average. Fig.2.10 shows the mean, maximum and minimum monthly rainfall for the period (1980-2006).

Most of the annual rainfall occurs in the eight months from October to May. The four remaining months are regularly dry. During the winter season, snow falls on the upper part of the surrounding mountains. A considerable number of thunderstorms and hail might occur in winter and spring. The recorded rainfall storm intensity in the area of study is seldom in excess of 10mm/hr. In Sulaimani, from 2-15 February 2006, 274 mm fell, of which 130 mm was recorded in one day only (3^{rd} of February).

A five-year moving average is used to minimize the random variability of the average annual rainfall as shown in fig.2.11.

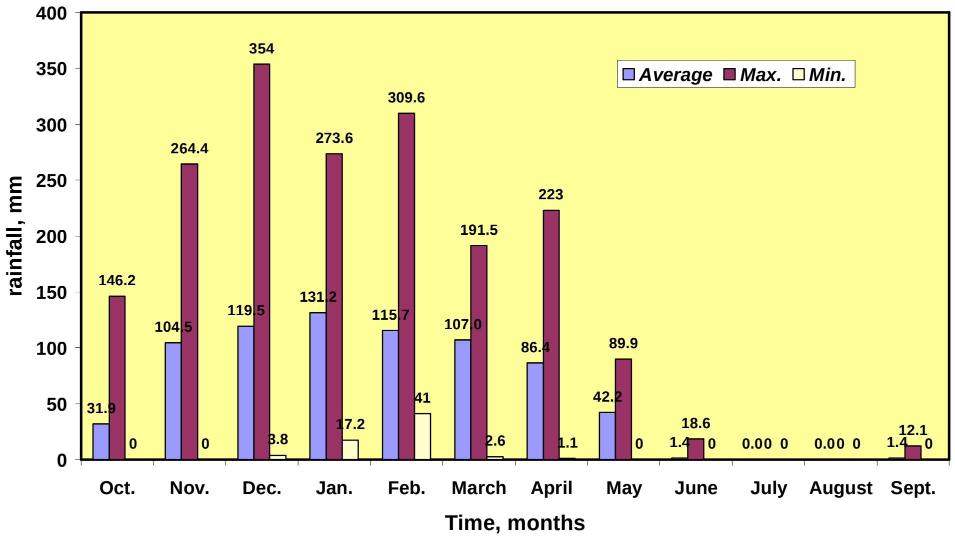

Fig.2.10 Average maximum and minimum monthly rainfall at Sulaimani station for the years 1980/1981-2005/2006.

It is clear from the moving average that throughout 26 years of recorded rainfall, the most severe drought started in 1998 and ended in 2001, while another drought cycle lasted only three years from 1981-1984.

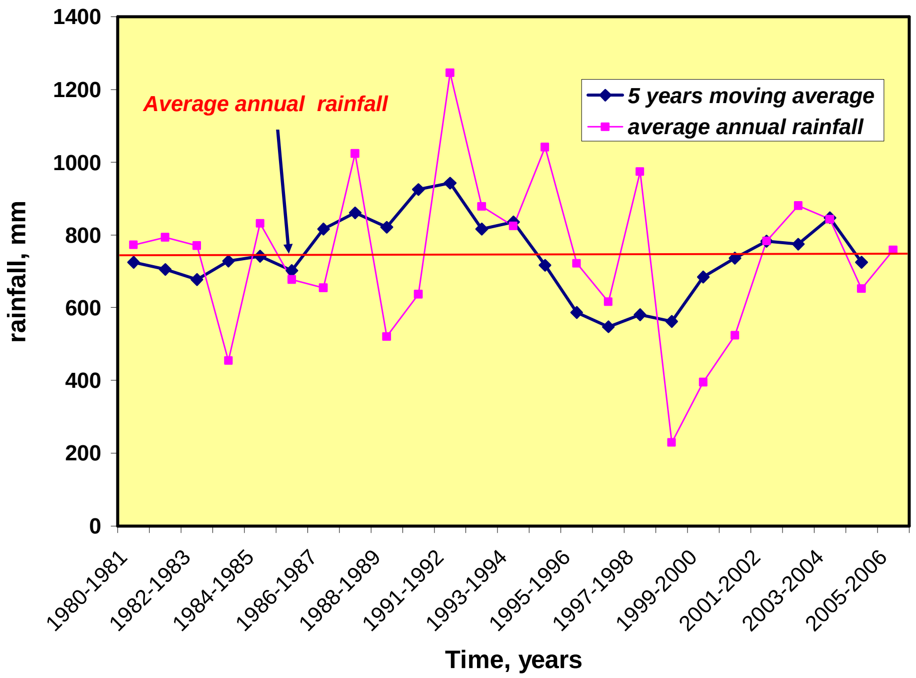

Fig.2.11 Trend of average annual rainfall and 5 years moving average at Sulaimani station 1980/1981-2005/2006.

- Relative Humidity:

The relative humidity is a cyclic variable; it is related reversely to temperature and evaporation. The average monthly relative humidity varies from 22% in July to 70% in January with an annual average value that reaches 45.5 % as shown in figure 2.12.

-Temperature

The average monthly temperature values for the period 1980-2006 are presented in figure 2.13. The maximum average annual temperature was 23.6^o C and the average annual temperature was 19.4^{o}C. The maximum monthly temperature recorded was 38.6^o C in July 2000, while the minimum was 1.4^o C in January 1983. As clear from figure 2.13, the temperature starts decreasing in July (33.6^{o}C) and reaches its minimum mean (5.9^{o}C) in January when it again starts to increase until reaching its peak value in July when the cycle repeats itself again.

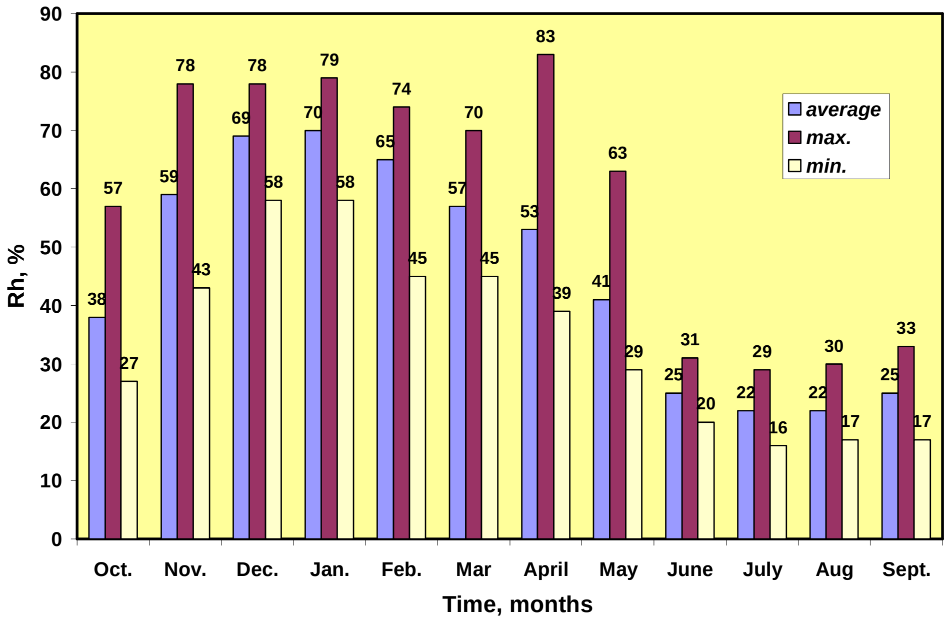

Fig.2.12 Average monthly relative humidity for the years 1980-2006 at Sulaimani Station.

Table 2.1 Average, maximum and minimum monthly rainfall of some metrological stations in and around Sharazoor- Piramagroon basin

stations	Sulaimani	Dokan Dam	Darbandikhan Dam	Penjween	Chwarta	Halabja	Arbat	Kani Panka	Barzinja	Sharazoor	Ahmad Awa	Biara	Total Average	Max	Min
Sep	3.7	2.3	1.8	6.5	3.0	6.1	0.0	1.1	0.0	0.0	0.0	0.0	2.0	6.5	0.0
Oct	21.8	10.8	5.9	36.5	19.8	2.8	33.4	8.7	24.0	16.4	0.3	10.0	15.9	36.5	0.3
Nov	42.9	49.6	46.7	107.5	64.2	52.0	14.4	30.3	39.6	28.3	39.6	45.5	46.7	107.5	14.4
Dec	148.1	211.3	171.8	244.5	176.8	195.1	116.1	116.3	191.2	153.4	184.8	194.3	175.3	244.5	116.1
Jan	208.4	174.6	322.2	305.0	207.0	184.7	182.7	195.7	277.0	230.4	244.0	159.0	224.2	322.2	159.0
Feb	64.6	27.1	83.5	149.5	58.8	96.5	64.3	76.1	91.9	82.7	87.0	100.5	81.9	149.5	27.1
Mar	134.2	114.8	141.5	214.0	125.3	159.3	117.4	114.5	147.1	129.0	87.0	145.7	135.8	214.0	87.0
Apr	131.6	110.3	107.4	202.0	137.4	153.2	124.6	107.3	152.1	94.1	210.7	202.9	144.5	210.7	94.1
Ma	27.2	19.3	4.5	16.0	18.6	2.1	4.6	3.0	14.5	3.8	3.0	6.0	10.2	27.2	2.1
∑	782.5	720.1	885.3	1281.5	810.9	851.8	657.5	653.0	937.4	738.1	856.4	863.9	836.5	1281.5	653.0

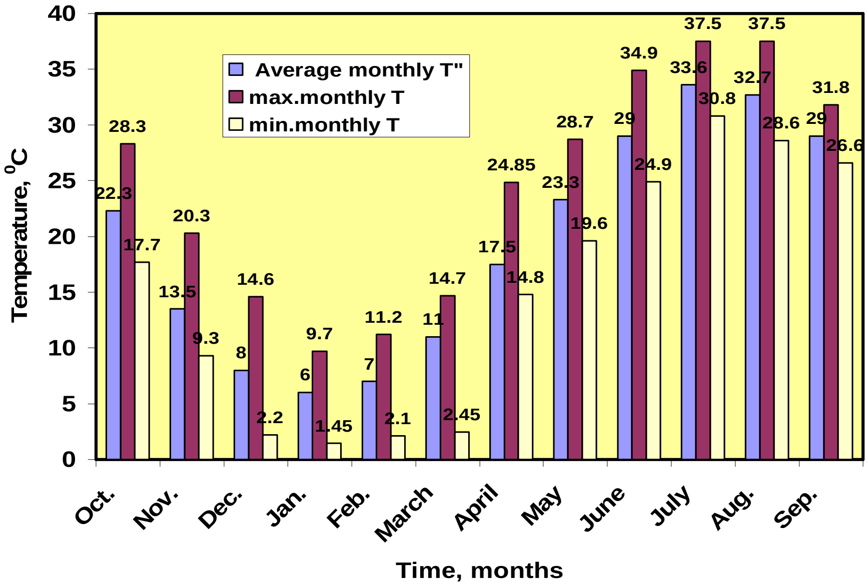

Fig.2.13 Average mean, maximum and minimum monthly temperature for the years 1980-2006 - Sulaimani station.

- Wind Speed

The prevailing wind direction in the studied area is east, which represents 20% of the monthly wind direction in the area. The next prevailing wind direction is west, which represents about 13.7% of the monthly wind direction. The mean wind speed was 2.3 m/sec. June, July and August are the months with the highest wind speeds.

- Sunshine:

The maximum sunshine duration occurred in July with an absolute value of 13.2 hrs/day in June 2001, and the minimum duration occurred in December with an absolute value of 3.5 hrs/day in 2002. The mean monthly maximum sunshine is 11.6 hrs/day in August, while the mean monthly minimum is 4.7 hrs/day which was recorded in January.

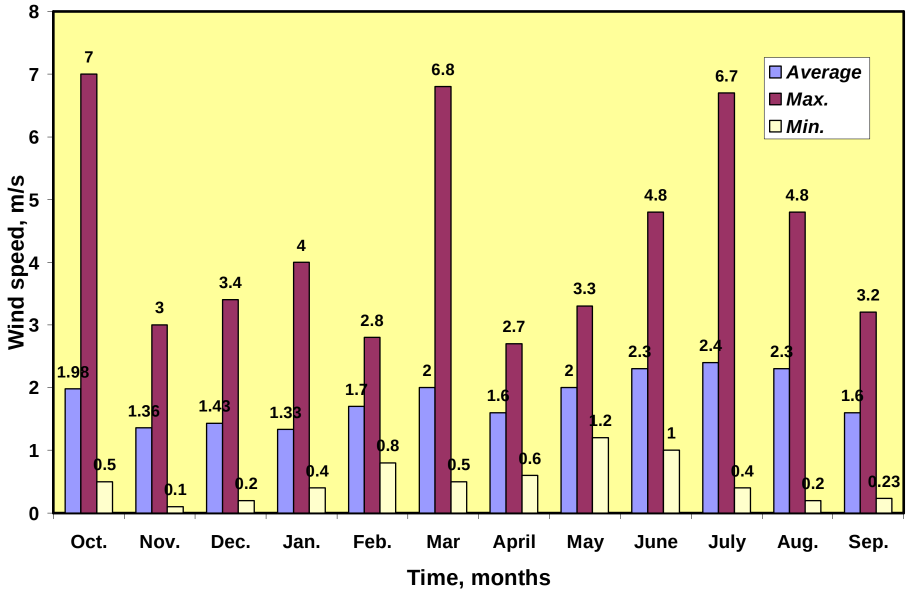

Fig.2.14 Mean, max. and min. average monthly wind speed, Sulaimani station, 1980-2006.

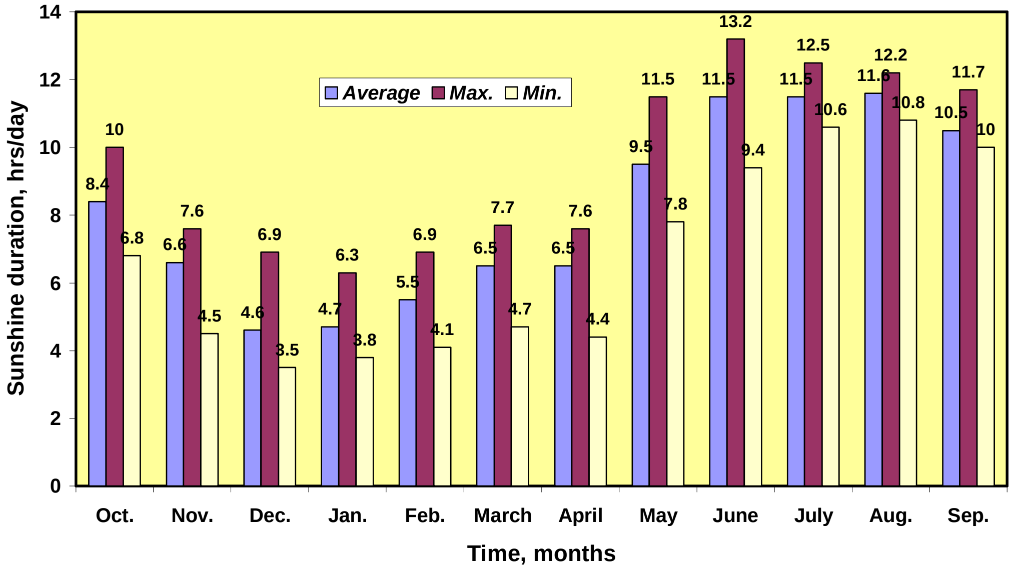

Fig.2.15 Mean, max. and min. average monthly sunshine duration of the years 1994 – 2006 at Sulaimani station.

--Evaporation and evapotranspiration

-Evaporation from class (A) pan

Evaporation is a cyclic variable and is affected by many other variables and physical factors (Fetter, 1980). The mean monthly values of evaporation from class (A) pan were measured as seen in fig (2.16) for the period 1980-2006. The histogram shows that there is a direct proportionality between the mean monthly temperature and mean monthly evaporation. The mean monthly evaporation increases as the mean monthly temperature increases.

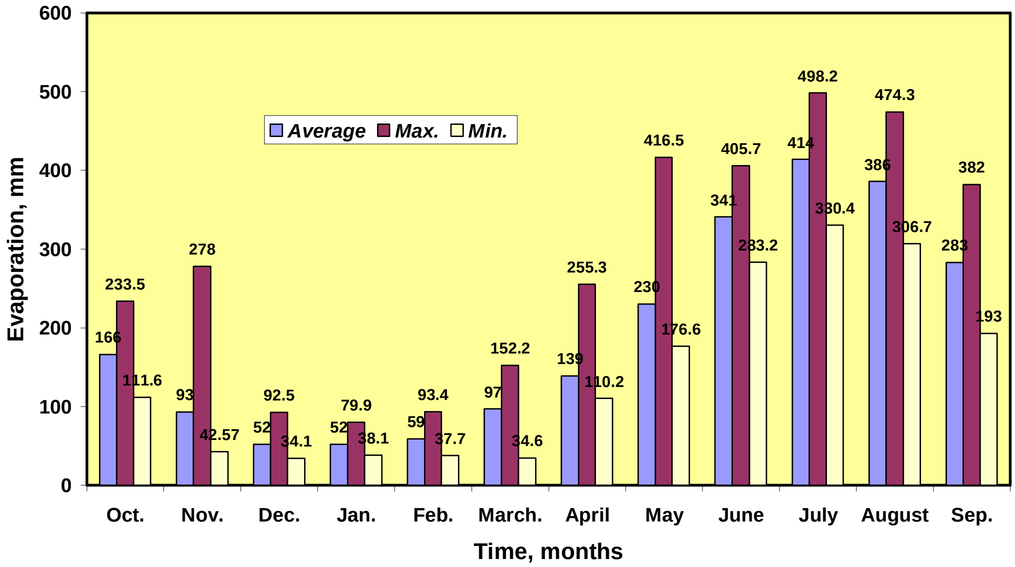

Fig.2.16 Mean, max. and min. average monthly evaporation from class A pan, Sulaimani station, 1980-2006.

Because the processes of evaporation and transpiration are difficult to separate, the term evapotranspiration is generally used to describe the combined process. Potential evapotranspiration (PET) is the maximum amount of water that would be removed from the surface by evapotranspiration if sufficient water were available in the soil to meet demand (Hamill and Bell, 1986). Potential evapotranspiration can be calculated by several methods. Depending on the available climatic data for Sulaimani station, the Thornthwait method was used to determine PET in the study area

-Potential Evapotranspiration (PET)

This variable is considered the most important factor in water balance calculations; it can be calculated by different methods. Several Iraqi researchers, among them Al-Kubaise (1996), Chnaraee (2003), Hassan (1998), Subramanya (1992), and Aqrawi (2003) used the Thornthwait method (1944), while others compared Blany-Cridle with Kharofa methods and statistically followed the most reliable and convenient one. Thornthwait and Wilm (1944) assumed that the amount of water lost through evapotranspiration from a soil surface covered with vegetation is governed by climatic factors. According to this method, the potential evapotranspiration for a given month is based on the mean monthly air temperature of that month and on the annual air temperature (Serrano, 1997). This method has been used by several researchers such as Issaq (1990), Subramanya (1992), Hassan (1998), Aqrawi (2003) and Al-Kubaise (1996).

$$PE = Ia \times 16\left(\frac{10\,t}{J}\right)^{a} \qquad \text{mm/ month}$$

$$J = \sum_{1}^{12} j \qquad \text{For each month}$$

$$j = \left(\frac{t}{5}\right)^{1.514}$$

$$a = (673 \times 10^{9})^{3} - (771 \times 10^{-7})J^{2} + (179 \times 10^{-4})J + 0.492$$

Where:

Ia =correction factor depending on latitude.

PE = potential evapotranspiration

=annual temperature constant

= monthly temperature parameter (Heat index)

t =mean monthly temperature, ºC

Data from the Sulaimani and Chwarta meteorological stations were used to determine the climatological characteristics of the studied area and the effect of climate on the water balance conditions. Thus, these data were used to evaluate the water surplus and water deficit periods, which in turn indicates and affects the ground water recharge.

Table 2.2 Evapotranspiration for Sulaimani station for the years 1980-2006 calculated by Thornthwait method.

Month / Factor	Oct	Nov.	Dec	Jan	Feb	Mar.	Apr.	May	June	July	Aug.	Sept.
T	22.3	13.5	8	6	7	11	17.5	23.3	29	33.6	32.7	29
Ia	0.94	0.86	0.82	0.84	0.92	0.99	1.09	1.17	1.21	1.19	1.12	1.03
j	9.6	4.5	2.0	1.32	1.66	3.3	6.6	10.2	14.3	17.9	17.2	14.3
PET	85.6	25.31	7.43	3.98	6.17	18.4	57.5	117.	198.9	272.5	241.3	169.4

- Water Surplus and Water Deficit

Water surplus means that the value of rainfall is greater than the potential evapotranspiration during a given period, while the water deficit means that potential evapotranspiration is greater than the rainfall (Brickle, et al. 1995):

WS = P – PET .... **P>PET**

WD = PET – P ……..… **P<PET**

Hassan and Al-Ansari (1978) pointed out that under a prevailing water surplus period the actual evapotranspiration approaches its potential value, while in a water deficit period the actual evapotranspiration is equal to the rainfall.

The water surplus (WS) represents the sum of surface runoff (Rs), groundwater recharge (Re) and the soil moisture (Ri). Generally the water table in the studied basin is relatively deep; the evaporation from the ground water is thus limited. Consequently, the soil moisture is consumed either by evaporation from the soil or by plants. Therefore it is considered as a part of water losses as that of potential evapotranspiration (Hassan, 1981). The general equation for water balance is as follows:

P = Rs +Re + AE

WS = (Rs + Re) = P - AE

If P > PET then PET = AE,

and if P < PET then P = AE

The annual PET values are much greater than the mean annual precipitation; therefore the annual could not be used for water surplus calculations. The mean monthly PET values which were calculated by the Thornthwait method were used to determine the mean monthly water surplus and water deficit, as shown in table 2.3 These values of monthly (WS) and (WD) and mean monthly precipitation (P) were used to construct a water surplus and water deficit graph (fig 2.17).

To calculate water balance there are many different methods which depend on climatological factors and influence the type of water balance, either for irrigation purposes, the free water table or groundwater recharge. Metrological data methods depend on the duration of the measurement time of the variables, on a daily, monthly, or annual basis. Annually means the method could not get a water surplus simply because the evaporation is always greater than precipitation, which is not the real case.

The water balance equation is a useful concept, and can be employed successfully if the metrological conditions and climatic elements of the basin are known. An estimation of the annual water balance is critical for water management and development. The first issue in the effort to achieve sustainable water management is to understand the annual water balance in the basin. This means finding out how much water comes into the system and then finding out where that water goes (Fikos et al, 2005).

The calculation of the net groundwater recharge is a big challenge for the hydrologist since there is no specific method to find out the net recharge reliability. There are many methods for quantification of groundwater recharge from rainfall. Each method has its limitations and difficulty in application (Baalousha, 2005).

Hassan (1996) used a method for water surplus calculation depending on the relationship between mean monthly temperature and mean monthly rainfall. He mentioned that while the mean monthly temperature $\mathbf{t_J}$ is a daily variable during the month, and the monthly evaporation is the mean sum during the month, the rainfall, occurring only a few days monthly, is not a daily parameter; accordingly, (Ws) is affected by temperature more than by evaporation directly. Hassan (1998) used the Kobin (1936) and Al-Shalash (1981) method of climate classification for correlation between rainfall and temperature.

Table 2.3 Water surplus and deficit using PET values calculated by Thornthwait method

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Total
(P) (mm)	31.9	104	120	131	116	107	86.4	42.2	1.44	0	0	1.36	741.3
(PE) (mm)	85.6	25.3	7.4	4.0	6.17	18.4	57.5	117	199	272.5	241.3	169.4	1204
AE (mm)	31.9	25.3	7.4	4.0	6.17	18.4	57.5	42.2	1.4	0	0	1.36	195.63
Ws (mm)	0	78.7	112.6	127	109.8	88.6	28.9	0					545.6
WD (mm)	53.7							74.8	197.6	272.5	241.3	168	1011.5

$$Ws\% = \frac{545.6}{741.3} \times 100 = 73.6\%$$

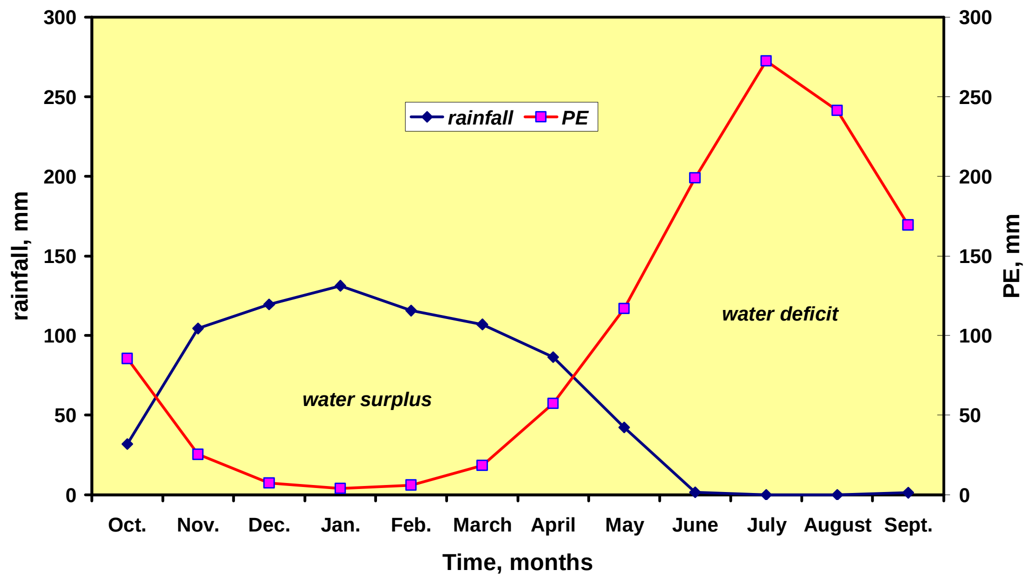

Fig.2.17 Water Surplus (WS) and water deficit (WD) diagram of the study area, calculated by Thornthwait method.

According to this method three cases exist for water surplus and water deficit calculations as shown in table 2.4.

Table 2.4 Water surplus estimation by maximum surplus method.

No.	Case	WS_J (mm)	WL_J (mm)
1	$P_J \le t_J$	0	$WL_J = P_J$
2	$t_J < P_J \le 2t_J$	$WS_J = P_J - t_J$	$WL_J = t_J$
3	$P_J > 2t_J$	$WS_J = P_J - 2t_J$	$WS_J = 2t_J$

where:

P_J = means monthly precipitation (mm)

t_J = means monthly temperature (^oC) (here it takes PE units in mm)

WS_J = means monthly water surplus (mm)

WL_J = means monthly water losses (mm)

This method applied to the data of the study basin (Sulaimani metrological station) and the results are shown in the table 2.5***.***

Table 2.5 water surplus and deficit for the study basin calculated by maximum water surplus method.

Months	t_J	P_J	Case	WS_J	WL_J
Oct	22.3	31.9	2	9.6	22.3
Nov.	13.5	104	3	77	27
Dec	8	120	3	104	16
Jan	6	131	3	119	12
Feb	7	116	3	102	14
Mar	11	107	3	85	22
Apr	17.5	86.4	3	51.4	35
May	23.3	42.2	2	18.9	23.3
Total				566.9	171.6

$$Ws = \frac{566.9}{741.3} \times 100 = 76.5\%$$

It is found that when using this method results show a slightly higher amount of water surplus than when using the Thornthwait method. A correlation test was performed to indicate the accuracy and reliability of the method, and it was found that the coefficient of determination is equal to 0.98, which indicates the reliability of the proposed method for water surplus calculations.

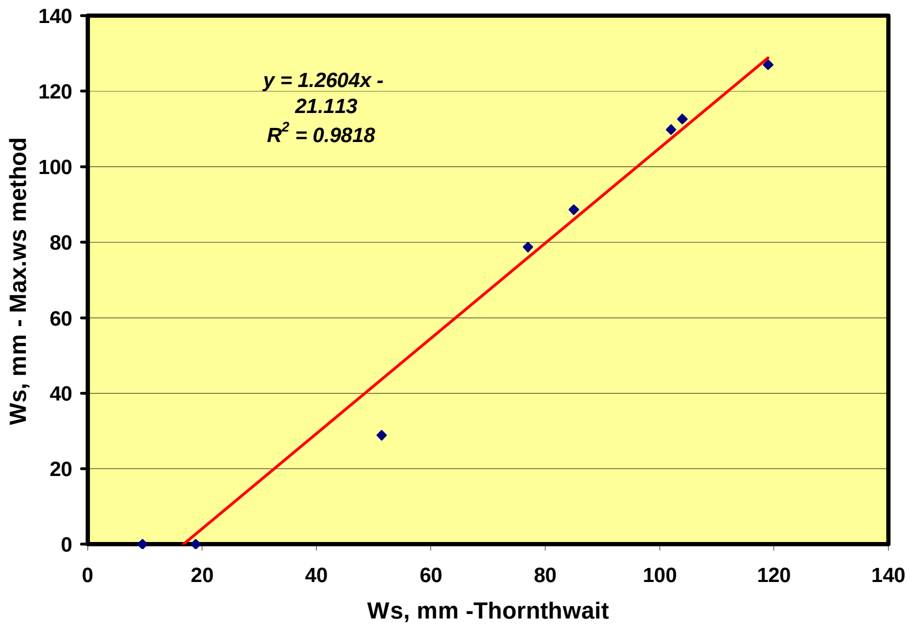

Fig.2.18 Correlation between water surplus calculated by Thornthwait and max.water surplus method at Sulaimani station 1980-2006.

After estimation of evapotranspiration by Thornthwait and maximum water surplus method (tables 2.7, 2.8.and 2.9), water surplus and water deficit are calculated for the areas located in elevations higher than 1200m. The extrapolated average monthly rainfall and temperature determined by the two empirical equations mentioned in the previous section are shown in table 2.6 and used for these calculations.

Table 2.6 The extrapolated average monthly rainfall and temperature of areas 1200m a.s.l.

Months / Factor	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep
P(mm)	34.3	109.8	125.6	137.8	121.5	112.5	91.11	45	2.5	0	0	0
T(C^0)	19	10.2	4.7	2.7	3.7	7.7	14	20	25.6	30.2	29.5	25.6

Table 2.7 Evapotranspiration of the areas of 1200m a.s.l of the study basin calculated by Thornthwait method

Month / Factor	Oct	Nov.	Dec	Jan	Feb	Mar.	Apr.	May	June	July	Aug.	Sept.
T	19	10.2	4.7	2.7	3.7	7.7	14	20	25.6	30.2	29.5	25.6
Ia	0.94	0.86	0.82	0.84	0.92	0.99	1.09	1.17	1.21	1.19	1.12	1.03
j	7.54	2.94	0.91	0.39	0.63	1.92	4.75	8.15	11.85	15.22	14.69	11.85
PE	66.5	20.62	5.1	1.99	3.77	14.55	45.34	90.53	143.8	188.62	170.4	122.5

Table 2.8 Water surplus, and water deficit for the areas of 1200m a.s.l of the study basin

Months	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Total
(P) (mm)	34.3	109.8	125.6	137.8	121.5	112.5	91.11	45	2.5	0	0	0	780
(PE) (mm)	66.5	20.62	5.1	1.99	3.77	14.55	45.34	90.53	143.8	188.6	170.4	122.5	873.7
AE (mm)	34.3	20.62	5.1	1.99	3.77	14.55	45.34	45	2.5	0	0	0	173.2
Ws (mm)		89.18	120.5	135.8	117.7	97.95	45.77	0	0	0	0	0	606.9
WD (mm)	32.2	0	0	0	0	0	0	45.53	141.3	188.62	170.4	122.5	700.5

Ws= 606.94mm

$$Ws\% = \frac{606.94}{780} \times 100 = 77.8\%$$

Table 2.9 Water Surplus calculation by maximum water surplus method, for the areas located above elevation of 1200m a.s.l in the study basin.

Months	t_J	P_J	Case	WS_J	WL_J
Oct	19	34.3	2	15.3	19
Nov.	10.2	109.8	3	89.4	20.4
Dec	4.7	125.6	3	116.2	9.4
Jan	2.7	137.8	3	132.4	5.4
Feb	3.7	121.5	3	114.1	7.4
Mar	7.7	112.5	3	97.1	15.4
Apr	14	91.11	3	63.11	28
May	20	45	3	5	40
Total				632.6	145

Again, the difference between the two applied methods is not large. The value of water surplus is used for annual recharge estimation of the mountainous area surrounding the basin, namely the area of karstic-fissured or karstic limestone outcrops. In chapter 4 of this thesis, calculation of annual recharge by spring discharge and water balance methods for certain catchment areas will be presented.

2.3 Hydrography

The Sharazoor-Piramagroon basin represents the majority of the northwestern part of the recharge area of Sirwan River; therefore it is closely related to meteorological conditions of these areas. The river courses and drainage pattern are controlled by structural conditions (including joint sets, faults directions) and properties of exposed rock units (Chow, 1964). The basin area is covered by several carbonate and clastic deposits.

Since carbonate rocks are dominant in the basin, a considerable amount of surface water recharges the aquifers.

All the water courses of this basin flow toward the Diala River (as the downstream portion of Sirwan River is called). The Sharazoor valley is intersected by several water-courses carrying water permanently or periodically to a recipient, namely the Darbandikhan reservoir. The largest water-course being a source of supply and intake for local irrigations are Chaqchaq, Chaqan, Reshen Zalim and Biara.

The discharge of the Diala River is controlled by the Darbandikhan Dam which was built in1962. The Darbandikhan dam is located in a gorge where the Sirwan river crosses Baranan Mountain 10 km before the river joins the Tanjero river.

The major recharge sources of the Darbandikhan reservoir are: 1- the Sirwan River which pours into the reservoir from the northeastern direction coming from Iranian territory. 2- The Tanjero River which pours from the northwestern direction.3- the Zalim Stream which pours from the northern direction which is a collection of spring waters from Zalim, Ahmed Awa and Khurmal. Other recharging sources of the reservoir are Reshen and Saraw from the north, and during the rainy season, Chaqan stream water from the north.

The reservoir is designed to receive a maximum recharge of 24570 m^3/s, including 22930 m^3/s as maximum runoff, 1540 m^3/s maximum flood from snow thawing, and 100 m^3/s from groundwater. Maximum discharge of 5000 m^3/s was recorded in 1957 (Al-Tamimi, 2007).

The high relief and slope of the area cause the concentration time of peak flows of the river in the region to be at its extreme values (short concentration time and high peak flows). Also, water losses through evaporation are very small because the surface water accumulates rapidly in the stream course.

The total catchment area of the Darbandikhan Dam (Fig.2.19) is 17850 km^2.The drainage area of the Diala River inside Iraq to the Darbandikhan dam site is about 3476 km^2. From this area the study basin covers 2680 km^2 (Fig.2.20).

2.4 Hydrology

There is a significant similarity in climatic conditions between the Sharazoor – Piramagroon basin and the downstream Sirwan basins. The mean annual discharge values of the Sirwan River expressed changes from one year to another depending on the climatic properties and if the weather that year was dry or wet. The mean annual discharge during the selected period was 170.5 m^3/s in a section installed on the right abutment upstream of the dam on 45º 45’ east and 35º 08’ north. Figure 2.21 presents the annual discharge values of the Diala River from1962-2004, which helped to reach the following conclusions

- There is a clear variation in mean discharge from one year to another, which is due to climatic changes.
- The highest mean annual discharge, 458 m^3/s, was in the flood year of 1969 Such high value refers to the contribution of both hydrologic and climatic factors.
- Dry years, on the other hand, obtain low discharge values as low as 94 m^3/s in 1962 (a dry year), and 98 m^3/s in 1984, while the extremely dry years 1999, 2000 and 2001 had a mean annual discharge of only 43, 45, and 43 m^3/s respectively.
- The succession of dry and wet years in the basin can be outlined as follows:

Dry years: 1962, 1965, 1966, 1967, 1971, 1980, 1982, 1984, 1986. 1989, 1990, 1993, 1996, 1999, 2000, 2001, 2002, 2003, 2004

Wet (Rainy) years: 1969, 1970, 1972, 1976, 1981, 1985, 1988, 1992, 1994, 1995, 1998.

-The rest of years within the period (1962-2004) are intermediate or very close to the average.

Fig 2.19 Darbandikhan Dam, after (General directory of dams-Iraq)

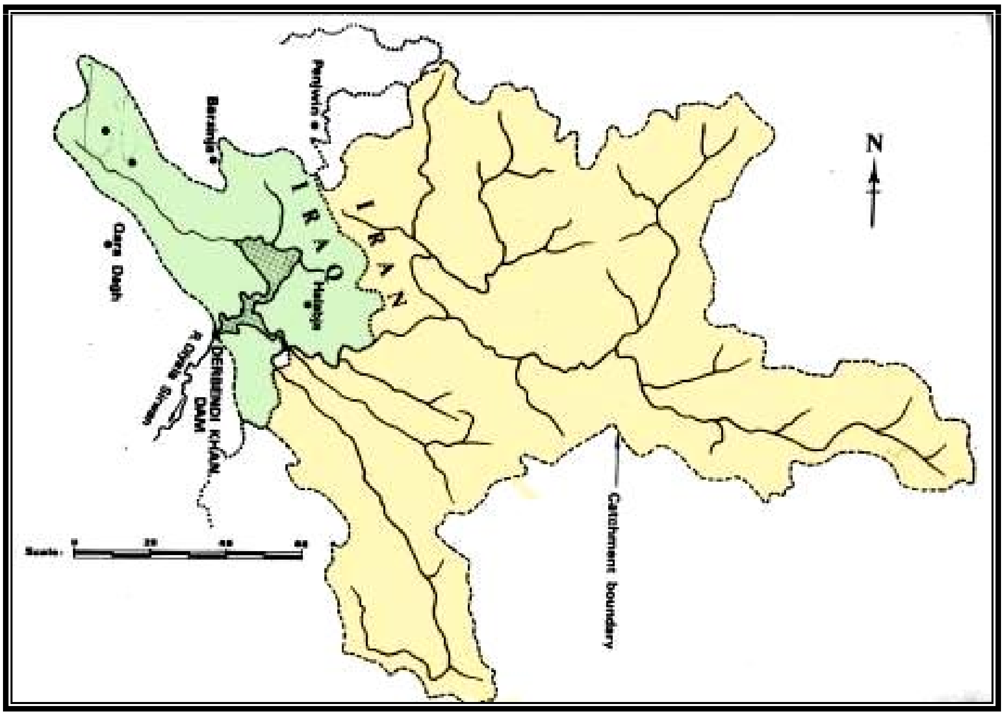

Fig 2.20 Catchment area of Darbandikhan reservoir, both Iraqi and Iranian parts

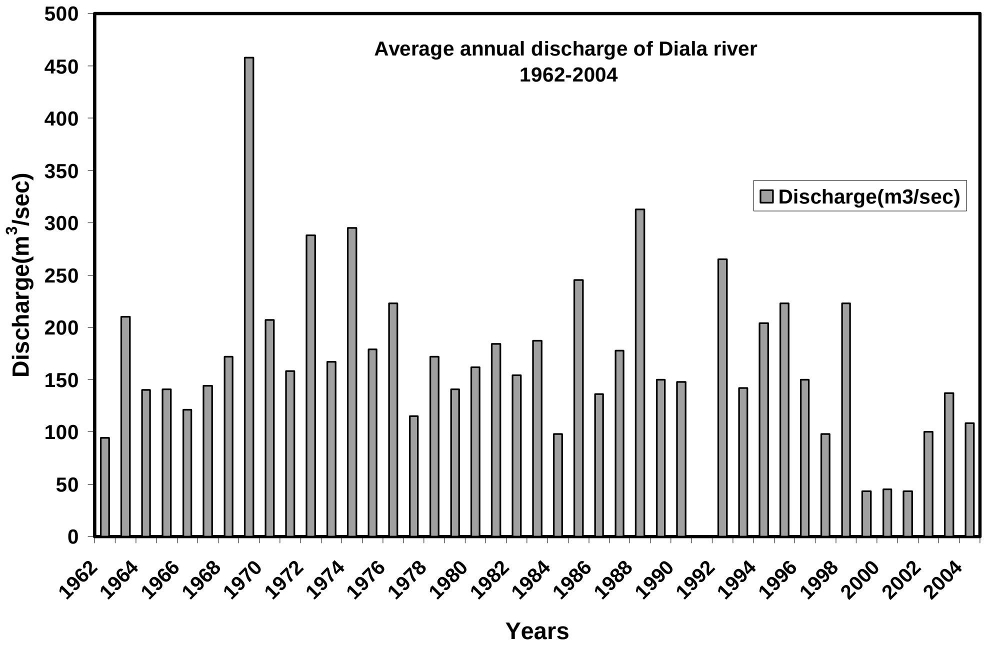

Fig.2.21 Average annual discharge of Diala River 1962-2004 in the upstream section after (GDOD)

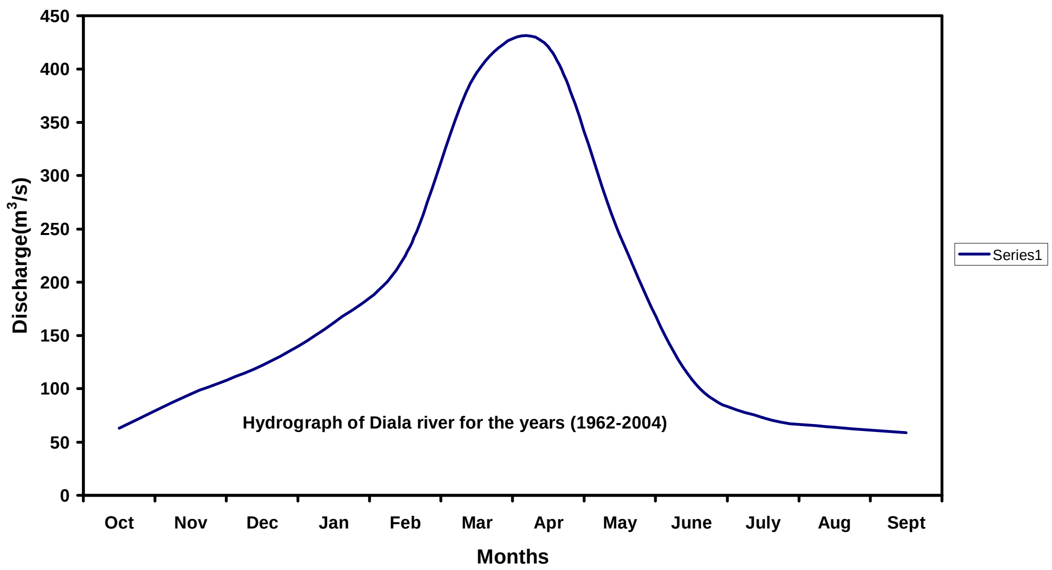

Fig 2.22 Average monthly discharge of the Diala River (1962-2004)

The following remarks can be concluded from fig 2.22.

1. March records include the highest average discharge, equal to 437 m^3/s. This indicates that the river relies mainly on rain (in spring) and thaw of snow in recharge areas, where the temperature increases in March. Accordingly, most of the floods occur in winter or the beginning of spring.
2. The minimal monthly values are recorded during September to be 70 m^3/s. This value is normally attributed to extremely dry air and lack of precipitation.

The daily discharge also manifested variation from one day to another, depending on rain storms.

- Other streams hydrology

The Sharazoor and Piramagroon plains are surrounded on all sides by mountain ridges of an altitude from approximately 1600m to over 3000m a.s.l. The highest elevation is located on the northeastern part, and the lowest on the western part, looking from the Tanjero River side.

It can be seen from the drainage map of the basin shown in fig.2.23 that all streams have their sources or highest watershed points located high in the mountains, and, therefore, the gradients in the upper parts are very steep. The water velocities occur in flood periods, which results in deformations of the river beds and in frequent changes of the bed level, significantly hindering the hydro, technical, and regulation works.

Because of decreasing the discharges of the larger springs which feed them and the higher consumption of these waters in the upstream areas, some of the streams such as Tanjero and Chaqan carry no water in the late summer seasons. The stream network of the valley itself, thanks to the low permeability of soils, small slopes and numerous springs, is well developed particularly in its northern and eastern parts. The southern parts of the basin are characterized by small water resources and few valleys; only the Diskara, Hasil and Merade valleys can be regarded as more important.

The remaining courses are much smaller and in most cases carry no water even in the late spring season. Some intermittent discharge measurements of some of these streams are presented in chapter 4 of this thesis.

All larger water-sources have a stony or gravelly bed. The flood valley beds are gravelly-clayey and often intersected by the existing network of natural channels for local irrigations. Only a few hydro technical facilities can be seen.

The author of Polservice (1980) achieved observations and measurements for some of these main streams in the basin and installed water level gauging stations for the period 1979-1980. This was part of the feasibility study for the Sharazoor irrigation project. The information about those stations is shown in the table 2.10.

Table2.10 The basic characteristics of the water level gauging stations on some main streams in the study basin installed by Polservice during 1978-1979.

Stream	Water level gauging station	Kilometers of stream course	Catchment area, Km^2	Equipment
Chaqchaq	Sulaimani	8.5	240	Staff water gauge
Tanjero	Qaragol	13.5	882.1	Staff water gauge
Chaqan	Lower Shanaderi	10.5	259	Limnigraph + staff gauge
Reshen	Qadafari	0.7	139.8	Staff gauge
Zalim	Ahmad Awa	10.5	22.5	Staff gauge
Zalim	Khurmal	7.5	36.8	Staff gauge
Zalim	Girdigo	0.5	169.3	Staff gauge
Biara	Biara	19	34.5	Staff gauge

The measurements achieved between Nov.1978 and June 1979 by estimating Manning roughness coefficient for each station, the stream discharge calculated accordingly with Manning formula. Due to the insecure situation in Baghdad, the real data concerning these measurements could not be obtained in the libraries of the Ministry of Irrigation, but some visible data on one rating curve in the report show the values presented in figure 2.23 for the Tanjero stream, and fig.2.24 for the Chaqan stream, fig.2.25 for Reshen, and fig.4.26 for Zalim.

As a result of their study and through the ratio of cubature flow in the streams and cubature of precipitation they assessed the runoff coefficients of the different sub-basins. Their estimated runoff coefficient for the Tanjero stream catchment was 0.34; for the Reshen catchment (part of Iraq), 0.37; and for Biara, 0.67. For Zalim, the runoff coefficient could not be determined as the majority of the stream flow comes from the Zalim spring outflow whose catchment is located outside Iraqi territory.

Moreover, with the aid of rational formula they estimated peak flood discharge for each of the main streams, as shown in table 2.11.

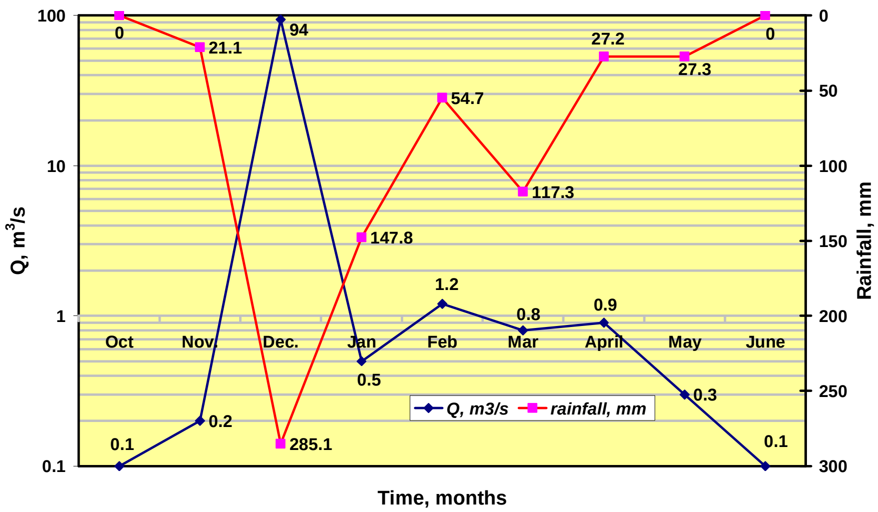

Fig.2.23 Tanjero stream discharge and Sulaimani monthly rainfall measured from Nov.1978 - June 1979, by Polservice (1980). The Q data shown on log scale.

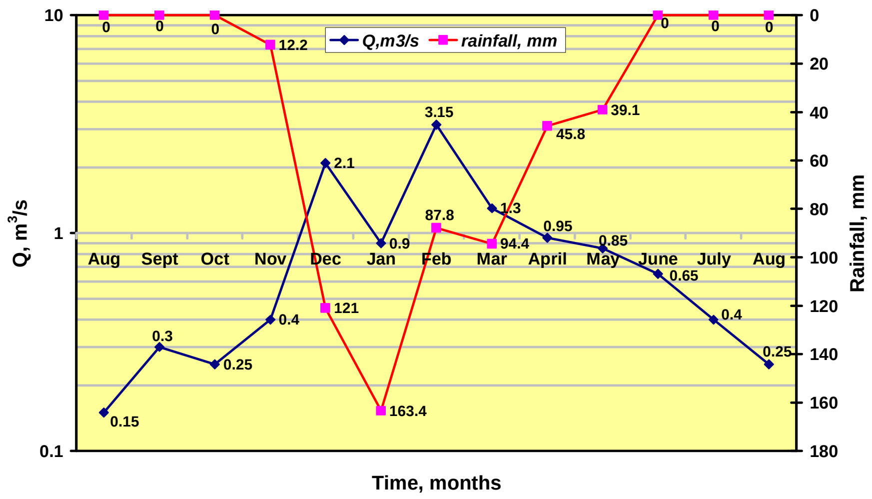

Fig.2.24 Reshen stream discharge and Halabja monthly rainfall measured from Aug.1978- August 1979, by Polservice (1980). The Q data shown on log. scale.

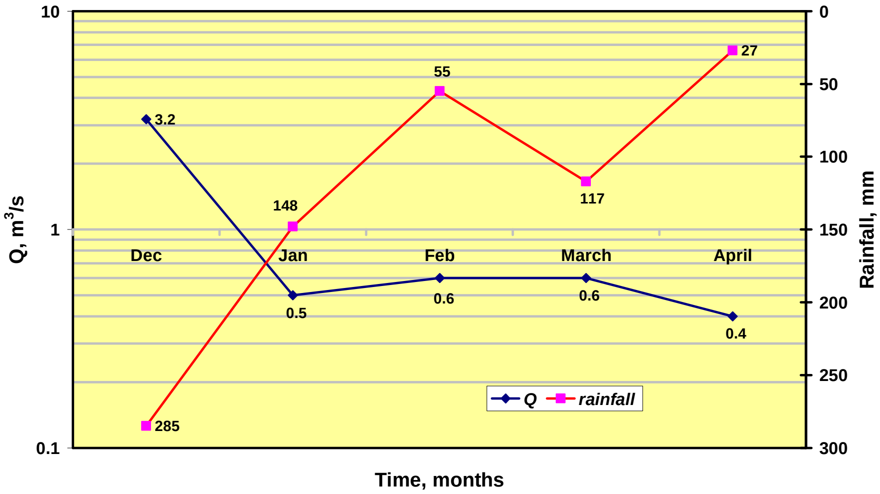

Fig.2.25 Chaqan stream discharge and Sulaimani monthly rainfall measured from Dec.1978- April 1979, by Polservice (1980). The Q data shown on log scale.

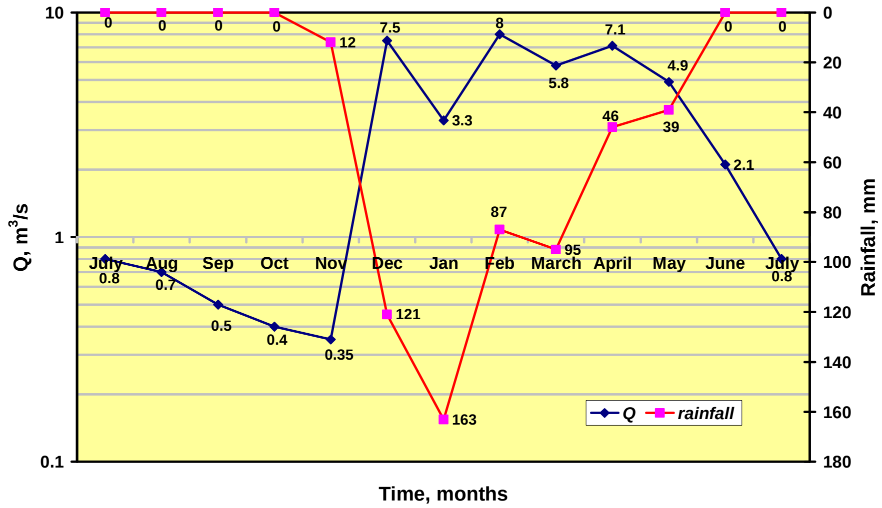

Fig.2.26 Zalim stream discharge at Ahmed Awa station and Halabja monthly rainfall measured from July 1978- July 1979, by Polservice(1980). The Q data shown on log. Scale.

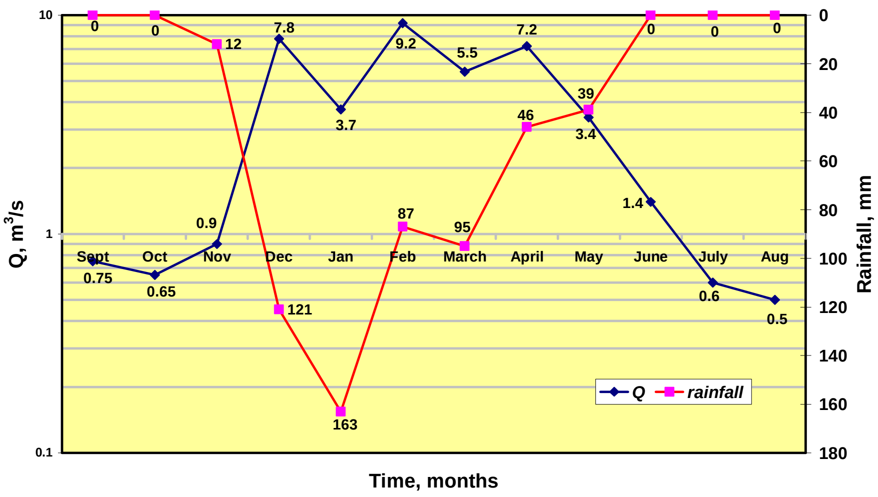

Fig.2.27 Zalim stream discharge at Grdigo station and Halabja monthly rainfall measured from July 1978- July 1979, by Polservice(1980). The Q data shown on log. Scale.

2.5 Geomorphology

Based on detailed field geology and with the support of satellite images and aerial photographs, Stevanovic and Markovic (2004), defined the most important active geomorphological processes prevailing in Iraqi Kurdistan region. They mentioned karstic, fluvial and slope (delluvial, prolluvial and colluvial) processes, besides traces of the aeolian process. Structural relief forms caused by inner, endogenic forces, and exposed by activity of different exogenic forces are also abundant.

Table 2.11 Peak flood discharge estimated for different gauging stations on some stream courses of the study basin (Polservice, 1980)

River name	Length(Km) to the measuring station	Catchment area(Km^2) to measuring point	Roughness coefficient	, tc* (hours)	Peak flood discharge m^3/sec
Tanjero	66.7	813.4	0.65	8	1865
Zalim	15.1	169.9	0.50	3	600
Reshen	13.0	141.1	0.45	2	450
Biara	26.7	95.8	0.50	3	300

**** refers to time of concentration***

Human activities as well as strong weathering due to specific climatic conditions such as fast alternation of high and low temperatures, temporary strong rains, and melting of snow play important roles in relief formation . This process does not produce specific morphological forms, but it prepares a huge amount of loose material that can be easily removed by any exogenic force (running water, wind, gravity) thus reinforcing their activity. The role of weathering, mechanical and chemical, in soil formation can by no means be neglected.

The area of study displays a general slope from north to south and east to south west. The diversity in geomorphologic features reflects the impact of the structural nature of sedimentary strata, climatic condition, weathering and erosion upon the morphology of the land.

The topographic map of 1: 100 000 scale enabled identification of the drainage patterns of valleys, which are controlled by exposed sediments and rocks.

The elevation of the study basin from sea level ranges from 2628 m in the northeastern side, to 490 m around Darbandikhan Lake. The most important geomorphological features are as follows:

-Type of Geomorphologic features

-Karst

During the long geological history of the Territory of Northern Iraq, especially in the Mesozoic and Tertiary periods, a lot of soluble rocks like limestone, dolomite and evaporite were deposited. This enabled the development of strong karstification and the formation of both surface and underground karstic morphology.

The main sedimentary cycle of carbonate rocks deposition started during the Lower Cretaceous period and ended in the Maastrichtian. During Upper Eocene, a new cycle of sedimentation of carbonate rocks repeated, forming thick deposits of Pila Spi limestone.

Alpine folding and uplifting of mountains built of carbonate rocks continuing until the present, has caused stronger penetration of surface water underground. This was reinforced by numerous fissures, joints and fault surfaces, and deepening of the basis of karstification. Two different levels of karst formed in different phases could be connected in some places, offering a false picture of the unique process of karstification.

Carbonate rocks in general show non-homogeneity with the prevailing presence of limestone, but also with insoluble varieties such as interstratified clays. In Balambo Fn. or in marly limestone in Shiranish Fn., uplifting of carbonate massifs and their intensive folding and faulting, repeated in several phases, caused the complex systems of faults and fractures as privileged ways for the water circulation (Stevanovic and Iurkiewicz, 2004).

"Surface karstic small forms, dimensions from cm to dm, occur in practically the whole limestone area. Compared with other karstic Euro-Asian mountainous ranges formed during the Alpine orogenic cycle (Alpides, Dinarides, Helenides, Taurides), typical larger surface forms, such as sinkholes or dolines, are not as frequent in this region. Some large depressions resemble the polje forms, but they are always open in the direction of the main drainage stream. Even if they are formed by karstic process, they have been strongly modified by surface fluvial process"[1]

In the study basin, limestone rocks of Triassic and Jurassic in the north and northeastern part of the basin responded more to karstification processes than the other Cretaceous and Paleocene - Eocene rocks. Qamchuqa and Sinjar rocks show relatively great karstification and many dry caves (small diameters from less than one meter to more than 4 meters) of previous groundwater tables now exist in these two formations. Due to relatively thin bedding layers of Kometan formation no great opportunity for karstification process occurred.

- Plains

Thick alluvial sediments composed a plain that covers the area west and south west of Sulaimani around Arbat, Halabja, and south and north Said Sadiq town. This plain appears to be slightly undulating from Halabja toward Darbandikhan Dam Lake. Many longitudinal valleys, along which valley plains lie, truncate the plain.

Pediment plains resulted from weathering at the foot of mountains. Near the mountain bordering the plain in the northeast and north, these plains can be found.

[1] Stevanovic and Markovic ,2004 , Hydrogeology of northern Iraq, Vol 1, p.60

- Valleys and Gorges

The main destructive geomorphologic features in the basin are valleys and gorges. The majority of valleys contain seasonal streams and only a few have perennial (permanent) streams. In the years when rainfall exceeds 700mm, both the Zalim and Tanjero streams are permanent, while they became intermittent in the three dry years of 1999 to 2001. The vertical erosion of streams is very clear because most valleys contain overlapping spurs. Each valley contains many smaller tributaries which join the main stream at an angle less than 80 degrees and form a dendritic pattern of drainage.

All small and main streams have one general direction of trend (flow). The cross- section of all the valleys has an acute v-shape. But in a few cases the valleys may have a U-shape, especially at the gorges. This is because hard and massive Qamchuqa or Pila Spi formations are over the softer formations which erode more quickly than the former ones. Therefore, a U-shaped segment is developed near the valley mouth such as in the Zalim Valley (Khurmal Valley).
During fieldwork the following types of valleys or streams were identified:

1- Subsequent valleys

This type of valley is the most prevalent type in the basin. This is connected to the nature of the geologic development of the basin, which consists of weathering or synclinal valleys formed between or on the limb of northwest-southeast anticlines. Among major subsequent valley are the Tanjero, Kaolos, Biara and Sirwan valleys. These valleys can also be called strike valleys because they developed nearly parallel to the strike of the strata on which they flow.

2-Consequent valleys

These valleys are less common and smaller than the previous ones and they extend parallel to the general trend of the regional slope of the whole northeastern Iraq. These valleys exist along the southwestern side of anticlines and mountains such as Goizha, Suren, and Avroman Mountains. The best examples of these valleys are the Zalim, Reshen, Suren valleys.

3-Obsequent valleys or streams

These valleys have a direction (course) opposite to the direction of the consequent valleys; in other words, they flow opposite to the dip of the local strata in the area. They are regarded mainly as tributaries of subsequent valleys. Examples of these valleys exist along the northeastern side of the Glazarda, Zirgwez and Bakir Agha mountains.

C- Hills

Another type of geomorphic feature is small hills formed by the destructive force of weathering and erosion. They are located in the mountain toe and developed when streams dissected the lower parts of the mountains, directly adjacent to Sharazoor plain.

These hills are divided into three types:

1- Anticlinal hills

They are small anticlines formed near the plunge of large anticlines. Examples of anticlinal hills are near Bestansur, Kani Panka and Arbat villages.

2- Synclinal hills

Exceptionally rare, three small synclinal hills are observed around Said Sadiq,

They are arranged along a line, which possibly coincides with the axis of the syncline. Here, although the strata are highly deformed, they can clearly be seen arranged concavely upward as a part of asymmetrical syncline.

3-Homoclinal hills

These hills have the same dips, which are regarded as a part of eroded anticline or syncline limb. These types of hills can be seen along the junction line of Sharazoor plain with Suren and Avroman mountains at the north boundary of the basin. Here the limestone layers of the lower part of the Qulqula Radiolarian Formation dip to the southwest as a homoclinal ridge around Suren Mountain.

When the consequent streams dissect this ridge, many small and elongated homoclinal hills are formed.

The other types of hills that have been constructed artificially or by geomorphological agents are:

- **Alluvial hills**

In many places, when dissected by streams, the surface of Sharazoor plain, especially the foothills of the mountains, is covered with a thick and wide mantle of coarse, partially lithified alluvial deposits. Consequently many low hills are formed, such as those which exist to the south of Halabja town around Pers village. The same type of hills also exists south of the basin around Qalbaza, Alan and Hasil villages (east of Zarain town).

- **Man-made hills**

Sharazoor plain contains about 20 conical hills distributed regularly on the surface of the food plain and near the springs. They are about 20meters high and 100 meters wide at the base. Field observation showed that they are man-made and archeological: they consist of soils and show many horizons (stratification). Each horizon represents a single stage of filling during tens of years. Many of these horizons contain sporadic building stones as well as coal remains of wood stoves from ancient times.

2.6 Morphometry of the basin

The morphometrical characteristics of a given basin deal with its quantitative morphological study, identification of the relation between basin area, dimensions and the quantitative analysis of the basin relief and its drainage density (El-Enin, 1990). Such kinds of studies are very important for determining the volume of runoff in the intermittent and perennial streams and must be considered in developing programs and designing irrigation projects.

In addition, these are useful to predict the relationship between different geomorphologic and hydrologic characteristics which fall into three classes: basin morphology, basin relief and drainage density.

The parameters determined relating to basin morphology are: Elongation ratio (Re), Circularity ratio (Rc), Compactness Coefficient (Cc), Form factor (Ff), and Shape factor (Sf);and the parameters relating to basin relief are: Relief ratio (Rf), Relative relief (Rr), Ruggedness value (Rv), Hypsometric integral (HI), and Texture ratio (Rt). The parameters relating to the drainage network of the basin are: stream lengths, stream orders, bifurcation ratio (Rb), Stream frequency (F), Drainage density (Dd), and Time of concentration (tc).

In order to study the morphometry of the study area, the basin is subdivided into three main watersheds, namely the Tanjero, Chaqan and Zalim watersheds. For each watershed, two or three sub-watersheds are analyzed. The drainage patterns and catchment area of the basin are shown in fig 2.28. Stream patterns may develop randomly on uniform soils, or in response to weakness in the underlying geology (Gorden et al, 1993***).***

From figs 2.28 – 2.31 it can be seen that the Tanjero watershed is more longitudinal in shape than circular, while the Zalim watershed shows a more circular (non-rectangular) shape. Based on the elongation, circularity ratios and form factors, both the Galal and Chaqan sub-watersheds show triangular shape. Meanwhile the Halabja sub-watershed is closer to a square shape.

Based on the data relating to relief, all sub-watersheds and watersheds categorized under weak relief ratios according to the classes of (Enin, 1990). Barzinji (2004) categorized Chaqan and Zalim under medium class. Low values of relief ratio are indicators of relative homogeneity in the rock formations of the watersheds.

Based on the relative relief values factor all the study watersheds can be categorized under very high class, according to the classification of (Enin, 1990).

Table (2.13) reveals that ruggedness values of the watersheds are more or less close to each other, classified as low in all sub-watersheds and watersheds.

Hypsometric integral (HI) of the watersheds varies from the lowest at 0.07 for the Chawtan sub-watershed to a maximum 0.85 for the Tanjero watershed. All values of HI are indicative of small drainage areas and an early stage of development. Even though the HI value of the Tanjero watershed is relatively higher, the main components of this large watershed are still in an early stage of development; however, the lower part of this watershed comprising a gentler area has been developed to a higher stage.

Values of drainage density range from a minimum of 1.46 for Chaqan to 2.27 for the Chawtan sub-watershed. It can be inferred from these results that the drainage density values of the existing watersheds are relatively low. This is an indication of a less developed network and a modest runoff due to the high permeability of the terrain (Sharma, 1979).

The relatively low values of stream frequency of the watersheds indicate the fact that these watersheds are situated in the arid region.

Table 2.12 Some parameters related to the shape of the study of watershed

#	Watershed	Elongation Ratio	Circularity Ratio	Form Factor	Shape Factor	Compactness Coefficient
1	Chaqchaq	0.5	0.32	0.2	5	1.75
2	KaniPan	0.58	0.44	0.26	3.75	1.5
3	Tanjero(all)	0.56	0.34	0.24	4	1.71
4	Chawtan	0.58	0.39	0.26	3.75	1.58
5	Galal	0.68	0.47	0.38	2.59	1.45
6	Chaqan(all)	0.65	0.2	0.33	3	2.23
7	Reshen	0.7	0.53	0.39	2.53	1.36
8	Zalim	0.63	0.54	0.31	3.2	1.35
9	Halabja	0.75	0.49	0.45	2.22	1.43
10	Zalim all	0.95	0.25	0.7	1.41	1.96

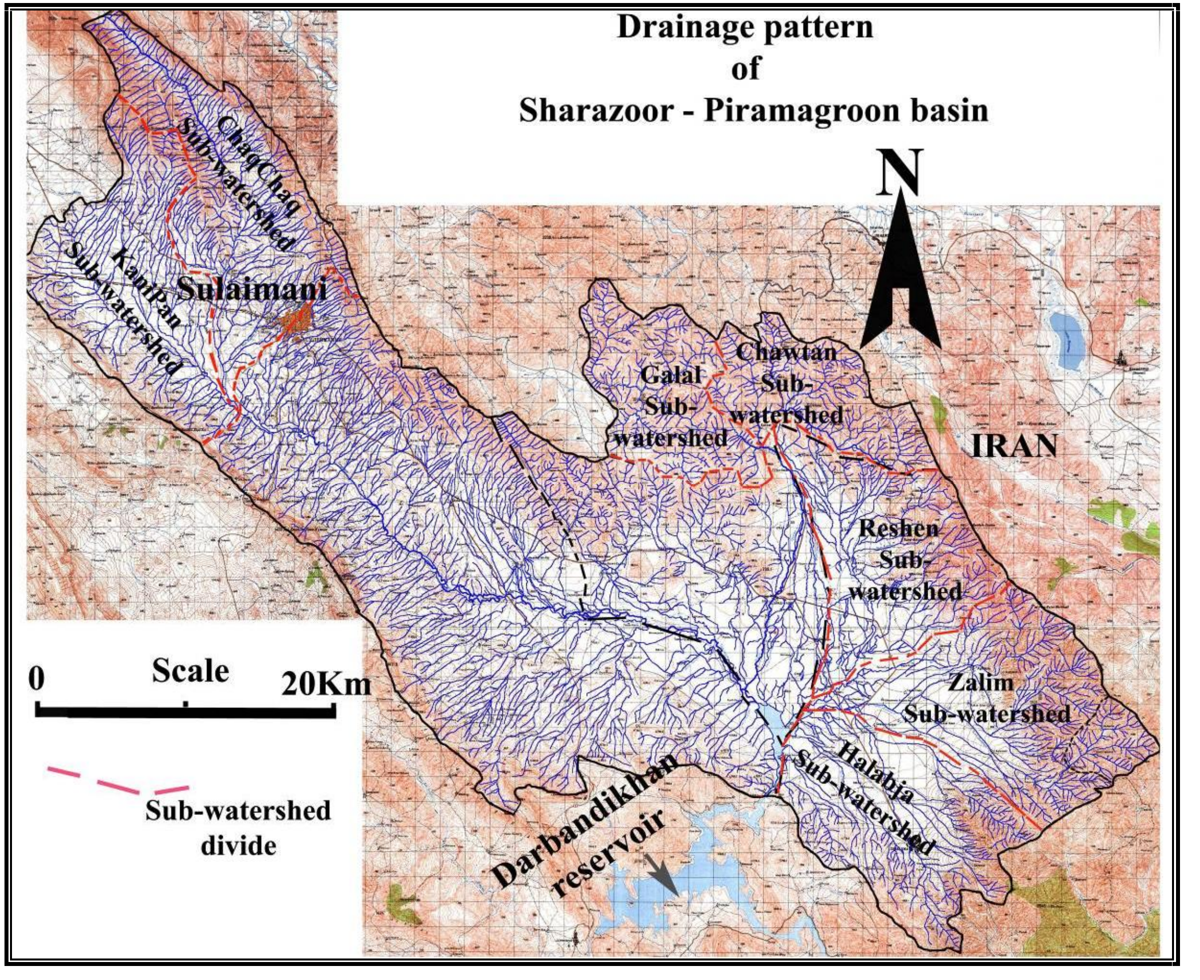

Fig 2.28 Drainage pattern of Sharazoor- Piramagroon basin.

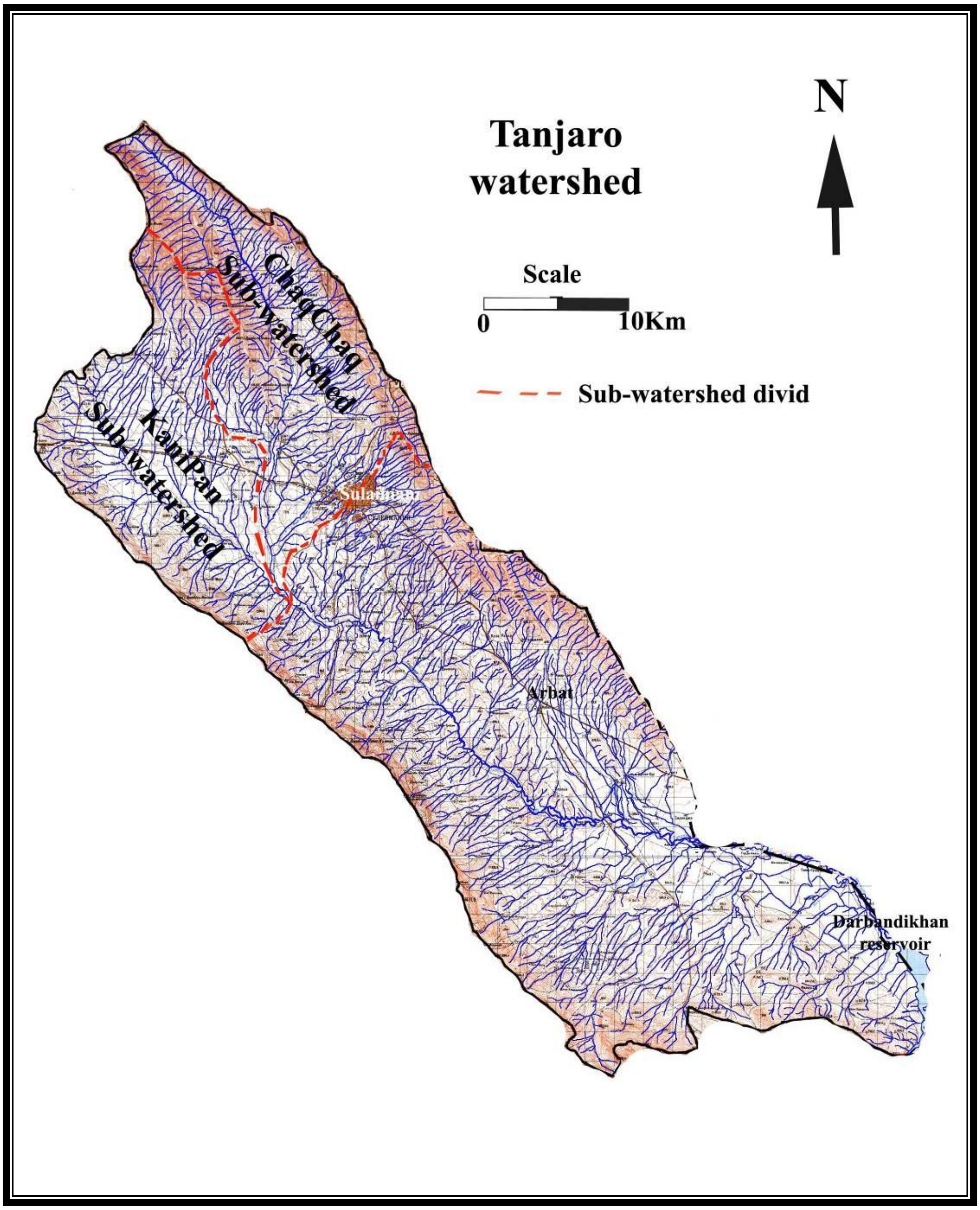

Fig.2.29 Drainage pattern of Tanjero watershed.

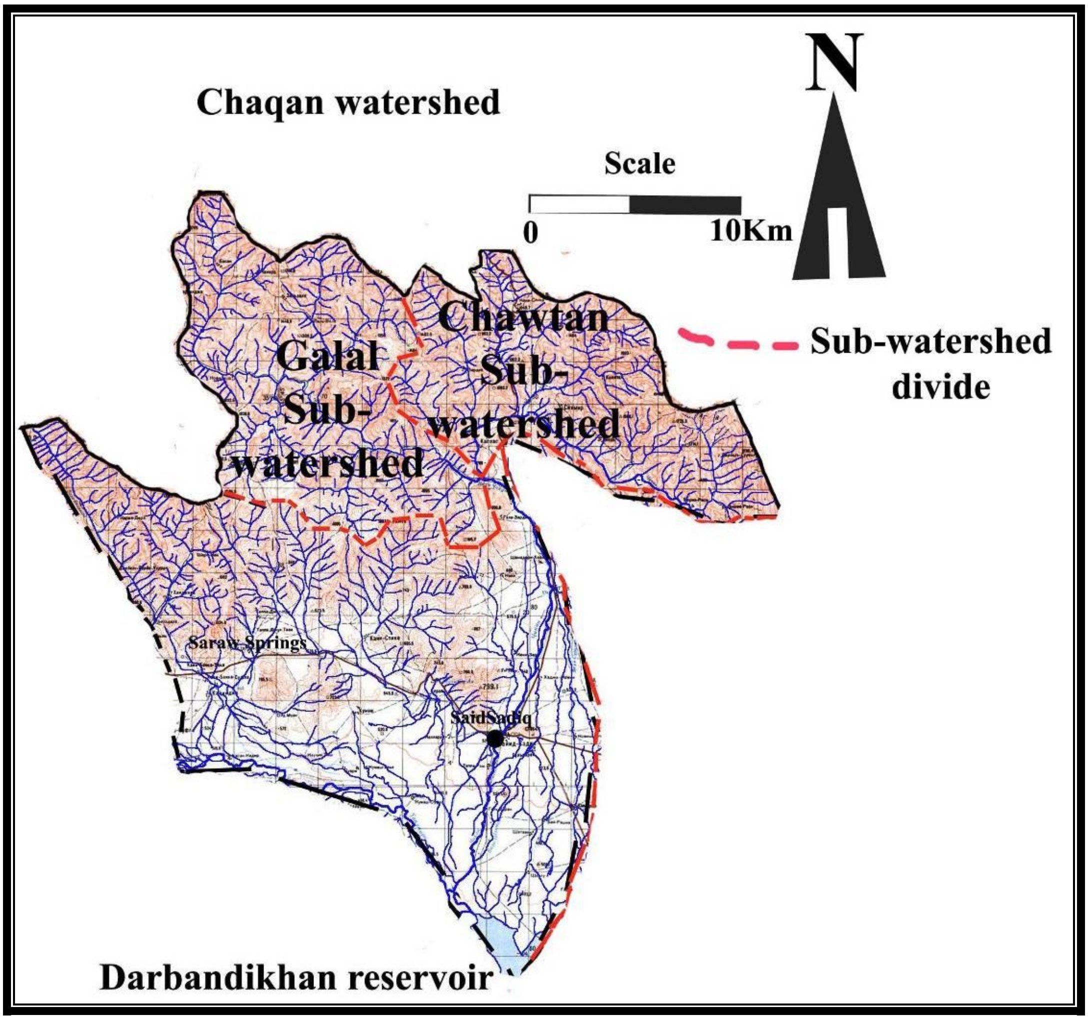

Fig.2.30 Drainage pattern of Chaqan watershed.

Table 2.13 Some parameters related to the relief of the study watersheds.

#	Watershed	Relief Ratio (Rf)	Relative Relief (Rr)	Hypsometric Integral(HI)	Ruggedness Value (Rv)
1	Chaqchaq	0.037	13.5	0.18	2.39
2	KaniPan	0.047	1.71	0.16	2.68
3	Tanjero (all)	0.021	0.7	0.85	2.93
4	Chawtan	0.072	2.48	0.07	3.28
5	Galal	0.072	2.24	0.1	2.95
6	Chaqan (all)	0.045	0.98	0.27	2.43
7	Reshen	0.09	2.97	0.098	3.56
8	Zalim	0.076	2.84	0.11	3.87
9	Halabja	0.061	1.8	0.16	2.198
10	Zalim (all)	0.069	1.17	0.317	3.654

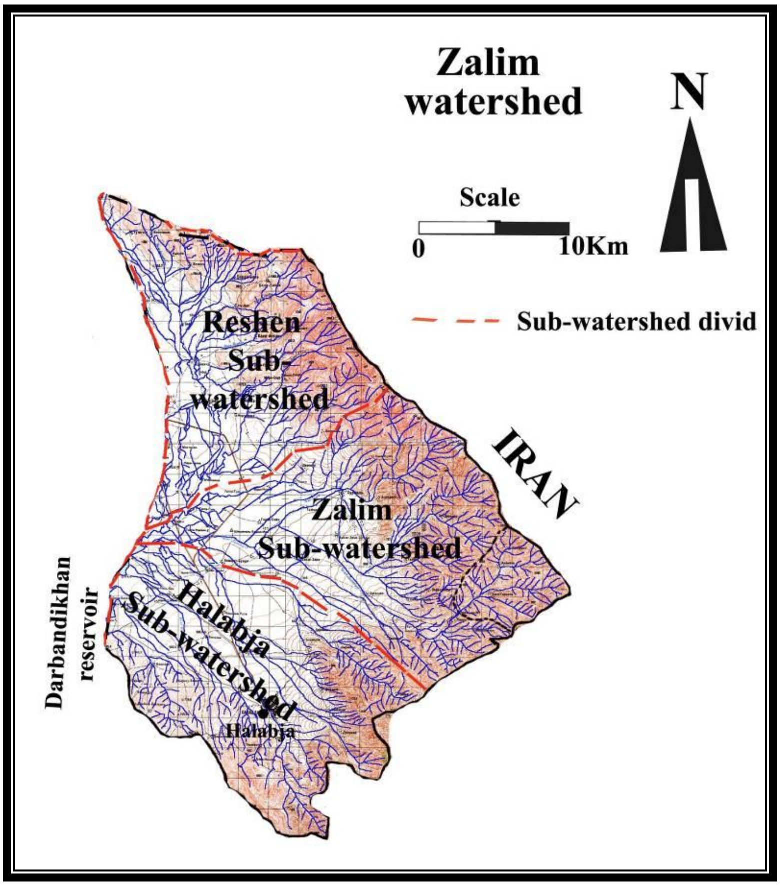

Fig.2.31 Drainage pattern of Zalim watershed.

Table 2.14 some parameters related to drainage networks of the watersheds.

#	Watersheds	Drainage Density D (Km/Km^2)	Stream Frequency F	Average Bifurcation (Rb)	Texture Ratio	Time of Concentration (tc) (min.)
1	Chaqchaq	1.88	4.15	4.16	3.92	77
2	KaniPan	1.96	2.71	3.88	2.93	197.1
3	Tanjero (all)	1.86	3.5	4.27	7.61	243.1
4	Chawtan	2.27	5.52	4.11	4.0	121.6
5	Galal	2.18	6.21	4.21	5.16	111.6
6	Chaqan (all)	1.46	3.38	4.17	3.53	267.1
7	Reshen	1.75	2.42	3.48	2.51	136.9
8	Zalim	1.81	3.18	3.94	3.98	162.5
9	Halabja	1.57	2.62	4.66	3.05	135
10	Zalim (all)	1.71	2.76	4.1	3.98	169.1

Table 2.15 some basic physiographical data of sub-watersheds in the study basin.

#	Watershed	Area (Km^2)	Perimeter (Km)	Axial length (Km)	Actual Length (Km)	ΔH (m)	Slope (%)	Stream Order(Nu)							Stream Length(Km)						
								1st	2nd	3rd	4th	5th	6th	Total	1st	2nd	3rd	4th	5th	6th	Total
1	Chaqchaq	231.5	94.5	34	40	1276	3.75	289	64	13	4	1	0	371	263	96	41	19.5	17	0	436.5
2	KaniPan	223.5	79.8	29	34.5	1371	4.7	182	41	8	2	1	0	234	272	94.5	48	8	17.5	0	440
3	Tanjero(all)	1337	222	73.5	96.5	1572	2.13	1294	297	76	18	5	1	1691	1410	571	325	84	85	23	2498
4	Chawtan	112	59.5	22.8	29.5	1479	7.2	197	33	6	2	1	0	239	170	39	29	11.5	5	0	254
5	Galal	136.5	60.4	18.8	29.5	1357	7.2	258	41	9	3	1	0	312	198	44	24	17.5	14.5	0	298
6	Chaqan(all)	455.5	169	37	50	1666	7.2	491	81	16	5	2	1	596	416	112	64	29	20	26	667
7	Reshen	200	68.5	22.5	29.8	2036	9.0	140	32	11	3	1	0	187	171	91	54	15	19	0	350
8	Zalim	244.5	75.2	28	34.2	2138	7.6	229	53	14	3	1	0	300	235	92	68	34	13.7	0	442.7
9	Halabja	234	77.5	22.8	24	1400	6.1	193	35	7	2	0	0	237	220	80	57	11.5	0	0	368.5
10	Reshen-Zalim-Halabja	678.5	181.4	31	34.2	2138	6.9	562	120	32	8	2	0	724	626	263	179	60.5	32.5	0	1161

CHAPTER THREE

GEOLOGY AND LITHOSTRATIGRAPHY OF THE BASIN

3.1 Geological setting of the basin

According to the tectonic classification of Buday (1980) and Buday and Jassim (1987), the area is located mainly in the High Folded Zone and partly in the Thrust and Imbricated Zones. Both SB1 and SB2 are located in the High Folded Zone while part of both SB3 and SB4 are located in the Imbricated and Thrust zones (Fig.3.1).

The basin is included in the Western Zagros Fold-Thrusted Belt which was deformed by Laramide and post Laramide orogenies. During these orogenies, both Iranian and Arabian Plates collided directly at the north of the studied area in the Miocene (Buday, 1987, Al-Qayim, 1989) or at Upper Cretaceous (Karim 2006, Karim and Surdashy, 2005b and 2005b). The northern and northeastern boundary of the SB1 and SB2 coincides with the boundary between the High Folded and Imbricated Zones. The northern boundary of the SB3 and SB4 is inside the Thrust Zone and coincides with the Iranian border.

In this basin, the anticlines and synclines are high in amplitude and tight; in most cases, they are turned toward the southwest due to the stress of the overriding Iranian plate. Nearly all the rocks of the basin are sedimentary and range in the age from Triassic to Recent.

The basin contains few small igneous bodies which are distributed along the southwestern sides of the Suren and Avroman mountains in the SB4. One of these igneous bodies is located 1km west of Biara town and the other two are located in the Zalim valley and 2km to the west of Zalim spring. The outcrops of these igneous bodies occupy no more than 0.5km^2.

In all four sub-basins, the wider distribution is of Cretaceous age rocks, which consist mostly of pelagic limestone and clastic rocks. The Clastic rocks belong to the Tanjero and Kolosh Formations (Upper Cretaceous and Paleocene) which are exposed in the synclines, while the resistive limestone is exposed along axes and limbs of anticlines (Annex1, Fig.3.2 and 3.3). These rocks are covered, sporadically, by thick layers of recent sediments in the low lands (plains and valleys).

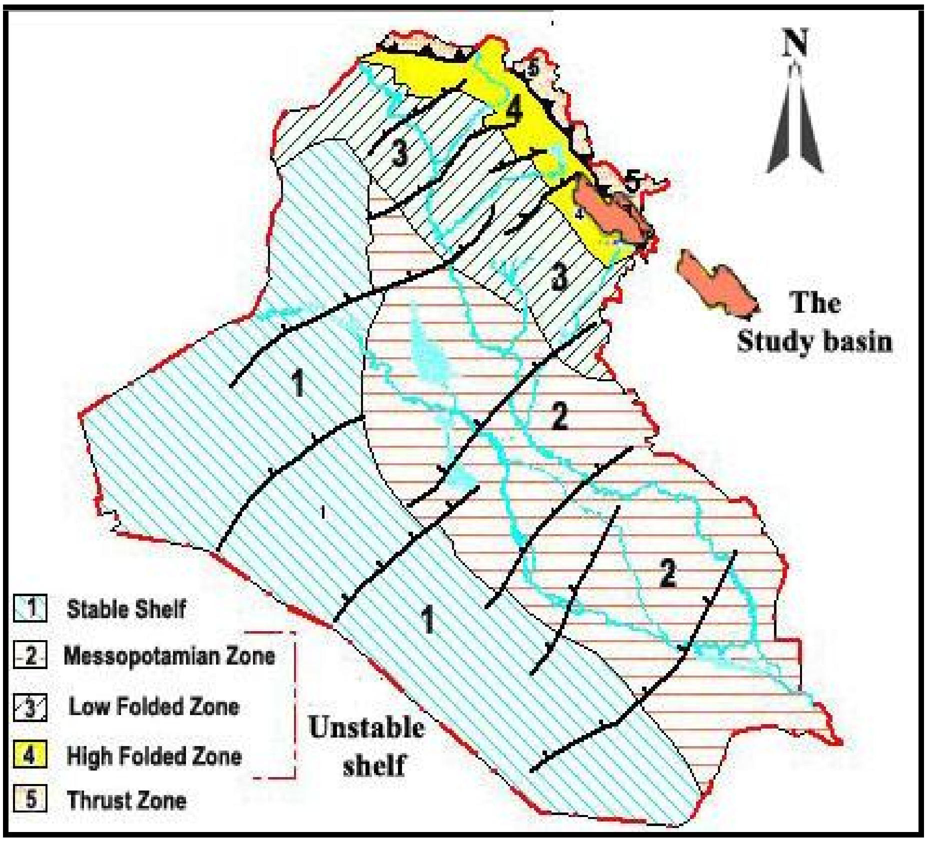

Fig.3.1 Location of the study basin with respect to tectonic division of Iraq. After Buday (1980).

In general, the age of the bedrocks in the area becomes progressively younger toward the southwest. There are some differences between the geologic development of the two western sub-basins, SB1 and SB2, and the eastern ones, SB3 and SB4. The two western ones consist of erosional and the subsequent valley, which was scored mainly by lateral and vertical erosion of the Tanjero and other streams during a prolonged period of time (Karim and Ali, 2004).

The eastern ones can be regarded as a circular syncline (inverted dome) developed by the plunging of five anticlines from all sides (Annex 1). In addition to plunging, two normal faults are more or less helpful in the shaping of this part (Fig.3.2 and Annex1), especially Qulqula, Qamchuqa, Balambo and Avroman Formations. This continuous deformation resulted from Alpine orogeny during which the overriding Iranian plate continuously moved toward the southwest.

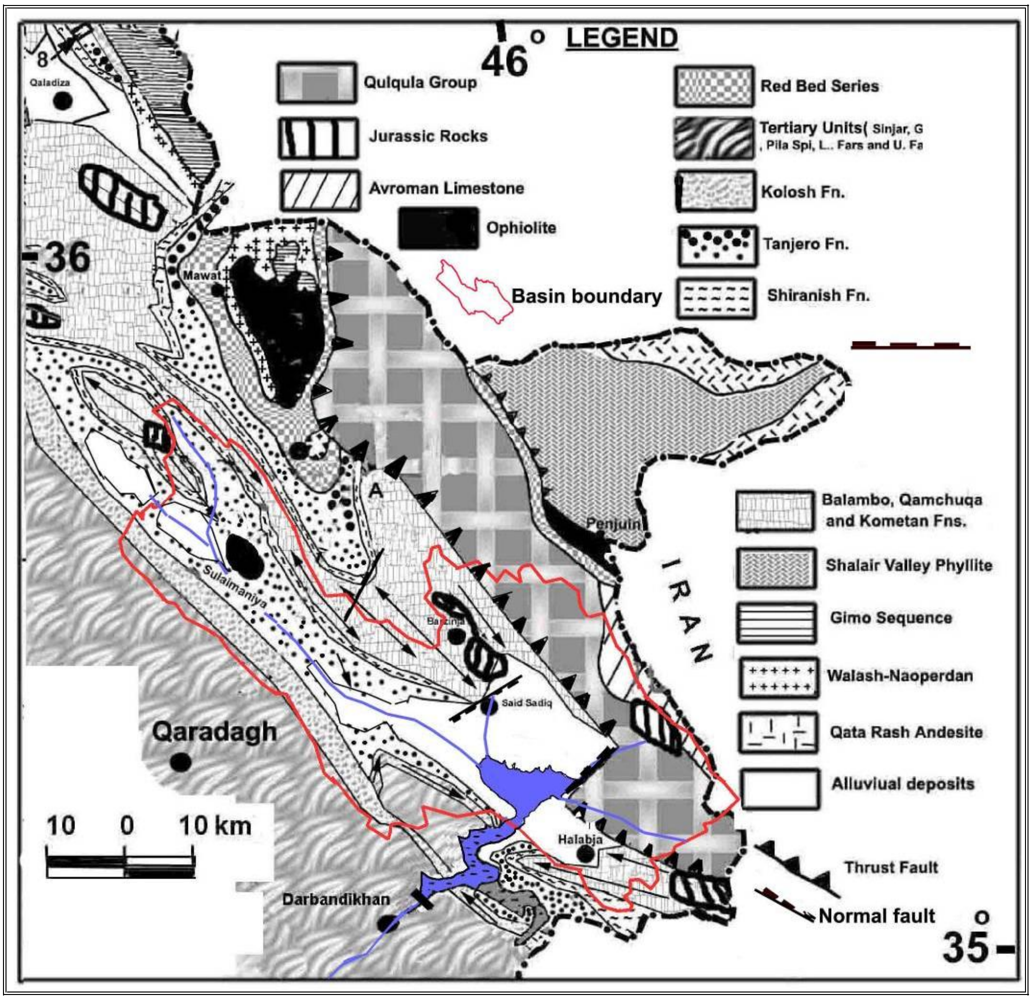

Fig.3.2 Geological map of the studied basin and the surrounding areas. (modified Sissakian, 2000).

Fig.3.3 Northwestern plunge of Balambo anticline at the Halabja --Khurmal sub-basin. The Avroman Mountain can be seen in the background.

3.2 Lithostratigraphy

The stratigraphic and lithologic studies are a key for the study of any basin, be it a watershed basin, hydrogeologic basin or depositional basin. The present basin has the properties of both watershed and hydrogeologic basins as it has well-defined surface water divide boundaries (flow divide) and nearly all (assured) ground water is gathered into and diverted to the basin.

The basin contains many well-defined stratigraphical units in addition to undifferentiated ones. The age of these units ranges from Triassic to recent. The well- defined units are those retuned to Cretaceous and Tertiary, while those older than Cretaceous are either not differentiated or given the rank of group only.

The older formations are exposed in the core of anticlines and the younger ones are exposed in between these anticlines or along their limbs and synclines.

-Avroman limestone Formation (Triassic)

This formation is located in the northeastern part of the basin, in the northeast and north of SB3 and SB4 respectively. In these two sub-basins, it is exposed above the contour line of 950m along the lower slope of the southwestern side of the Avroman and Suren mountains which can be seen to the north of Nawe, Kani Askan, Bardabal, Tazade and Walasmit villages in the SB3 (Annex 1,2). The formation consists of grey, thick-bedded, pure limestone and contains many fossils with a total thickness of 3000 meters.

The main fossils are oncoids, gastropod, algae and ooids (Fig. 3.4 and 3.5). The formation constitutes the whole body of the Avroman and Suren Mountains which are more than 2500 meters a.s.l. near their summit, these mountains are divided longitudinally into equal halves by the Iraq-Iran border at the east and northeast of Said Sadiq, Khurmal and Biara towns. It forms the crest and core of an anticline (called the “Avroman-Suren anticline”), which consists of a deformed and unidentified anticline that looks over the western part of Sharazoor plain.

According to Karim (2006b), the lower boundary and possibly the important thickness of the formation are not exposed. Therefore, the stratigraphy of the formation is not clear. He also mentions that the upper boundary is tectonic and the formation is overlain apparently by two different rock units. In Iran, it is overlain by Miocene Merga Red Beds (sandstone and red clay stone) which can be seen directly to the north of the border inside a small syncline on the summit of Suren anticline. In Iraq, it is overlain by Qulqula Radiolarite Formation.

-Jurassic Rocks

These formations are exposed only in the SB3. Their occurrence in this area is not mentioned by either Bellen *et al.* (1959) or Buday (1980). But Jovanovic and Gabre (1979) recorded and studied them petrographyically and paleontologically. They identified Sarki and Sargalu Formations in the area to the north and northwest of the proposed Kaolos dam. Sargelu, Naukelekan and Barsarine Formations are ascertained, located under Cretaceous units, but in the present study no evidence is found for the existence of Sarki Formation. Sargalu consists of well-bedded and well-crystallized, black bituminous limestone and dolomitic limestone and occasionally contains shells of posidonia. The lower part is massive and thick, forming a cliff. Barsarine exists as thin bedded and stromatolitic limestone with a thickness of 70m (Fig.3.6 & Fig.3.7). These formations are exposed along both sides of Galal valleys which are deeply dissected by an emepheral stream of the same name.

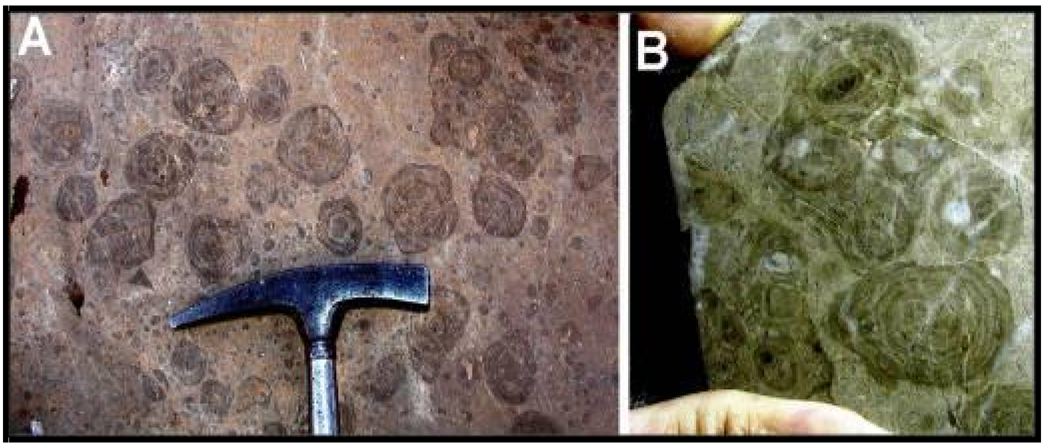

Fig. 3.4 Simple and composite oncoids in Avroman Formation as seen in polished slabs

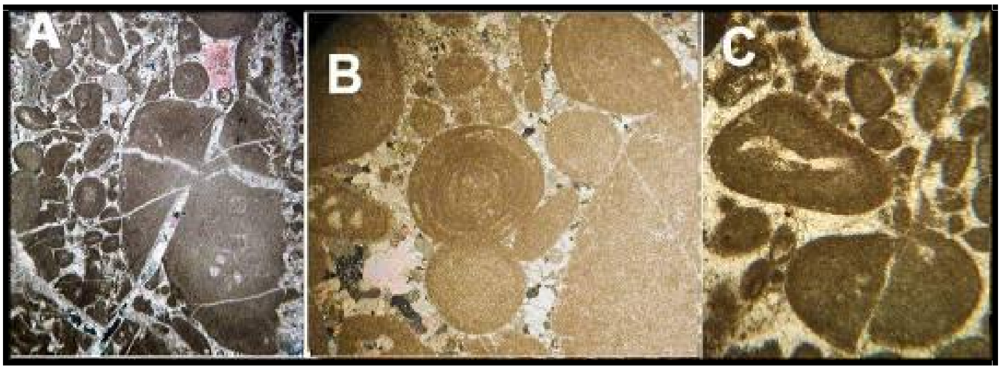

Fig.3.5 Tectonically broken peloids (A and C) with ooids (B) in the grain stone of the Avroman Formation (Taken from Karim 2006b). X20, ppL.

-Qulqula Radiolarian Formation

The Qulqula Group consists of two formations, the Qulqula Radiolarian Formation and the Qulqula conglomerate Formation. In the Sharazoor-Piramagroon basin, this group exists only in the two eastern sub-basins (SB3 and SB4). It covers the lower part of the southwestern limb of the Avroman and Suren anticlines. The covering is not continuous but it intermittently eroded, as in the case between Ahmad Awa and Shiramar villages. Recently, it has been proved by Baziany (2006) and Karim and Baziany (2007), that the latter formation does not exist and has been mistaken for the Red Bed Series. According to these authors, the Qulqula Conglomerate Formation in this basin, which is mentioned by Bolton (1958) and Buday (1980), is equivalent to the Quaternary sediments which exist in the foothills of the Piramagroon and Suren mountains (Fig.3.12).

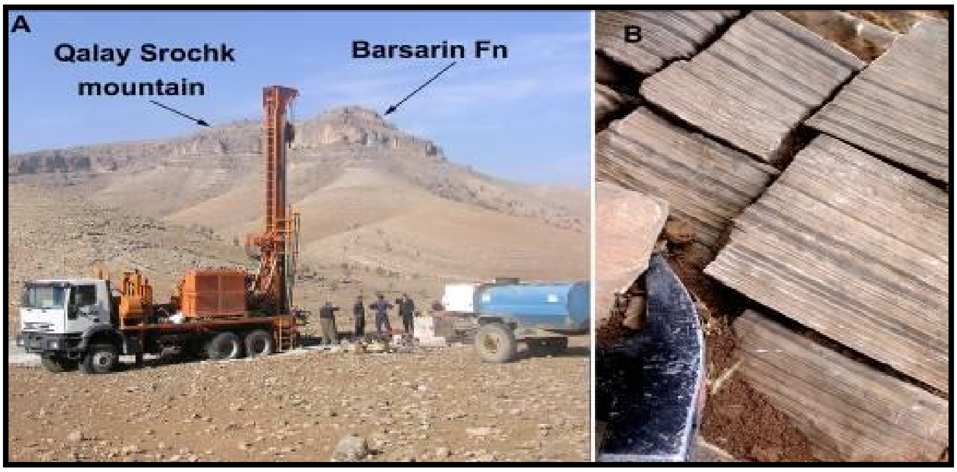

Fig.3.6 A: Outcrops of Jurassic Barsarine and Sargelo Formations background and new drilling machinery at work for groundwater exploitation at Galal Valley in SB3. B: stromatolitic dolomitic limestone of Barsarine Formation

It is worth mentioning that this conglomerate was previously called Qamchuqa Formation by Jovanovic and Gabre (1979) and Ali and Ameen (2005). This is because this conglomerate appears in some places as thick massive limestone and shows no granularity which is similar in color, thickness and stratification to the Qamchuqa Formation. Therefore, in the present basin only the Qulqula Radiolarian Formation is cropped out at the north and northeastern boundary of the basin.

Lithologically the formation is composed of very thick packages of chert, marls, siliceous shale and limestone beds. These rocks are highly deformed and their thickness is variable due to intense deformation and possible suffering from multiplication by tectonic imbrications (Fig.3.8). The authors, in cross sections near Kaolos Village, measured the thickness of 1400 meters of the Qulqula Formation. The colors of both chert and marl are variegated including red, grey, yellow, brown and white, while the limestone color is generally black or grey.

The general structure in which the layers of this formation is arranged is not known yet, but one can see several highly deformed local synclines and anticlines around Nawe, Qalbaza, Reshen, DolaChawt, Chawtan, DeKon and Sargat villages in addition to the west of Halabja town (Figs. 3.9 and 3.10).

-Qamchuqa Formation (Lower Cretaceous)

This formation is exposed in the western part of the basin in the SB1 and regarded as a lateral change of the Balambo Formation in the basin. In the past this formation was mentioned as having occurred in the eastern part of the basin (Fig. 3.11A). But Baziany (2006) proved that no outcrops of this formation occur in this area and actually what was previously called Qamchuqa was only Quaternary sediments. Therefore, it is clear that this formation is exposed only in the western part of the basin which is cropped out along the upper slope and crest of the Piramagroon anticline and northwestern end of the Azmir anticline where it is called the Daban anticline. The lithologic difference between the Balambo and Qamchuqa Formations can be recorded in the field, where the Balambo Formation is characterized by the yellowish white, medium and well-bedded limestone. The Qamchuqa Formation consists of grey massive dolomites and dolomitic limestone with a thickness of more than 500m.

It is suggested that this formation was deposited on isolated platforms in warm climates in continuously subsiding basins during the Lower Cretaceous age. Both the lower and upper boundaries are gradational in the studied basin with Kometan and

Sarmord Formation. All surveyed outcrop sections are barren of fossils due to intense dolomitization and recrystallization. The recorded fossils occur along thin intervals which contain gastropods, pelecypods and corals with their bioclasts.

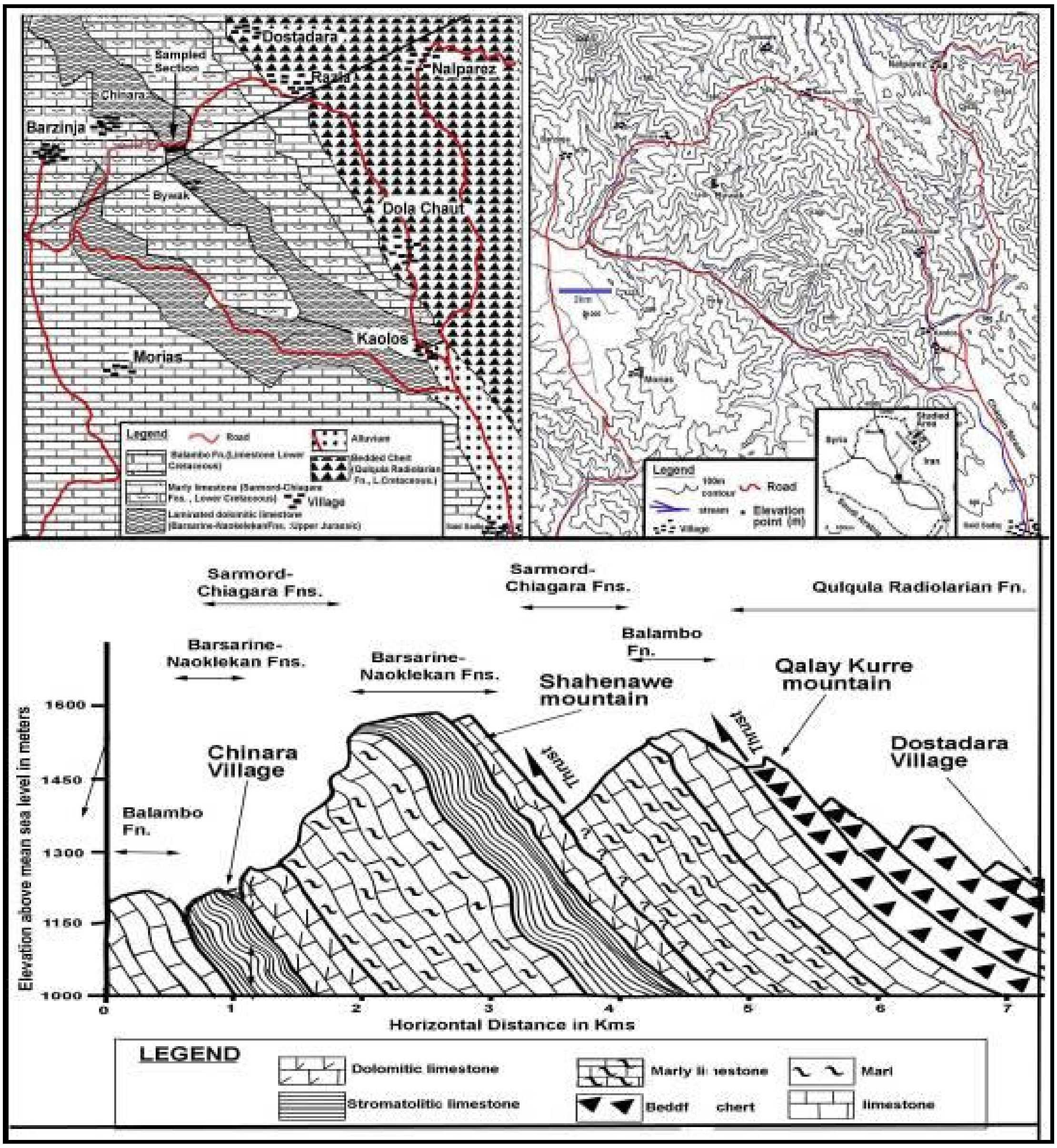

Fig. 3.7 Geologic map, topographic maps and cross section of the Galal Valley (modified from Daoud and Karim, in press).

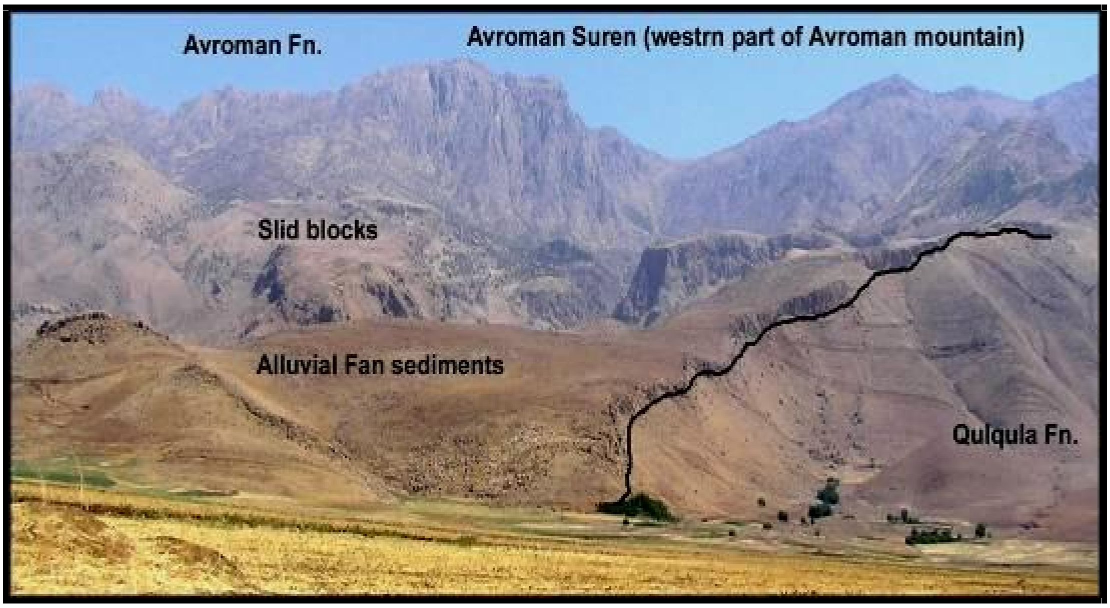

Fig.3.8 Outcrops of Qulqula Conglomerate Formation (alluvial fan and slid blocks) and Qulqula Radiolarian Formation at the Suren mountain toe (taken from Baziany, 2006)

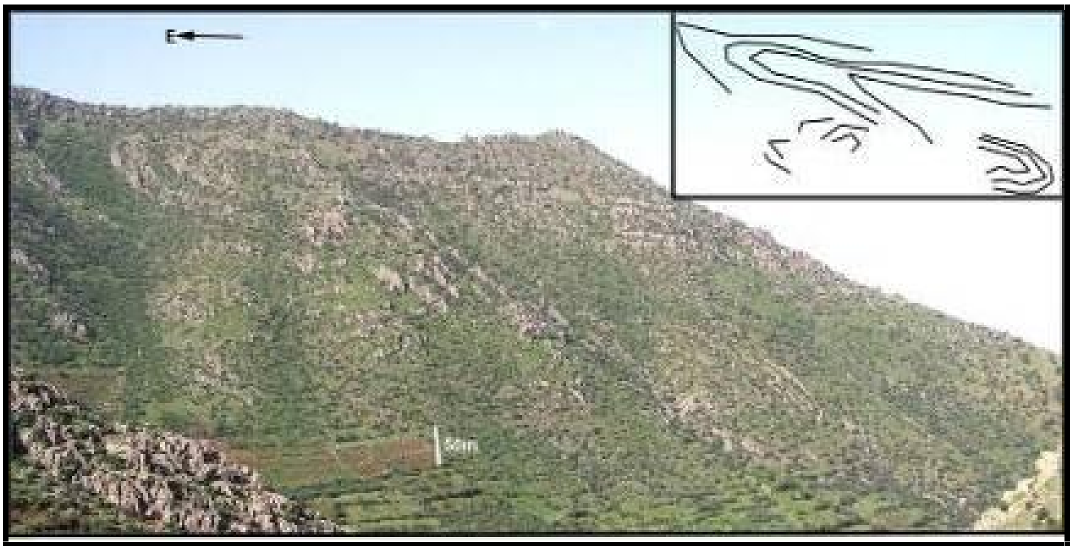

Fig.3.9 Sharam Mountain to the east of Sargat village (Hawraman area) formed from the main eastward imbricated anticline and other deformed structures as can be seen in the photo and sketch

Fig 3.10 Mesoscopic deformation of one of the siliceous limestone package of the Qulqula Formation

- Kometan and Balambo Formations

The Upper Cretaceous Kometan (Turonian) and Lower Cretaceous Balambo (Valanginian-Cenomanian) Formations are widespread in the Sharazoor-Piramagroon basin and are exposed in all four sub-basins. Both are, lithologically, very similar, composed of well–bedded, white or grey pelagic limestone (mudstone). The only difference is that the limestone of the latter formation is occasionally marly and contains interbeds of marl. Their thicknesses are more than 250m in the north and east of the basin. The boundary between the two formations is gradational and there is no sign of any break in the sedimentation with Shiranish and Qamchuqa or Balambo Formations. The white and chalky limestone is widely used in Sulaimani city as building stone.

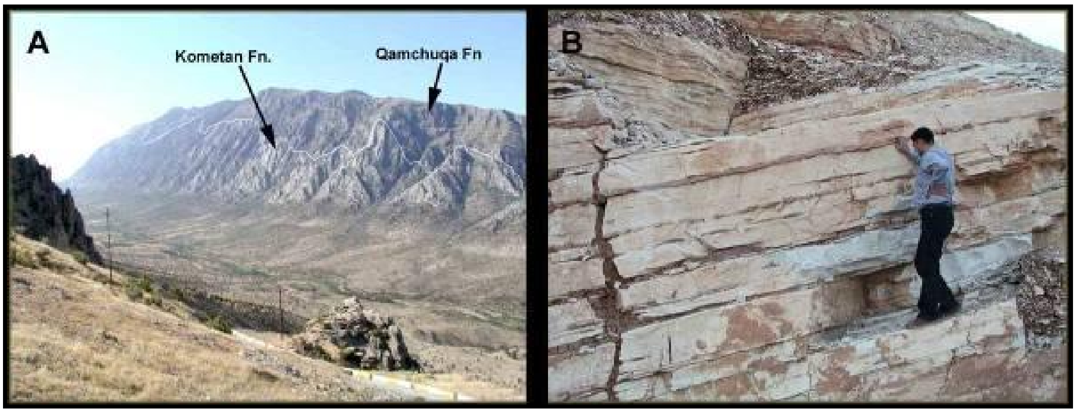

Fig.3.11 A: Outcrop of Kometan and Qamchuqa Formation exposed along the northeastern limb of Piramagroon anticline .B: white well bedded limestone of Kometan Formation in the quarry of building stone at Chaqchaq valley.

-Shiranish, Tanjero and Kolosh Formations

Shiranish Formation (Campanian) is composed of a succession of bluish white marl and marly limestone which is about 200m thick. It has gradational contact with both underlying Kometan Formation and overlying Tanjero Formation (Maastrichtian).

Lithologically, Tanjero Formation is composed mainly of an alternation of thin beds of sandstone or siltstone with interbeds of shale, marl or—rarely--marly limestone. These two formations crop out in the central and northwestern boundary of the basin in the SB1 and SB2. The outcrops of Tanjero Formation are more common than that of Shiranish Formation which is exposed along the lower part of the limbs of the anticlines except Avroman.

In the basin, especially in the western part, the Tanjero Formation contains a thick succession of bluish white marl which is extremely similar to the lithology of the Shiranish Formation.

This succession belongs to the middle and upper parts of the Tanjero Formation which deposited during transgressive and high stand system tract marls in the middle part of Tanjero Formation (Karim and Surdashy, 2006). In many places, the intense deformation or weathering changed the marl and marly limestone to loose and porous materials with high porosity.

Fig.3.12 A: Outcrops of Kolosh Formation near KalkaSmaq village showing alternation of medium beds of shale and marl. B: Gradational contact between Kolosh and Sinjar Formations represented by shale and limestone beds.

Kolosh Formation (Paleocene) is similar to Tanjero Formation but contains more shale and marl and less sandstone (Fig.3.12). Its thickness is more than 500m which is exposed only in the southern boundary of the western part of the basin in SB1 and SB2. The outcrops can be seen along the southern side of the Tanjero stream on the lower slope of the Baranan and Bakir Agha mountains.

-Sinjar, Gercus and Pila Spi Formations

Sinjar Formation refers to the Upper Paleocene-Lower Eocene which consists of thick bedded fossilliferous limestone. Toward the top of the formation, the dolomitic limestone and clastic rocks increase. The thickness of the formation is around 120m and has gradational contact with the underlying Kolosh and overlying Gercus Formations. The formation crops out at the southern boundary along the scarp slope (northwestern side) of the Baranan homocline. Along this homocline, the outcrops extend from Tasluja town, to the northwest, to the Sirwan river to the southwest, south of Halabja Town, (Fig.3.13 and Annex 1)

The most common fossils are benthonic forams such as nummulites, miliolids and alveolina. Other fossils include gastropods, algae, coral and pelecypods.

Gercus Formation refers to the middle Eocene clastic rock of molasses facies which consist of red clay stone, sandstone and lensoidal conglomerate. The thickness is more than 70m and the outcrops are associated, almost everywhere, with Sinjar Formation.

In rare cases it consists mainly of 60m of pebbly cobble conglomerate as can be seen 10km to the south of Zarain town where the conglomerate forms a mountain about 200m high known as Barda Asin Mountain.

Pila Spi Formation is an Upper Eocene which consists of white, chalky and dolomitic limestone. The thickness is variable in the basin, ranging between 60-130m.

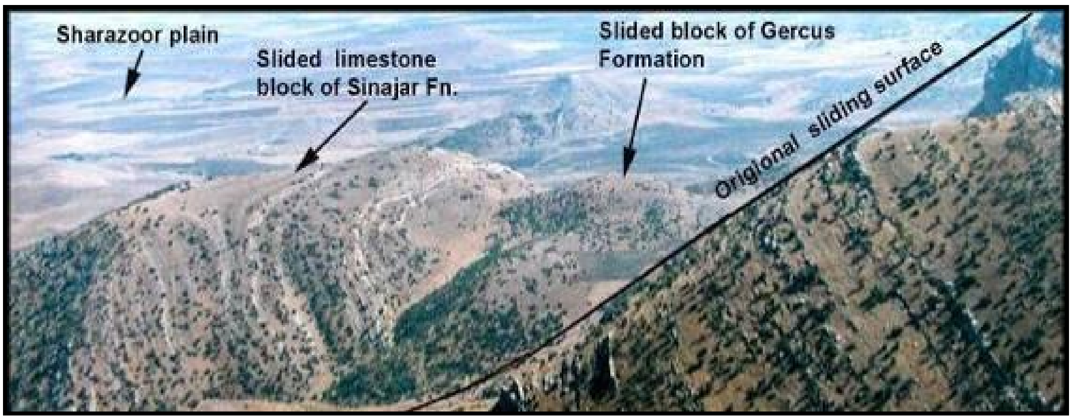

Fig.3.13 Large block of fossilliferous limestone of Sinjar Formation which has slid toward the eastern part of Sharazoor plain (Taken from Karim and Ali, 2004).

- Alluvium deposits

The basin is surrounded on all sides by high mountains which consist of different types of limestone and in some cases of chert successions. These mountains are dissected by tens of both perennial and emepheral streams. These streams scored more or less deep valleys both by erosion and with the aid of mass wasting in the limestone chert successions.

The products of erosion and weathering, as angular clasts, are accumulated in the steep valley sides and in the valley bottoms. The accumulated rock fragments are transported seasonally by stream floods during heavy rainfall. Then large quantities of boulder, gravel and sands are carried down stream and deposited on the plains and lower slopes of mountain sides.

These sediments are deposited as debris flow on the gently sloping plains or as channel deposits (lag and channel fills deposits), or as channel margin deposits and over bank deposits.

The mass wasting other than debris flow also has a part in the accumulation of these sediments along the mountain slopes (as colluviums), in the central part of the Sharazoor-Piramagroon basin. Repetition of these accumulations forms a thick succession of recent sediment. Generally these sediments consist of angular and badly sorted clasts of boulder, gavel and sand with more or fewer amounts of clay as separate deposits. Lithologically, they are composed mostly of limestone and chert fragments.

-Alluvial Fans

Field study showed that tens of large and small alluvial fans start from the feet of the high Mountains such as Piramagroon, Azmir, Goizha, Avroman, Suren, Shinrwe and Balambo. These fans stretch from the mouths (outlets) of the large or small valleys of these mountains into the lowland of the Sharazoor and Piramagroon plains (Figs. 3.16, 3.17, 3.18, and 3.19).

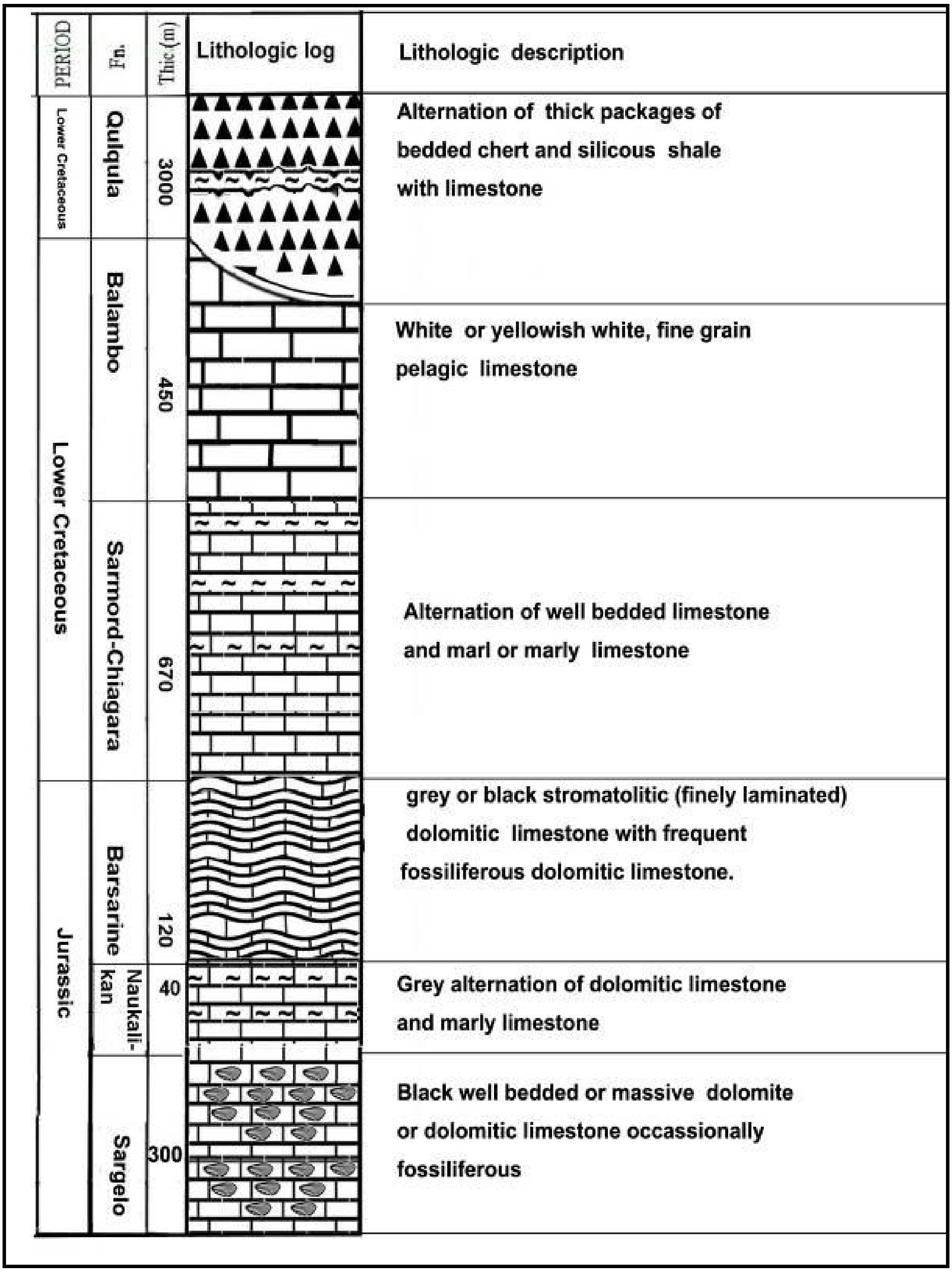

Fig. 3.14 Stratigraphic column of the Said Sadiq sub-basin (SB3)

The fans are formed when the heavily loaded flood or debris flow reaches the narrow outlets of the deep valleys where the flow attains high thickness. Then when it passes through a tight passage and reaches the plain, the debris flow spreads over the downstream plain as a fan. The spreading is due to the decrease of both slope and channel depth (abrupt widening) as compared to the steep slope and lightness of the valleys. The depositions of sediments are accelerated by channel loss of water by infiltration.

Most of the large fans are prograded into the central part of the Sharazoor plain. Now these fans can hardly be distinguished by their fan-like shape because they have been dissected by several small emepheral streams which have modified their shape. Another reason is that the adjacent fans are coalesced laterally so that a single fan cannot be separated. Nevertheless, these fans can be distinguished from their sediment which consists of heterogeneous, unsorted and angular rock fragments and clay.

These fans are very common in the basin as the basin has an arid climate and intermittent seasonal rainfall. The absence of weak vegetation and loose soil cover are main factors in the generation of alluvial fans. Many places of the basin are covered with alluvial deposits derived either from Qulqula Radiolarian and Avroman Formations at the Avroman and Suren mountain toe or from the Balambo and Kometan Formations at other places in the basin (Fig. 3.16, 3.19).

At the southern boundary of the basin, small fans are derived from the Sinjar and Pila Spi Formations.

-Flood plain

Since Sharazoor plain is surrounded by steep-sided mountains, the existing streams are still at a youthful stage of development. Therefore, the heavy loads of these streams are released on the plain during heavy rainfall. When the stream reaches the plains the velocity decreases and the coarse load is therefore deposited as channel lag deposits (channel deposits) or as fanglomerates while the fine materials (clay and silt) are deposited on the flood plain on both the flat areas around the streams.

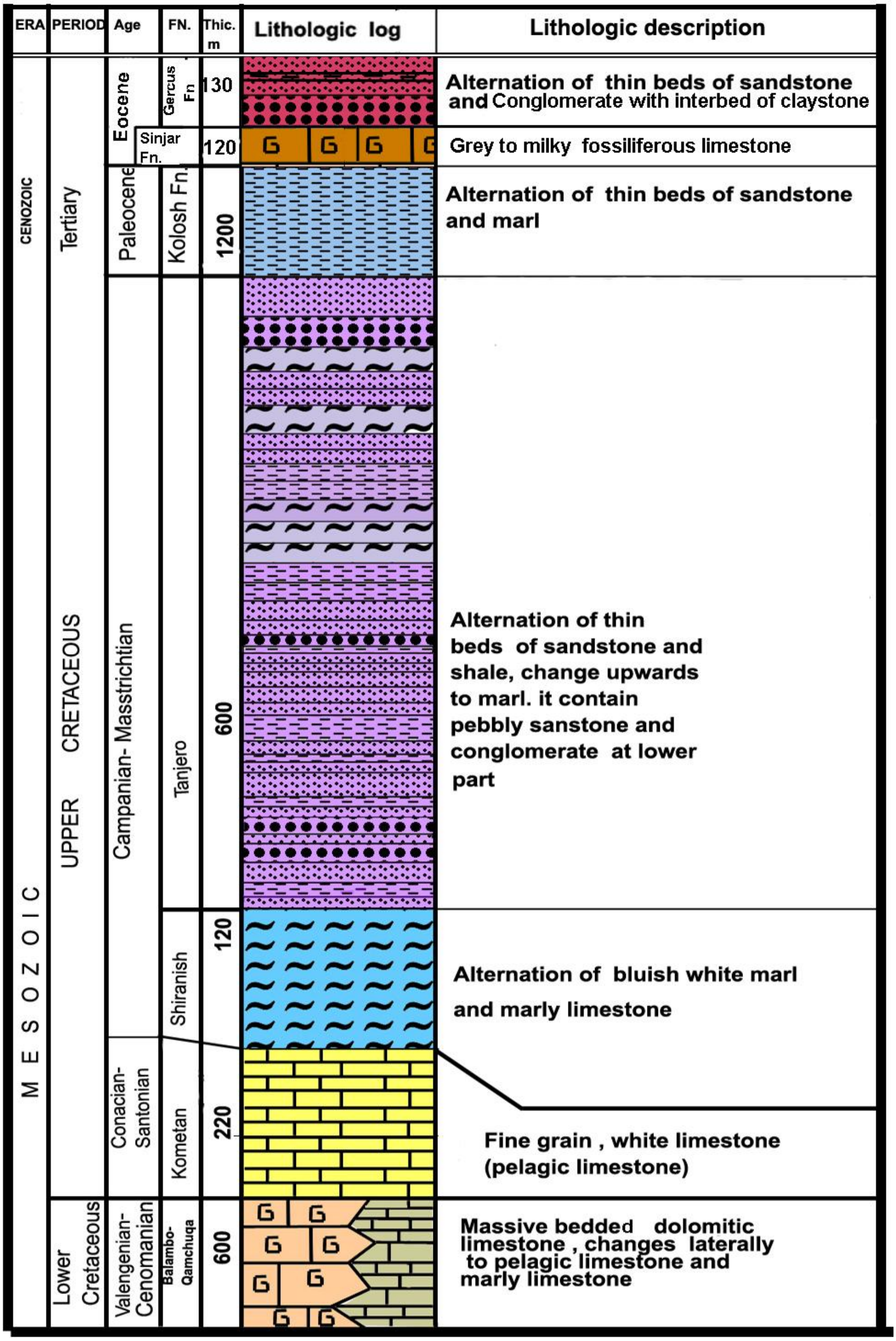

Fig.3.15 Stratigraphic column of the western part of the Sharazoor–Piramagroon basin (SB1 and SB2)

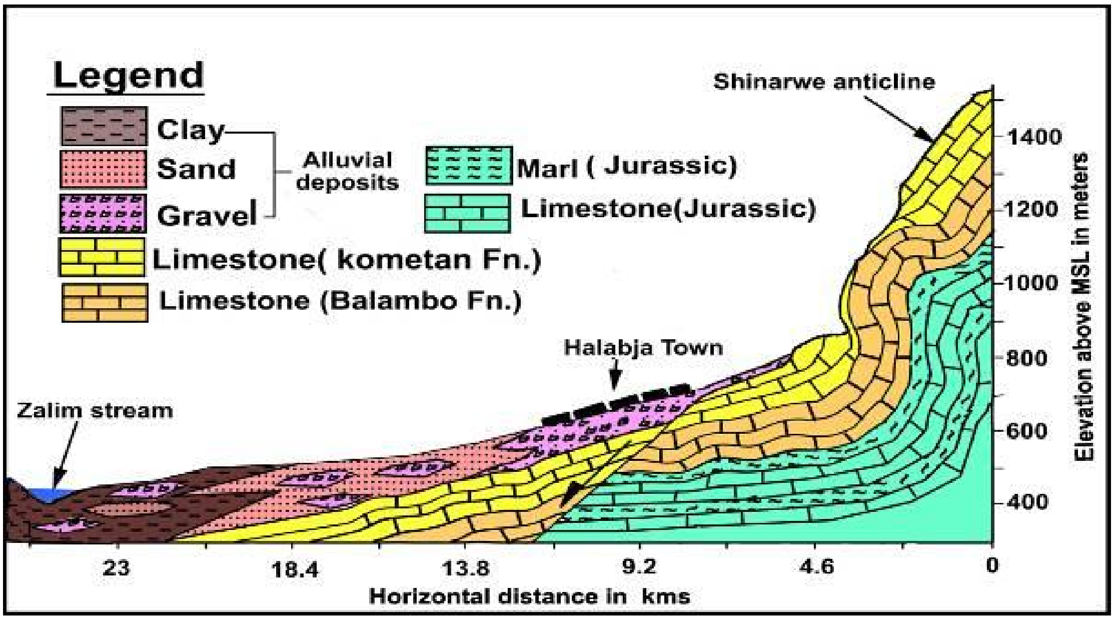

Fig. 3.16 Geologic cross section of the Shinrwe Mountain, passing through Halabja town and the alluvium fan at the mountain toe.

From this, a relatively broad area is converted to flood plains in the areas which have a slope of less than 3 degrees. The areas located directly to the northeast, north and northwest of Darbandikhan Lake are regarded as a flood plain of Biara and Zalim Streams while the rest, such as the area located to the south to Said Sadiq town, is developed by Chaqan stream. The flood plain of Tanjero stream can be seen around Zarain town.

These flood plains, as constructive features, are formed by deposition through either the northward retreat (erosion) of Avroman, Suren, Goizha, Azmir and Piramagroon Mountains or by the southwest retreat of Baranan Mountain. According to Karim and Ali (2004) and Ali (2005), the southwest retreat is caused mainly by landslide and stream erosion of the Tanjero stream, while the northern retreat is attributed mainly to stream erosion, mass wasting and chemical weathering.

These flood plains, as constructive features, are formed by deposition through either the northward retreat (erosion) of Avroman, Suren, Goizha, Azmir and Piramagroon Mountains or by the southwest retreat of Baranan Mountain. According to Karim and Ali (2004) and Ali (2005), the southwest retreat is caused mainly by landslide and stream erosion of the Tanjero stream, while the northern retreat is attributed mainly to stream erosion, mass wasting and chemical weathering.

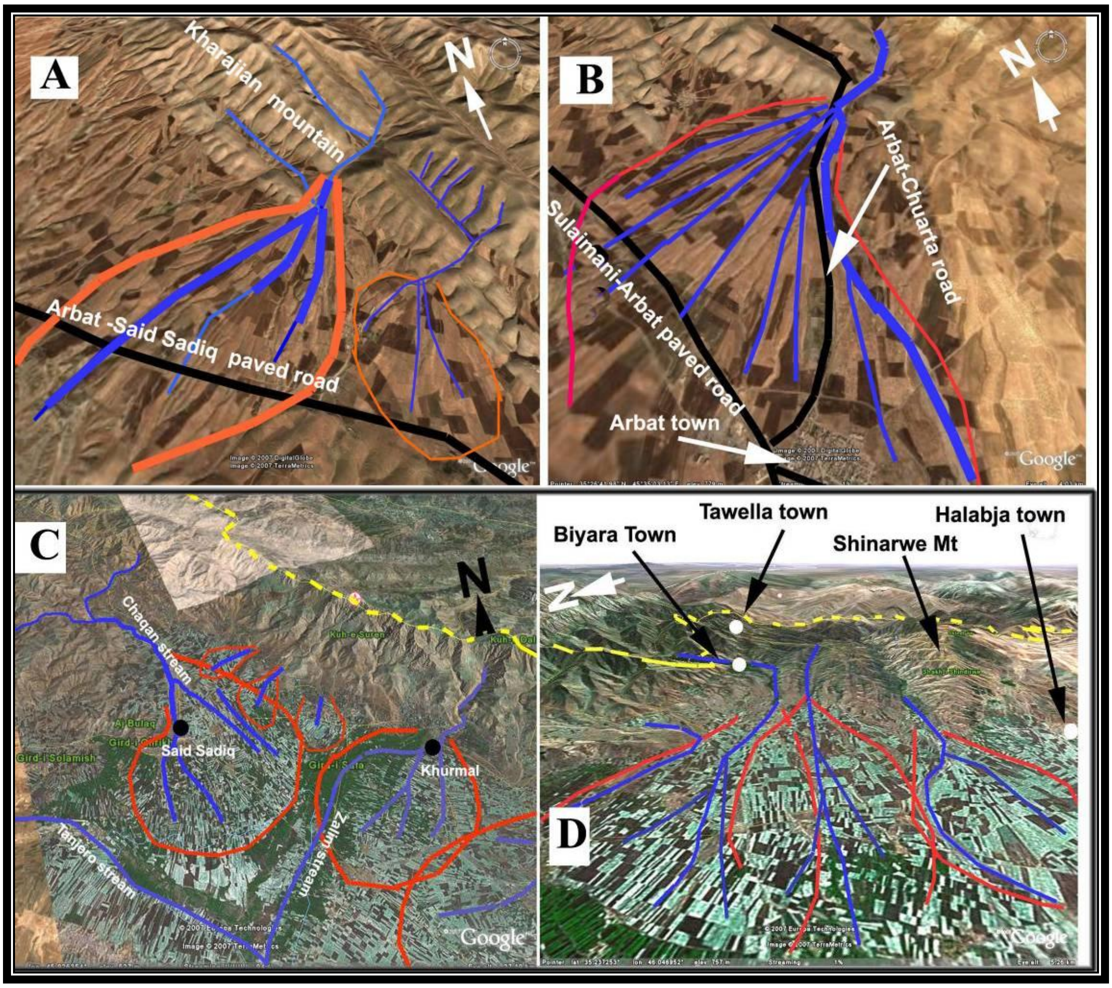

Fig. 3.17 Different large and small alluvial fans in the Sharazoor-Piramagroon basin (only the proximal fans are shown. A: East Arbat fans in the SB2. B: north Arbat fan. C: Chaqan (Said Sadiq) fans in the SB3 and Khurmal fans in SB4. D: Avroman fans in the SB4. The red and blue lines indicate fan boundary and stream respectively (From Google Earth website).

Fig.3.18 Foreground: pediment of Goizha Mountain (northeastern of Sulaimani city), shows proximal part of several alluvial fans. Background: Baranan Homocline which forms part of the southern boundary of the basin.

The lateral erosion and shifting of the streams have a clear role in the development and widening of the flood plains. The flood plain deposits, in most places, alternate with the coarse sediments of either alluvial fan or stream channel deposits. Therefore the flood plain deposits exit as several horizons, the thickness of each one ranging between 10cm-4m. The total thickness of the recent deposits is broadly changing; it ranges between 0-180m (Fig. 3.21). In the basin, in some place these deposits consist of three horizons:

A. The upper horizon is composed mainly of silt; clay with few lenses of gravels with a thickness which may reach (1 to 3m) meters. This is interpreted as flood plain deposits

B. The lower horizon is composed of sand and sorted gravels which may be attributed to bed load and is laterally replaced by unsorted alluvial fan deposits near the Mountains feet.

C. In most cases these two horizons alternate, forming a thick layer of alluvium and fluvial deposits which reaches 200 meters in thickness such as in the Shanadari and Halabja area.

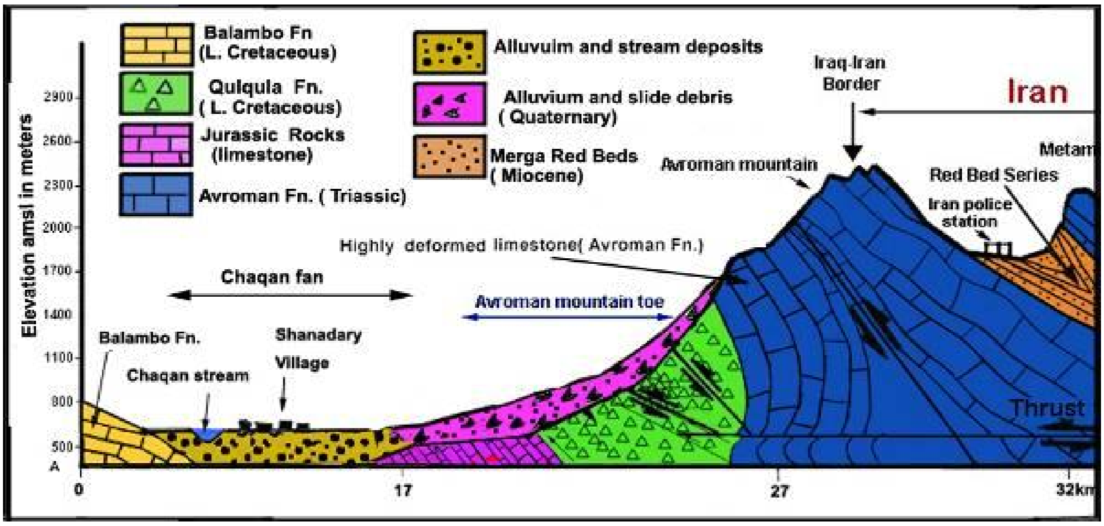

Fig.3.19 Geologic cross section of the southwestern side of Suren Mountain passing through Chaqan fan (alluvial deposits).

-Slide debris and blocks

As slide debris and blocks are commonly mixed with alluvium sediments and cannot be distinguished easily from each other, these types of sediments are described and grouped with alluvium deposits. Ali (2005) found more than 15 separate accumulations of brecciated slide debris and slide blocks at the southern part of SB1 and SB2 along the northeastern side of Baranan Mountain. Baziany (2006) found the same type of mass wasting along the Suren and Avroman Mountain (Fig. 3.8, 3.13, and 3.20). The debris and blocks are located at the toe of the above Mountains and some of them rest on the Sharazoor plain.

Originally the plain, without the slide blocks is nearly barren of water. This can be explained as follows: the surface of the plain is covered, to a depth of about 300, by an impervious bed of either Paleocene Kolosh or Maastrichtian Tanjero Formations. These formations consist of a very thick succession of sandstone, siltstone and marl which alternate rhythmically as southwest low dipping strata (Buday, 1980, Al-Rawi, 1981, Jazza, 1993, Karim, 2004 and Karim, 2005).

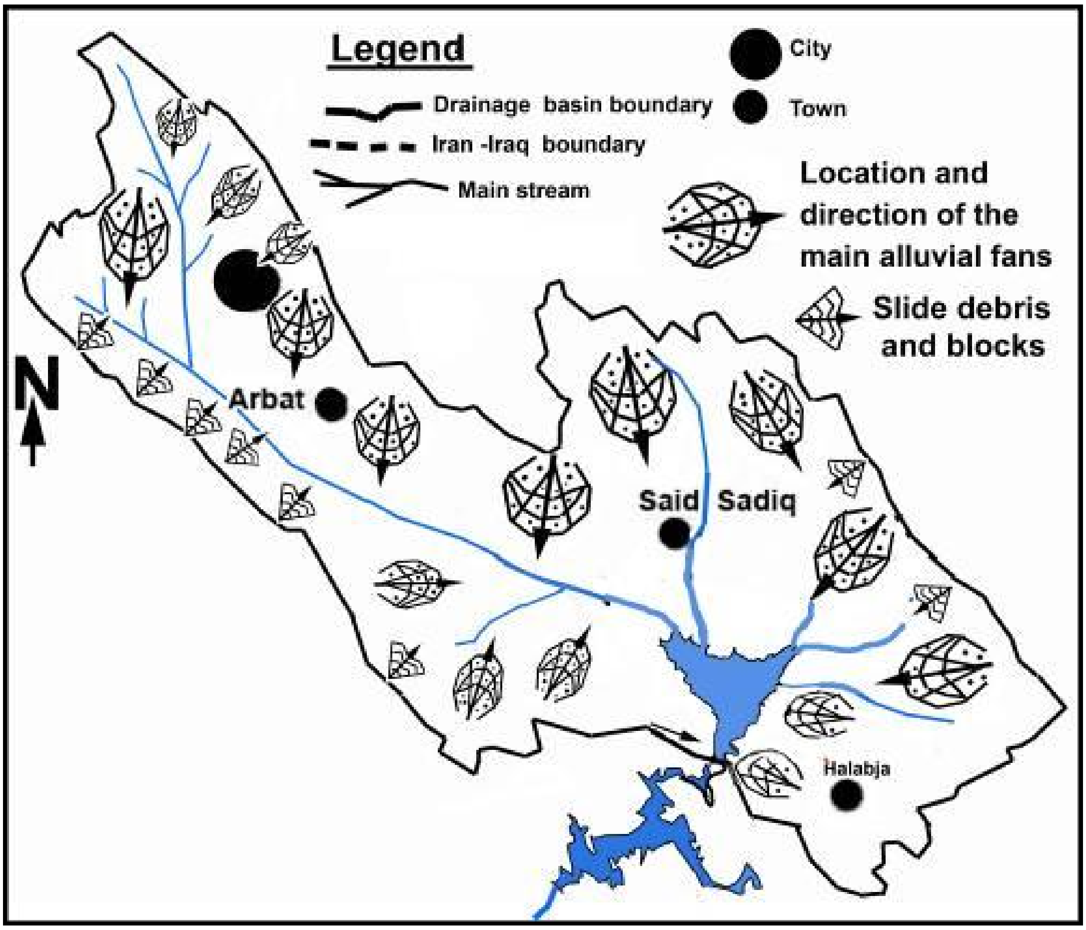

Fig.3.20 Position and direction of the main alluvial fans and slide debris in the Sharazoor-Piramagroon basin.

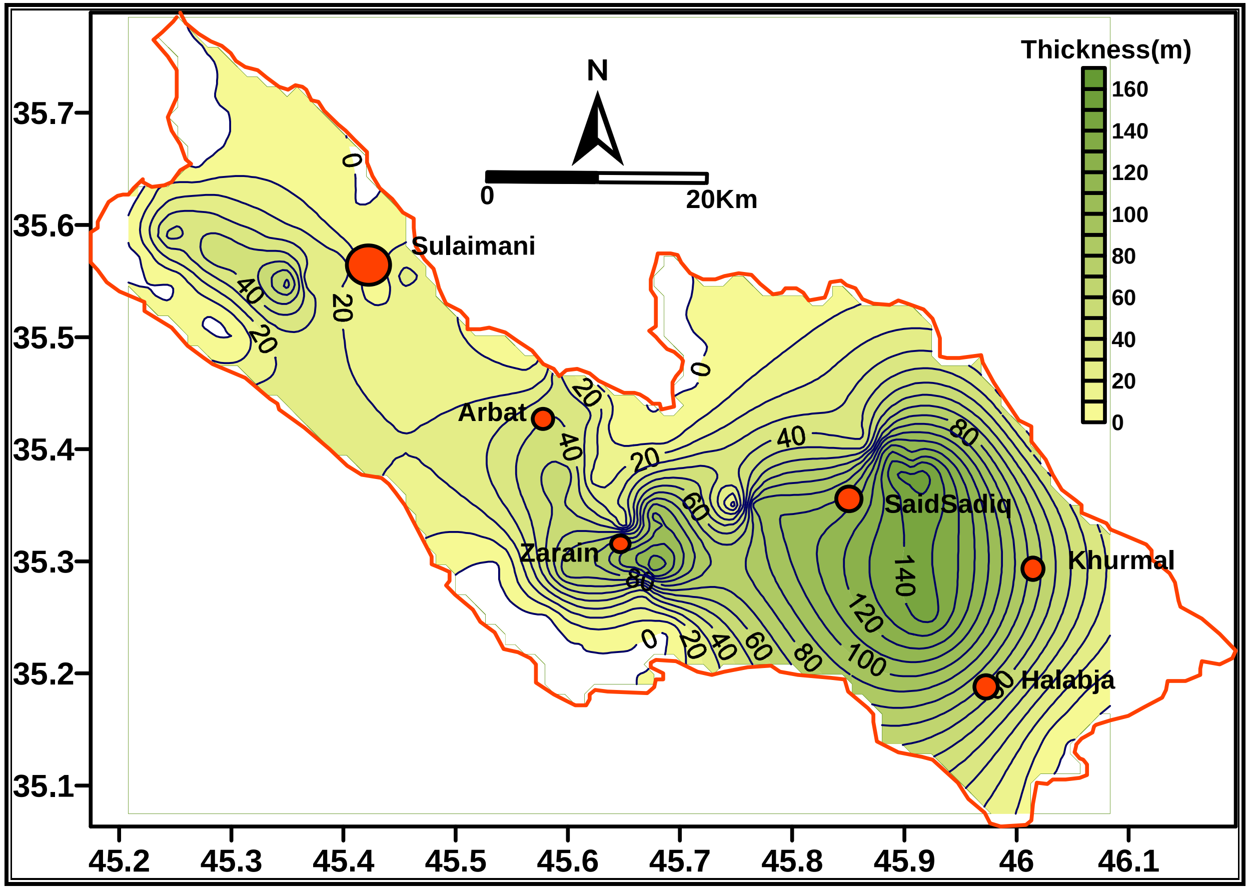

Fig 3.21 Isopach map of alluvium deposit in the study basin, drawn based on the collected data of the drilled well, field survey and some sporadic geophysical surveys. In some areas the thickness is uncertain because the data represent only the max. depth of drilled wells.

3.3 Tectonic and structure

-General tectonic of the region

Buday and Jassim (1987) presented the most widely used regional tectonic division of the entire Iraqi territory. According to them, it can be divided into three main tectonic units:

- *Geosyncline* on the furthermost northeastern part of Iraq, consisting of Eugeosyncline and Miogeosyncline.
- *Unstable Shelf* located to the SW from the Geosyncline contains three zones: High Folded, Low Folded and Mesopotamian Zone.
- *Stable Shelf* occupies the biggest part of southwestern Iraq and consists of two distinguishable zones: Salman Zone and Rutba-Jazira Zone.

In the terms of orogenetic theory, the first unit in which the northern part of the study basin is located represents an active orogenic area, characterized by faulting, folding and over-thrusting. Morphologically, it is a high mountainous area. This unit is also named Zagros Mountain area, as the mountain belt is on the Iraq-Iran border.

The second unit, Unstable Shelf, represents a transitional zone between the orogenic belt and the stable platform. From the High Folded Zone, it turns into the Low Folded Zone, with a long, asymmetrical linear fold, spreading along NW-SE (Zagros direction) in the eastern, and E-W (Taurus direction) in the western part.

Stable shelf, with its undisturbed or slightly inclined beds, lies in the south of Iraq, out of the territory of the Iraqi Kurdistan Region.

"New, modern theory treats regional tectonic division of the northern Iraq in terms of the plate tectonics. Numan (1997) modified and completed former works of Bolton (1958), Dunnington (1958) and Bolton et al (1959)"*[1]

The regional tectono-stratigraphic provinces of Iraq are distinguished according to the nature, structure and geotectonic position in a plate tectonic context of the basement rocks, including interplate, marginal cratonal platform, quasi-platform, foreland basin of the passive continental margin, and in the region of subduction, fore-arc, arc, inter-arc, intra-arc and back-arc regions. New tectonic division displays Fig.3.22.

[1] ***Stevanovic and Markovic, 2004: Hydrogeology of northern Iraq, Vol.1, p82.***

The correlation between tectonic subdivisions of Iraq made by Buday and Jassim (1987) and modern major tectonic divisions of Iraq modified and completed by Numan 1997, after Bolton, 1958 and Dunnington, 1958, shows the following facts:

- The Geosyncline Unit corresponds to the Subductional Tectonic Zone of the Zagros Thrust and Zone of Imbrication of the Foreland Basin.
- The High and Low Folded Zones of the Unstable Shelf are equivalent to the Highly Folded Zone of the Forland Basin, and Suspended Basins, Foothill Zone of the Quasi-platform Foreland.
- the Mesopotamian Zone of Unstable Shelf is treated as the basin of the Mesopotamian Zone of the Quasi-platform Foreland.
- All Zones: Miogeosyncline, High, Low Folded and Mesopotamian Zones are considered as Foreland Belt of the Arabian Plate.
- the Stable Shelf completely corresponds to the Stable Platform.

The extreme northern and north-eastern borders of the North Iraqi Territory (Geosyncline Unit or Subductional Zone) are characterized by over-thrusting, with the general movements towards south and southwest. The Tectonic characteristic of the High and Low Folded Zones of the Unstable Shelf (Highly Folded Zone of the Forland Basin, and Suspended Basins, Foothill Zone of the Quasi-platform Foreland) is an example of long folded structures, with generally southern/southern-western limbs steeper than those on the north/northeastern direction.

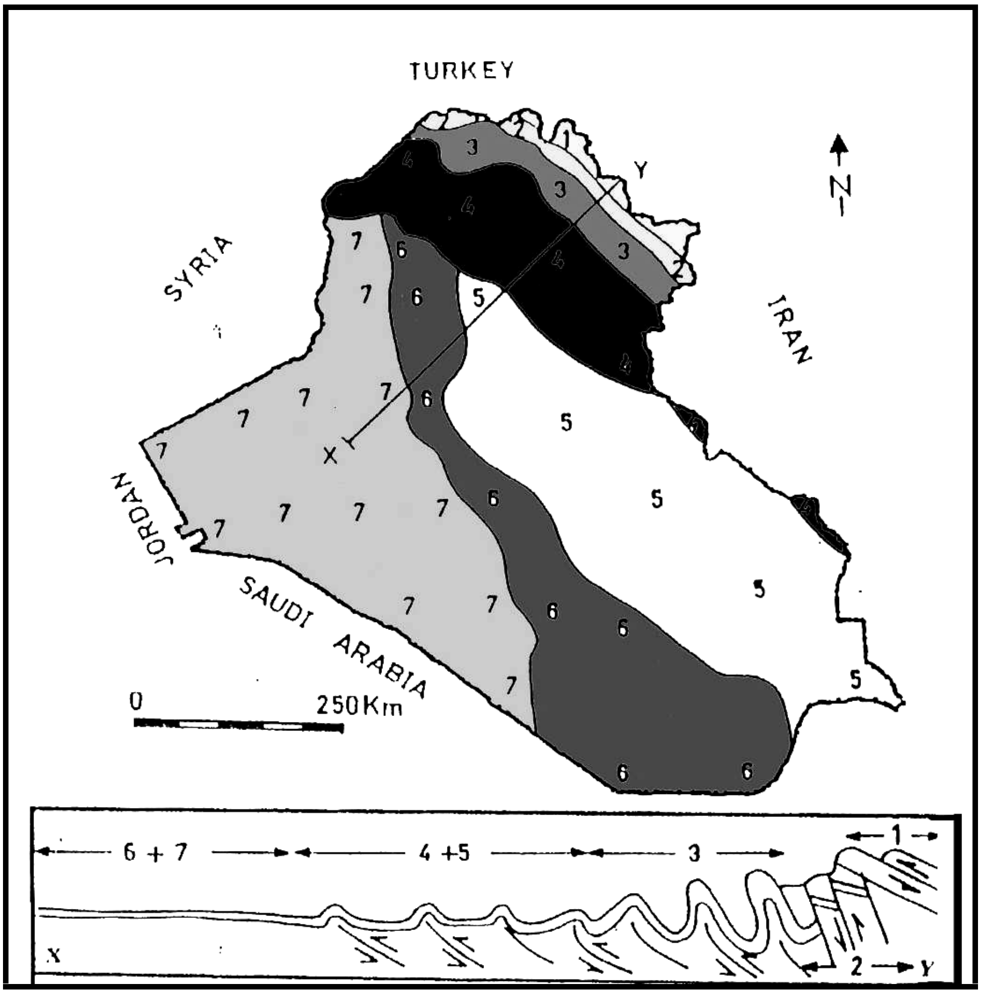

Fig. 3.22 Major tectonic division of Iraq (after Bolton, 1958; Dunnington, 1959 & Numan 1997) cited in Stevanovic and Markovic (2004)

Subductional tectonic facies of the Zagros thrust; 2. Zone of imbrications of the foreland basin; 3. Highly folded zone of the foreland basin; 2+3. Foreland basin;4. Suspended basins, foothill zone of the quaziplatform foreland; 5. Sagged basins of the Mesopotamian zone of the quaziplatform foreland; 4+5. Quaziplatform foreland; 2+3+4+5. Foreland belt of the Arabian Plate; 6. Salman zone; 7. Rutba-Jezira zone; 6+7. Stable platform deposition.

Regional tectonic framework of northern Iraq

The regional tectonic framework of Iraqi Kurdistan is described by Stevanovic and Markovic (2004) in terms of geoflexures. On a geotectonic scale, geoflexures could be parts of high uplifted lands (geoanticlines), or parts of subsided areas (geosynclines or basins). The geoflexures detected by Numan and Ameen (1983) in Iraq and those investigated by Falcon in Iran (1961) are generally monoclinal.

In Iraq, they are mostly double plunging with an echelon arrangement. Their axial lengths range from 50 to 107 k. and usually coincide with the hinges of major anticline structures.

The trend of the Alpine geoflexures in Iraq coincides with the two main trends in the Foreland Folds Belt of northern Iraq (the Zagros trend NW-SE in northeastern, and the Taurus trend, E-W north and northwestern Iraq). Zagros geoflexures in Iraq seem to be the continuation of the Alpine geoflexuring investigated by Falcon (1961) in SW Iran. The amplitude of the Alpine geoflexures in Iraq has a maximum value of about 3200 m in the Sulaimani area and decreases gradually to a minimum value of about 1200 m in Zakho, (Stevanovic and Markovic, 2004).

The Piramagroon Geoflexure (which is part of the study area) beside the Darband Bazian Geoflexure is the one of the two main geoflexures detected in the Sulaimani area. It extends from Sulaimani northwestwards for about 58 km. Its amplitude is about 2900 m. The hinge line of the geoflexures coincides with that of Piramagroon Anticline. The mountain front is parallel to the hinge line of the geoflexures, and is situated at about 31 km southwestward. The observed width of the geoflexures is about 34 km.

In contrast, synclines of the Foreland Folds Belt are in general physiographically insignificant. They form relatively narrow valleys between successive anticlines in the high mountains zone. In the Foothill Zone of the Foreland Folds Belt, however, successive anticlines are separated by very wide expanses of terrain that are generally flat or hummocky.

For this reason, description of the Foreland Folds Belt of the northern Iraq would emphasize anticlines more than synclines.

-Structural setting of the basin

The structure of the basin is relatively complex due to three factors. The first is that the basin, as mentioned before, is located in the thrust, imbricate and high folded zone. The folds in the High Folded Zone are relatively tight and with high amplitude. They are either symmetrical or slightly asymmetrical and can be distinguished clearly. Among these anticlines in the high Folded Zone, Balambo and Piramagroon anticlines are symmetrical to slightly asymmetrical. Conversely, the folds of the imbricated Zone are more or less obscured and show minor refolding so can be called anticlinorium. Moreover, they are overturned and, in most cases, both limbs are imbricated like playing cards so that the strata of both limbs dip toward the northeast. In the area to the north of Kani Panka and Saraw spring, the folds are so stacked together that the synclines and anticlines cannot be separated. In this area and along the axis of synclines, the limestone beds of Balambo or Kometan Formation are so intensely deformed that they have suffered from crenulations (fig 3.23).

The second fact is that the rocks in the Thrust Zone are more complicated than in the High Folded and imbricated Zones. This complexity is attributed to the extreme deformation of this zone and the separation of the rocks into several thrust sheets of even nappies; this is clear from the admixture of sedimentary, igneous and low grade metamorphic rocks.

Fig. 3.23 Crenulations in the Balambo Formation at the northwest of Said Sadiq

According to some authors, the rocks of this zone were transported from Iran (from northeast) to their present position in Iraq by tectonic stresses (Heron and Less, 1943). This is also confirmed by Bolton (1958) who indicated the rock of this zone (especially Qulqula Formation) as allochthonous unit which was transported from the east to the present location. Simirnov and Nelidov (1962) considered the Qulqula Formation as autochthonous rock unit which has not undergone any change in position except faulting, Buday and Jassim (1987) reported thrusting of Qulqula on Balambo Formation for about 15 km at the area between Chwarta and Said Sadiq towns (northwest of the basin).

The Thrust Zone outcrops in the northeast, north and northwest of the boundary of the basin (as can be seen in the fig.3.19 and 3.24). The stratigraphic units that underwent the thrusting are Avroman (Triassic) and Qulqula Radiolarian Formation (Lower Cretaceous). The rocks of this zone are so deformed that they show contouring and several stockings of each formation several times. This contouring and heaping could be observed easily in the field, as the same bed of Qulqula Radiolarian repeats more than three times on the same traverse (Fig.3.8, & Fig.3.9). In some cases, the direction of thrusting and imbrications deviates from its normal path (towards the southwest) and possibly thrusts toward east or west (Fig.3.8).

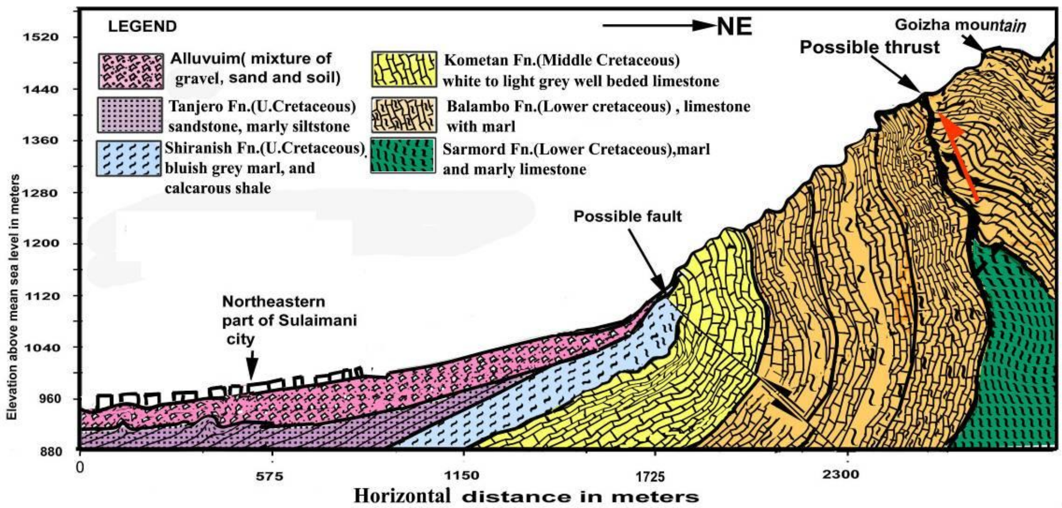

Fig. 3.24 Geologic cross section of the Goizha anticline showing overturned southwestern limb.

In most places the rocks of the zone are brecciated and slightly metamorphosed so that the fossil content cannot be recognized easily.

The third factor is that the basin is disturbed by several transverse faults. These faults are normal and form horst and graben in the northeast Iraq. One of the possible graben forms the eastern part of the Sharazoor plain which is bounded on east and west by two large faults in addition to the thrust fault at the northern boundary (annex 1 and fig.3.24).

- The main anticlines in the basin

In the Piramagroon - Sharazoor basin there are more than 20 anticlines as well as synclines which can be recognized. The main bodies of some of these anticlines are located outside the basin and only one of their plunges is located in the basin. The names of most of these anticlines are derived by Stevanovic and Markovic, (2004) from the name of the related mountain, while other ones are named in the present study.

In plain view, fold axes in the studied area show variable lengths ranging from a few km up to 100 km, usually with swing axial trends (Azmer, Goizha), or horizontally displaced by strike slip faults (Piramagroon anticline).

Axial interference is rare and fold plunges usually passed each other producing complex interference zones and even plateau (northern plunge of Piramagroon anticlines, Mergapan with Chaqchaq Synclines). It could be concluded that axial position is not simple and it is most likely controlled by older structures such as basin forming graben and half graben (Stevanovic and Markovic, 2004).

The folds show different geometry. Some of them are open folds; some have box-like fold geometry (Piramagroon and Azmer). Some of the parasitic folds of the isoclinals type developed on the sides of the major folds. That is case in the Tanjero and Balambo Formation in Said Sadiq. Most of the folds are mainly asymmetrical with south and southwest vergence. Some have thrusted southern flanks and a few, thrusted northern flanks. There are many minor and major normal faults located in the northern or southern limbs of the anticline or synclinal structures.

The anticlines are not equal in dip angles, amplitude and size, the position and direction of the large anticline are indicated by a large arrow in the fig.3.25, while the smaller is indicated by a smaller arrow. There are many other small anticlines which are not shown because of partial covering by soil such as in the Sharazoor–Piramagroon plains. In this plain the Tanjero and Shiranish Formations show many minor foldings which are not shown in the above mentioned figure.

These include the anticlines bordering the basin on different sides in addition to the aboard syncline beneath the fluvial deposit of Sharazoor and Piramagroon plain. The structures are mainly the following:

- *Piramagroon Anticline*

It is one of the largest anticlines in the studied basin. It is double plunging fold, extending about 58 km in a NW-SE direction. Its plunge is gentle; the anticline is normal and asymmetrical with a southward vergence. The dips of the northeastern and southwestern limbs are 30º and 70º respectively. The amplitude and half wavelength of the anticline are 2 040 and 12000m.
The profile section of this anticline shows a close similarity to a monocline. Rather large anticlines occur in the northeastern and southwestern limbs of the Piramagroon Anticline. On the southwestern limb, at about 18 km west of Sulaimani, an anticline (called Yakhyan anticline) with a width of about 1.25 km and axial length of 8 km occurs. The anticline has a single plunge in the SE direction. Only the small southeastern part of this anticline is located in the study basin.

Two similar anticlines occur on the northeastern limb (Harmetool and Chaqchaq anticlines); their axial lengths are 25 km and their widths are 2.5 km and 3.75 km respectively. The first plunges in Sulaimani, the second about 7.5 km to the northwest; both plunges are in SE direction. The great amplitude of the Piramagroon Anticline, relative to adjacent structures, and the occurrence of the relatively large anticlines on its limbs, reflect the effects of a possible deep-seated major longitudinal fault or a system of faults parallel to the Piramagroon structure.

- *Azmer and Goizha Anticline*

These two series of anticlines surrounding Sulaimani from the southeast extend northwest for a distance of about 33 km. They are open asymmetrical anticlines with NE limb 44/30 and SW limb 211/54. Imbrications affected this anticline in such a way that many small anticlines and synclines formed inside this series; thus, it is sometimes called an Azmer- Goizha anticlinorium. The northwestern part of this anticline is called

Qaywan which swings to the west, and at the end in the adjacent basin it is called the Daban anticline. The axial plane of this anticline is not planar one as it has different attitude by its intense deformation due to the tectonic stress of Alpine orogeny started from Maastrichtian to Quaternary (Karim and Surdashy, 2005). Along the trend, the axial plane is dipping in some places 70 degrees toward southwest, while in others is towards the northeast. This characteristic is most possibly related to the high contrast of the mechanical stratigraphy of the surrounded formation which changes from shale to conglomerate as in Tanjero Formation. In these places the anticlines shows criterion of reverse faults.

- Bardakar Anticline

This anticline located in the northwest of the basin is an asymmetrical double plunging anticline, the south east plunge lying inside the plain, while the northwestern plunge is outside the plain. The southwestern limb is steeper than the northern one. The axial plain is parallel to the axis of Zagros belt. The length of the hingeing line is about (11 km) as mapped.

- Warsaka Anticline

This anticline is a large asymmetrical anticline lying north and northwest to Said Sadiq city; the southwestern limb is steeper than the northeastern limb. The axial plain direction is NW-SE. The length of the hinge line is about (33 km). At the core of the anticline the Balambo Formation is exposed.

- Salamish Anticline

This anticline represents a small asymmetrical double plunging anticline, located to the west of Saraw town. The axial plain direction is NW – SE. The length of the hinge line is about (5 km). The Balambo Formation is exposed at the core of the anticline.

- Shinrawe Anticline

This anticline lies at the southeastern side of the studied area. The anticline is asymmetrical double plunging; the southeastern plunge lies at the Iraqi – Iranian border. The formations exposed by this anticline are Balambo, Kometan, Shiranish and Tanjero.

In addition to the above mentioned anticlines there are few other anticlines of lesser heights and extensions.

Synclines

There are several synclines lying in between the above-mentioned anticlines.

- Chaqchaq syncline- is considered one of the largest intermountain visible synclines. It is an open asymmetrical anticline extending with a swing axis in an almost north-south direction for a distance of about 32 km. It is located between the Azmer-Goizha anticline and Piramagroon anticline. The NE limb dips 217/56 while the SW limb dips 76/35.
The other synclines are not as visible or are covered by recent sediments.

Lineaments and Faults

Lineaments and fault structures, mostly interpreted from satellite images and aerial photos, are presented on regional maps, especially Main lineaments and catchments areas of northern Iraq with the rose chart diagrams orientation by Travaglia and Dainelli (2003; cited in Stevanovic and Iurkiewicz, 2004).
The map of the main lineaments and catchments areas of northern Iraq with the rose chart diagrams orientation prepared by FAO shows a very high density of lineaments, (Fig.3.26). Rose chart diagrams of lineament orientation for the whole northern Iraqi region, one using as ponder lineament frequency, the other their length, show almost the same picture. The majority of lineaments are oriented in NE-SW direction, perpendicular to the strike of folded structures (Fig.4.27).

Rose chart diagrams show the main orientation of lineaments is E-W, i.e., oblique to the strike of folded structures. Orientation N-S and NW-SE is negligible. Assuming that the lineaments of the same orientation are of the same age, it could be concluded that the oldest lineaments are those belonging to the N-S orientation. They could have inherited Precambrian N-S trends. The E-W and NW-SE lineaments are younger, and are related to the opening of the Neo-Tethys Ocean, which involved the separation of the Iranian and Turkish plates in the Triassic. The NE-SW lineaments are the youngest and have developed during the closure of the Neo-Tethys Ocean and the following continental plate collision. A development of lineaments in the basement rocks of the studied region can be envisaged in relation to the opening of the Neo-Tethys Ocean in the Late Triassic and the closure of this ocean during the Alpine Orogeny from the Late Cretaceous to the Pliocene. The north-south lineaments seem to have been inherited from the Precambrian Orogeny.

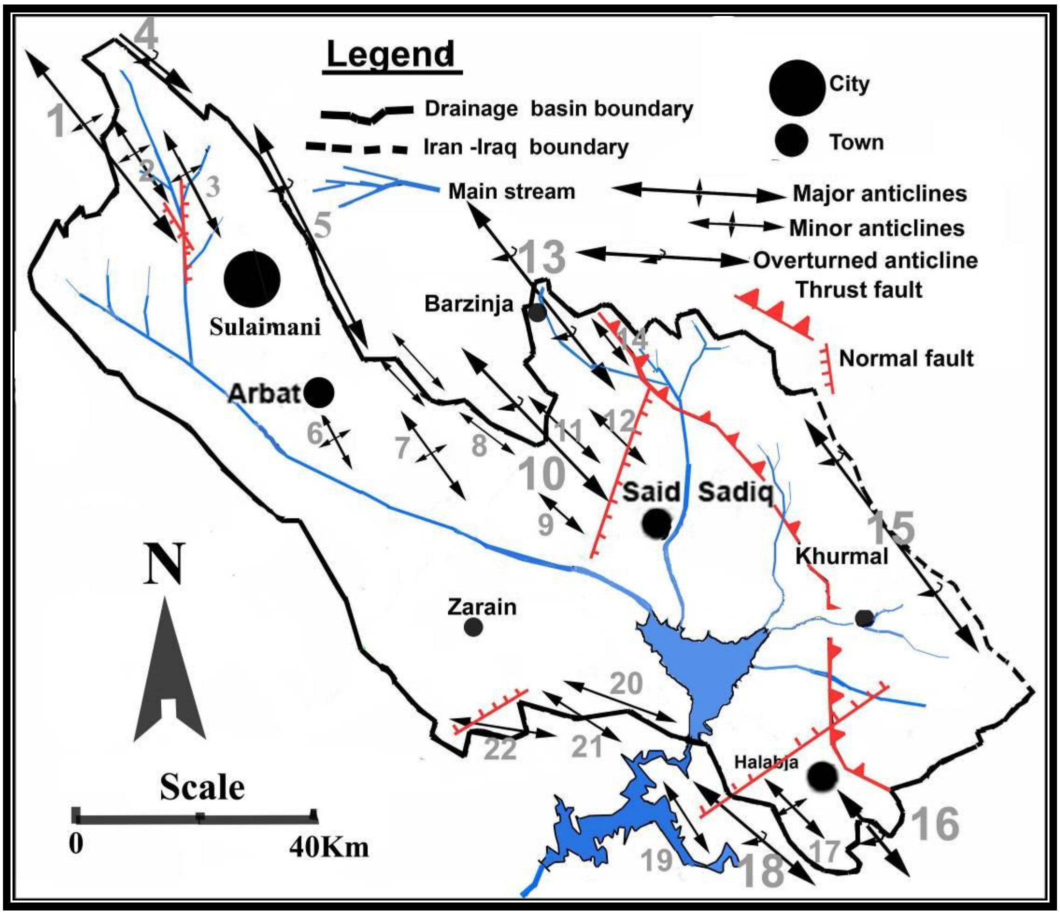

Fig.3.25 The name and location of the main structures of the studied basin: 1- Piramagroon anticline, 2- Harmetool anticline , 3- Chaqchaq anticline , 4- Daban anticline, 5- Azmir -Goizha anticline , 6- Bestansur anticline, 7-Greza anticline, 8-Barda Kar anticline, 9- Kani Panka anticline, 10- Barda Rash anticline 11- Warsaka anticline, 12-Maw anticline, 13-Kura Kazhaw anticline, 14- Dola Chawt anticline, 15- Suren–Avroman overturned anticline, 16-Shinarwe overturned anticline, 17-Chawg anticline, 18- Balambo anticline,19-Bamo Anticline, 20- Barda Asin anticline , 21-Bakir Agha anticline . 22- Merade.anticline

Fault structures

The major faults have trends corresponding to the transversal, longitudinal, and oblique joint sets. The oblique and longitudinal faults are prevalent in the region. However, local manifestations of transversal faults can be seen in rotational faulting on steep limbs of some anticlines.

The minor faults observed in the field and sometimes on aerial photographs cannot be shown on small-scale maps. They are mostly wrench, reverse, and normal faults, generally consistent with the transversal, longitudinal, and, to a lesser degree, with the oblique sets. The minor faults are mostly local adjustments to the regional faults. It can be concluded that there is a general directional consistency between faults and joints (Stevanovic and Markovic, 2004)

Stevanovic and Markovic (2004) found the minor faults have the same relative prevalence as joint sets in the Folded Zone of Iraq. In major faults, however, the situation is different. They found that the major faults correspond to the longitudinal and oblique sets. Oblique joints were shown by the aerial photographs to be of a larger scale and more frequent than the transversal and longitudinal joints.

One of the major regional faults mentioned by Stevanovic and Markovic, 2004, is the Zagros thrust fault, which extended for hundreds of kilometers along the north and northeastern boundary of the basin starting from the Avroman Mountain and reaching the area north of Qaladiza. Some displacements due to this thrust in some places reach a few Kilometers. Another they mentioned is the Arbat fault which extends from the North of Arbat reaching southwest near Sangaw. Strikeslip and Wrench faults in the Said Sadiq area are mentioned by Rao,et al(1980). Ali, et al (2007) and Al Rawi et al, (1990) mentioned the trace of normal fault along the Chaqchaq valley. The fault plain strikes nearly toward north from the north and dips about 70 toward the east. From this fault the southeastern end of the Piramagroon plunge (locally called Girdy Sarchiar) subsides suddenly which can be seen from both sides of the Chaqchaq stream near the stream. Along the Balambo Mountain north of Halabja sets of faults normal faults exist, creating graben-like structures in some places. Traces of some normal faults have been detected in the southern part of the basin along the Baranan and Bakir Agha mountains.

3.4-Historical development of the basin

It can be inferred from the facies distribution maps given by Buday, (1980) that the basin's paleo-slope direction (depositional dip), in the studied area was toward northeast during the Lower Cretaceous till the Middle Turonian age. Before this age, the west and southwest of the basin was occupied by Qamchuqa submerged ridge (part of the Arabian platform). During later ages (Coniacian and Santonian), the general basin paleo-slope direction was reversed 180 degrees toward southwest during the Upper Cretaceous age.

According to Karim and Surdashy (2005b) this reversal was caused by the collision of continental parts of the Arabian and Iranian Plates. Before the reversal, Qamchuqa (reefal limestone) and Balambo Formations (basinal limestone) were deposited in the Lower Cretaceous to the southwest and northeast of the studied area respectively.

This collision occurred after the oceanic crust was exhausted and then the two related continents collided. Before this (during the deposition of the Balambo and Qamchuqa formations), the studied area was part of the passive continental margin (carbonate platform) and bordered on the north by subduction trench (active continental margin).The collision finally changed the area of subduction to positive land and the studied area to foreland basin

According to Karim (2004), during this process the previously deposited Qulqula Formation compressed and accumulated as an accretionary prism between two plates and uplifted, forming positive land during the Upper Cretaceous age which generated a source area for the Tanjero and Kolosh Formations.

Therefore, positive land was created near the northern boundary of the studied basin. This land consisted mainly of Qulqula Radiolarian Formation with a minor share of ophiolite. This is inferred from the presence of the huge thickness (1500m) of terrigeneous rock fragments as the main constituent of the Tanjero Formation and Red Bed Series which were deposited during Maastrichtian and Paleocene periods. From the Upper Cretaceous to the Quaternary age, the studied area was part of a large foreland basin in which Red Bed Series, Shiranish, Tanjero, Kolosh, Sinjar and Pila Spi Formation were deposited (Fig.3.25). During the deposition of these formations, the clastic sediments influx from Qulqula Formation was more or less continuous. What is important in the basin is that this latter formation now covers more than 20% of the studied area.

Therefore, the development of the present Sharazoor–Piramagroon basin, especially the extreme northern boundary, started in the Upper Cretaceous age. This is so because the regional slope direction (toward south and southwest) remained nearly constant from Upper Cretaceous to the present day. This is due to the southwest transfer of the Iranian plate toward southeast along the Main Zagros Thrust Fault. This fault is not represented by one or two certain surfaces but thrusting has occurred along numerous surface and zones making many thrust sheets.

These paleo-current directions during different times of the geologic time span of the foreland basin have been ascertained by Ameen (2006), Karim and Surdashy (2005a), and Al-Barzinji (2005). Therefore the surface runoff and groundwater flow which entered from the northwest were more or less similar to that of present day; the foreland basin occupied the present position of the Sharazoor-Piramagroon plain and the Dokan-Darbandikhan reservoir (Fig.3.3,) in addition to most of northeastern Iraq. It is probable that the porosity and permeability of the present rock is the result of cumulative deformation of the rocks in the studied area

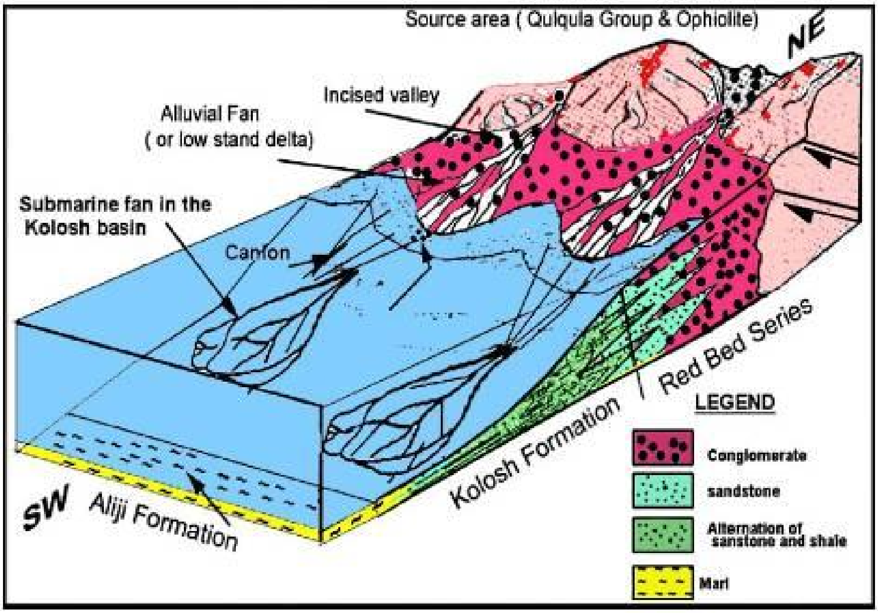

Fig.3.28 Tectonic and paleogeographic setting of the Paleocene foreland basin in the studied area (Modified from Al-Barzinji, 2005), which is nearly similar to the present day concerning surface and groundwater flow

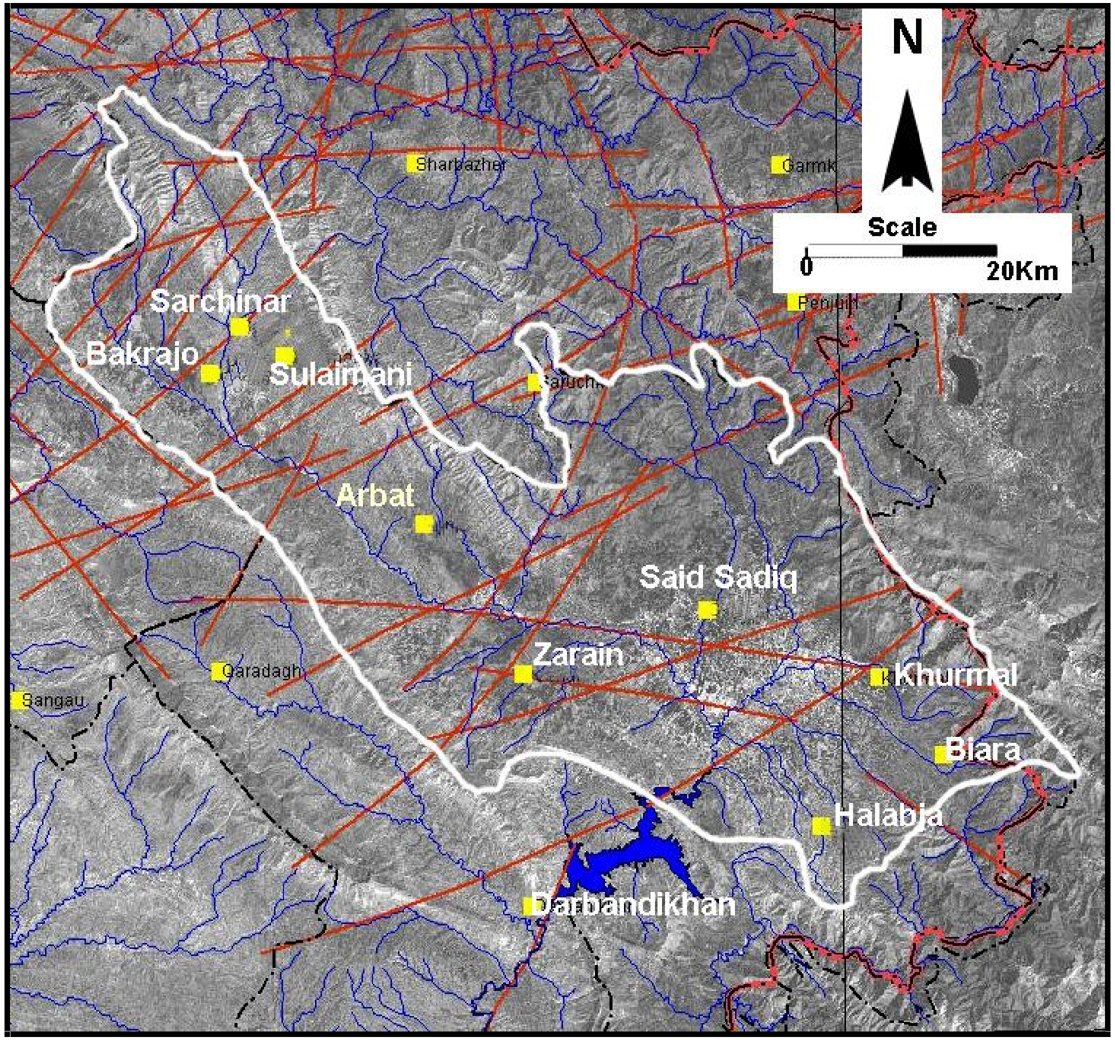

Fig.3.26 Lineament map of Sharazoor-Piramagroon basin and the surrounding area (Stevanovic and Markovic, 2004)

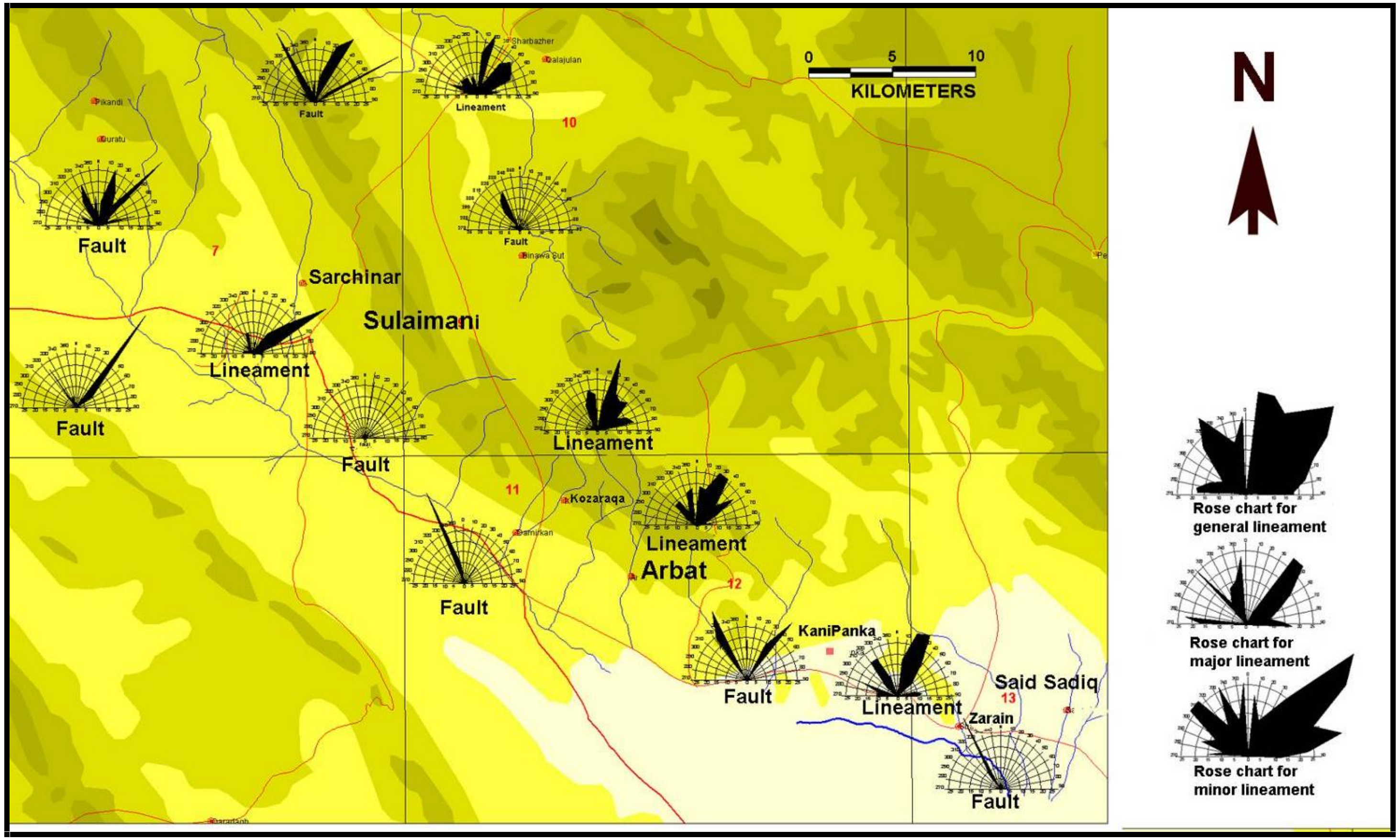

Fig.3.27 Rose chart for the major and minor lineament and faults in part of the study basin. (Stevanovic and Markovic, 2004)

CHAPTER FOUR

HYDROGEOLOGY

The Sharazoor - Piramagroon basin has a relatively complex geological and hydrogeological setting since its development is attributed to 1) geomorphology, 2) stratigraphy, and 3) structure. The groundwater recharge of the Sharazoor and Piramagroon plain and surrounding mountain area is influenced by the three above allied factors. The Sharazoor - Piramagroon basin is considered one of the most important basins in Iraq from the point view of the availability of groundwater and fertility of the land. The role of each factor is clarified below. The stratigraphy and structure in addition to geomorphology generally have a positive role in the availability of the groundwater in the basin. However, the occurrence and movement of groundwater are relativity complicated and uncertain. Some uncertainty may continue for some time unresolved because of the limited depth of the drilled wells.

1) Geomorphologically, the basin is located among several mountains, some of which are regarded as the highest in the area, such as Balambo, Shinrwe, Avroman, Suren, and Kura Kazhaw, Greza and Goizha to the east and northeast. The main mountains to the west and northwest are the Azmir, Daban and Piramagroon mountains. The south and southeast are bounded by mountains of lesser elevation than those mentioned above, such as the Tasluja, Baranan, and Zirgwez and Shafa Rash Mountains.

These mountains have a large role in raising the groundwater level in the plain and recharging the aquifers annually. This is because of three points; the first is that these mountains have more than 15% more rain and snow precipitation than the surrounding lowlands. The second point is that these mountains consist of fractured and jointed limestone rocks with a high infiltration coefficient. This property makes up the only annual recharging source for shallow and deep aquifers by snow and rain. The third point is that the peaks of some of these mountains are covered by snow from winter until mid-spring except in abnormally dry years. The slow melting of the snow on these mountains, together with infiltration, acts as a buffer during summer for a continuous supply of water to the aquifers and karstic springs.

2) Stratigraphically, the dominantly impermeable rocks of the Shiranish and Tanjero Formations and some fine alluvium sediments cover the central part of the basin and the foot of some of the mountains. These strata are a great merit to the

basin as they prevent underground draining of the groundwater to the centre of the valleys, i.e. the valley now occupied by the Darbandikhan reservoir. Many springs such as Sarchinar, Saraw, Bestansur, Chawg, Alan-Hasil, Shiramar, Greza and Kani Panka flow from the contact of these two formations with karstic aquifers such as Avroman, Balambo, and Kometan formations (annex 2)

3) Structurally, many anticlines plunge at the basin, generating lowland (i.e. the eastern and western parts of Sharazoor plain, Fig 4.1). Near the plunges of these anticlines are some of the most important springs in the basin. Sarchinar, Bestansur and Saraw are located at the southeast plunge of Piramagroon, Azmir and Greza anticlines respectively. Even though the role of the faults is not fully known, one can guess that the transverse faults facilitate the diversion of groundwater to certain places and create springs such as the Sarchinar, Zalim and Jomarase springs.

As mentioned in section 3.4 (Historical development of the basin) the structure of the basin is inherited from the more or less continuous deformation of the rock layers from the Upper Cretaceous period to recent time. The structural elements have been modified by groundwater during this long period. But the erosion affected the aquifers negatively as it continuously removed the surfacial part of the aquifers (epikarst) and exposed deeper and fresher rocks on the surface.

4.1 Grouping of the hydrogeological units

Stevanovic and Iurkiewicz (2004) classified formations with similarities in age, lithology, permeability and other hydrogeological characteristics into the same aquifer system and named them according to the most widespread and well-known formation in the whole group. Their classification is clarified below:

1. **“Karst aquifer “Bekhme”** (including Qamchuqa, Dokan, Kometan, Bekhme, Aqra, Sarmord and other Cretaceous / Paleocene age formations developed mainly in carbonate facies (limestone and dolomites and their varieties). The aquifer system is widespread in northern and central northern Iraq;
2. **Fissured-karstic “Pila Spi” aquifer** in the central-southern area (Eocene limestone, including Sinjar and Khurmala carbonate formations of similar ages);
3. **Intergranular Bakhtiari aquifer** (including overlying Pleistocene terrace and recent alluvium deposits) mostly in the southern area of the region.

4. **Complex aquifers** composed of a combination of the two or three aquifers mentioned above, mostly fissured-karstic or karstic type often over-laid by younger or recent sediments." *[1]

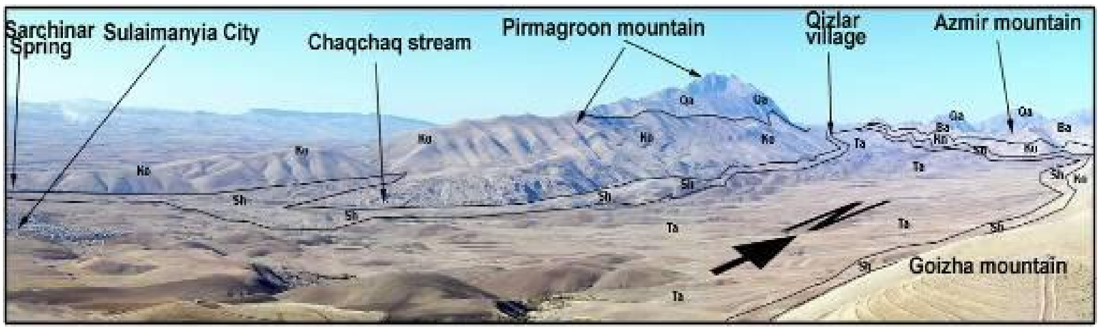

Fig.4.1. Sarchinar spring at the south eastern plunge of Piramagroon anticline (Ali, 2007).

In this thesis, the stratigraphic units (formations and recent sediments) are grouped as shown below. The aim of this classification or grouping is to collect genetically similar units on the basis of the common characteristics of porosity and permeability in addition to lithologic properties (mineralogy). This grouping is done according to the following factors:

1- Capacity (or response) of the formations or sediments to bear water; according to this property the formations are classified as aquifer, aquitard and aquiclude.

2- The aquifers are further grouped according to the type of porosity. According to this the aquifers are divided into Karstic, Karstic-Fissured, Fissured and Intergranular aquifers.

3-The aquifers are further grouped according to mineralogy or chemical composition. This includes grouping the limestone formations of the same age into one category. This grouping is aided by the fact that all these limestone formations have secondary porosity which includes cavity, fracture and joints as seen in the table (4.1).

4-The ages of the formations are inserted automatically into the grouping, because the formations of certain places and certain stratigraphic interval belong to one age (e.g., Jurassic, Cretaceous and Tertiary). The Cretaceous, Jurassic and Triassic Formations are grouped at the extreme north and northeast of the studied area, while the Tertiary Formations are located at the south and southwest of the studied area and the Cretaceous ones are in between the two groups (annex 1, 2).

---

[1] ***Stevanovic and Iurkiewicz, 2004 Hydrogeology of northern Iraq, Vol.2, p.30***

4.1.1 Aquifers of the basin

The aquifers of the basin consist of sedimentary rocks or sediments of either chemically deposited rocks (marine origin), or clastic rocks and sediments (continental origin). The chemical rocks include limestone, dolomitic limestone and cherts, while the clastic rocks include conglomerates, sandstone, and siltstones in addition to unconsolidated sediments or recent deposits.

Table 4.1 Grouping of the formations and sediments according to some hydrologeologic and stratigraphic properties.

Aquifer type	Stratigraphic unit	Mineralogy	Porosity	Hydrogeological group name	Abbreviation
Karstic	Avroman group	Calcite-Dolomite	Fractures, joints caverns	Triassic karstic Aquifer	TKA
	Jurassic Formations	Calcite or Dolomite	Fractures ,joints and caverns	Jurassic Karstic Aquifer	JKA
Karstic Fissured	Cretaceous Formations (Kometan, Balambo, Qamchuqa)	Calcite or Dolomite	Fractures, joints and caverns	Cretaceous Karstic-Fissured Aquifer	CKFA
	Eocene Formations (Sinjar, Pila Spi)	Calcite and Dolomite	Fractures ,joints and caverns	Eocene Karstic-Fissured Aquifer	EKFA
Fissured	Cretaceous Qulqula Formation	Quartz or Chalcedony and Calcite	Fracture and joints	Cretaceous Fissured Aquifer	CFA
Intergranular	Recent Sediments, including alluvial fans, flood plains, river deposits , buried valley sediments , river terraces	Polygenetic	Intergranular	Alluvium Intergranular Aquifer	AIA
	Eocene Gercus Formation	Conglomerate of Polygenetic	Intergranular with some fissures	Eocene Intergranular Aquifer	EIA

Complex	**Slide debris mainly from (Eocene Sinjar Formation), or Triassic and cretaceous Formations.**	**Slide debris limestone (calcite and dolomite)**	**Intergranular and karstic-fissured (fractures or caverns)**	**Slide Debris Aquifer**	**SDA**
Aquitard	**Tanjero Formation**	**Mainly mixture of sand and clay size silica and calcium**	**Fissures and joints , occasionally with fault breccias**	**Tanjero Aquitard**	**TAT**
Aquiclude	**Shiranish, Kolosh, Gercus and impervious packages of Qulqula Formation**	**Mainly mixture of clay minerals and silica**	**No effective porosity**	**Aquiclude**	**-**

The first group of aquifers represented by fissured, karstic, and fissure-karstic types of aquifer, which is due to secondary porosities, developed in chemical rocks resulting from tectonic forces during the geological evolution of the basin. These fractures, joints, and bedding planes were enlarged by the dissolving effects of groundwater, forming canals and cavities in the massive limestone, and dolomitic limestone.

4.1.2 Karstic Aquifers

This type of aquifers is characterized by its high permeability and transimissivity values, as groundwater flows through channels and cavities of different diameters that depend on the degree of the karstification development. Also the drawdown values in the wells that are drilled in such aquifers are relatively small. The karstic aquifer units or formations in the study basin are:

- TKA (Avroman Limestone Formation)

This unit is highly deformed, located in the Crushed Zone (after Stocklin, 1974) or the Thrust Zone (Buday and Jassim, 1987). The deformation includes folding, faulting, jointing and intense fracturing. It is possible that the extensive thickness is attributed to imbrications or the thrusting of many segments onto each other. These tectonic structures generated high secondary porosity and permeability.

The fissures are locally developed into large cavities which changed gradually into large caves especially at the intersection of ancient or recent water table with surface. The karstification is also stimulated by extensive thickness, high elevation and high average rainfall, which exceeds more than 800 mm annually.

The surface of this unit is regarded as an important recharge area and aquifer for Zalim, Khurmal, Shiramar, Jomarase and Reshen springs (annex1, Fig.4.2). These large springs are located at the foot of the Avroman and Suren anticlines. In addition, the unit is located at a high elevation (more than 1500 meters from the surrounding plains), so it caused the elevation of the water table in the eastern part of Sharazoor plain, particularly around SaidSadiq, where in some localities ground water discharged to the surface and made many swamps and marshes Fig (4.3).

- JKA (Jurassic Karstic Aquifer)

These rocks act as relatively good aquifer. This fact has been recently confirmed by drilled wells in these formations in the Galal valley to the west and north of Qalay Srochik Mountain (the northern boundary of Sharazoor plain near Bardarash Village). These wells yield more than 5 l/s of water with relatively low drawdown (Fig.4.4). During drilling, relatively large cavities were struck in these rocks which show more or less karstic aquifer characteristics.

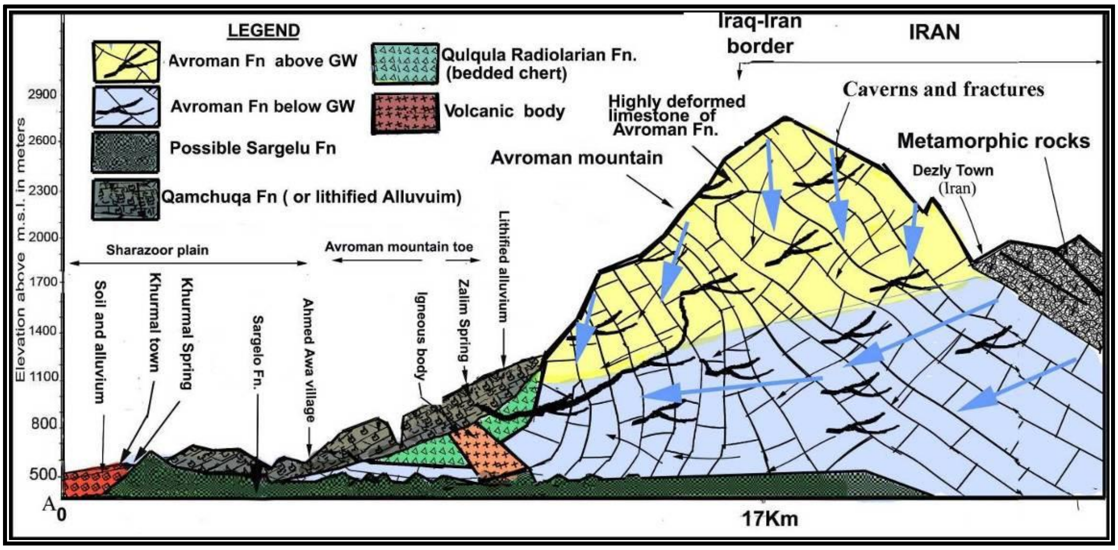

Fig.4.2 Geologic cross section of the Avroman Mountain passing through Zalim spring (Ali and Amin, 2005).

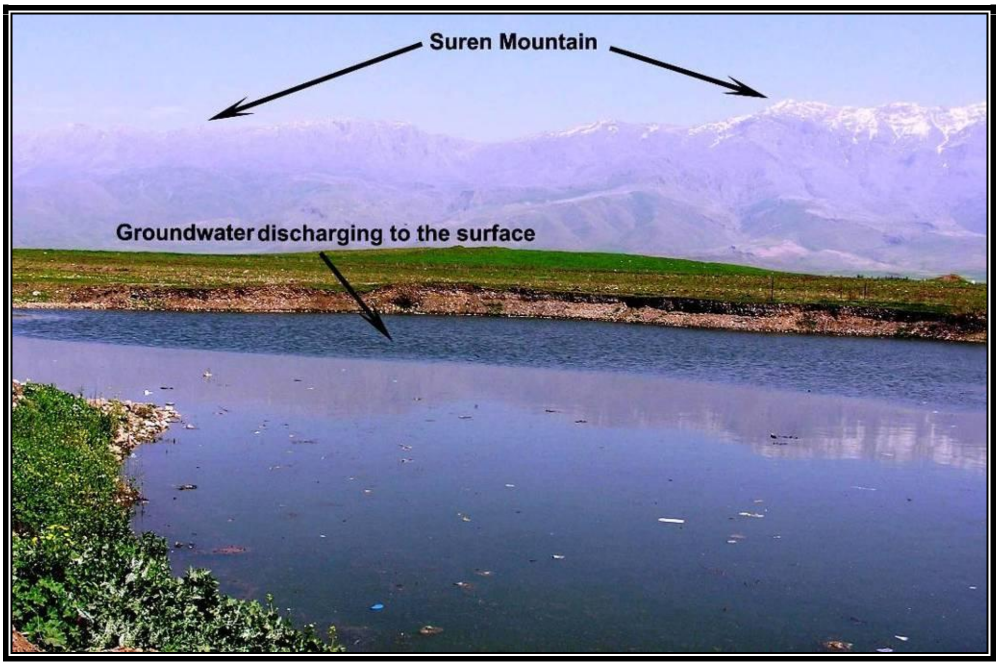

Fig 4.3 A Swamp east of Said Sadiq (SB4), April 200

The Jurassic rocks form very thick aquifer. No lower boundary of these rocks is exposed on the surface, and no deep well has been drilled to reach the bottom of these rocks. Due to the cavernous properties of these rocks, the catchment area of the Galal valley is drained mostly through underground karstic openings. This aquifer is considered one of the most possible partial sources for the Saraw group springs (Fig 4.5). Part of the reserve of this aquifer feeds the alluvium aquifer (AIA) north of Said Sadiq area (Energoprojekt, 1980).

4.1.3. Karstic– Fissured Aquifers

This type is developed in the marly limestone, dolomitic limestone, limestone, and dolomite. The high density fracturing sets along these rocks prevent karstification processes from developing the hydrogeologic unit into a pure karstic aquifer, as the accumulated water flows through a great number of fractures and fissures. The karstic-fissured aquifers are characterized by high permeability and transimissivity values, but to a lesser extent than those in karstic aquifer.

- **CKFA (Cretaceous Karstic-Fissured aquifers)**

The karstic-fissured aquifer units in the basin are the Qamchuqa, Balambo and Kometan formations. The porosities of these formations consist of cavities, solution channels and fractures. Because of their massiveness, the sets of joint are not clear but where the thickness of the beds decreases to about 1 meter at least two sets of joints can be seen. However the tectonic fractures and large or small faults are frequent in all outcrops; thus, good porosity for groundwater storing is created.

Fig.4.4 Drilling deep wells in (JKA) in Galal valley (SB3)

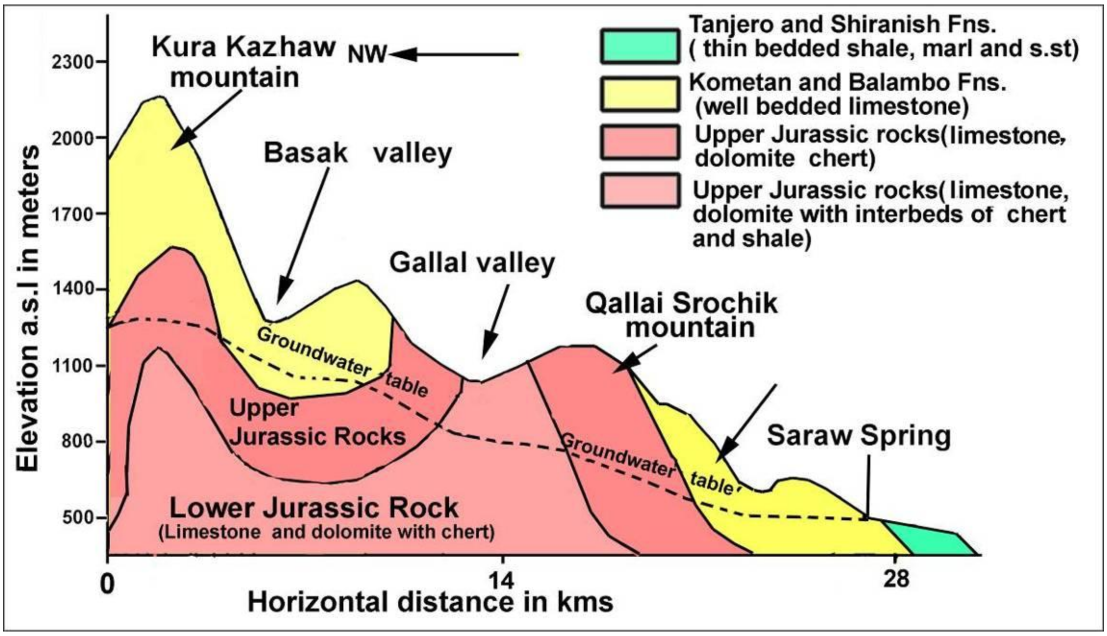

Fig. 4.5 Geological cross section of Saraw springs.

In the low lands (plains) of the basin, these formations are located at great depths; thus, the groundwater cannot be easily pumped out. The Qamchuqa Formation crops out only in SB1 and makes up large parts of the Piramagroon and Daban mountains (Fig.4.6). They form a significant part of the recharging areas and aquifer of the Sarchinar spring (Fig.4.7).

It is important to mention that because these shallow aquifers plunge deeply under the two plains and are overlain by the Shiranish and Tanjero formations,

formations such as Qamchuqa, Kometan and Balambo form deep aquifer under the Sharazoor and Piramagroon plain which can be exploited in future by drilling very deep wells. The depth of these aquifers is more than 300 - 400m under Sulaimani city but this depth is more than 700m under the Tanjero Stream in the central part of basin.

Kometan and Balambo formations comprise many large mountains (anticlines) such as Shinrwe, Warsaka, Azmir and Goizha. The surfaces of these mountains are regarded as an important catchment area and also aquifer for many large springs such as Saraw, Bestansur, Kani Panka and Sarchinar springs.

The joints and fractures in many cases transformed to fissures and caverns in the deeper part of the unit. This is evident in the drilling of two deep wells (400m) through these two formations in the northeastern limb of the Azmir Anticline at the mouth of the Azmir tourist valley.

These wells were drilled during summer 2004 and in spite of significant depth, no water was reached. Moreover, at 100 m depth from the surface, a large cavern of 10m diameter was discovered during drilling.

During the preparation of this thesis, a horizontal traffic tunnel was drilled in the Azmir Mountain which is about 2300m long and cuts through the Kometan and Balambo formations. This tunnel revealed some facts about these two formations. The first fact is that the two formations contain no groundwater at this level (zone of aeration). Most intervals along the tunnel route are fresh and contain no water while short intervals of fewer than 10 meters contain groundwater and show moisture and subsurface weathering and erosion. The intervals are probably intensely fractured or faulted. The second fact is that the passage of groundwater in these two formations is complicated and has no straight route.

The Kometan aquifer unit forms a strip around the anticlines of the northern part of Arbat basin. In some cases to the south of Arbat and the north Bestansur village it forms more than three elongated hills. The large Bestansur spring flows from the south eastern plunge of the one of the two hills (small anticlines) (Fig 4.8).

It seems that most of the large springs in this basin emerge from or near the plunge of one of the anticlines.

This aquifer unit around Bestansur and Kani Panka villages is located at a shallow enough depth that the groundwater table can be reached by drilling deep wells of depths less than 150 meters.

The stratigraphic position of the formation is suitable for the flowing out of many large springs like those in Bestansur and Saraw. This is due to impervious Shiranish and Tanjero formations which act as barriers or natural obstacles to the accumulation of groundwater and the predisposed position of the springs at the contact of the aquifers and impermeable rocks

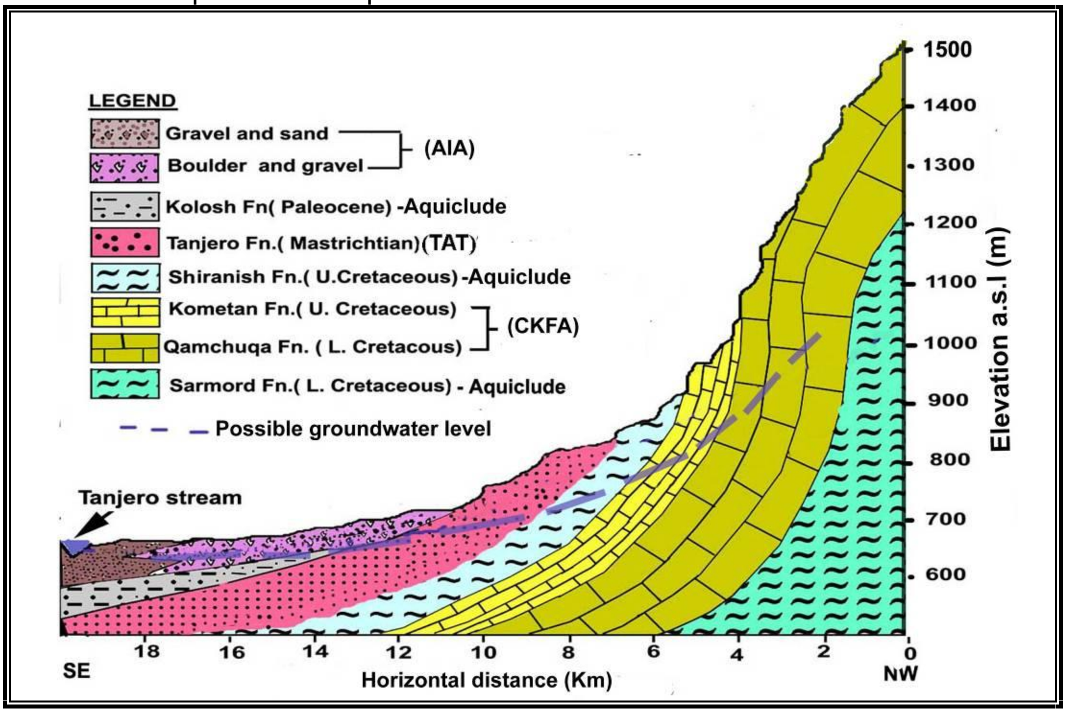

Fig.4.6. Geologic cross section of the southwestern limb of Piramagroon anticline, passing through Sulaimani airport showing the AIA and CKFA.

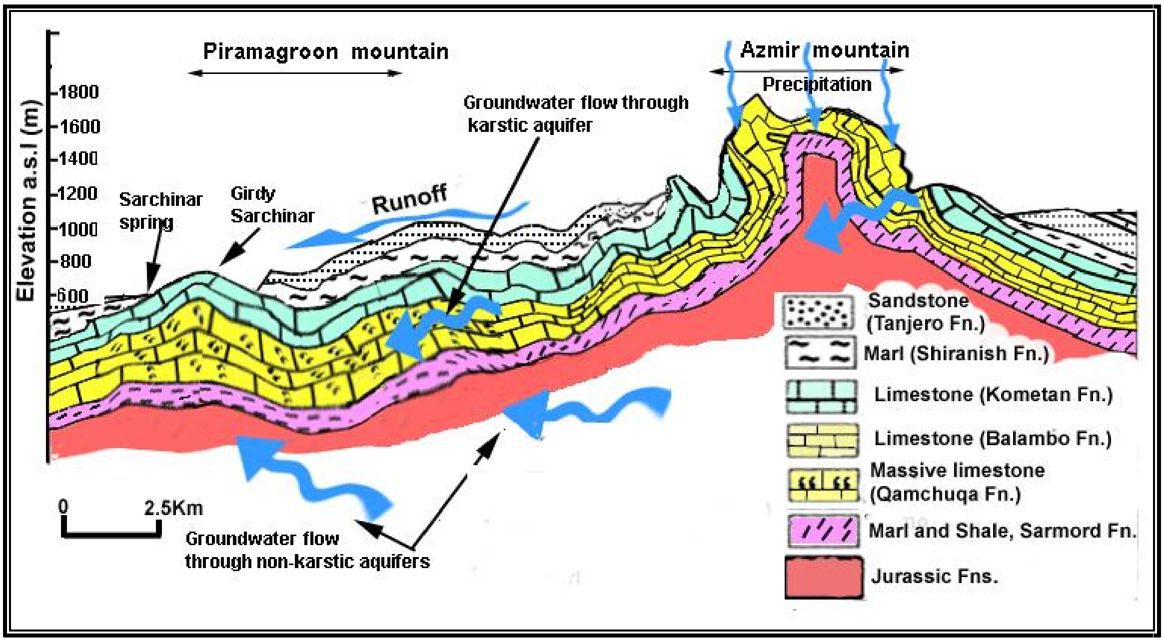

Fig.4.7 Geologic cross section passes through the Sarchinar spring and Azmir anticline

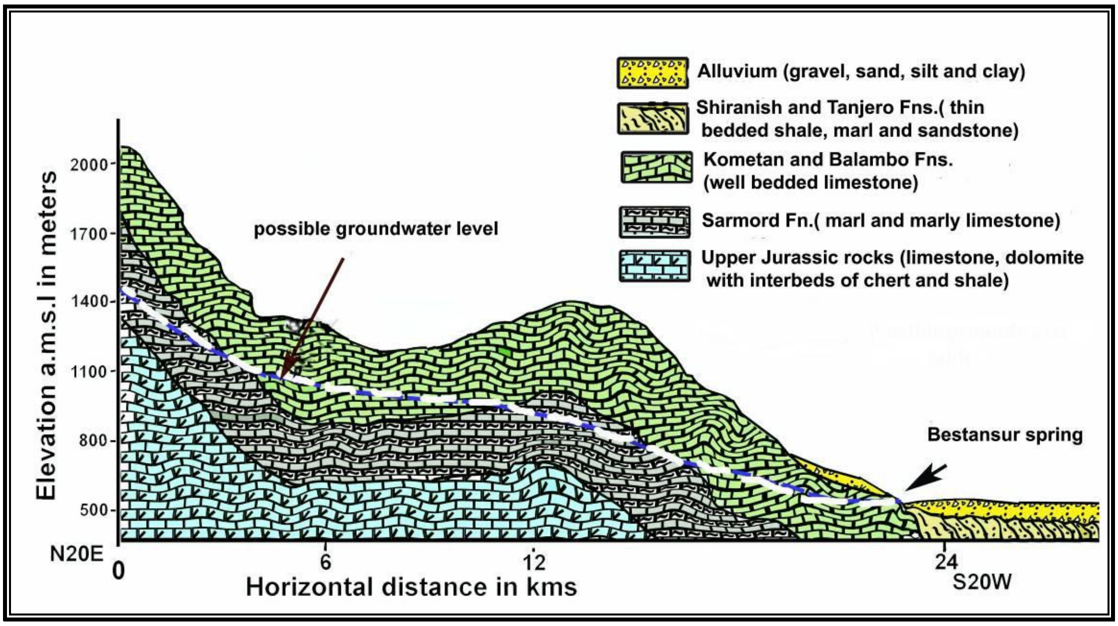

Fig.4.8 Geological cross section of Bestansur spring.

.

- EKFA (Eocene Karstic-Fissured aquifer)

This aquifer is located to the south of the basin and has very limited outcrops. The Sinjar formation, as an aquifer, is underlain by the impermeable Kolosh formation (which acts as a barrier). This unit provides many villages such as Zirgouez and Gomau villages with water from the springs or hand dug wells.

Outside and southwest of the studied basin at the Bazian valley, tens of wells have been drilled within this formation; all of them yield a good quantity of groundwater.

Ali (2005) studied the large slide block of the Sinjar Formation at the southern boundary of the basin. He found that the sliding of these blocks diverted the direction of some groundwater from a southwestern direction to a northeastern direction (Fig.4.9) The slide limestone blocks generated local aquifer that discharges through many small springs.

The porosity of the Pila Spi Formation, like the Sinjar formation, consists of fractures and fissures, in addition to joints. This unit at the southern part of the basin has very limited outcrops. In the foothills of Baranan, Shafa Rash and Zirgouez mountains, EKFA is either well-permeable (Sinjar or Pila Spi formations) or impermeable (Gercus Formation). In some locations, Gercus Formation is perched aquifer with stratigraphically controlled springs. The springs yield a small quantity of water, enough just for small villages. The Pila Spi Formation, as an aquifer, is regularly underlain by the impermeable Gercus Formation (which acts as a barrier). This type of occurrence provides many villages with water, such as, Merade village (on the southeastern border of this basin).

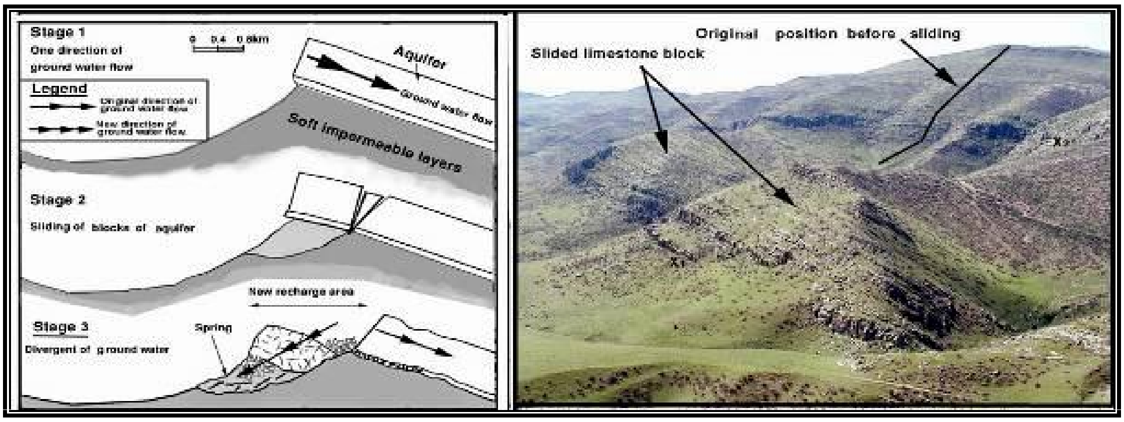

Fig. 4.9 Left: Southern boundary of the basin where landslide diverts direction of groundwater towards northeast. Right: slide block of limestone form shallow aquifer for several springs in the southern boundary of the basin (Ali, 2005).

4.1.4 Fissured Aquifer

This aquifer is composed mainly of layers of different lithology such as limestone, shale, chert, dolomite, and marly limestone. Generally it is fractured to a lesser extent than that of previously mentioned types and its fractures are narrower. Generally these aquifers are of less importance and their transimissivity is much less than the karstic and karstic-fissured aquifers and of less extent exposures. This type of aquifers is represented by the Qulqula (marly limestone + chert) formation.

Several sets of joints and complicated fractures comprise the main porosity of these aquifers. The jointing is so intense and closely spaced that it is difficult to distinguish from the fractures. The outcrop of this formation is located mainly in the Thrust Zone. In most cases, the competent beds (chert and limestone) are totally crushed or pulverized while the shale and marl show plastic flowage around the rigid bodies and are extremely compressed and even partially metamorphosed. These beds act as highly impervious rocks and facilitate the conditions for competent beds to perform as perched aquifers or relatively small springs.

The most important hydrogeological properties of the Qulqula Radiolarian Formation are the existence of local aquifers. The formation is mostly in the low lands. It often acts as a barrier by groundwater and springs for the groundwater from karstic aquifers as in case of Jomarase, Reshen and Zalim springs, which exist in the direct contact. These springs have a minimum yield of about $1m^3$ /s.

4.1.5. Intergranular Aquifers

This type of aquifers is formed within pores between grains of different sizes (from boulders to fine sands). The hydraulic characteristics are variable from place to place according to the variation of the size of the particle mixtures.

The coarser deposits had higher values of transimissivity and the wells drilled through it had higher values of specific capacity. The intergranular aquifer can be classified into two types:

- AIA (Alluvial Intergranular aquifer)

The most important accumulations of alluvium deposits are located in the SB3 and SB4, while in SB1 and SB2 there is sporadic distribution. The alluvium deposits in SB1 are located mainly west of Sulaimani city (namely Piramagroon plain), between Sulaimani and Tasluja town, which has a surface area of $228km^2$ and a variable thickness of 10m to 100m (Fig.3.23).

More than 400 wells are drilled in this alluvium aquifer. It is recharged by rainfall and sinking streams that descend from the eastern part of Piramagroon Mountain.

This aquifer in the SB3 and SB4 comprises the most promising area for the drilling of highly productive wells. In SB2, the highly productive wells drilled around Zarain town confirm that AIA is the most important in the studied basin.

The coarse sediments of the alluvial fans share a role in generating shallow aquifers. These fans can be seen everywhere on the Sharazoor and Piramagroon plains. Although these fans are now modified by stream dissection and continual cultivation, their sediment can be easily identified. They consist of coarse fragments of poorly sorted and sub-angular flat clasts of limestone, derived from surrounding mountains.

The sizes of discoid (flat) clasts are in the range of gravel with sporadic boulders which shows clear imbricated structures. The direction of the transporting current can be indicated by the direction of the plunging of imbricated clasts.

The grain size decreases toward the Tanjero stream and the Darbandikhan reservoir, where the alluvium changes mostly to fine clastic (silts and clays). When the sediments of the fans cover the Tanjero and Shiranish formations, they can store water in quantities great enough for exploitation by shallow wells and springs or kahrezes. This is because these two formations act as a barrier for the lower boundary of the alluvial sediments while the fine clastic acts as a lateral boundary (barrier) for AIA.

It is estimated that some groundwater from the alluvium percolates into the underlying Tanjero Formation. It is also possible that when the topography is suitable the Tanjero Formation recharges the AIA.

The riverbed sediments are characterized by better sorting and roundness than those of alluvial fans. The main streams that cross the Sharazoor and Piramagroon plains are the Tanjero, Chaqan and Zalim steams. They are braided streams which have coarse sediments of gravels and little boulders. The continuous shifting of the route of these streams is very obvious when one walks in the lower part of Sharazoor plain around New Halabja town and Mowan village. The existence of riverbed sediments 5-20 m thick with an overlay of 1-3m thick of flood plain clay and mud is evidence of such shifts. In many cases these streams traversally cut the alluvial fans;

therefore, the main source of coarse sediments is derived from the reworking of the fan sediments. Therefore, it is possible to find unsorted and angular sections of gravel exposed beside sorted and rounded sections of the same sediment along the stream bank.

The flood plain sediments are deposited from the rivers that pass the Sharazoor plain. The heavy loads of these streams are released at the plain when the velocity of the streams' water decreases.

There are two horizons of alluvial deposits in the area.

1. The upper horizon is composed mainly of silt, clay and less gravely deposits with a thickness which may reach 1 to 3 meters, like those around Grdi Go village.

2. The lower horizon, called the Bed load, is composed of sand and gravel; sometimes this part is replaced by talluvium near the foot of the mountain.

In most cases these two horizons alternate, forming a thick layer of more than 150 meters. Each of a great number of large hand or shovel–dug wells drilled in the plain around Said Sadiq and south of Halabja town can irrigate more than 1 hectare (Fig.4.10). Most deep wells were also drilled through these deposits, which sometimes represents the only deposits that are penetrated by the deep wells.

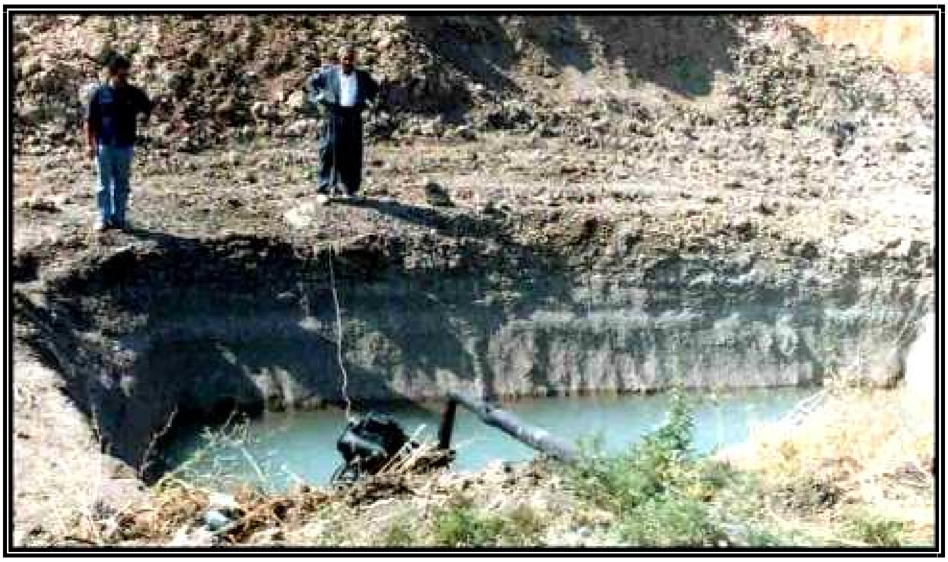

Fig.4.10 Shovel dug shallow well (4mx8mx3m) at west of Halabja town in the eastern part of the basin which yields water sufficient for more than 1 hectare irrigation

- EIA (Eocene Intergranular aquifer)

In contrast to impermeable red claystone, the conglomeratic part of Gercus Formation is permeable. It is worth mentioning that due to the high degree of compactness of these layers, joints and fractures represent the other aspect of its effective porosity. When the layers start to become more saturated with water the intergranular pores will be triggered, while the fractures work as additional effective transmission zones for groundwater movement. The term intergranular is preferable to fissured for this aquifer because it is more similar to conglomerate lithology. Therefore, the conglomerate is relatively good aquifer for supplying water for villages around the Bakir Agha and Barda Asin Mountains. Examples of these springs are those of Qleja, Merade with relatively limited discharge (4 l/s as an average), Alan and Hasil which emerge from the ground as several seepages which yield about 20 l/s in average.

4.1.6 SDA (Complex Slide Debris aquifer)

The slide blocks in the study basin are almost of two types. First are those with relatively high porosity and permeability due to the intergranular porosity of the brecciation, and the second are blocks which remained coherent and unbroken but with secondary porosities resulting from the joints and fractures which have finally been modified to fissures. According to Ali (2005), the volume of some blocks is more than 1,500,000 m^3 and each of them is associated with a spring draining the aquifer. Examples of these springs are Zirgwez, Kanishaswar, Daragha, Kazan, Tapa Rash, and Derasha.

Field work showed that the masses are underlain by impervious shale and marl. Due to the occurrence of these masses, about 20 springs in the area emerge at the frontal line of the masses in contact between the masses and the underlying impervious strata of Kolosh Formation. Both have characteristics of shallow aquifers with the highly variable discharge of the related springs which ranges from 0.1-3 l/s (Fig. 4.11).

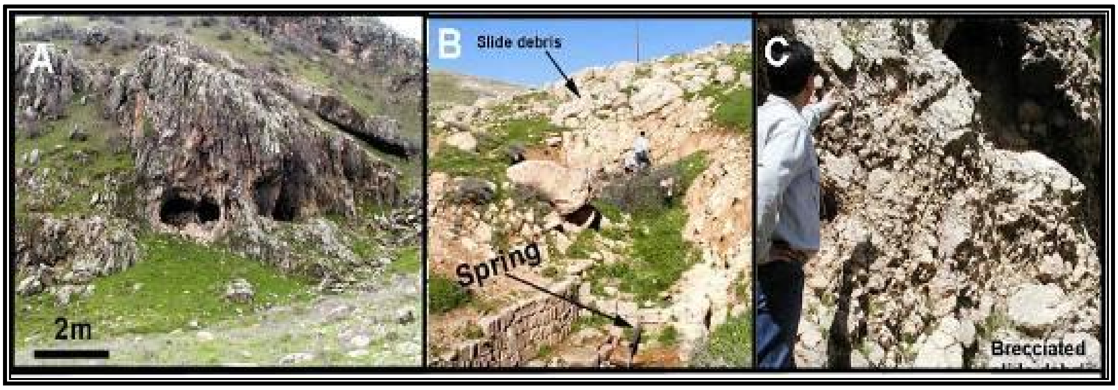

Fig.4.11 A: caves in the slide block of Sinjar Formation at the foot hill of Baranan Mountain. B: A spring in slide brecciated slide debris. C: breccias of slide debris. (Ali, 2005).

4.1.7 TAT (Tanjero Aquitard)

The Tanjero Formation in some localities contains medium beds of limestone and sandstone, which, because of jointing and fracturing, conquer sufficient effective porosity to reserve and transmit groundwater and acts as aquitards. Therefore, many wells drilled in the Tanjero Formation inside and around Sulaimani city have good groundwater yield for a few household purposes. Moreover, in the Sulaimani city many kahrezes exist which have been excavated in the coarse recent sediments and the Tanjero Formation. Some of these kahrezes can supply water to more than 50 houses.

4.2 Stratification of the aquifers

- Stratification of the western part (SB1 and SB2)

Field work showed that in many places the ground water accumulates in multi-aquifers, which are stratified over each other and separated by confining units (Fig.4.12). In this stratification, the following hydrogeologic units are part of the western part of the basin SB1 and SB2:

1. Recent sediment or alluvium sediments AIA and Tanjero Formation TAT (acts as both aquitard and aquifer) rocks in this area form stratification. The alluvium and Tanjero Formation aquifers are called upper aquifers in this thesis.

2. Kometan, Balambo and Qamchuqa Formations which act as lower aquifers and are recharged by the outcrops that cover the Piramagroon, Azmir and Goizha anticlines (Fig 4.6) and (Fig.4.7).

3. Shiranish Formation (marl), as an aquiclude, acts as a barrier for separating the upper and lower aquifers.

This stratification of the aquifers is sketched out in the distribution of the springs and hydrogeological columns of the drilled wells in the area. For instance, at the mouth of the Chaqchaq valley is the Sarchinar large spring which discharges the water of Kometan Formation, while 3km to the north at a higher elevation many small springs exist, which discharge the water of either the Tanjero Formation or of alluvium sediments. Sarchinar spring is a large spring which could, according to its depth, be considered an intermediate spring, while the springs that discharge the groundwater of the Tanjero Formation and alluvium are shallow springs. Examples of villages supplied by these springs are: Kani Bardina, Kalakin, Chalga, Sardaw, Fayal and Hanaran villages.

The stratification is also clear from the wells drilled to date. There are many wells drilled in alluvium and the Tanjero Formation which yield a good amount of water, while the underlying Shiranish represents aquiclude (impervious).

The fact that the Tanjero Formation acts as aquifer is well-explained by Karim and Surdashy (2005 and 2006), who divided the formation into three parts (lower, middle and upper). According to these studies the lower part of the Tanjero Formation in the basin is composed of nearly 400m of successive thin layers of sandstone. Sometimes these layers act as aquitard or aquifer where they are subjected to intense fracturing and jointing. This case exists in the area around Sulaimani city and around Arbat. According to Karim (op. cit.), the middle and upper parts are composed of soft rocks (mostly marl). This soft rock is easily eroded and the remaining sandstone that later is covered by alluvium is exposed in different places.

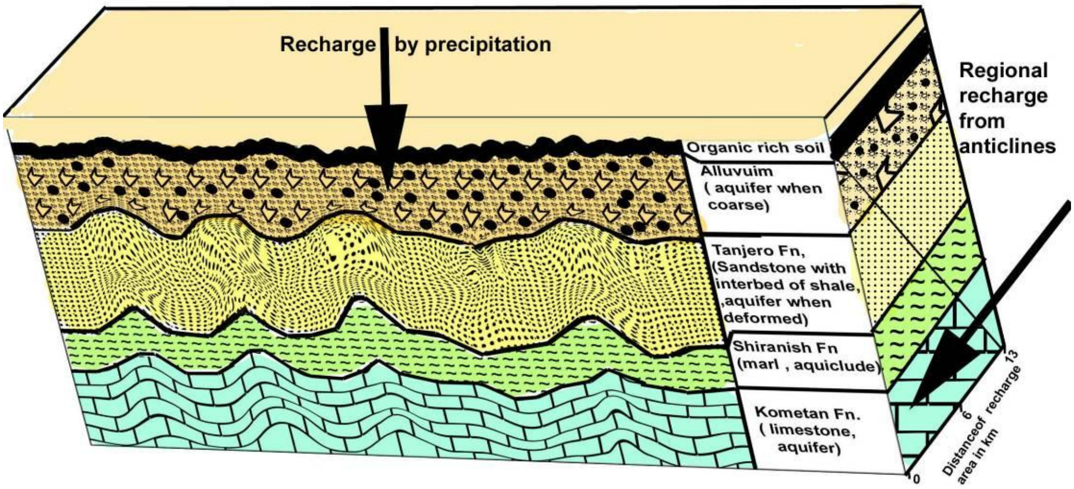

Fig.4.12 Conceptual model for stratification of aquifer into upper and lower aquifers in the western part of the basin especially around Sulaimani city.

- Stratification of the eastern part (SB3 and SB4)

The stratification of the upper and lower aquifers exists in the eastern part of the basin, especially in the SB4. In the northeastern part of the basin, near the border of Iran, these aquifers consist of TKA and JKA. Fossilliferous limestone of the Avroman Formation and black bituminous limestone of the Sargelo Formation comprise these two aquifer types respectively (Fig.4.13). In these places, one spring has all the characteristics of having emerged from deeper aquifer. The spring, which is acidic, is inside the Khurmal town and has an annual constant discharge of 5 l/s and temperature 29°C. This spring is named Khurmal acidic spring to differentiate it from the freshwater spring that is also inside the town.

In this area, the Triassic Avroman Formation has thrust over Sargelo and Qulqula Radiolarian Formations; therefore, these two formations are located parentally under the former formation (Fig.4.2). This thrust is also indicated by Bolton (1958), Buday (1980), Jovanovic and Gabre (1979) and Nunna et al. (1981) who indicated the Zagros suture zone near the mentioned spring and in front of TKA.

The outcrops of these formations are located topographically 1500m below the highest part of TKA. The part of the TKA that is located above 1500m forms upper and middle aquifer. Leakage of groundwater from the upper aquifer to the lower bituminous aquifer JKA is possible. The organic matter with pyrite or gypsum and with the aid of anoxic bacteria finally generates dissolved H_2SO_4 through sets of complex chemical reactions. The stratification of the aquifers from upper to middle to lower (or deeper) is as follows:

1. Qulqula Radiolarian Formation, as discussed previously, consists of the alternation of several packages of thin bedded chert, marl and limestone which are intensely deformed by the degree of crushing (Fig.4.14). These packages are always imbricated on each other in such a way that thick successions more than 1500m thick form. The deformed chert and limestone form several local shallow and small springs. The lateral and underlying barrier for these springs are the impervious marl. Furthermore, the marl packages prevent the ground water from penetrating to the intermediate aquifers JKA and TKA. Examples of these shallow aquifers are the small springs that are located in villages such as Dekon, Tawera, Dola Chawt, Dola Simt and Khirpane.

2. The avroman Formation, as discussed, consists of massive fractured and jointed limestone which has a thickness of more than 3000m. The outcrop of this formation covers most parts of the Avroman Mountain (imbricated anticline) while some parts, especially the southwestern limb of the mountain, are covered by the Qulqula Radiolarian Formation. The precipitation infiltrates downward to an intermediate depth and accumulates more than 300m below the summit of the mountain (as no spring exists above this elevation).

Springs of the middle aquifers emerge either at the contact between the Qulqula Formation and the Avroman Formation (such as Zalim and Jomarase springs) or flow beneath the latter formation and emerge at the point of contact of the Sargelo and Qulqula Formations (such as Reshen and Khurmal springs.).

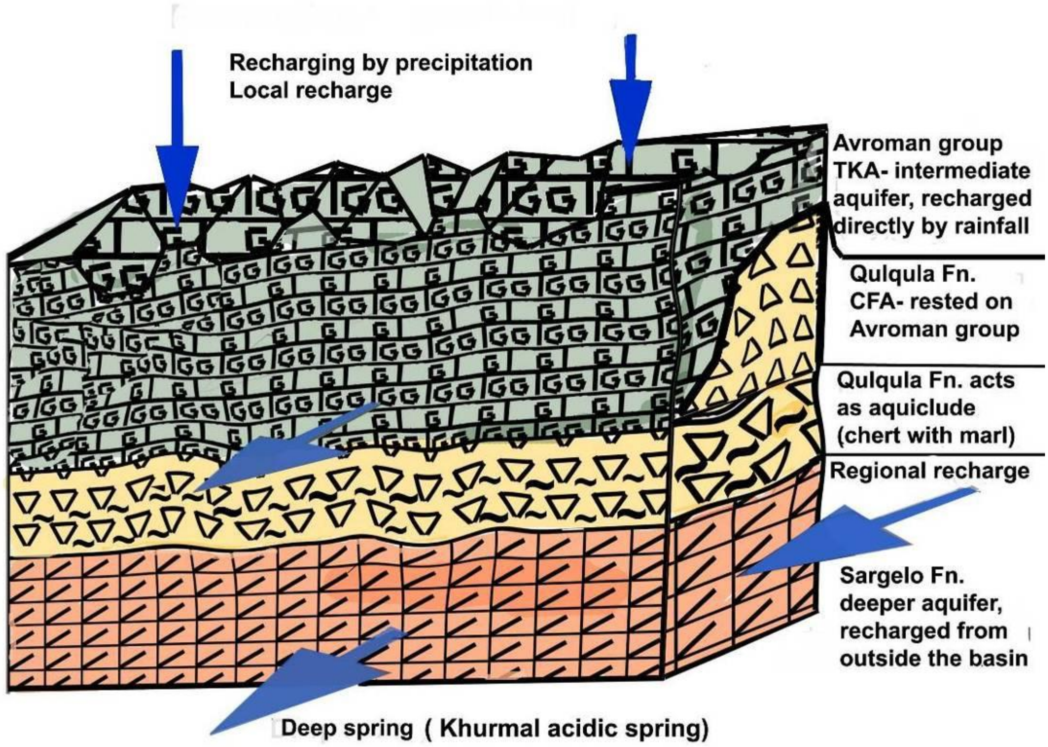

Fig.4.13 A- Conceptual model for stratification of aquifer into middle and lower deep aquifers in the eastern part of the basin especially around Khurmal town in the SB4.

3. The Sargelo Formation consists of bituminous black limestone which is exposed at the foot of the Avroman and Suren Mountains. Although this formation is younger than the Avroman group, it is located beneath this group. This is attributed to the thrusting of the group over the Sargelo and Qulqula Formations and the formation of the stratification of lower and middle aquifers (Fig. 3.20, Fig.4.2). It is possible that the surface, by thrusting with the Qulqula Formation, acts as a barrier to prevent groundwater of the middle aquifer from infiltrating to the lower aquifer which has acidic water, such as Khurmal (Fig 4.15). The recharge area of the lower deep aquifer is not known but it is possible that it is recharged from outside the basin. The existing topography aids the hypothesis that the recharging comes from Iranian territory. The Marivan Lake (Zirebar) inside Iran, which is located at a distance 27 km northeast of the Khurmal acidic spring, is one of the possible sources of recharging of the deep aquifer (Fig.4.22).

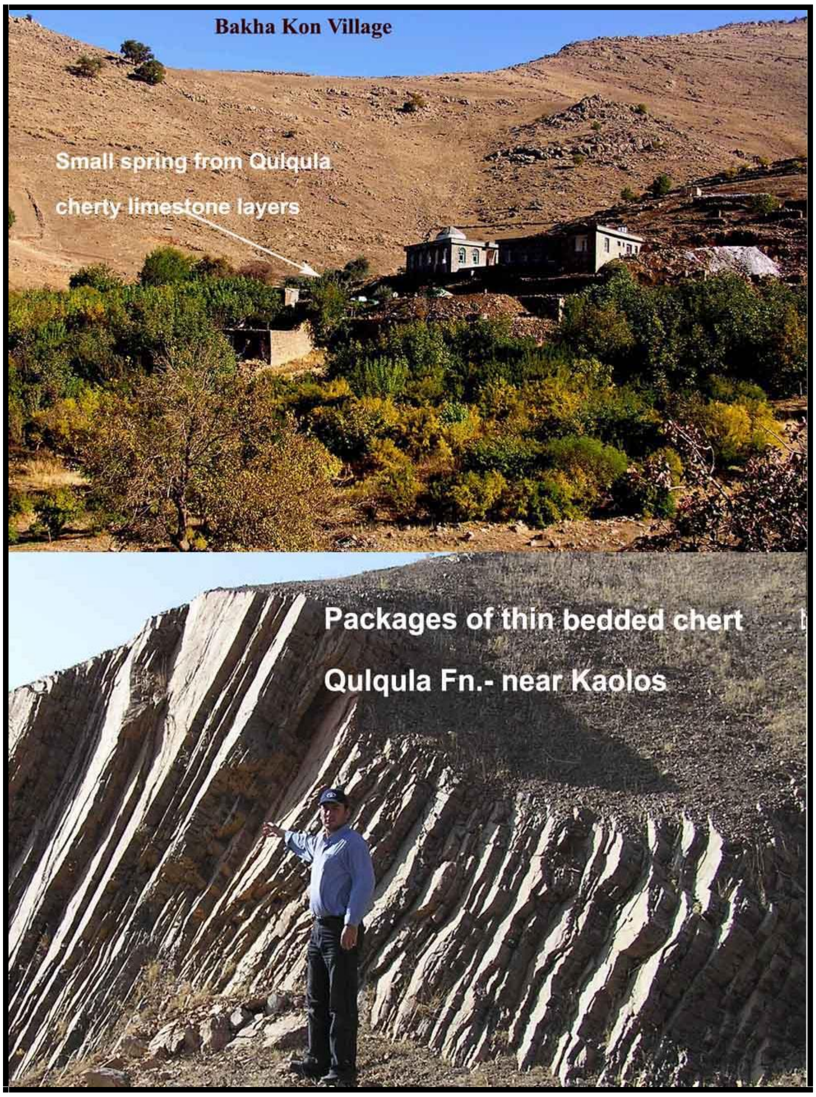

Fig.4.14 A part of thick package of thin bedded chert (jointed and fractured) of Qulqula Formation 1km northeast of Kaolos village on the road to Penjween. The formation contains tens of these packages and when they exist in a suitable place they form small shallow and perched aquifers as in Bakhakon village east of Khurmal town.

4.3. Conceptual model for ground and surface water flow in the basin

A flow net map is constructed from the collected data of static water level for the wells that could not be measured during October 2005 (Fig 4.16). It is clear from the map that high groundwater levels occur in the areas surrounding the basin from all sides, with higher elevation in the eastern, northeastern and northwestern parts. The western and southwestern parts have lower elevations. Also, it is obvious that the mountainous area comprises the recharge area and almost all the groundwater flow is more or less in the same direction as the surface flow which is oriented towards the Darbandikhan reservoir.

The Said Sadiq, Sirwan and Zarain plains are evidently the most important potential area for groundwater accumulation, with the lowest hydraulic gradient and higher hydraulic conductivities respectively.

The data for creating the model is connected in the field by topography, wells (both deep and shallow), spring and kahrezes. To determine the groundwater flow and confirm the absence of leakage to the other basins, the regional geology of the surrounding area is considered.

It is worth mentioning that the delineation of the groundwater boundary is a complicated and difficult task in this study, particularly for the north and northeastern parts of the basin, namely the areas located inside Iran. However, through geological field reconnaissance and surveying the water points existing in Iranian territory, some uncertain boundaries could be estimated and drawn.

The regional geology showed that the basin (according to the suggested groundwater divide) is surrounded on the north and northeast by Phyllite of the Qandil Metamorphic group, while on the east and northwest it is surrounded by shale of the Cretaceous Shiranish, Tanjero and Sarmord formations. The south and southwest are sealed by shale and claystone of the Tertiary (Kolosh and Gercus Formations).

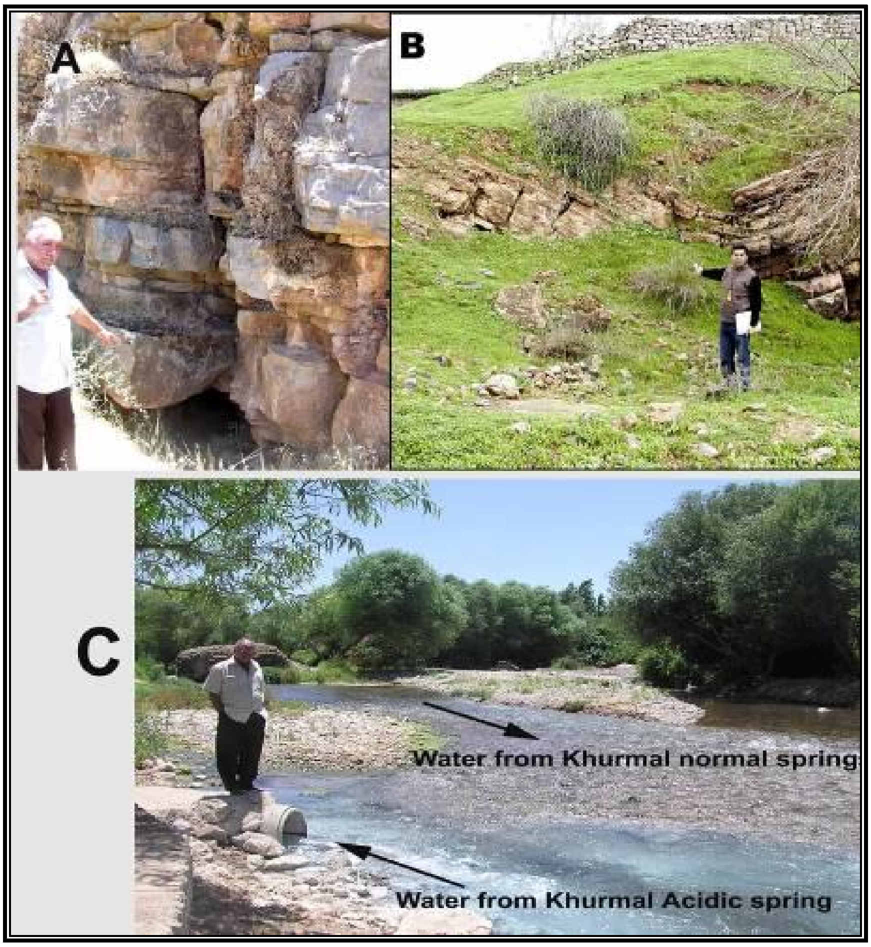

Fig.4.15. Collapse of limestone beds of Sargelo Formation above the acidic spring at the north of Khurmal town. The collapse is associated with solution breccia due to the effect of acidity of the spring.

In addition to these, the model for the ground and surface water flow in the basin is named in this thesis as **"Oasis model"** since the basin is analogous to a desert oasis which collects water from all sides and at the time of a flood may escape in one passage.

This model is valid for areas characterized by arid and semi-arid climates. The aim of this model is to simplify and envisage the general characteristics of the basin, especially for those living outside the area and who do not know the fine detail of the basin.

The main factor in the development of the basin is the topography which is controlled by lithology, climate and local structures of the area. The regional structure of northeast Iraq or western Zagros also has an effect on the general shape of the basin as it stretches in the direction northwest - southeast. This direction has been inherited from the direction of collision of the Arabian and Iranian plates which has nearly the same direction of strike as the basin.

4.4. Aquifer Characteristics

In regional groundwater studies usually only a few pumping tests can be performed and the limited data they provide are not sufficient to compile the maps of hydraulic conductivity, storage coefficient, or specific yield or capacity. Supplementary data thus have to be collected by other, perhaps less accurate, methods such as granulometric analysis, laboratory permeability tests and double ring infiltration tests. An advantage of some of these methods, however, is that they can be used on existing wells or boreholes. An example is the well test, which consists of pumping an existing well at a constant rate and measuring the draw down in the well.

During their study in 1979-1980 on the Kaolos dam project, the authors of Energoprojekt, Belgrade, depending on the pumping test data from the existing wells, estimated values of transimissivity for AIA aquifer in the Shanadari area north of Said Sadiq (SB4). They assumed the steady-state flow towards the pumped wells and by using the discharge and the stabilized drawdown approximated rough values of hydraulic conductivity coefficients. At the same time they used groundwater fluctuation values throughout a year of measurement for estimating piezo-conductivity, while a limited number of granulometric analysis allowed them to estimate the range of permeability coefficients.

Their resulting values show great variability from as low as 1.2×10^{-8} m/s to as high as 1.6×10^{-3} m/s; They assessed the water-bearing gravel strata as moderately to highly permeable sediments.

Most recently, from 2000 to 2003, FAO / Groundwater unit -North Iraq set a comprehensive and scientific base for the study of the hydraulic properties of all the aquifers in the region according to a program of monitoring network system. They installed piezometers on a number of wells representing different kinds of existing aquifers, covering the whole region of the three governorates of Iraqi Kurdistan. They selected some of these wells with piezometers and periodically performed pumping tests. Few wells in Sharazoor- Piramagroon basin were among this testing program.

Most Iraqi researchers, such as Hasan (1981), Hassan (1998), Chnaray (2003) and Aqrawi, (2003), often used the Thiem equation for steady state condition for both confined and unconfined aquifers. Appreciable errors can be made in calculating the transimissivity in this way, especially when information on the well constructions is not available, or when the well screen is partly clogged (Bonstra and De Rider, 1981).

For the current study, pumping tests on 22 productive wells were carried out covering all four sub-basins and penetrating different types of the aquifers. Technical obstruction and constraints (such as deficiency of electricity) restricted the pumping period. As much as the author is convinced that the installed pumps were not exactly at their appropriate optimum capacity, the wells were let recover after switching off the pump and recovery measurements were immediately done. The data of recovery are considered more reasonable; therefore assuming the non-steady state flow to be prevalent, except in some wells which stabilized after a short period of pumping and recovered directly after switching off the pumps, particularly those wells penetrating AIA in Said Sadiq and some part of Halabja area, the data of recovery are used to find the transimissivity of the aquifers.

The results of the tests are tabulated in table 4.2 and shown in figs 4.18-4.33.

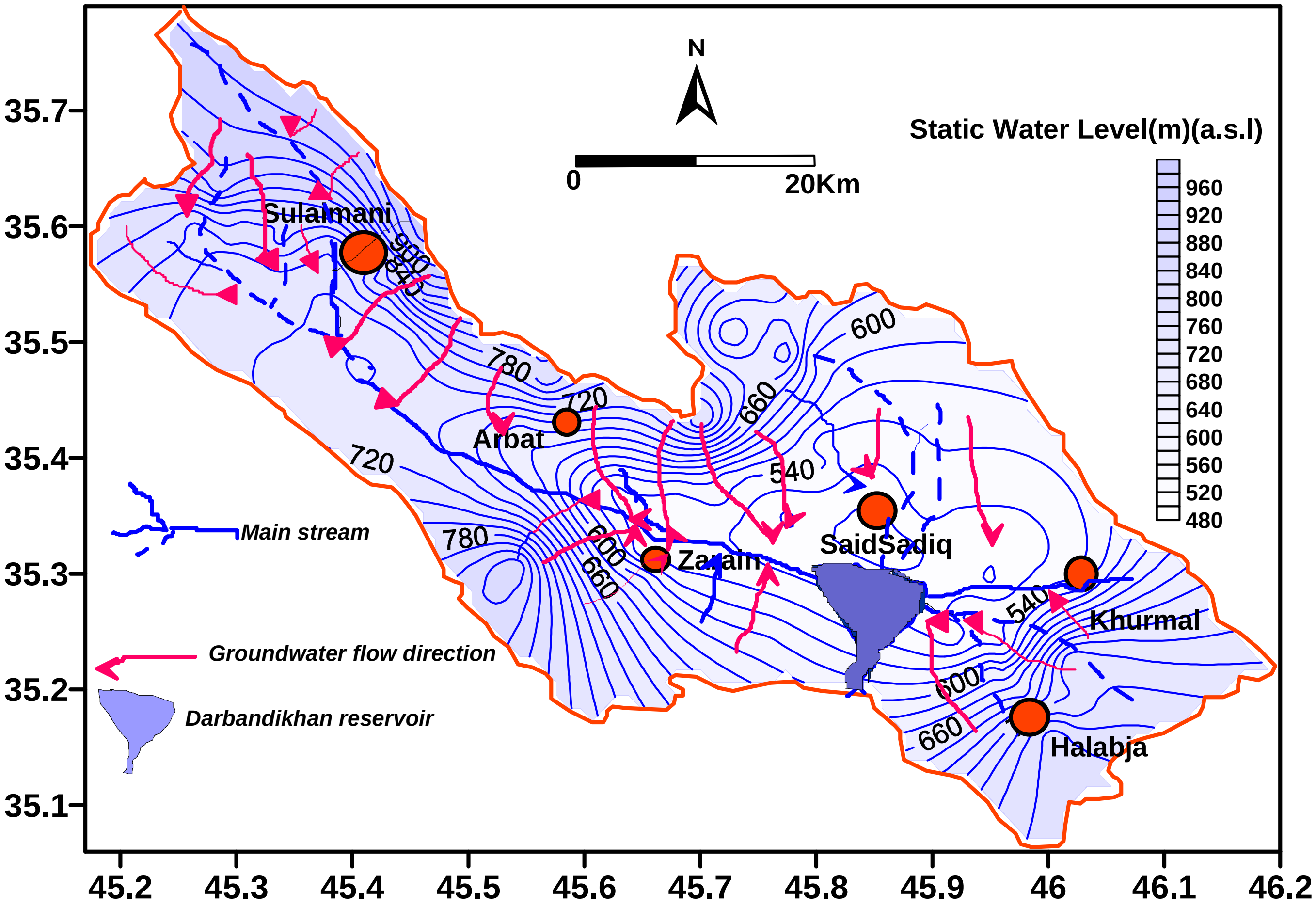

Fig.4.16 Flow net map and groundwater flow in the study basin

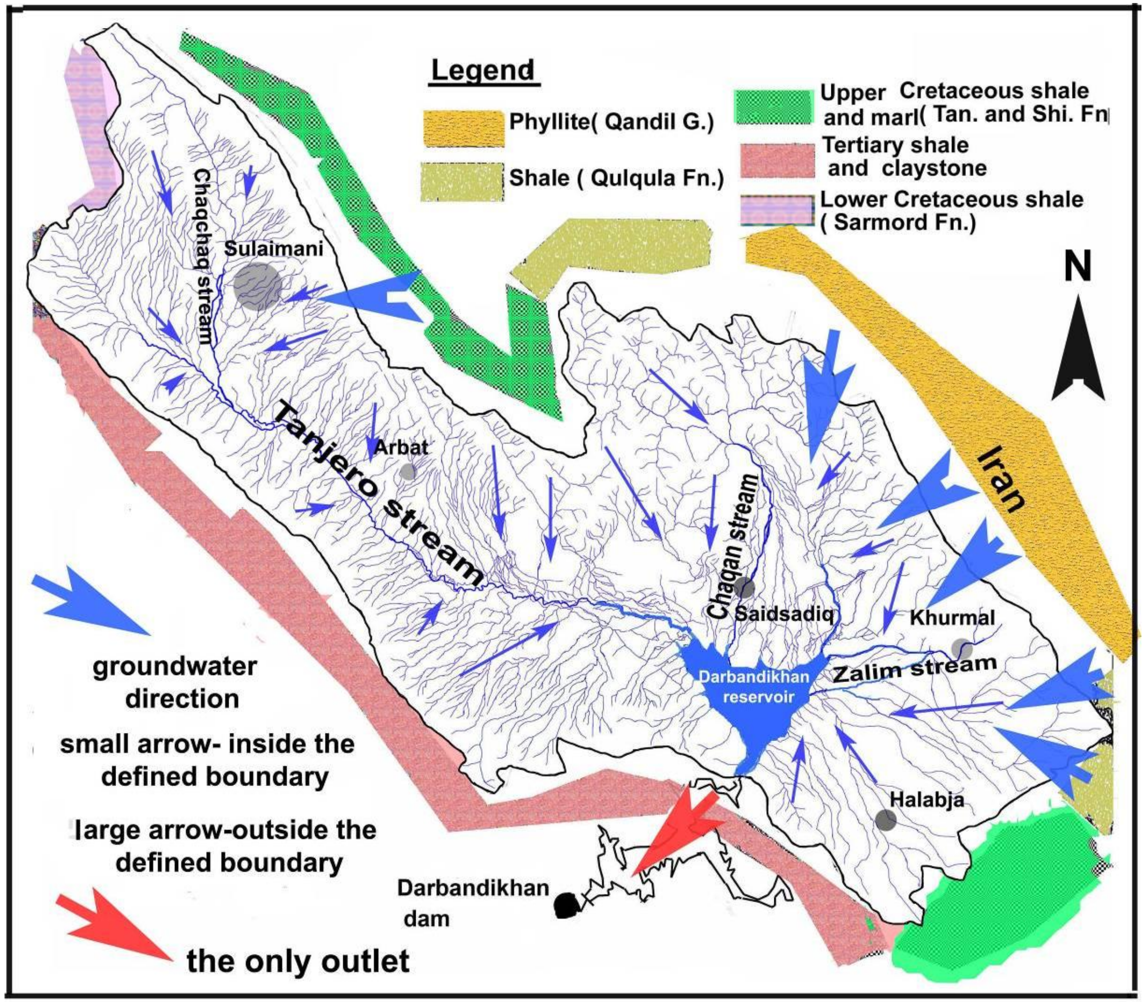

Fig.4.17 Oasis model for the accumulation of groundwater and surface runoff in the Sharazoor- Piramagroon basin.

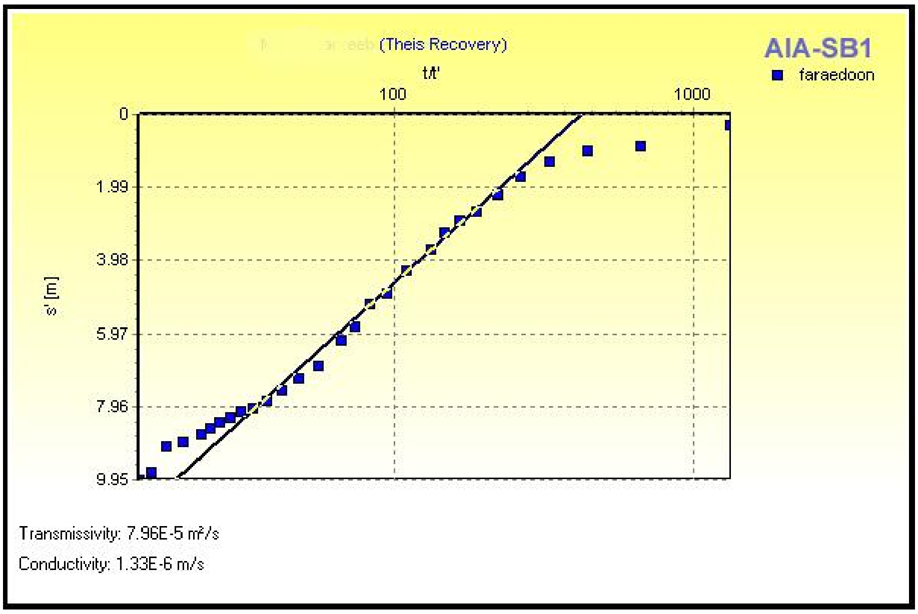

Fig.4.18 Theis recovery analysis of Faredoon well –AIA in SB1

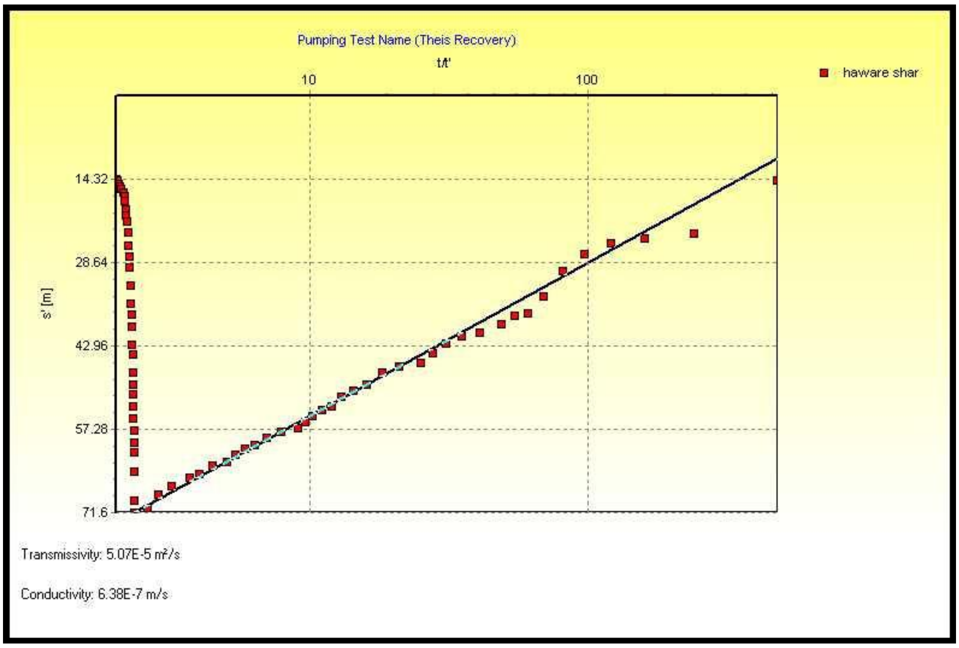

Fig.4.19 Theis recovery analysis for Hawari Shar well – TAT in SB1

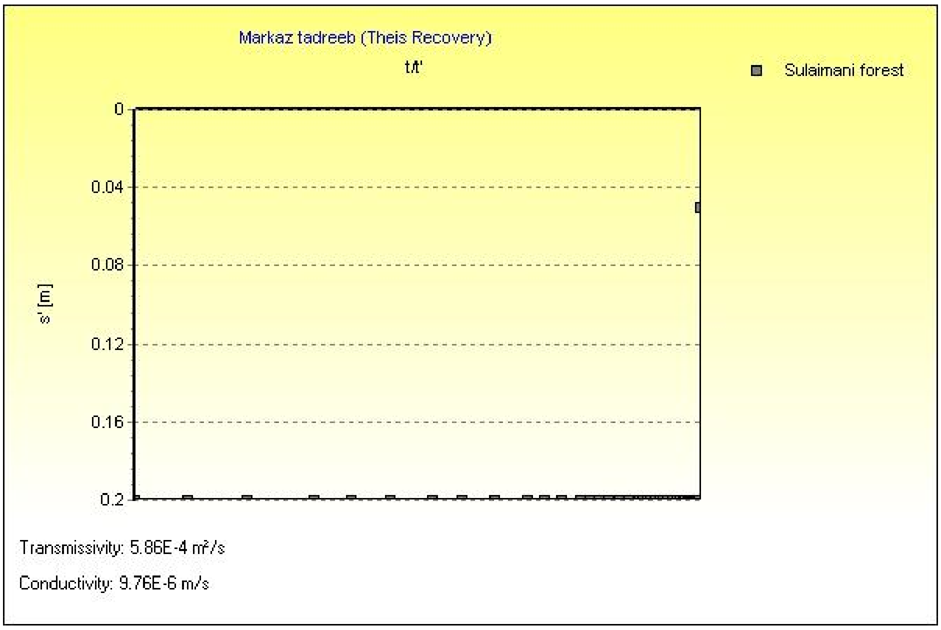

Fig.4.20 Theis pumping analysis for Sulaimani forest well –CKFA in SB1

.

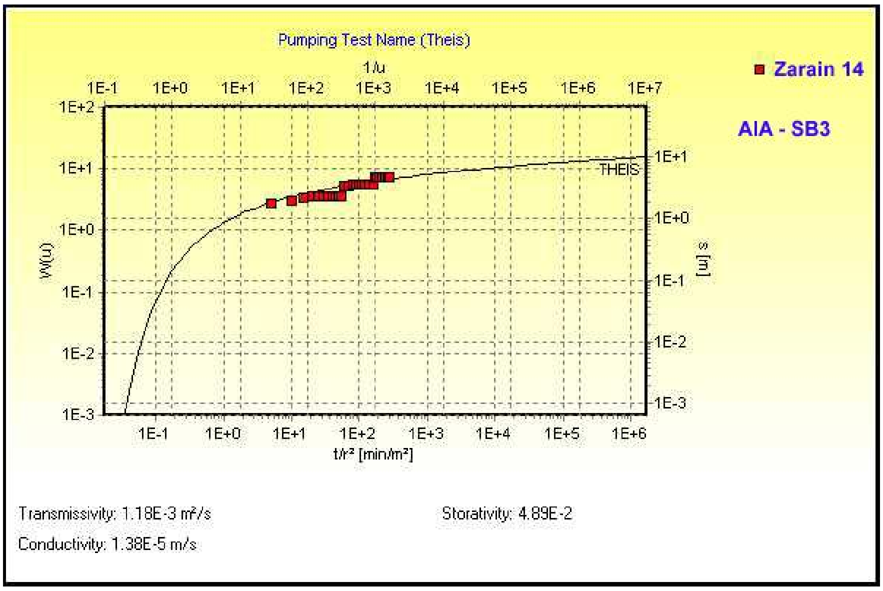

Fig.4.21 Theis pumping analysis for Zarain/14 well –AIA in SB2.

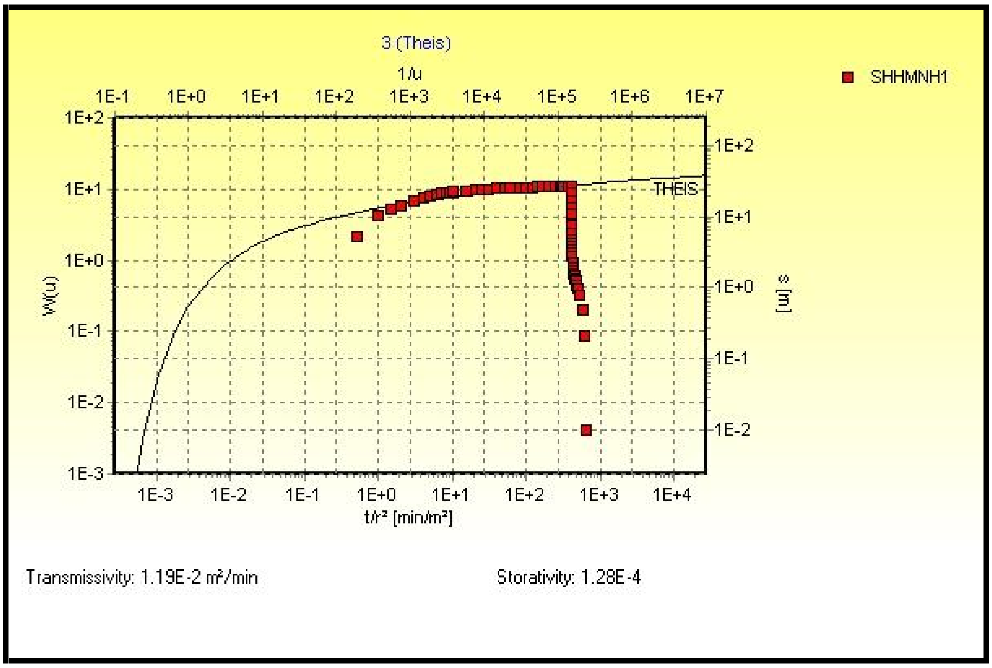

Fig.4.22 Theis pumping test analysis of SHHMNH1-AIA in SB4, FAO,2003.

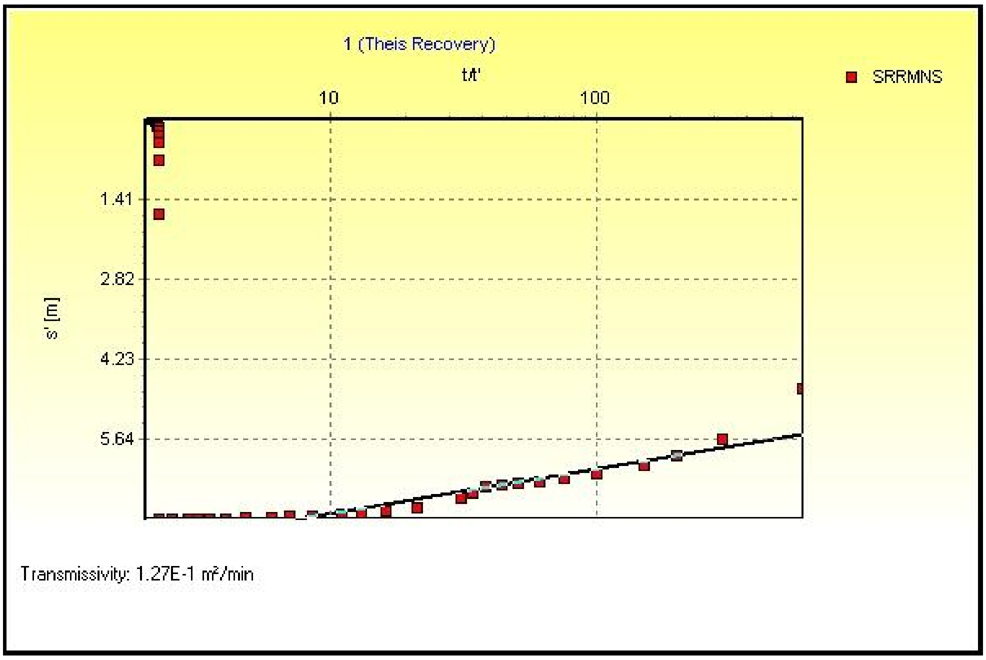

Fig.4.23 Theis pumping test analysis of SRRMNS-AIA in SB, FAO,2003

Table 4.2. Hydraulic properties of different aquifers in the study basin.

Well name	Depth (m)	Draw down m	Q l/s	K m/s X 10^{-6}	T m^2/s X 10^{-4}	Sc m^2/min x 10^{-2}	Type Of aquifer	Sub-basin	attitude
W1	100	16.8	6.8	1.02	0.8	2.4	AIA	SB1	35 34 57 45 26 35
W2	100	9.3	12.75	6.8	3.9	8.2	AIA + TAT	SB1	35 33 51 45 26 35
W3	220	60.9	7.27	0.64	0.5	0.7	TAT	SB1	35 36 6.1 45 26 9.1
W4	80	15.9	9.0	5.54	2.7	3.4	TAT+AIA	SB1	35 34 51 45 19 23
W5	121	1.1	9.0	9.7	5.8	49.0	CKFA	SB1	35 35 06 45 24 34
W6	90	14.9	8.0	1.33	0.8	3.2	AIA+TAT	SB1	35 35 54 45 15 49
W7	54	15	5.5	1.6	0.6	2.2	AIA	SB1	35 34 06 45 17 56
W8	102	10.4	3.37	1.7	1.3	2.1	TAT	SB2	35 25 32 45 37 54
W9	110	7.1	17	29	25.8	14.3	AIA	SB2	35 20 10 45 39 25
W10	112	22.7	3.0	0.2	0.2	0.79	AIA	SB2	35 21 35 45 40 02
W11	102	4.8	9.5	13.8	11.8	11.8	AIA	SB2	35 18 10 45 48 40
W12	97	31.5	7.5	2.7	2.4	1.4	CKFA	SB2	35 22 30 45 43 30
W13	119	8.0	19.0	31.4	31.4	14.2	AIA	SB2	35 19 50 45 40 08
W14	130	3	6.8	24.1	27.2	13.6	AIA	SB3	35 23 32 45 54 12
W15	154	9	15.7	14.0	20.4	10.5	AIA	SB3	35 22 56 45 55 08
W16	124	14	15	10.0	11.0	6.4	AIA	SB3	35 21 36

									45 53 54
W17	69	2	11.25	91.1	61.9	33.7	AIA	SB3	35 20 31 45 55 13
W18	150	40	6.7	1.9	2.8	1.0	AIA	SB4	35 13 05 45 57 55
W19	94	7	22.5	108	39.2	19.2	AIA	SB4	35 14 20 45 56 10
W20	90	9	7.5	9.1	13.3	5.0	AIA	SB4	35 17 40 46 01 35
W21	95	21	4.5	2.6	5.7	1.2	AIA	SB4	35 15 30 45 55 33
W22	145	15	6.3	3.5	1.2	2.5	AIA	SB4	35 11 54 45 59 13

-For the AIA in SB1 the values of (T) range from 0.6 x 10^{-4} to 0.8 x10^{-4} m^2/s. The average value representing 2 wells amounts to 0.7 x 10^{-4} m^2/s, while for AIA+TAT as most of the wells in SB1 penetrate these two successive aquifers; the (T) values range from 0.8 x 10^{-4} to 3.9 x 10^{-4} m^2/s, with an average of three wells amounting to 2.46 x 10^{-4} m^2/s.

- For AIA in SB2, the values of (T) range from as low as 0.2 x 10^{-4} m^2/s to as high as 31.4 x 10^{-4} m^2/s, with an average value representing 4 wells amounts 17.3 x 10^{-4} m^2/s.

-For AIA in SB3, the values of (T) range from as low as 11 x 10^{-4} m^2/s to as high as 62 x 10^{-4} m^2/s, with an average value of 4 wells amounts 30.1 x 10^{-4} m^2/s, while the value range of this parameter for AIA in SB4 is from 1.2 x 10^{-4} to 39.2 x 10^{-4} m^2/s with an average of 12.4 x 10^{-4} m^2/s.

Accordingly, the hydraulic conductivity (K) values of the intergranular aquifers AIA of all four sub- basins show a relatively similar variation to that of (T). AIA in SB3 has the highest hydraulic conductivity (K) compared to a similar aquifer type in other sub-basins. The average K for AIA in SB3 equals 34.7 x 10^{-6} m/s while in SB1 it is 4.5 x10^{-6} m/s. This parameter for AIA aquifers shows great variation in SB2 and SB4, ranging from 0.2 x 10^{-6} to 31.4 x 10^{-6} m/s in SB2 and from 1.9 x 10^{-6} to 108 x 10^{-6} m/s in SB4, while this variation in K value of AIA in SB1 is low. This is attributed to the morphometrical and morphological differences between these sub-basins, the type of the connecting streams and the source area of the stream loads, which consequently affected the type and the texture of the sediments.

The values of (T) of TAT determined for two wells in SB1and SB2 were found relatively to be the lowest at 0.5 x 10^{-4} m^2/s and 1.3 x 10^{-4} m^2/s respectively.

For the two tested wells penetrating CKFA in SB1 and SB2, the value of (T) was found to be higher in SB1 (5.8 x 10^{-4} m^2/s) than in SB2 (1.4 x 10^{-4} m^2/s). This is attributed to the heterogeneity nature of Kometan rock joint systems.

Generally, it is to be expected that the resulting values of the hydrogeological parameters should be lower than the actual ones. The wells were probably not thoroughly developed and the resulting drawdowns include not only the linear formation losses but also the square losses due to the turbulent flow toward the pumped wells.

The storage capacity of the aquifers shows a great variation. CKFA aquifer in SB1 shows the highest value due to the very limited drawdown (only 1.1m) in comparison to the high yield of the well (9.0 l/s), while in the same sub-basin TAT shows the lowest storage capacity.

In general, it is concluded that the relatively thick aquifers of AIA in SB3, SB2, and SB4 sequentially, could be considered the most promising area for drilling successful and productive wells, while AIA in SB1 comes second to them because of the relatively limited thickness of the alluvial sediments.

As far as the storage coefficient is concerned, limited data are available to be calculated. It is, however, to be pointed out that this aquifer parameter generally changes with the time of aquifer exploitation, but in particular under conditions of free level and relatively low artesian head of groundwater. That is to say, although the intergranular aquifer may react as confined at the beginning of a larger scale withdrawal through production wells, especially in its downstream portion, later on it should behave at least as a semi-confined one.

Due to de-watering of the water-bearing beds, the upstream portion of the alluvial aquifer may even react as unconfined aquifer. This means that the storage coefficient of the AIA must be within the range of 10^{-3} to 10^{-1}. To be more precise, the storage coefficient of about 10^{-3} may be characteristic of the confined part of the aquifer until the drawdown due to production pumping reaches the top of the water-bearing beds after which the storage coefficient would be changed and increased. The greater the water level decline, the larger the storage coefficient that would take place. However, based on the data from the pumping test of some of the tested wells it was found that the storage coefficient of the aquifers is variable from as much as a low of 8 $\times 10^{-4}$ for TAT in SB1 to the highest value of 4.9 $\times$ 10^{-2} for AIA aquifers in the Zarain area (SB2).

4.5. General recharge condition

Identification of the net groundwater recharge is essential for groundwater modeling and water resources management. The calculation of the net groundwater recharge is a big challenge for the hydrogeologist since there is no specific method for finding out the net recharge reliably. There are many methods for quantification of groundwater recharge from rainfall. Each method has its limitations and difficulty in application. All the methods which have been used in this regard have resulted in an estimation of the actual value (Baalousha, 2005).

Delineation of the potential groundwater recharge zone is of vital importance to augment groundwater resources. It is particularly significant in hard rock regions where groundwater is the primary source of potable water and continues to diminish due to indiscriminate exploitation (Mondal and Singh, 2004).

Mondal and Singh (2004) evolved a rapid and cost-effective procedure for the estimation of recharge through analysis of unconfined aquifer response in terms of a rise in water level due to precipitation. They established cross-correlations of increases in water level and precipitation, then classified the entire area into various zones depending on the variability in the coefficient of correlation.

In the absence of the discharge gauge stations on most of the streams in Sharazoor – Piramagroon basin, the calculation of the portion of runoff and groundwater in the drainage basin is impossible without finding either the runoff coefficient or the infiltration coefficient.

In chapter two of this thesis the effective amount of rainfall (water surplus) is estimated. Part of this amount input parameter becomes surface runoff and the rest represents recharge of the shallow and deep aquifers.

For the estimation of the annual volume of runoff in the study basin, the SCS (Soil Conservation Service) method is applied.

The SCS curve number method is a simple, widely-used, efficient method for determining the approximate amount of runoff from a rainfall event in a particular area. The method is also designed for a single storm event. It can be scaled to find average annual runoff values. The variable requirements of this method are low: it needs only rainfall amount and curve number. The curve number is based on the area's hydrologic soil group, land use, treatment and hydrologic condition. The first two variables are of the greatest importance. The equation for calculation of the discharge of all or part of the basin by using SCS curves is as follows. The application of this equation is further simplified by changing it to a graphical solution as shown in fig.4.24

$$Q = \frac{(P - 0.2\,S)^2}{(P + 0.8\,S)} \qquad \text{For } P > 0.2S \text{ .... (1)}$$

Where:

Q = Runoff in (mm) of depth

P = Total precipitation (mm) (average monthly record)

S = Retention including the initial abstraction which is assumed to be 0.2S

$$S = \frac{25400}{CN} - 254 \qquad \text{.................................... (2)}$$

Where - *CN* is curve number

The available infiltration tests performed by the author of Polservice (1980) for part of the Sharazoor plain and by Barzinji (2003) for some parts of Sulaimani was useful (to a certain extent) in the classification of the plains areas of the study basin into different zones of CN number.

The most problematic issue in the comparison was finding a suitable curve number for the highly fractured and jointed limestone and chert terrains which are not given in the booklet of SCS of American Soil Service. These terrains make up an important part of the surface areas of the Sharazoor-Piramagroon basin; especially the limestones that cover the side and summit of all mountains surrounding the basin.

For this method, the basin is divided according to the natural surface materials by using the tables of American Soil Conservation Service USDA, 2004 (table 4.3., Fig.4.24). Due to the absence of suitable surface maps for the basin, detailed field study is achieved for dividing the basin into different zones with different curve numbers (Figs.4.25, 4.26). This is done by comparing the characteristics of each curve number with the closest counterpart in the basin under study.

The field observation of the streams and springs in these terrains showed that these terrains have a relatively high infiltration coefficient (low runoff coefficient). In the booklet, the areas with the highest infiltration coefficient are the terrains densely vegetated by woods. But how can the CN of these woods be applied to the limestone terrains in the present basin? The modification is as follows:

1. These terrains must be put into hydrologic groups of A or B which has moderately low runoff even or when thoroughly wetted.
2. The joint and fracture network comprising excellent paths for infiltrations and the undulated surfaces of the mountains lessen the opportunity for the flooded water to flow to the lower elevated lands, before finding its way to the existing discontinuities.

How is the modification achieved?

During fieldwork in winter 2004 and spring 2005 in different areas of Sharazoor - Piramagroon basin, by knowing both the daily and the cumulative daily rainfall during these two seasons the time and condition of the flooding of seasonal and permanent streams were observed and the stream discharges carefully assessed (Tables 4.4, 4.5, 4.7, 4.9, 4.11, and 4.13, and Figs. 4.27 - 4.30). These observations led to the awareness that the study area has different characteristics concerning the infiltration coefficients.

These characteristics are demonstrated by the verity that the streams of some basins are not flooded until the middle of spring (April) when more than 400 mm of rainfall have fallen, while other basins are flooded at the beginning of winter when the cumulative rainfall has reached only 150 mm. These phenomena are directly related to the executed fieldwork in the hydrogeology.

In the same manner, the discharge of the springs, such as Sarchinar, Bestansur, Saraw, Reshen and Zalim, is monitored. All their discharges reached the minimum at the middle of autumn but after about 200 mm of rainfall, the discharges were doubled or even tripled and the mean discharges happened after precipitation of more than 250 mm. Maximum discharge is reached at the beginning of April. The discharges of these springs increased rapidly between 100 to 250 mm of precipitation and when the precipitation stopped for about a week, their discharge also decreased rapidly (Table 4.4).

Table 4.3 Runoff curve numbers of agricultural lands[1/] (USDA, 2004).

Cover description: cover type	treatment[2]	hydrologic condition[3]	CN for hydrologic soil group: A	B	C	D
Fallow	Bare Soil	---	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C & T)	Poor	66	74	80	82
		Good	62	71	78	81
	C & T + CR	Poor	65	73	79	81
		Good	61	70	77	80
Small grain	SR	Poor	65	76	84	88
		Good	63	75	83	87
	SR + CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C + CR	Poor	62	73	81	84
		Good	60	72	80	83
	C & T	Poor	61	72	79	82
		Good	59	70	78	81
	C & T + CR	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded or broadcast legumes or rotation meadow	SR	Poor	66	77	85	89
		Good	58	72	81	85
	C	Poor	64	75	83	85
		Good	55	69	78	83
	C & T	Poor	63	73	80	83
		Good	51	67	76	80

Continued

Pasture, grassland, or range- continuous forage for grazing [4/]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow-continuous grass, protected from grazing and generally mowed for hay	Good	30	58	71	78
Brush-brush-forbs-grass mixture with brush the major element [5/]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30 [6/]	48	65	73
Woods-grass combination (orchard or tree farm) [7/]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods [8/]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30	55	70	77
Farmstead--buildings, lanes, driveways, and surrounding lots	---	59	74	82	86
Roads (including right-of-way):					
Dirt	---	72	82	87	89
Gravel	---	76	85	89	91

1/ Average runoff condition, and I_a=0.2s.

2/ Crop residue cover applies only if residue is on at least 5 percent of the surface throughout the year.

3/ Hydrologic condition is based on combinations of factors that affect infiltration and runoff, including (a) density and canopy of vegetative areas, (b) amount of year-round cover, (c) amount of grass or close-seeded legumes, (d) percent of residue cover on the land surface (good ≥20%), and (e) degree of surface toughness.

Poor: Factors impair infiltration and tend to increase runoff.

Good: Factors encourage average and better then average infiltration and tend to decrease runoff.

For conservation tillage poor hydrologic condition, 5 to 20 percent of the surface is covered with residue (less than 750 pounds per acre for row crops or 300 pounds per acre for small grain).

For conservation tillage good hydrologic condition, more than 20 percent of the surface is covered with residue (greater than 750 pounds per acre for row crops or 300 pounds per acre for small grain).

4/ Poor: < 50% ground cover or heavily grazed with no mulch.
Fair: 50 to 75% ground cover and not heavily grazed.
Good: > 75% ground cover and lightly or only occasionally grazed.

5/ Poor: < 50% ground cover.
Fair: 50 to 75% ground cover.
Good: > 75% ground cover.

6/ If actual curve number is less than 30, use CN = 30 for runoff computation.

7/ CNs shown were computed for areas with 50 percent woods and 50 percent grass (pasture) cover. Other combinations of conditions may be computed from the CNs for woods and pasture.

8/ Poor: Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: Woods are grazed, but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

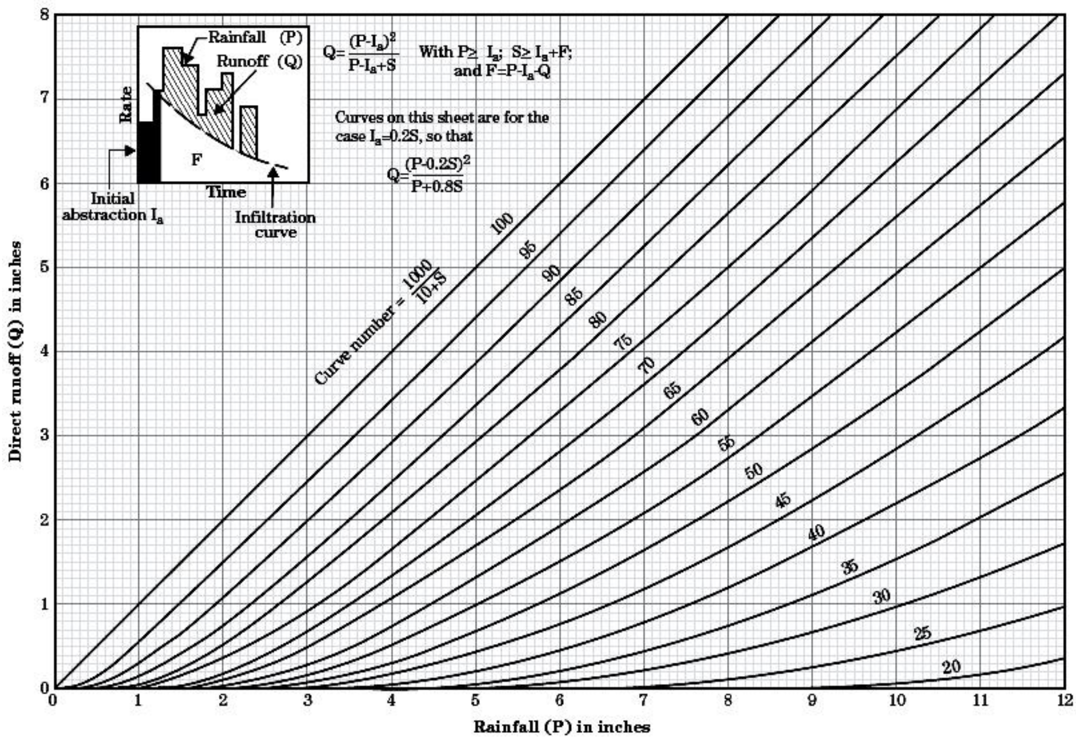

Fig.4.24 The graphical solution of the SCS equation.

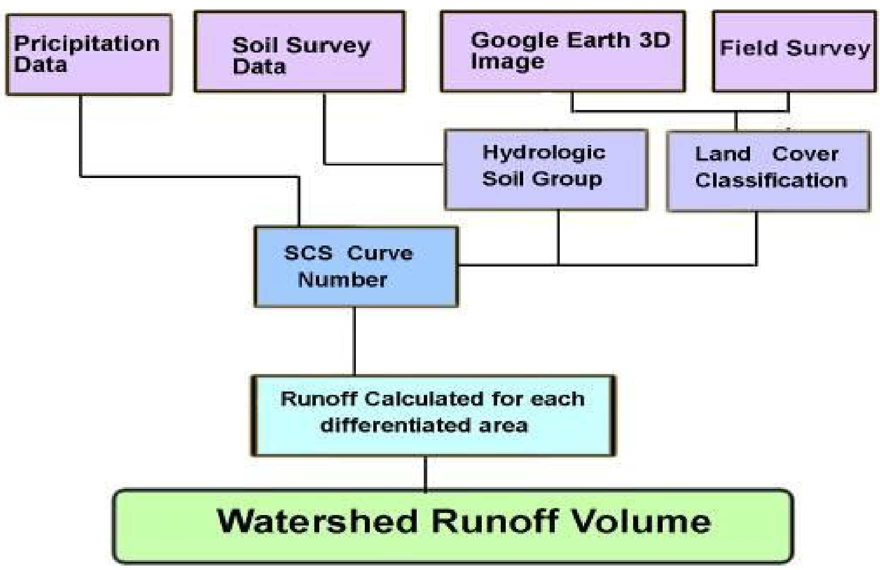

Fig. 4.25 The method followed for the estimation of watershed runoff coefficients.

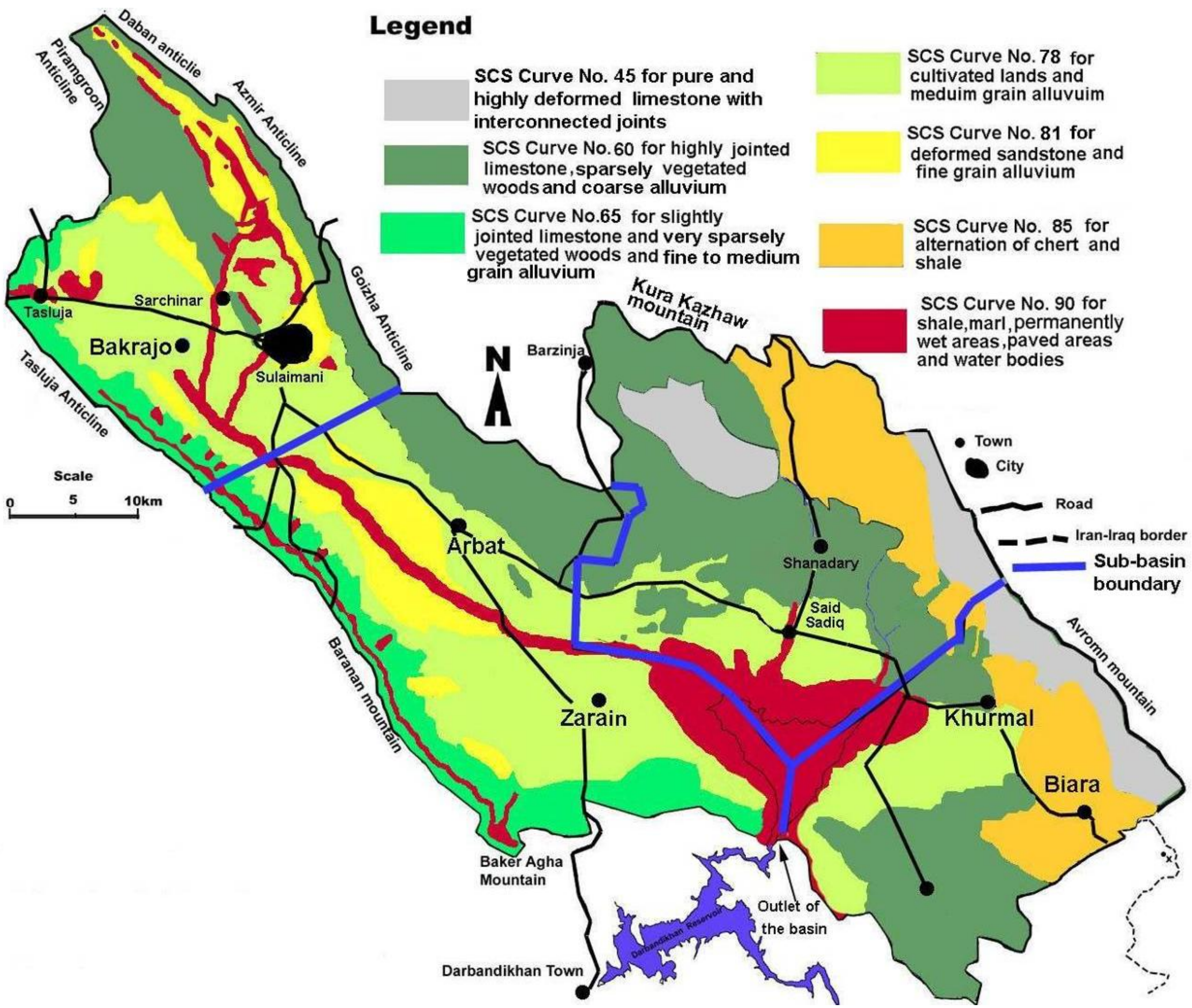

Fig.4.26 Differentiation of the basin surface area into different runoff zones according to runoff coefficient and curve numbers.

Table 4.4 Variation of discharge of some large springs with rainfall in Sharazoor-Piramagroon basin.

Spring name	Cumulative Rainfall (mm)	Spring discharge l/s	Date of measurement	Cumulative Rainfall (mm)	Spring discharge l/s	Date of measurement
Sarchinar	125	750	23/11/2004	227	2475	7/1/2005
Bestansur	125	760	23/11/2004	227	760	7/1/2005
Reshen	125	716	23/11/2004	227	6170	7/1/2005
Qalabo	125	630	23/11/2004	227	990	7/1/2005
Zalim	125	2334	23/11/2004	227	6840	7/1/2005

From these observations of the streams and springs a conclusion has been drawn: the late flooding streams and early increase of the spring's discharges are closely related: both are located in areas of jointed and fractured limestone terrains. This indicates that the limestone terrain has a low runoff coefficient which is not tabulated in the table of USDA (2004). However, this conservative estimation of the recharge is to a certain extent subject to some possible errors such as the exact delineation of the contributing surface area, and the selection of the convenient CN value.

In the following sections of this chapter, the recharge amount estimated by the water balance method will be compared to the response of real measured stream and spring discharge values.

Fikos et al. (2005) estimated the infiltration coefficient for the Anthemountas river basin in Macedonia, based on a 20x20m grid digitized map. Their estimation was based on geologic information, slope and land coverage as the infiltration varied from 30% for calcareous rocks to 5% in hard metamorphic fractured rock.

Milenic (2004) estimated the surface runoff for the intergranular and karst aquifers within the Cork-Midleton and Cloyne synclines, Ireland to be 10% of total rainfall after evapotranspiration, while for the fractured aquifer of the Great Island Anticline it was estimated at 75% of total rainfall after evapotranspiration.

Table 4.5 Some physiographic data relating to flooding periods of the main valleys in Sharazoor - Piramagroon basin.

Basin	Stream valley	Exposed Fn	Month at which Flow is occurred	Max. cumulative Rainfall at flow period mm	Basin average slope In degree	Approximate discharge m^3/s
Sharazoor – Piramagroon	Chaqchaq	Tanjero & Shiranish	January to June	200	15	0 - 8
	Tanjero	Tanjero and Kolosh	February to June	250	7	0.5- 50
	Chawtan-Dola Chawt	Qulqula	January to June	150	20	0.6 -15
	Galal	Mainly Jurassic	Few days of March	400	20	0 - 2
	Zalim	Qulqula and Avroman	January to June	200	18	0.4 - 8

As mentioned in the previous section, one of the other most complicated issues in recharge estimation is the delineation of the groundwater divide, particularly for the areas located along the trans-boundary areas with Iranian territory. Based on some field surveys and investigations inside the Iranian part of the catchment during July 2005, some uncertain contributing areas for groundwater recharge are defined (Fig.4.31). The results of this survey are supported by the study of Baziany (2006), who covered similar areas inside Iran for his study of the stratigraphy of the region.

Hydrogeological analysis of the spring discharge regime for the large springs which are most probably partially fed from Iranian territory led to a conclusion that it is more reliable to say that greater areas more likely contribute through Avroman aquifer TKA outside the defined basin than expected.

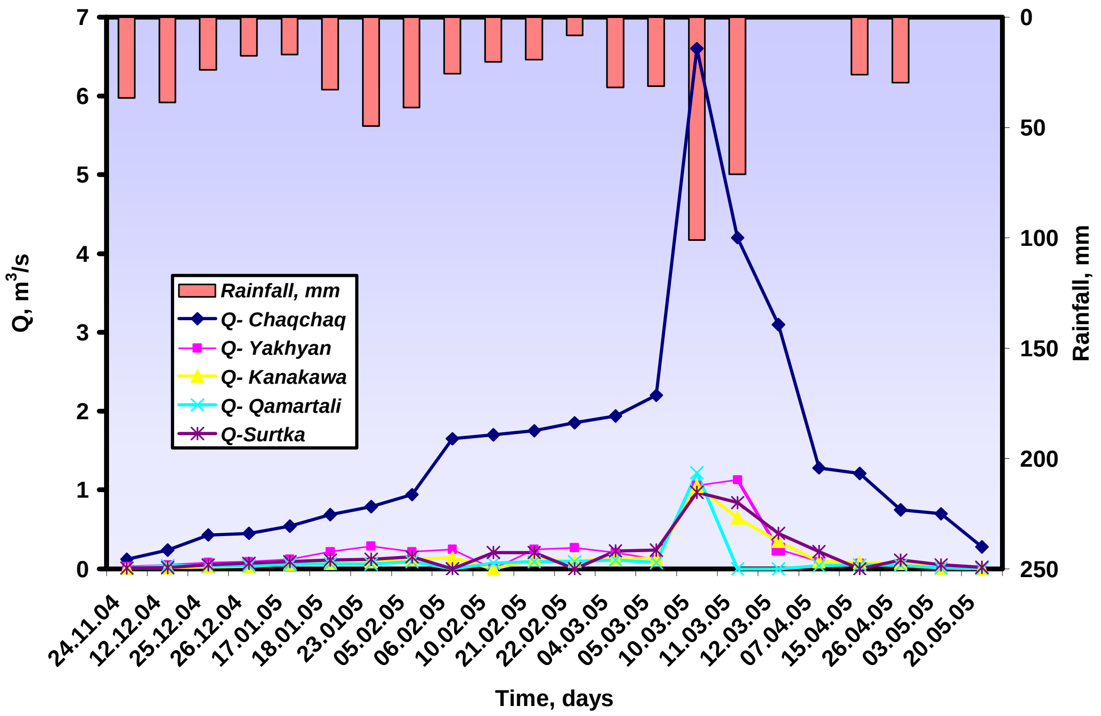

Fig 4.27 Hydrograph of some intermittent streams in SB1, Nov. 2004 – end May 2005.

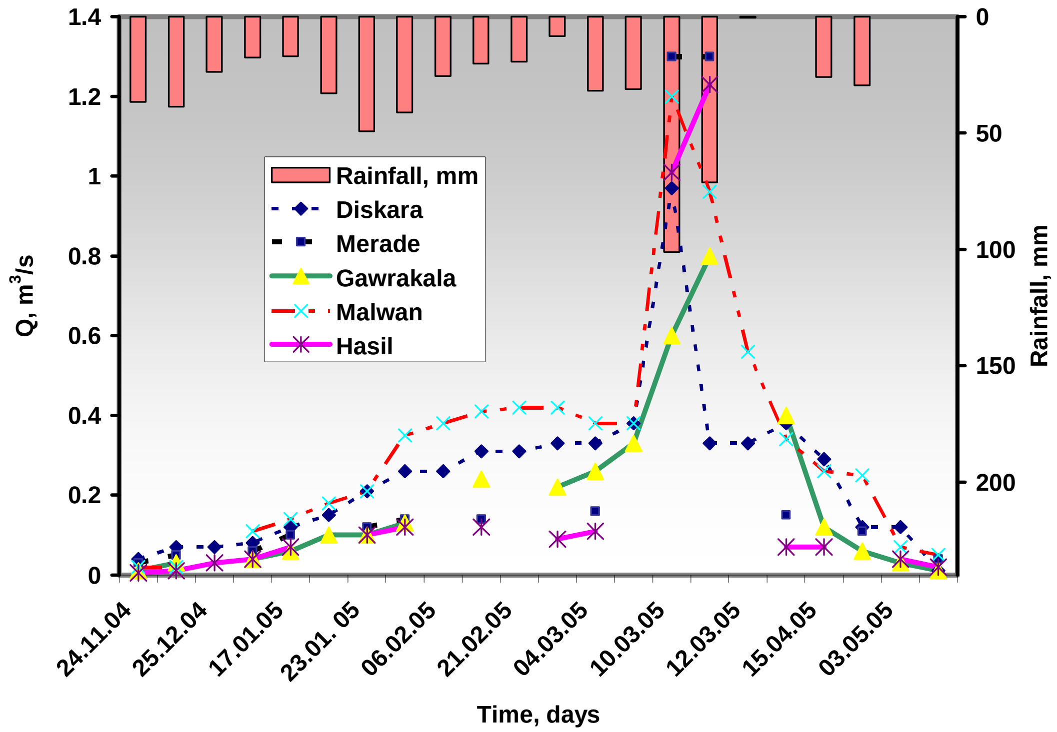

Fig. 4.28 Hydrograph of some intermittent streams in SB2, Nov.2004 – June 200

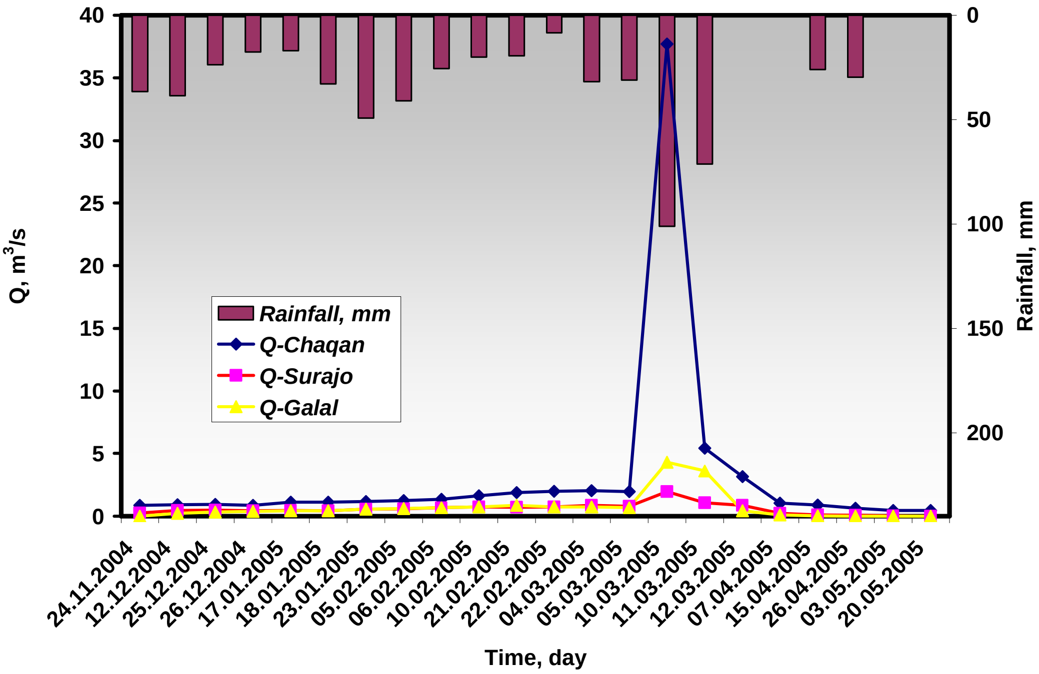

Fig.4.29 Hydrograph of some intermittent streams in SB2, Nov.2004 – June 2005.

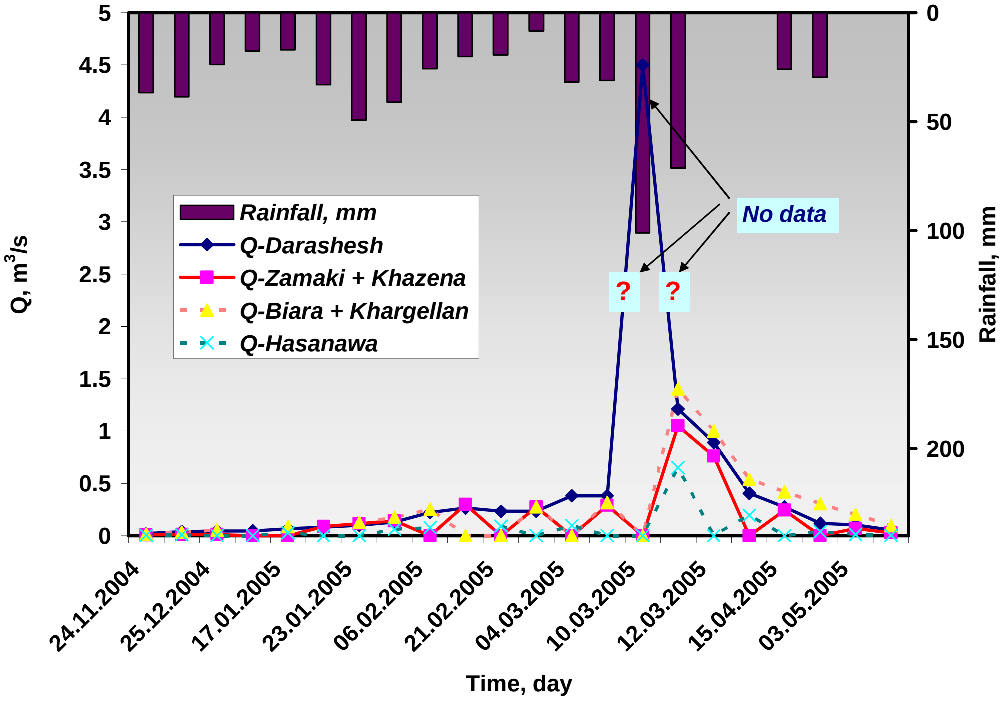

Fig.4.30 Hydrograph of some intermittent streams in SB2, Nov.2004 – June 2005.

Example of calculations:

Aquifer - CKFA

Location - SB1

Proposed CN = 60

Contributing area inside the drainage basin = 152.6 km^2

Roughly estimated contributing area outside drainage basin = 35 km^2

Total area = 187.6 km^2

Monthly amount of surface runoff (Rs) of each month calculated using SCS equations.

Monthly amount of recharge Re = Ws – Rs in mm, where Ws is water surplus calculated in chapter 2.

Annual sum of Re = 442 mm

Annual volume of recharge (Re) = 442 mm x 187.6 Km^2 = 82.9 x 10^6 m^3

%Re = 442/780 x 100 = %56.6

Table 4.6 Example of runoff and recharge calculation of a portion of CKFA in SB1.

Months	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July Aug Sep	Total
(P) (mm)	34.3	109.8	125.6	137.8	121.5	112.5	91.1	45	2.5	0	780
Ws (mm)		89.2	120.5	135.8	117.7	97.9	45.7	0	0	0	606.9
Rs (mm)	0	23.5	32.3	39.6	29.9	25.0	14.5	0.7	0	0	165.5
Re (mm)	0	65.7	88.2	96.2	87.8	72.9	31.2	0	0	0	442

P-average monthly precipitation in mm, Ws- average monthly water surplus in mm, Rs- average monthly surface runoff in mm, Re- average monthly recharge in mm.

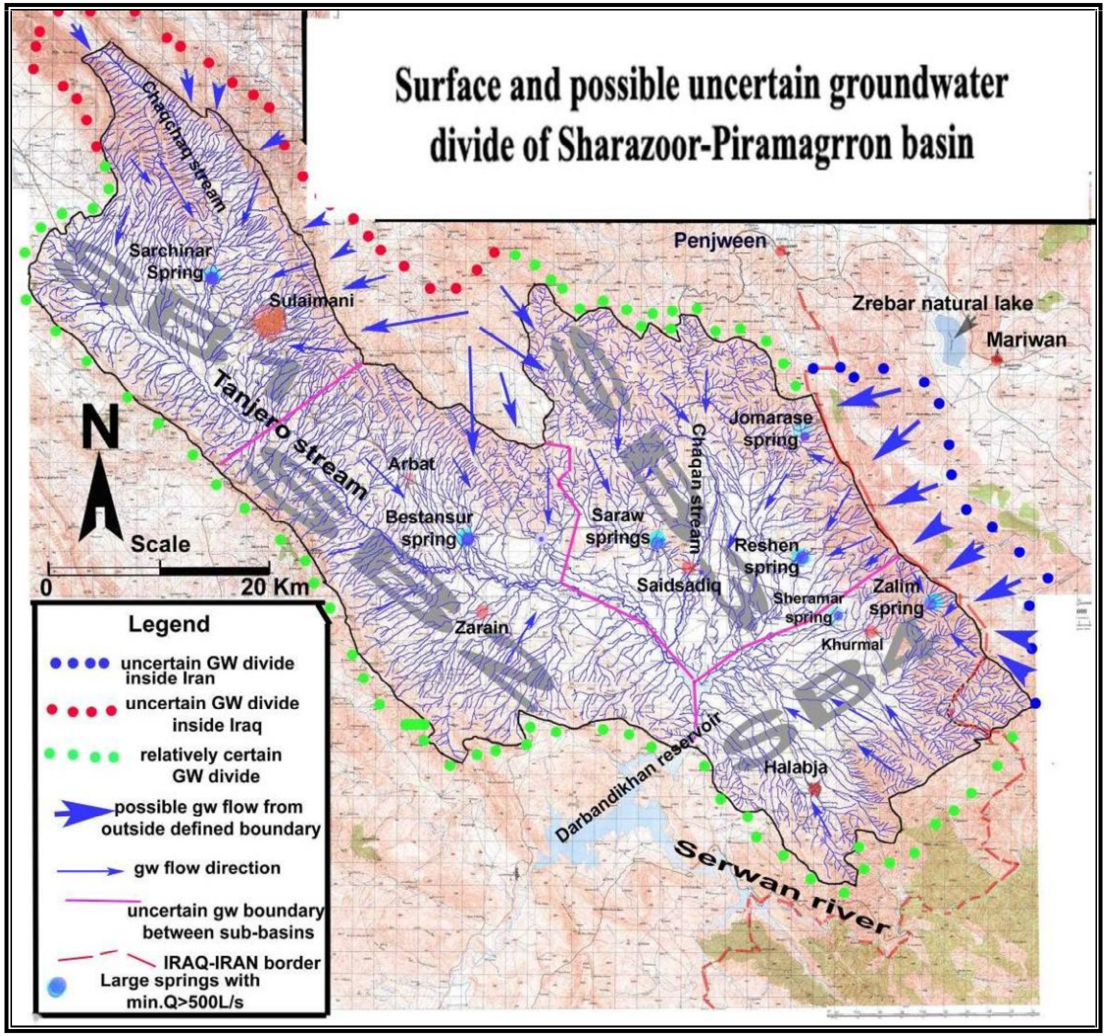

Fig.4.31 Possible and uncertain groundwater divide of Sharazoor – Piramagroon basin

4.5.1 Groundwater recharge of Sulaimani Sub-basin (SB1)

- CKFA

Structural geology controls the overall position and orientation of limestone outcrops as well as the fractures that develop in the rock and serve as pathways for water movement. Conduits within the aquifer develop by preferential dissolution along some of these structural elements (Sasowsky, 1999) (Palmer, 2003). Accordingly, a cave represents either a past or present route of preferential flow in the aquifers. Former routes are often dry, while the presently active ones are wet (at least seasonally).

The highly jointed, intensified tectonic ruptures, bedding planes, and tension fractures comprise the main recharging paths for the infiltration of rainfall to groundwater. Snow melting on the crest and limbs of the Azmer, Goizha, Qaywan and Piramagroon mountains also infiltrates into the aquifer through these routes. These outcrops cover an area of 152.6 km^2, which is about 36.5% of the whole sub-basin.

Outcrops of CKFA and the structural attitude of the layers and discontinuities in the other northeastern limb of the first three mentioned mountains above reveal that percolated waters from this limb also contribute to CKFA recharge of the study basin. On the other hand, the Piramagroon double plunging anticline drains the majority of its groundwater reserve towards the study basin. The absence of any large springs like that of Sarchinar in the adjacent Chwarta - Penjween basin north of the study basin, and the existence of the only spring of Tabin (with average Q= 600 l/sec) in the other northwestern plunge of the Piramagroon anticline verify the two above facts. Accordingly, an additional 35 km^2 area as a rough estimate is added to the contributing area.

Structural and morphological settings create good conditions for a high rate of infiltration. Stevanovic and Iurkiewicz (2004) estimated the rate of infiltration to be more than 50% of total rainfall. Their assessment relied on the occurrence of highly fractured and karstified rocks, lack of vegetation (bare steep mountain sides) and the lack of perennial or even temporary streams. During the wet season, the reduced evaporation rate, rainfall and even attitude of the beds contribute to the above-mentioned rate. Neotectonic uplifting of the Cretaceous limestone sequence and associated extension fractures probably reinforced recharge potential.

Percolation of water through a longitudinal fault crossing Chachaq stream is another part of the recharging source of the main aquifer which feed and buffer the Sarchinar spring particularly during recession periods or decreasing pressure periods. No continuous discharge measurements have been achieved for the Chachaq stream, but periodical monitoring during the whole period of the study caused some rough assessments to be consistent (table 4.7).

The estimated mean magnitude of the discharge which percolates to underground is around 0.36 m^3/s from November till mid or end of June.

- AIA

The western and south western parts of the area of the Sulaimani basin are covered by alluvial deposits and some patches by slope deposits. These deposits constitute good potential aquifers if morphology is supportive. The main sources of recharge are:

1. Direct infiltration of the rainfall through these sediments occupying an area of 228 km^2.
2. Percolation of water through the gravelly beds of some valley streams such as the tributaries that drain the Kani Panka stream before joining the Tanjero stream to the southwest of Bakrajo. The most effective among these valleys are Yakhyan, Surtka, Sheikh Ali, Chami Kanakawa and Qamartle valleys. The cumulative amount of water percolating from these valleys is estimated to be in the range of 200 l/s during November to the end of May (table 4.7).

The Yakhyan Wadi is the one which contributes the most, as more than 50% of the runoff (110 l/s) percolates underground during November to mid or end-May. This assessment is realized based on some rough measurements performed in different sections of these valleys during different periods of the year throughout the field study period.

- TAT

The Tanjero formation has complex characteristics concerning the storing and yielding of groundwater as it acts as both aquitards and aquiclude. The deformed (fracture and jointed) succession act as aquifer, but the shale and marl ones have characteristics of aquiclude.

Thick layers of siltstone, sandstone and shale of the Tanjero Formation are prevalent in most of the eastern and southeastern part of the sub-basin beside the area covering Chaqchaq valley. Limited rainfall and some runoff water inside the small valleys and ravines tributaries infiltrate to a shallow depth which provide the yearly replenishment of some low yielding springs and shallow wells drilled inside the city and in the outskirts. The area occupying these type of outcrops is measured to be 91 km^2 (table 4.8).

- EKFA and SDA

The slide portion of the Sinjar limestone blocks of Baranan Homocline, which borders the southwestern part of this sub-basin, makes up the main bulk of this aquifer. It is recharged from the direct infiltration of rainfall through fissured and karstified surfaces.

This type of aquifer occupies an area of 50 km^2. The infiltrated water is supposed to flow for a short distance underground and then pour out as low discharging springs on the foot of the slide blocks and along the plane of the slide scarp. The aquifers comprising this side of the basin are most likely not connected with each other, due to the isolated nature of the entity blocks.

4.5.2. Groundwater recharge of Arbat-Zarain Sub-Basin (SB2)-

- CKFA

The high mountains of Bardarash, Greza and Bardakar which surround the north and north eastern boundary of the sub-basin comprise the main recharging area. These mountains occupy an area of 123 km^2 and are composed mainly of highly jointed layers of limestone of the Balambo and Kometan Formations. Direct infiltration of precipitation through the densely developed discontinuities is the main recharging source. Some 50 km^2 areas outside the sub-basin (outside the surface water divide) are supposed to contribute to groundwater recharge.

Table 4.7 Intermittent discharge measurements of the main seasonal streams in SB1.

Date of measurement of both discharge and daily rainfall with cumulative rainfall			Discharge, m^3/s upstream and down stream sections Stream or valley name+									
			Chaqchaq		Yakhyan		Kanakawa		Qamartle		Surtka	
Date	(1) P mm	(2) ∑P mm	U.S	D.S.	U.S	D.S.	U.S.	D.S.	U.S.	D	U.S.	D.S.
			Catchment area, Km^2									
			100	145	14	18	12	17	9	13	12	28
24.11.04	36.7	113.0	0.12	0.09	0.03	0	0.009	0	0.01	0	0.01	0
12.12.04	38.6	154.6	0.24	0.16	0.05	0.02	0.014	0.007	0.04	0.02	0.015	0.01
25.12.04	23.8	180.7	0.43	0.21	0.08	0.04	0.024	0.019	0.04	0.02	0.05	0.04
26.12.04	17.6	180.7	0.45	0.2	0.09	0.03	0.03	0.022	0.04	0.02	0.07	0.05
17.01.05	17.0	230.8	0.54	0.35	0.12	0.05	0.06	0.04	0.058	0.035	0.09	0.08
18.01.05	32.9	246.7	0.69	0.45	0.22	0.08	0.07	0.05	0.065	0.045	0.11	0.10
23.0105	49.3	296.4	0.79	0.51	0.29	0.10	0.09	0.07	0.06	0.04	0.12	0.10
05.02.05	41.1	357.9	0.94	0.76	0.22	0.17	0.12	0.1	0.09	0.07	0.15	0.13
06.02.05	25.6	374.1	1.65	1.1	0.25	0.15	0.14	0.12	-	-	-	-
10.02.05	20.2	406.1	1.70	1.25	-	-	-	-	0.07	0.06	0.21	0.19
21.02.05	19.4	427.8	1.75	1.25	0.25	0.13	0.12	0.07	0.09	0.07	0.21	0.19
22.02.05	8.4	427.8	1.85	1.20	0.27	0.13	0.10	0.06	0.09	0.07	-	-
04.03.05	31.8	459.6	1.94	1.39	0.21	0.10	0.13	0.09	0.11	0.07	0.23	0.20
05.03.05	31.2	462.7	2.20	1.58	0.12	0.08	0.13	0.11	0.08	0.07	0.24	0.20
10.03.05	101.1	572.1	6.60	6.10	1.06	0.67	1.05	0.94	1.22	1.18	0.97	0.80
11.03.05	71.3	572.4	4.20	3.65	1.13	0.54	0.65	0.56	-	-	0.84	0.7
12.03.05	0.3	572.4	3.10	2.62	0.25	0.20	0.35	0.30	-	-	0.45	0.35
07.04.05	0	572.4	1.28	0.75	0.09	0.03	0.09	0.08	0.04	0.02	0.22	0.19
15.04.05	26	598.4	1.21	0.75	0.07	0.02	0.08	0.04	0.05	0.02	-	-
26.04.05	29.6	628.0	0.75	0.46	0.05	0.01	0.07	0.05	0.045	0.03	0.11	0.09
03.05.05	0	628.0	0.7	0.35	0.01	0.0	0.009	0.003	0.009	0.004	0.05	0.03
20.05.05	0	628.0	0.28	0.17	0	0	0.005	0	0.004	0.0	0.02	0.01
Mean			1.52	1.15	0.23	0.12	0.16	0.13	0.12	0.10	0.22	0.18
Average losses			0.36		0.11		0.03		0.02		0.04	

+The sections of measurements are shown in annex 2.

(1) Rainfall in the day or the day before stream discharge measurement

(2) Cumulative rainfall within certain period

Table 4.8 Estimated annual groundwater recharge for SB1

Type of aquifer	*Area km^2*	*Proposed CN-value*	*%Re*	*Re mm*	*Re $x10^6$ m^3/year*	*Source of recharge*
CKFA	**152.6+35***	**60**	**56.6**	**442**	**82.9**	**Direct infiltration**
				0.36 m^3/s x 210 days	**7.5**	**Percolation from Chaqchaq stream**
	Sub-total				**90.4**	
AIA	**228.4**	**78**	**27.1**	**201**	**45.9**	**Direct Infiltration**
				0.35 m^3/s x210 days	**6.3**	**Percolation from connecting streams**
	Sub-total				**52.2**	
TAT	**91.6**	**81**	**23.4**	**173.7**	**15.9**	**Direct infiltration**
	Sub-total				**15.9**	
EKFA SDA	**50.3**	**65**	**51.7**	**383**	**19.2**	**Direct infiltration**
	Total annual recharge of SB1				**177.7**	

**** represent roughly estimated area that might contribute recharging of CKFA outside the surface divide drawn.***

- AIA

Alluvial deposits cover (as relatively thin layers) the north and northwestern part of the SB2, while they are a thicker layer in the central and southern part. These layers are recharged mainly by direct infiltration of rainfall but an additional partial recharging source comes from the percolation of running waters of some main valleys and ravines, such as Gawra Qala, Diskara, Hasil, Alan, Merade, Malwan and Sartka. A rough estimation realized from periodical monitoring of some of these valleys of 0.3 m^3/s (as a cumulative amount of recharge) is a more or less reliable average for seven months of the year (table 4.9).

- TAT

In this sub-basin the rocks of the Tanjero Formation crop out over 86.7 km^2 of the western and southwestern part of this sub-basin. Relatively limited infiltration of rainfall water takes place through the joint and fractures of these rocks, penetrating only shallow depths. Some waters more likely infiltrate via thin alluvial deposits overlying these rocks. The Kolosh Formation (as aquiclude) crops out as patches in piedmont at the foot of Baranan, Bardakar and Baker Agha mountains, and occupies an area of 87 km^2.

- EIA and SDA

The fractured and jointed limestone of Sinjar, Pila Spi and Gercus Formations comprise the main aquifer of EIA and SDA. The outcrops of these units that cover Baker Agha and Baranan mountains form the aquifer and recharging area. The slide blocks of these units also participate in preserving an appreciable portion of the infiltrated water as shallow groundwater. These blocks rest in the foothills of the Baranan and Baker Agha mountains over Kolosh impervious rocks. These slide masses have been studied in detail both hydrogeologically and geotechnically by Karim and Ali (2004) and Ali, (2005).

Thick conglomerate layers (as Gercus Formation) form relatively high elevated mountains around Merade and Qleja villages. These layers act as small perched aquifers which drain some low discharge springs (with an average Q= 1 l/s), such as the Merade and Qleja springs.

Table 4.9 intermittent discharge measurements of the main seasonal streams in SB2.

Date of measurement of both discharge and daily rainfall with cumulative rainfall			Discharge, m^3/s (upstream and down stream sections) Stream or valley name+									
			Diskara		Merade		Gawrakala		Malwan		Hasil	
	(1) P mm	(2) ∑P mm	U.S	D.S.	U.S	D.S.	U.S.	D.S.	U.S.	D.S.	U.S.	D.S.
			Catchment area, Km^2									
Date			8	12	14	22	7	13	11	15	10	16
24.11.04	36.7	113.0	0.04	0.01	0.03	0.01	0.01	0	0.02	0	0.005	0
12.12.04	38.6	154.6	0.07	0.04	0.05	0.03	0.03	0.025	0.02	0.01	0.01	0.01
25.12.04	23.8	180.7	-								0.03	0.02
26.12.04	17.6	180.7	0.08	0.04	0.06	0.04	0.04	0.03	0.11	0.07	0.04	0.03
17.01.05	17.0	230.8	0.12	0.07	0.1	0.09	0.06	0.05	0.14	0.09	0.07	0.03
18.01.05	32.9	246.7	0.15	0.12			0.1	0.08	0.18	0.15		
23.01. 05	49.3	296.4	0.21	0.18	0.12	0.09	0.1	0.09	0.21	0.18	0.1	0.08
05.02.05	41.1	357.9	0.26	0.22	0.14	0.12	0.13	0.12	0.35	0.30	0.12	0.1
06.02.05	25.6	374.1	-						0.38	0.33		
10.02.05	20.2	406.1	0.31	0.29	0.14	0.12	0.24	0.19	0.41	0.36	0.12	0.09
21.02.05	19.4	427.8	-						0.42	0.37		
22.02.05	8.4	427.8	0.33	0.26			0.22	0.19	0.42	0.38	0.09	0.06
04.03.05	31.8	459.6	-		0.16	0.12	0.26	0.21	0.38	0.34	0.11	0.09
05.03.05	31.2	462.7	0.38	0.33			0.33	0.27	0.38	0.32		
10.03.05	101.1	572.1	0.97	0.86	1.3	1.20	0.6	0.5	1.2	1.1	1.01	0.07
11.03.05	71.3	572.4	1.08	0.93	1.3	1.0	0.8	0.6	0.96	0.85	1.23	0.98
12.03.05	0.3	572.4	-						0.56	0.39		
07.04.05	0	572.4	0.38	0.31	0.15	0.12	0.4	0.33	0.34	0.22	0.07	0.04
15.04.05	26	598.4	0.29	0.21			0.12	0.1	0.26	0.17	0.07	0.05
26.04.05	29.6	628.0	0.12	0.07	0.11	0.07	0.06	0.03	0.25	0.19		
03.05.05	0	628.0	-				0.03	0.01	0.07	0.034	0.04	0.0
20.05.05	0	628.0	0.01	0.005	0.04	0.01	0.01	0	0.05	0.02	0.02	0.0
Mean			0.3	0.24	0.28	0.23	0.19	0.15	0.33	0.28	0.19	0.10
Average loss			0.06		0.05		0.04		0.05		0.09	

+The sections of measurements are shown in annex 2.

(1) Rainfall in the day or the day before stream discharge measurement

(2) Cumulative rainfall

Table 4.10 Estimated annual groundwater recharge for SB2

Type of aquifer	Area Km^2	Proposed CN value	%Re	Re mm	Re $x10^6$ m^3/year	Source of recharge
CKFA	123.2+50*	60	56.6	442	76.5	Direct infiltration
	Sub-total				76.5	
AIA	341.2	78	27.1	201	68.6	Direct infiltration
				0.3 m^3/s X210 days	5.4	Percolation from connecting streams
	Sub-total				74	
TAT	86.7	81	23.4	173.7	15	Direct infiltration
	Sub-total				15	
EKFA SDA	150.9	65	51.7	383	57.8	Direct infiltration
	Total annual recharge of SB2				223.3	

4.5.3. Groundwater recharge of Said Sadiq Sub-basin (SB3)-

- TKA, JKA and CKFA

The highest mountains surrounding this sub-basin occupy the majority of the area--about 60%--of this basin, while the rest is plain. The west and northwestern part is covered by Balambo, Kometan 188.7 km^2 and Jurassic rocks 57.2 km^2. TKA, which is represented by the Avroman Formation, covers an area of 35 km^2 of the eastern part of the sub-basin.

Conservatively, 100 km^2 is supposed to contribute to the eastern part of the Avroman aquifer (from Iranian territory), from which the main largest springs of Jomarase and Reshen issue.

These rocks are all located in the Thrust and Imbricate Zones; therefore, they are intensively deformed. These deformations during prolonged underground weathering transformed to karstified aquifer which has merit for precipitation infiltration. The perennial valley flows, originating from the existing springs in the Qulqula Formations, occur in Khartok, Jonan and Kaghrtina valleys, percolate underground to a considerable degree along the left Chaqan streambed across the JKA.

Hydrological measurements performed by the authors of Energoprojekt (1980) gave evidence that about 300 l/s of water percolate along the stream gravelly bed from the Dolasur Bridge to Kaolos. These water losses along a relatively short valley bed interval also indicate good conditions of recharge into the Jurassic karstic aquifers.

- AIA

The outcrops of JKA cover most of the Galal valley watershed. The Galal valley is dry most days of the year. Ephemeral flows in this valley occur after exceptionally intense rainfalls. This fact suggests that the underground drainage of the Galal watershed prevails. In other words, the karstic aquifers are fairly replenished.

The AIA are partially recharged, as already stated, by the underflow from the Jurassic karstic aquifers. In addition, ground water recharge of the alluvium aquifer may take place in two ways: infiltration from precipitation and percolation of the Chaqan stream flow.

Since the uppermost portion of the alluvium deposits represents the silty and clayey materials, direct infiltration of rain into this aquifer is relatively limited. Moreover, the main water-bearing beds of the AIA aquifer, occurring at relatively great depth, can be recharged from infiltration of precipitation only in the upstream (Northern) part of the aquifer. The downstream part of the aquifer is under certain artesian head, so that the infiltrated water is kept in the overlying low permeable clayey-silty sediments. The artesian head most probably exists in the isolated buried channel deposits and coarse alluvial fans.

Thus, direct infiltration of water from precipitation is probably a secondary source of the aquifer recharge. Much more important recharge into the AIA aquifer comes from percolation of the Chaqan stream flow.

Evidence obtained from the hydro metrological study shows that an average percolation rate of the Chaqan valley flow, from the Kaolos gorge to the Said Sadiq, amounts to 1.0 m^3/s, (Energoprojekt, 1980). This means that channel deposits of the Chaqan valley and its branch Surajo valley provide good conditions for the alluvial aquifer recharge. The channel coarse deposits are connected with the main water-bearing beds of these aquifers.

- CFA

The Qulqula Radiolarian Formation is composed mainly of chert, marls, siliceous shale and limestone. The joints and fractures act as the most possible route of infiltration of rainfall and snow melting, through which recharging of shallow perched aquifers takes place. This recharge amount forms source of small springs in the Chaqan and Chawtan valleys. The area covered by this formation in this sub-basin is estimated to be 41 km^2.

4.5.4. Groundwater recharge of Halabja-Khurmal Sub-basin (SB4)

- CKFA

The southeastern and northeastern boundaries of this sub-basin are surrounded by the Avroman and Shinrawe – Balambo mountains which are covered by TKA and CKFA respectively. Part of TKA, as a recharging area and aquifer of Zalim spring, is located inside Iran (Fig.3.22). Due to intense tectonic deformation, these rocks act as an excellent recharging area. Because of the great differences in the elevation of the hinterland and the Halabja-Khurmal plain area, the snow is the most frequent form of precipitation during the winter season. Gradual melting is considered the main source to supply the karstic aquifer’s reserves. Unfortunately, there are no snow-measuring stations in the area.

The area occupied by these rocks inside Iraq is measured to be 100 km^2 for CKFA and 65 km^2 for TKA.

Table 4.11 Intermittent discharge measurements for seasonal streams in SB3

Date of measurement of both discharge and daily rainfall with cumulative rainfall			Discharge, m^3/s (upstream and down stream sections) Stream or valley name+					
			Chaqan		Surajo		Galal	
Date	(1) P mm	(2) ∑P mm	U.S	D.S.	U.S	D.S.	U.S.	D.S.
			Catchment area, Km^2					
			250	270	18	34	76	132
24.11.2004	36.7	113.0	0.86	0.40	0.24	0.1	0	0
12.12.2004	38.6	154.6	0.92	0.40	0.46	0.11	0.21	0
25.12.2004	23.8	180.7	0.95	0.38	0.49	0.12	0.35	0
26.12.2004	17.6	180.7	0.87	0.40	0.42	0.13	0.36	0
17.01.2005	17.0	230.8	1.12	0.54	0.45	0.12	0.43	0.105
18.01.2005	32.9	246.7	1.13	0.6	0.43	0.13	0.44	0.094
23.01.2005	49.3	296.4	1.17	0.65	0.55	0.15	0.54	0.095
05.02.2005	41.1	357.9	1.24	0.78	0.57	0.20	0.61	0.145
06.02.2005	25.6	374.1	1.34	0.86	0.66	0.26	0.68	0.145
10.02.2005	20.2	406.1	1.61	0.84	0.72	0.21	0.74	0.19
21.02.2005	19.4	427.8	1.88	1.11	0.70	0.24	0.86	0.19
22.02.2005	8.4	427.8	2.0	1.19	0.74	0.33	0.73	0.18
04.03.2005	31.8	459.6	2.05	1.07	0.85	0.31	0.74	0.19
05.03.2005	31.2	462.7	1.94	1.09	0.80	0.28	0.66	0.37
10.03.2005	101.1	572.1	37.7	36.3	1.96	1.15	4.32	1.32
11.03.2005	71.3	572.4	5.45	4.23	1.06	0.55	3.6	1.92
12.03.2005	0.3	572.4	3.15	2.4	0.87	0.43	0.43	0.16
07.04.2005	0	572.4	1.05	0.46	0.21	0.06	0.08	0.09
15.04.2005	26	598.4	0.88	0.23	0.105	0.05	0.04	0.07
26.04.2005	29.6	628.0	0.65	0.15	0.054	0.02	0	0.04
03.05.2005	0	628.0	0.45	0.02	0.031	0.01	0	0
20.05.2005	0	628.0	0.45	0.012	0.012	0.004	0	0
Mean			3.13	2.45	0.56	0.22	0.72	0.24
Average loss			0.68		0.34		0.48	

+The sections of measurements are shown in annex2.

(1) rainfall in the day or the day before stream discharge measurement

(2) cumulative rainfall .

Table 4.12 Estimated annual groundwater recharge for SB3

Type of aquifer	*Area Km²*	*CN-value*	*%Re*	*Re mm*	*Re x10⁶ m³/year*	*Source of recharge*
CKFA	188.7	60	56.6	441.7	83.3	Direct infiltration
JKA	57.2	45	69.6	543	31.0	
TKA	35.1 + 100*	45	69.6	543	73.3	
Sub-total					187.6	
AIA	87.8	60	53.8	399	35.0	Direct infiltration
	135	78	27.1	201	27.1	
				1.02 (m³/sec) x 210days	18.5	Percolation from Chaqan ,Surajo and others
				0.48 (m³/sec) X210days	8.7	Subsurface recharge from Jurassic karstic channels
	Sub-total				89.3	
CFA	41.1	85	5.5	41	1.7	Direct infiltration
	Sub-Total				1.7	
	Total annual recharge of SB3				270	

- AIA

Due the heterogeneity of the alluvial deposits in the plain of the Halabja –Khurmal area, AIA are divided according to their constituents, texture and infiltration capacities: areas with high infiltration ratio, moderate-infiltration ratio and low infiltration ratio. In most parts of the low infiltration capacities of the plains the absorbed water or the stagnant waters are returned as evapotranspiration output, so no surface runoff could be calculated. Percolation of water from the valleys draining the plains from the surrounding mountains is another recharging source of alluvial aquifers. The main valleys supplying these aquifers with water are Darashesh, Zamaki, Khazena, Hasan Awa, Biara, Khakelan and the main Zalm stream. The average cumulative contributing amount from these valleys is estimated to be 0.13 m^3/s from November to mid-May each year.

- CFA

Qulqula radiolarian packages of chert, marl, shale and siliceous limestone comprise some patches, and parts of the Avroman, and Bafre Mere Mountains surround Khurmal, Bakhakon, Sargat, Biara and Khakelan villages. The Chert packages, in most cases, are underlain by shale or marl which make suitable stratigraphic conditions for numerous perched aquifers in both SB3 and SB4. The infiltration of rainfall or snow melting recharges the limited depth of these rocks and flows through the underground for a short distance until discharging as small springs, depressions or contact springs. The surface area of these rocks is estimated to equal 131Km^2.

4.6. Aquifer discharge

Three kinds of drainage characterise aquifers in the study basin:

1. Drainage through springs
2. Subsurface drainage
3. Artificial drainage by pumping the wells

4.6.1. Aquifer discharge through springs

Spring discharge represents the main groundwater outflow, especially in the case of karstic and karstic-fissured aquifers of JKA, CKFA and TKA.

A variety of factors influenced the emergence of springs at particular locations, for example the location of water bearing layers and impermeable rocks, and the presence and distribution of tectonic elements. Moreover, climatic conditions and resources of the aquifer system actually dictate the amount of water discharged through outlet points (Stevanovic and Iurkiewicz, 2004).

Table 4.10 Intermittent discharge measurement of some seasonal streams in SB4

Date of measurement of both discharge and daily rainfall with cumulative rainfall			Discharge, m^3/s (upstream and down stream sections) Stream or valley name+							
			Darashesh		Zamaki +Khazena		Biara+ Khargellan		Hasanawa	
Date	(1) P mm	(2) ∑P mm	U.S	D.S.	U.S	D.S.	U.S.	D.S.	U.S.	D.S.
			Catchment area, Km^2							
			8	18	40	53	42	56	18	27
24.11.2004	36.7	113.0	0.02	0.012	0.008	0	0.016	0.010	0.004	0
12.12.2004	38.6	154.6	0.04	0.027	0.011	0.005	0.035	0.023	0.009	0
25.12.2004	23.8	180.7	0.045	0.033	0.013	0.008	0.052	0.046	-	-
26.12.2004	17.6	180.7	0.045	0.035	--	--			-	-
17.01.2005	17.0	230.8	0.065	0.058	--	--	0.086	0.077	0.025	0.013
18.01.2005	32.9	246.7	0.082	0.077	0.086	0.034			-	-
23.01.2005	49.3	296.4	0.10	0.091	0.116	0.045	0.125	0.098	-	-
05.02.2005	41.1	357.9	0.130	0.117	0.143	0.108	0.174	0.134	0.060	0.045
06.02.2005	25.6	374.1	0.223	0.206	--	--	0.253	0.227	0.075	0.055
10.02.2005	20.2	406.1	0.265	0.244	0.298	0.221	-	-		
21.02.2005	19.4	427.8	0.233	0.211	--	--	-	-	0.093	0.079
22.02.2005	8.4	427.8	-	-	0.276	0.200	0.276	0.245	--	--
04.03.2005	31.8	459.6	0.382	0.362	--	--	-	-	0.096	0.084
05.03.2005	31.2	462.7			0.290	0.230	0.318	0.294	-	-
10.03.2005	101.1	572.1	-	-	--	--	-	-	--	-
11.03.2005	71.3	572.4	1.211	1.190	1.05	1.01	1.406	1.370	0.650	0.530
12.03.2005	0.3	572.4	0.890	0.800	0.760	0.730	1.00	0.86	-	-
07.04.2005	0	572.4	0.405	0.385	-	-	0.538	0.488	0.196	0.120
15.04.2005	26	598.4	0.273	0.213	0.243	0.170	0.421	0.390	--	--
26.04.2005	29.6	628.0	0.119	0.102	-	-	0.304	0.237	0.038	0.009
03.05.2005	0	628.0	0.102	0.078	0.07	0.022	0.204	0.166	0.011	0
20.05.2005	0	628.0	0.054	0.034	0.028	0	0.094	0.050	0.005	0
Mean			0.24	0.22	0.24	0.20	0.33	0.29	0.10	0.07
Average losses			0.02		0.04		0.04		0.03	

+The sections of measurements are shown in annex 2.

(1) Rainfall in the day or the day before stream discharge measurement

(2) Cumulative rainfall.

Table 4.14 Estimated annual groundwater recharge for SB4.

Type of aquifer	*Area Km²*	*Proposed CN-value*	*%Re*	*Re mm*	*Re x10⁶ m³/year*	*Source of recharge*
TKA	65.5+ 100*	45	69.6	543	89.8	Direct infiltration
CKFA	100+40*	60	56.6	441.7	61.8	
	Sub- total				151.6	
AIA	108.4	78	27.1	201	21.8	Direct infiltration
	81.6	60	53.8	399	32.5	
				0.13 m^3/sec X 210 days	2.7	Percolation from connecting streams
	Sub-total				57	
CFA	131.7	85	5.5	41	5.4	Direct infiltration
	Sub-total				5.4	
	Total annual recharge of SB4				214	

Refers to areas locating out side defined surface boundary.

Numerous diffuse or concentrated springs with highly varying discharge have been registered in this region. The springs registered in the basin and in the present study are categorized according to their discharge values and geologic settings into:

1. Large karstic and karstic-fissured springs; includes those springs with minimum discharge varying between 500 l/s - >2000 l/s. TKA, JKA and CKFA comprise their main aquifers. Sarchinar, Bestansur, Saraw group, Reshen and Zalm springs are categorized under this group.

2. Medium discharge karstic-fissured springs, with a discharge magnitude varying between 100 l/s and <2000 l/s, such as Kani Panka, Greza, Shiramar, Said Sadiq, Sargat Jomarase and Bawa Kochak.

3. Low discharge springs, which cluster all the springs with very low discharge rate during recession periods; they reach less than 0.1 l/s and maximum discharge sometimes exceeds 500 l/s. A relatively large number of springs in this category occur in the studied area with different geological settings. They can be classified as the following:

a) Those discharging from CFA, covering a great number of springs appearing either under structural control or contact springs by topography. Examples of these springs are Biara, Dola Chawt, Qolitan, Chawtan, Dekon, Dolasmt, Kani Askan, Khurmal, Kani Spika, Tarantawa etc.

b) Those discharging from TAT. The Tanjero Formation covers a large area around Sulaimani and Arbat. Examples of these springs are Hanarani Khwaroo, Fayal, Kani Bardena, Karezi Shakraw, and Karezi Sarchawa around Sulaimani and Damirkan in the Arbat area.

c) Those issuing from SDA which mostly occupy the area comprising the south and southwest extending to the south eastern divide of the basin along Baranan homocline as far as Shafa Rash and the Bardakar Mountain piedmont. The discharge of these springs is variable from as low as 0.1 l/s to 400 l/s. Examples of these springs are Derasha, Taparash, Qazan, Dawooblagh, Hazarmerd, Zergoez, Kanishaswr, Dara agha, etc.

d) Those issuing from AIA. These types of springs are spread over the area of the basin around Sulaimani, Said Sadiq, Arbat and Khurmal.

e) A small number of springs, which emerge from Balambo rocks north and northeast of Sulaimani and Arbat, such as Azmer Spring, Weladar springs, etc., also exist. As well, small springs which emerge and accompany the large springs also come under this category, such as those appearing near Zalim spring or near Sarchinar, and Reshen springs.

Due to the great economic importance of the first category in terms of irrigation and city water supply, extra attention was paid to these springs. Their daily discharge was directly measured from the 1st Oct. 2004 to the end of June 2006. In the next section the mechanism of the flow of these karstic springs is discussed based on time series analysis and spectral Fourier analysis. In addition, the dynamic reserves of these springs are estimated based on the Mailet equation for the recession portion of the spring hydrographs.

Spring discharge flow regime

Karst aquifers are characterized by high heterogeneity, discontinuity and the spatial variability of hydrogeological parameters (Jemcov et al, 1998). Therefore, it is necessary to point to the duality of karst (Kiraily, 1995), especially the duality of the groundwater flow (White 1969, Atkinson 1997). The first represents the channel-networks of great transmissibility and the second consists of voluminous media with poor permeability in block matrixes. The presence of this duality causes a widely known phenomenon named “inversion hydraulic gradient” (Drogue, 1980). Therefore, it is very important to establish the relationship between those two types of interconnected flows, because they provide valuable information about storage capacity, an essential parameter for groundwater management. Its determination is not an easy task, thus, analysis of spring hydrographs could provide valuable indirect information on the structure of karst hydrogeological system. (Mangin 1988, Bonacci 1993, Kresic 2007). Geomorphology and geologic fabric (rock type and tectonic features such as folds and faults) play the key role in the emergence of springs (Kresic, 2007).

- Sarchinar spring

This spring is among the largest in the studied area located in the SB1 and supplies water to Sulaimani city during winter and spring (Fig.4.42). CKFA comprises the main aquifer feeding this spring. The flow regime of this spring has been studied in detail by Ali et al. (2007) depending on the monitoring of the daily discharge measurements with the aid of rainfall data from the Sulaimani metrological station for the years 2003 and 2004. As an initial step in the characterization of a karst aquifer, the results of auto-correlation, cross-correlation and spectral density should be taken into consideration (Jemcov, 2007).

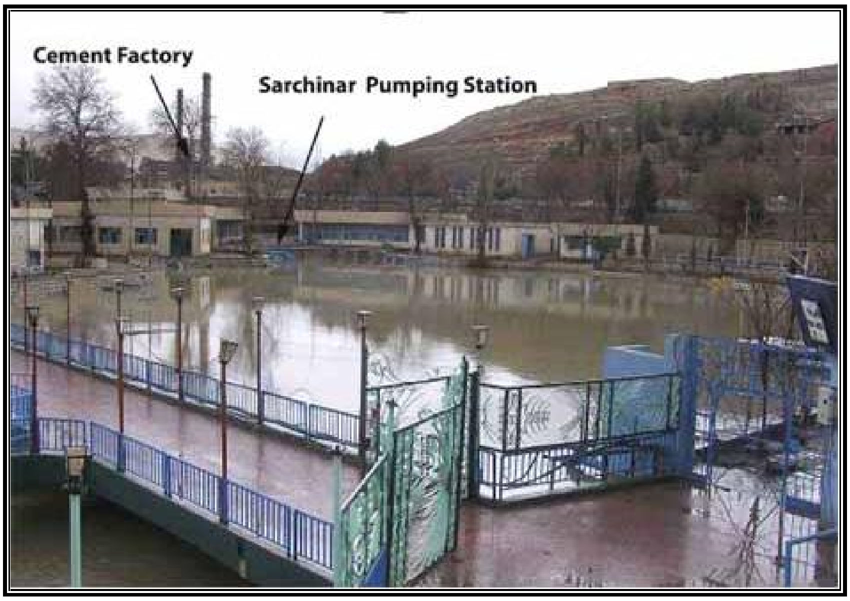

Fig. 4.32 Sarchinar spring intake, May 2005.

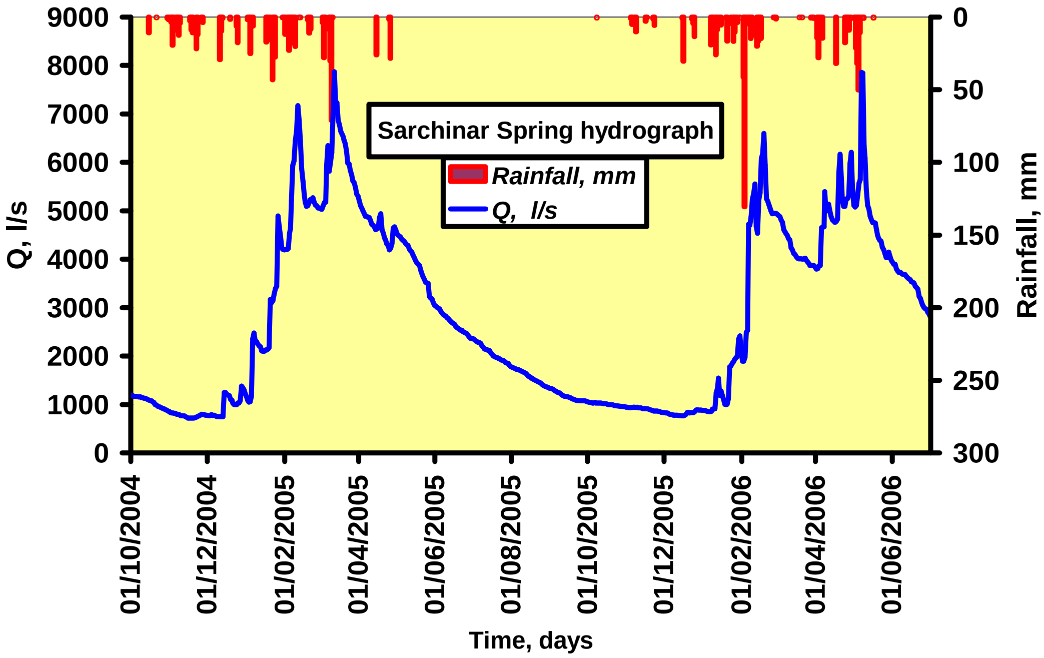

Fig. 4.33 Sarchinar spring hydrograph for the period Oct. 2004 - July2006

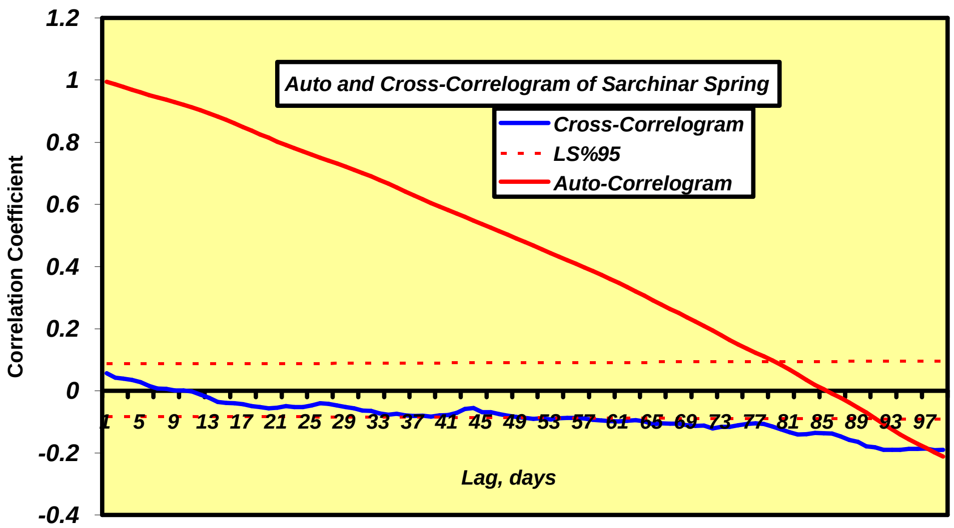

Fig.4.34 Auto and cross – Correlogram of Sarchinar spring, Oct. 2004 – July 2006.

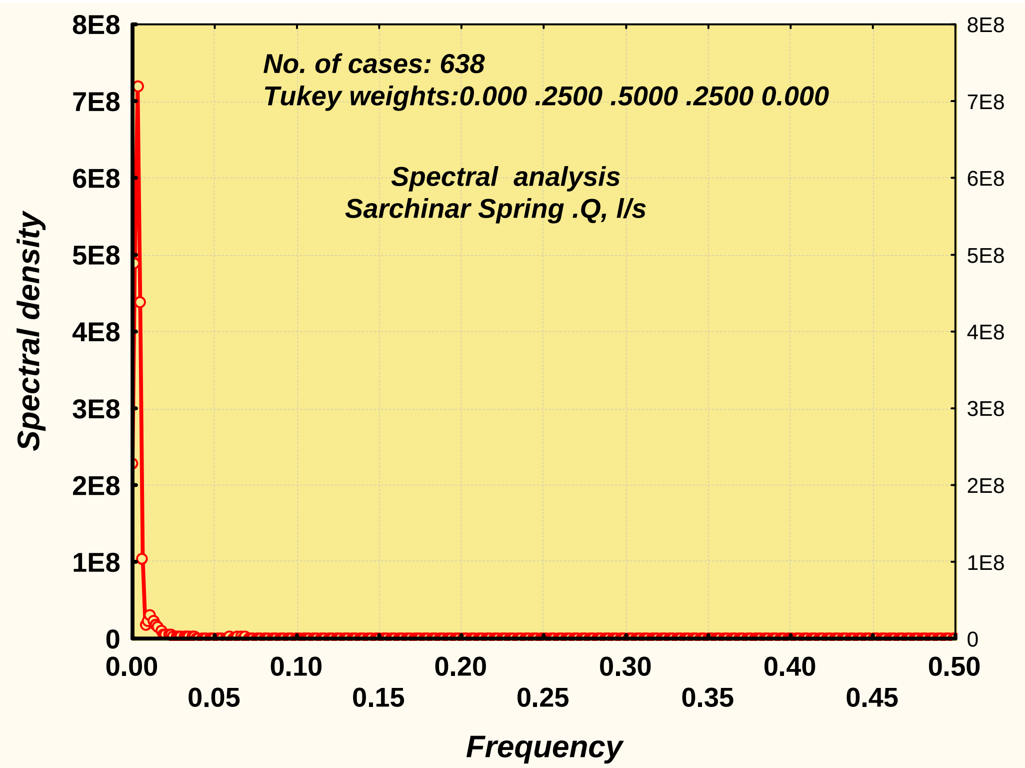

Fig.4.35 Spectral density analysis of Sarchinar spring, Oct. 2004 – July 2006.

According to such analysis applied in the case of the Sarchinar hydrograph for the years 2004-2006 (Fig.4.33), the auto-correlogram of discharges rates of the spring exceeds the confidence limits for approximately 79 days (Fig.4.34). This implies that aquifer storage is significant and that it releases water gradually. Also, the very slow decline of the auto-correlogram shows a relatively stable discharge regime, conditioned by the limited dimensions of the karst channel. The system reacts to rainfall events with a delay of 2-3 days, representing the minimum travel time for the recharging inputs (Fig.4.34).

Cross-correlogram for the spring flow and precipitation shows a very minor level of significance from 2 to 10 days, but after that is insignificant. Low cross-correlation values show that the influence of infiltration is significantly attenuated by the karst hydrogeological system.

Table 4-15 Characteristic data recorded for Sarchinar spring

Spring Name	Q max (l/s)	Qmin (l/s)	Qav (l/s)	Qmax/Qmin
Sarchinar	**7875**	**715**	**2812**	**11.0**

Altogether, the analysis shows a large storage capacity for the Sarchinar aquifer. Water is stored within this karst hydrogeological system during the recharge period and is later slowly released during the dry season. Dynamic resources are the consequence of small fissures and matrix porosity (slow subsequent water release following de-saturation of larger fractures) as well as the large subsurface reservoir extending from the Piramagroon anticline towards the outlet.

The spectral density function of the spring discharges shows high peaks at a low frequency of 0.003135 (319 days), which confirms the presence of an annual cycle (Fig.4.35). Considerable peaks at the frequencies (from about 212 and 159 days) show the seasonal cycle of the spring. Peaks at the middle frequencies (from about 40 days), show relatively low densities; as well, at high frequencies even the low density does not exist. This analysis confirms that the Sarchinar spring is characterized by seasonal recharge and discharge cyclicity.

Application of Mailet recession coefficient

This method provides an assessment of the dynamic and static volume of resources stored or in transit within the aquifer throughout the hydrologic year, and during the recession period in particular (Stevanovic and Iurkiewicz, 2004).

Spring hydrograph recession curves may be used to define the degree of karstification and conduit/diffuse flow regimes in karst aquifers (Samani, 2001). Application of the recession coefficient method was attempted for the Sarchinar spring and based on the spring hydrograph recorded during October 2004 until the end of June 2006. By using the Mailet recession curve, two recession coefficients were obtained.

Considering that the second recession coefficient $\alpha 2$ characterizes a very slow drainage through the well-karstified and rich aquifer of Piramagroon-Azmer Mountains, it was inferred that the complete exhaustion of the dynamic resources of the Sarchinar reservoir, estimated to be about 37.58×10^6 m^3 (1.19 m^3/s), would theoretically enable a period of almost four years for the aquifer to be exhausted without any additional recharge.

The first recession period starts with a decrease in discharge of the spring and coincides directly with the time after the last period when rainwater and snowmelt have been infiltrated into the aquifer. During this period, the groundwater level is relatively high, and due to the steep hydraulic gradient, water discharges at a higher rate. The second recession period coincides with the dry season when no recharge from rain or snowmelt occurs. Even though the recession coefficients are smaller for the second recession period than the first, the differences are not significant (Fig.4.36).

The relatively intense jointing of limestone layers has resulted in a dense network of pores, small fissures, and joints that have inhibited the development of large conduits. The differences between the first and second recession coefficients could be related to the hydraulic behavior of the aquifer system and the ability of the porous media to retain water.

These differences in the first and second recession coefficients ($\alpha 1$ and $\alpha 2$) are not due to the type of flow. The slightly higher discharge gradient during $\alpha 1$ period is caused by the slower rate of the water table level drop (Raeisi and Karimi, 1997). This slower drop during the first recession period may be explained first, by a continuous recharge from rainfall and snowmelt; and second, by rapid drainage through larger fissures and pores of the vadose zone (Raeisi and Karimi, 1997).

Zurawska (2003) attributed the bipartite pattern of the recession curves to the existence of two probable reservoirs recharging each spring, one locally and the other, regionally. Both the local and the regional contributions exhibit a steeper recession curve, while the regional, resulting to the gentle slope, indicates the existence of two reservoirs recharging each spring--a local and a regional one.

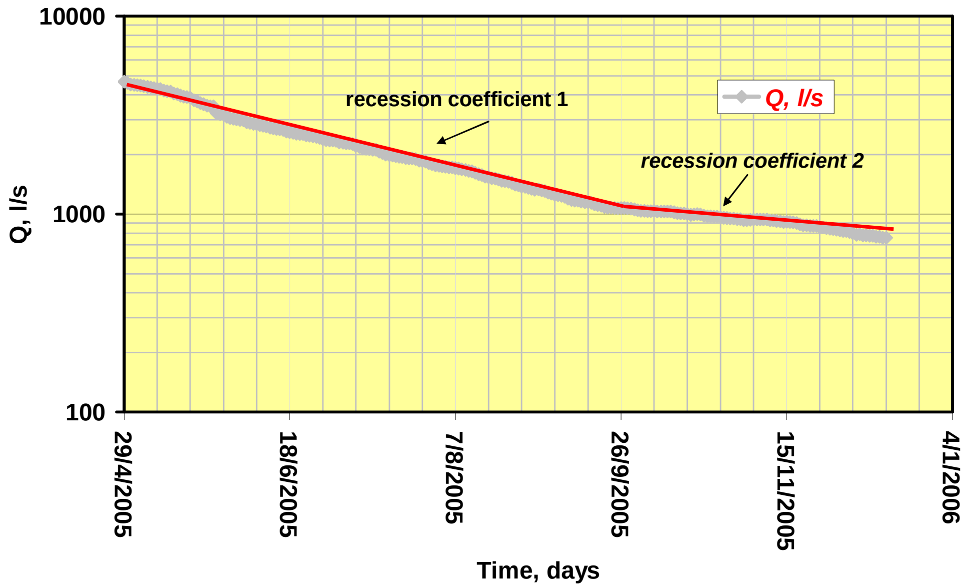

Fig.4.36 Recession coefficient of Sarchinar spring discharge.

Table 4.16 Recession coefficients and dynamic reserves of Sarchinar spring.

Spring Name	α_1	α_2	***V total*** $x\,10^6\ m^3$
Sarchinar	**0.009 Per 147 days**	**0.0042 Per 83 days**	**37.53 Per 230 days**

The two values of recession coefficient obtained for Sarchinar Spring relatively coincide with the pattern of the first and third categories of Komac's (2001) suggestion, but with a lesser coefficient. The first recession coefficient is at the level of 10^{-1}, while the second recession coefficient is at the level of 10^{-3}. For (α1), the recession is fastest when water flows through conduits and large fissures. The lower value of the second recession (α2) reflects a dispersed flow through fractures, fissures and narrow passages but under high hydrostatic pressure (Komac, 2001). Accordingly, the first recession coefficient could be connected to conduits and large fissures, but with a lower degree of development than that of the Komac concept.

Under normal conditions, water flows through different passages at the same time. The ratio between different types of passages depends on the hydrostatic pressure and it is thus connected to the changes of the piezometeric level and quantity of water left in the system. Conduit flow dominates and water reserves empty proportionally faster at the beginning of the recession. After some time (days), dispersed flow prevails over conduit flow, and the discharge slowly and asymptotically approaches the zero value (Komac, 2001).

- Saraw springs system

This large spring consists of three smaller springs named Sarchawi Saraw, Qalabo and Qurena. This group of springs is recharged by infiltration through Cretaceous limestone and Jurassic limestone outcrops. CKFA and JKA are the main draining aquifers of these springs all of which have vauclusian (artesian) character.

The three springs are most probably controlled by the outlets of the same karstic system (Figs.4.37, 4.38 and 4.39) named the Saraw-Galal system by Stevanovic and Iurkiewicz (2004), due to the hydraulic connection of these springs with karstic rocks of Jurassic age in the Galal valley. During the three years of drought (1999, 2000 and 2001), one of the springs dried up. This one, which is located at a few metres higher elevation than the others, is called Sarchaway Saraw. It suddenly became active after the heavy rains at the end of December 2001 (Stevanovic and Iurkiewicz, 2004). The sudden activity of the spring increasing in one day from 50 to 600 - 700 l/s validates the hypothesis of an overflow spring draining the same karst system regularly discharged through accidental springs of Qalabo, and probably Qurena located in its close vicinity.

The large discharge and fluctuations, when the spring recovered after two years of drought, are the result of the fast component of recharge transferred to the flooded zone of the aquifer. The spring returned to its normal capacity during March, 2002 with top discharges at the end of April, 2002.

Figs. 4.40, 4.42 and 4.43 show the hydrograph of the three springs forming the Saraw-Galal system, based on the daily discharge measurements from October 2004 until the end of June 2006.

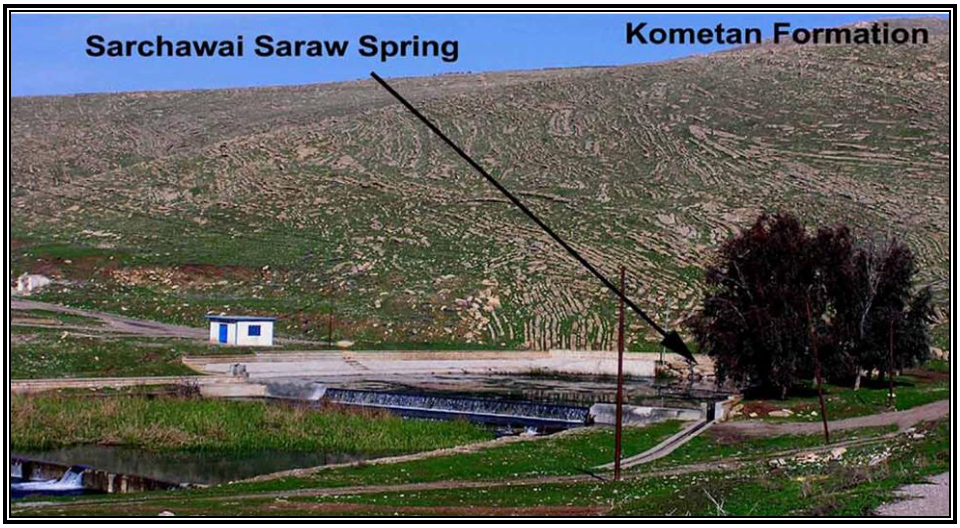

Fig.4.37 Sarchawai Saraw spring, May 2005.

Fig.4.38 Qalabo spring outlet, Feb. 2007.

It is clear from the hydrograph that the three springs react similarly to rainfall events. The flooding of the reservoir starts with a sudden increase in the reserve due to the transfer of water from the JKA and CKFA which constitutes the main recharge sources.

For a more understandable description of the flow mechanism of this system, auto-cross regression analysis is performed. Auto-correlational and cross-correlational analysis gives insight into the structure of the karst system, characteristics of the discharge regime, and discharge rate (Kresic, 1991). Auto-correlogram and cross-correlogram were made daily for a period of 99 days..

Fig.4.39 Qurena spring, Feb.2007.

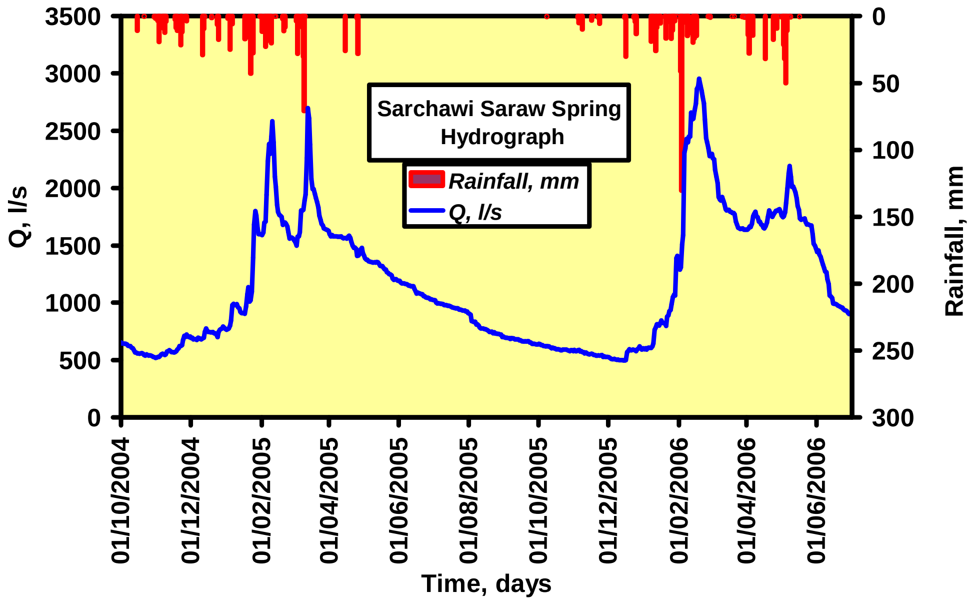

Fig.4.40 Sarchawai Saraw spring hydrograph for the period Oct 2004 – July 2006.

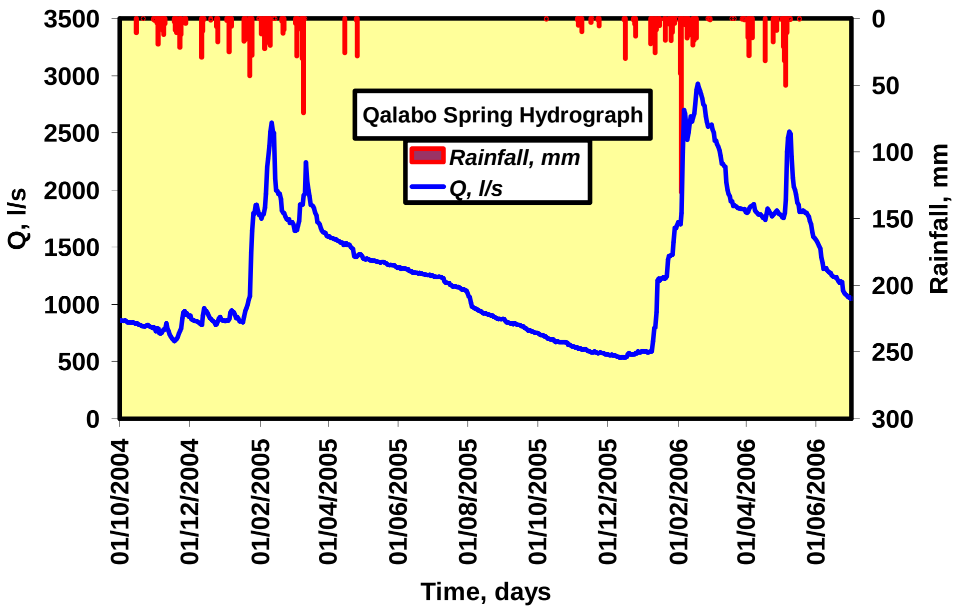

Fig.4.41 Qalabo spring hydrograph for the period Oct 2004 – July 2006.

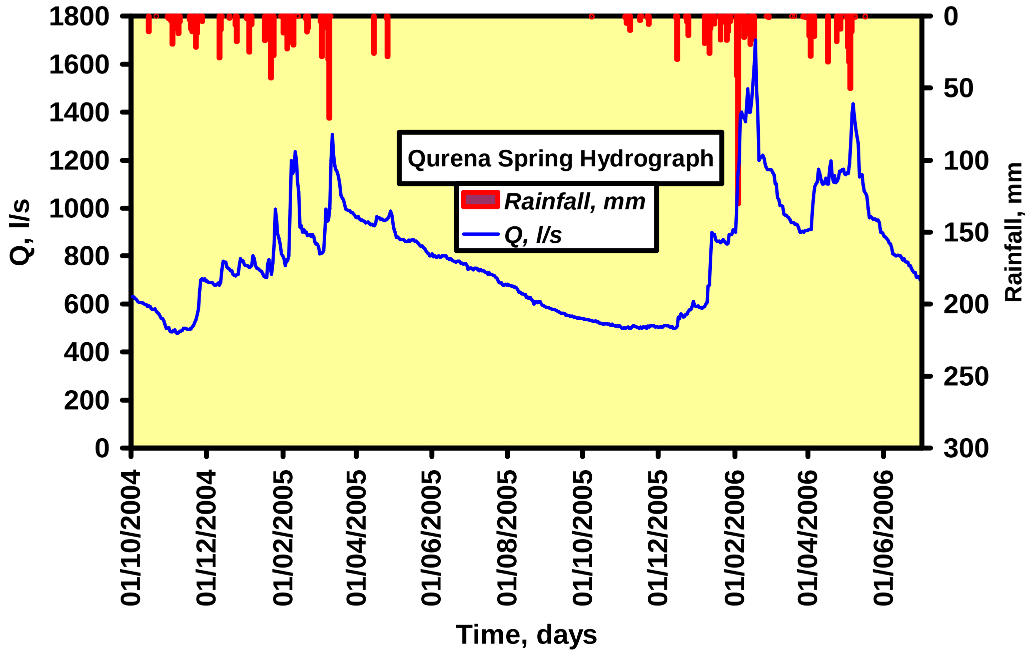

Fig.4.42 Qurena spring hydrograph for the period Oct 2004 – July 2006

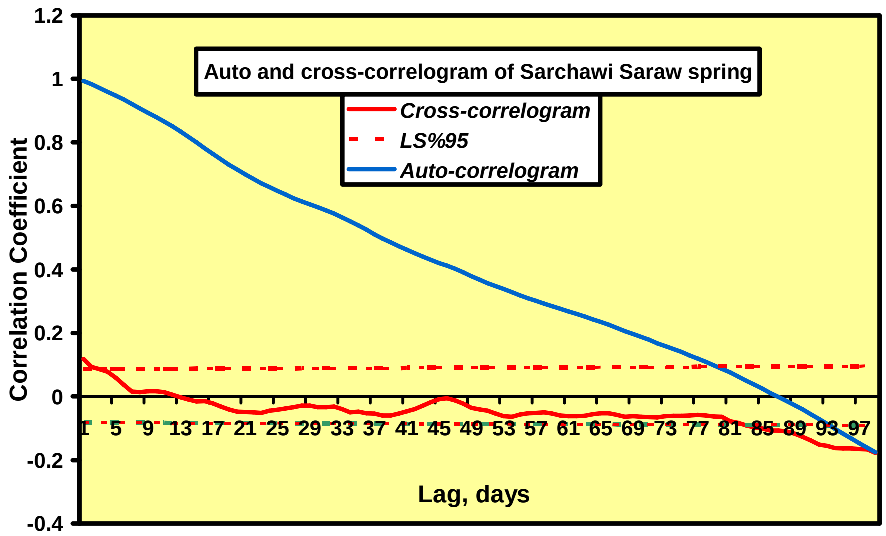

Fig.4.43 Auto and cross – correlogram of Sarchawi Saraw spring, Oct.2004 – July 2006.

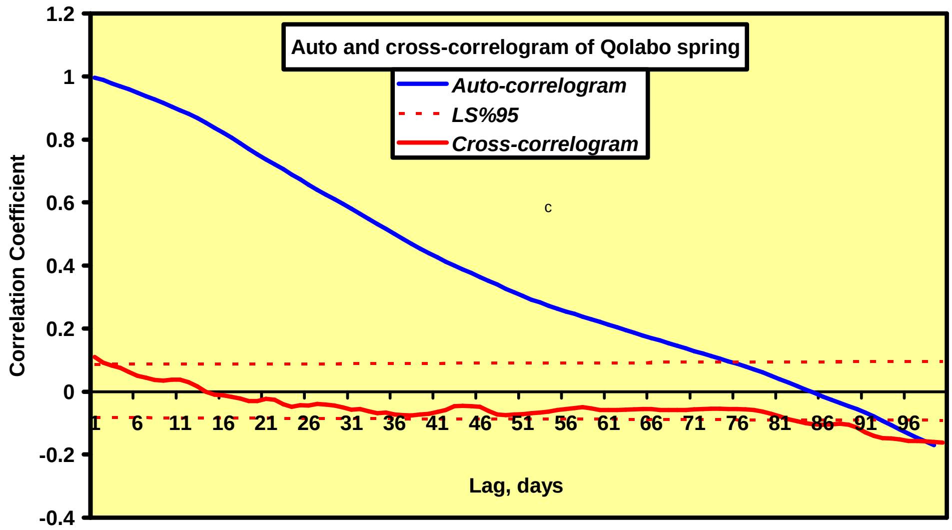

Fig.4.44 Auto and cross – correlogram of Qalabo spring, Oct.2004 – July 2006

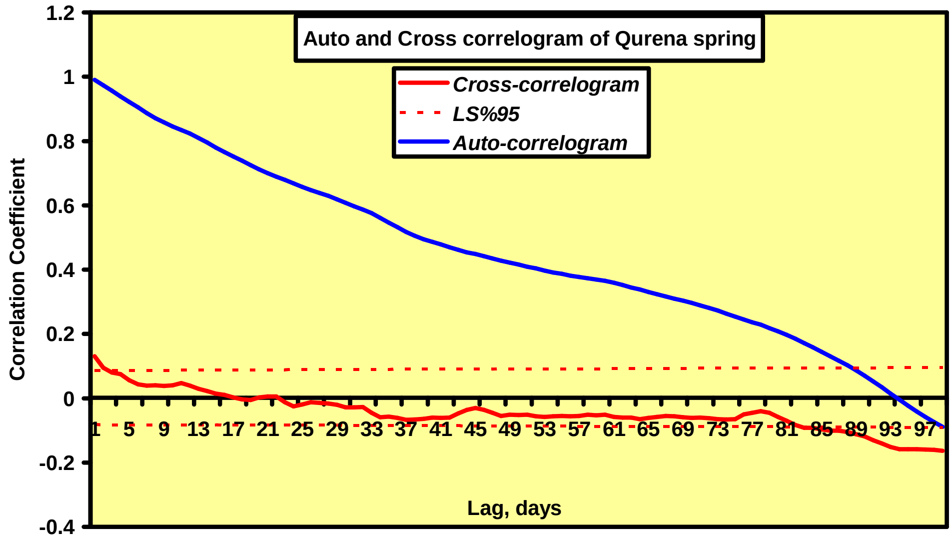

Fig.4.45 Auto and cross – correlogram of Qurena spring, Oct.2004 – July 2006.

From the auto-correlogram of the three springs, Figs. 4.43, 4.44 and 4.45, a high correlation between discharge rates of the springs could be observed with a statistical significance of 80, 75 and 88 days for Sarchawi Saraw, Qalabo and Qurena respectively, which indicates the prevailing role of long term reserves. It is important to mention here that the gentle declining of the auto-correlogram with no inter- subsistence of any peaks during that period indicates a type of homogeneity in the fissured systems (karstic aquifer) with no significant double porosity

The cross-correlogram of the three springs shows an almost similar shape, which again confirms the hydraulic connection and the dominancy of one main source of karstic aquifer for the three springs. The cross-correlogram shows that the stochastic connection between precipitation and discharge rate is weakly synchronized. This confirms dominant discharge through small fissures of the aquifer. Relatively quick response by the discharge to the precipitation was observed in the first few steps. The late reactions of the bigger channels can be forecasted according to the highly significant correlation of the first two days. This correlation is repeated with a descending correlation coefficient throughout the seasonal period, but with less statistical significance.

Table 4.17 Characteristic data recorded for Saraw springs.

Spring name	Q_{max} (l/s)	Q_{min} (l/s)	Q_{av} (l/s)	Q_{max}/Q_{min}
Sarchawi Saraw	2 956	495	1160	5.97
Qalabo	2930	530	1280	5.52
Qurena	1700	477	793	3.56
Total	7586	1502	3233	5.01

Spectral density analyses of the three springs are shown in Figs. 4.46, 4.47, and 4.48. Behavior of the frequency–density curve, similar to that of the Sarchinar spring, is noticeable, which substantiates the annual cyclicity nature of the system.

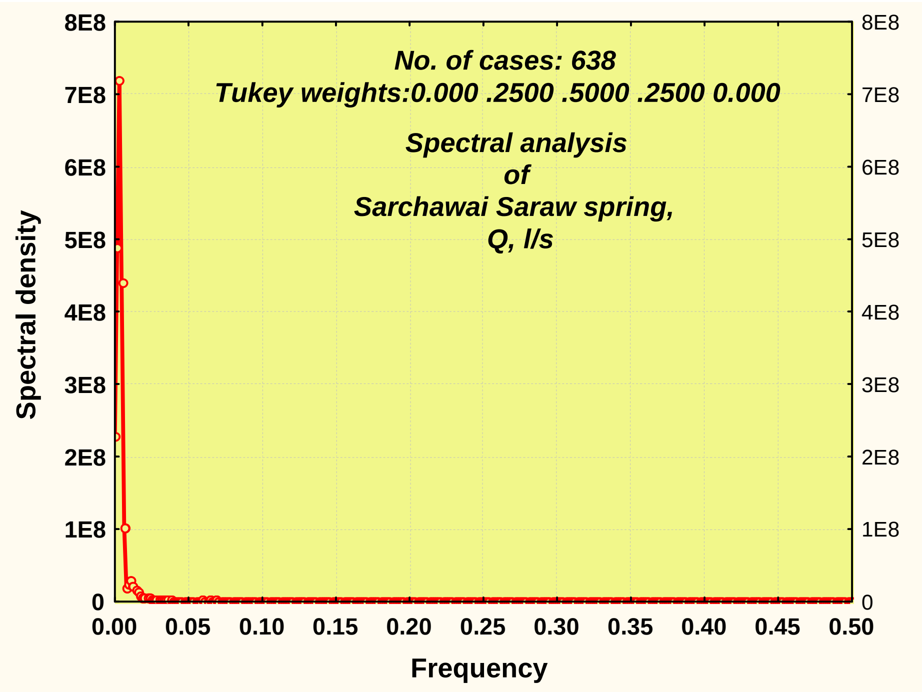

Fig.4.46 Spectral density analysis of Sarchawi Saraw spring, Oct.2004 – July 2006.

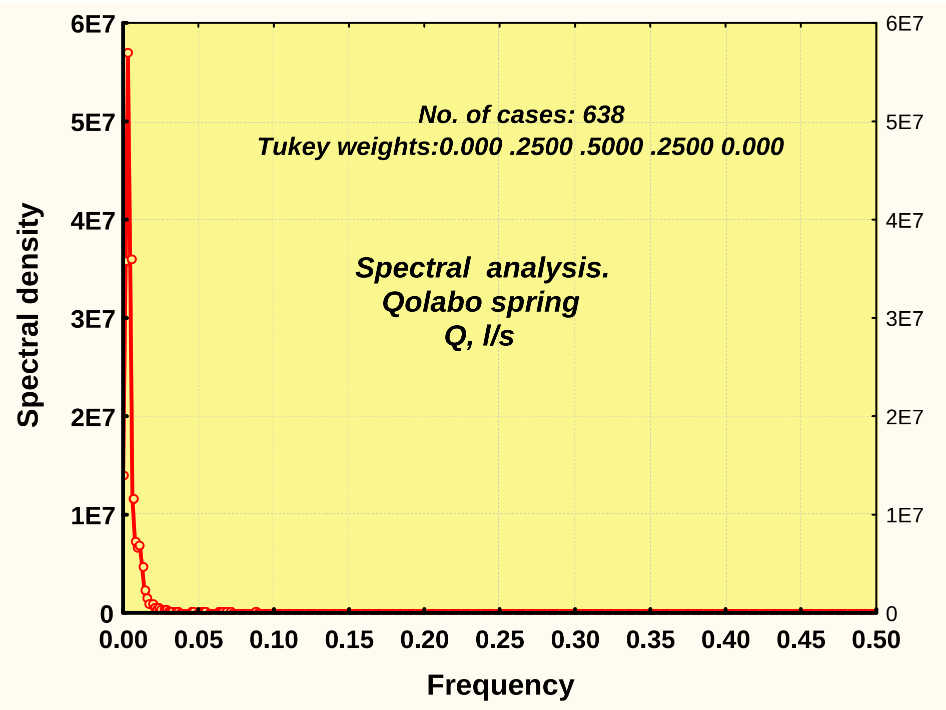

Fig.4.47 Spectral density analysis of Qalabo spring, Oct.2004 – July 2006.

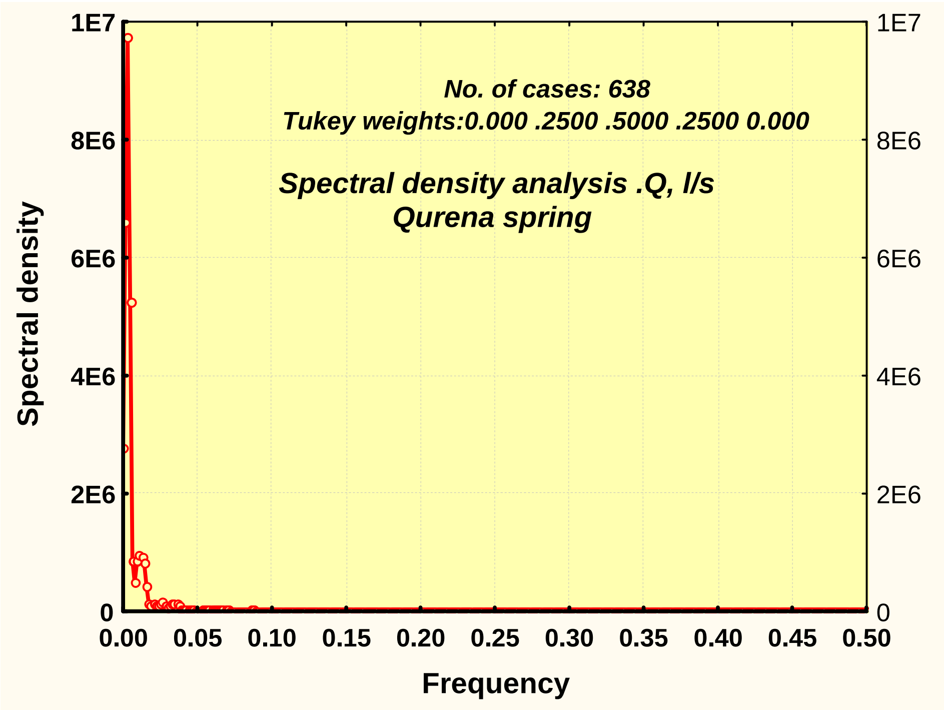

Fig.4.48 Spectral density analysis of Qurena spring, Oct.2004 – July 2006.

Application of Mailet recession coefficient

The three springs react to the rainfall events similarly, and follow a similar way of discharging. Relatively rapid emptying during the end of the wet season with a steep recession curve within an average of 20 days is followed by a gradual gentle discharge of the potential reserve inside the fissures of the aquifer under descending pressure.

The Mailet recession curve from the hydrograph is prepared and recession coefficients have been determined, moreover, the dynamic reserves are estimated based on the Tarisman method, and are shown in the table below (Figs.4.49, 4.50, 4.51). The average total dynamic reserve for the three springs equals 22.1 x 10^6 m^3 per 276.9 days. This is equivalent to 0.92 m^3/s, theoretically meaning that approximately four years are required for the springs to be exhausted totally without any recharge.

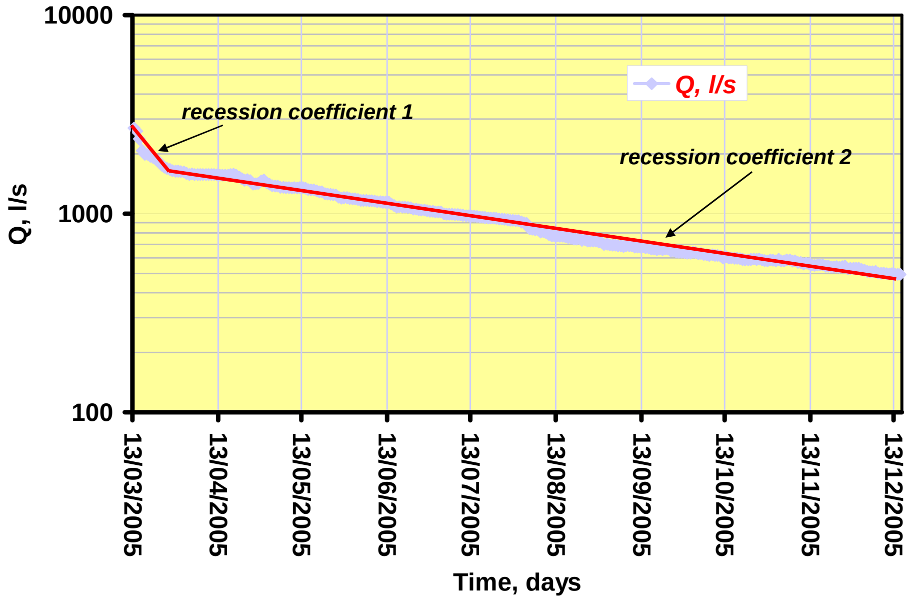

Fig.4.49 Recession coefficient estimation of Sarchawai Saraw spring.

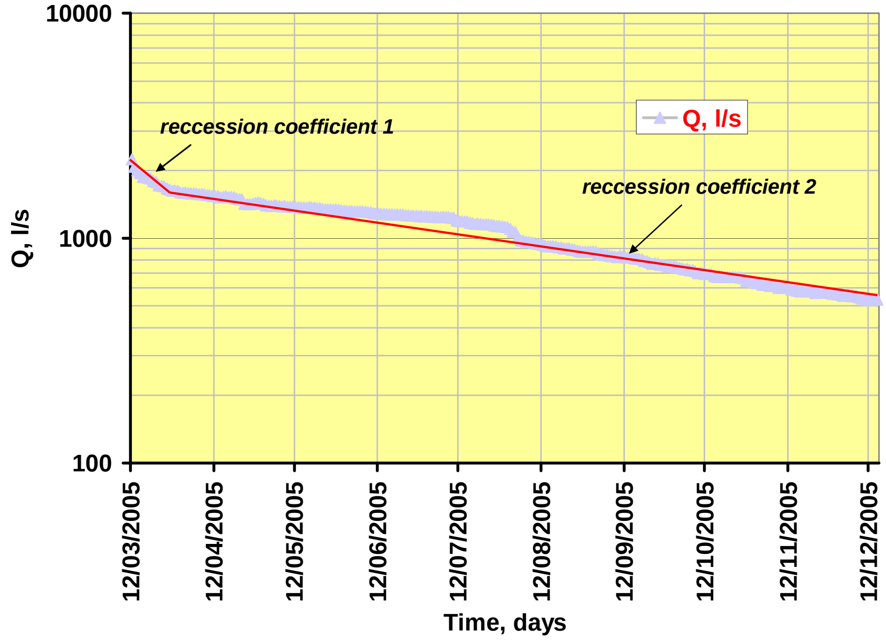

Fig.4.50 Recession coefficient estimation of Qalabo spring.

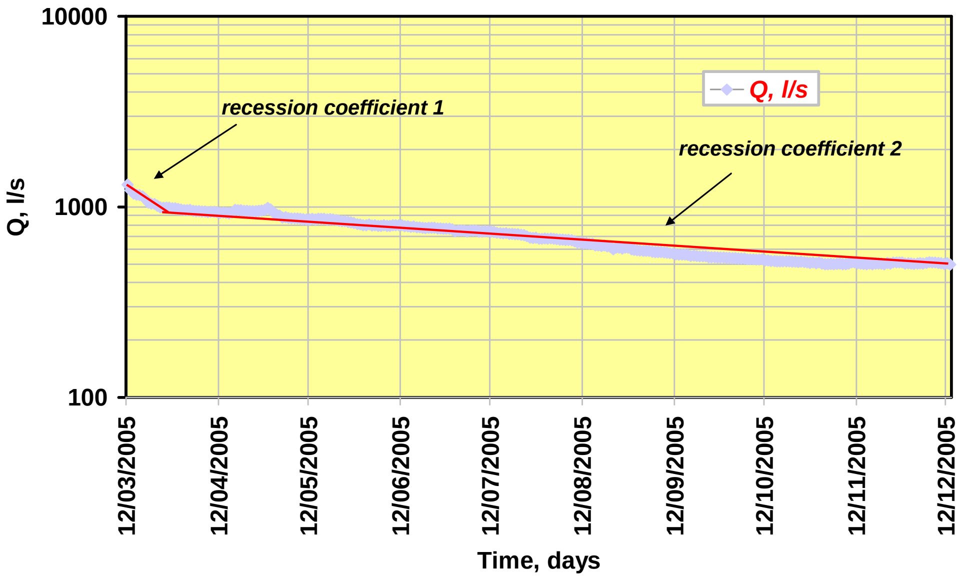

Fig.4.51 Recession coefficient estimation of Qurena spring.

Table 4.18 Recession coefficients and dynamic reserves of Saraw springs.

Spring Name	α_1	α_2	Vtotal $\times 10^6$ m^3
Sarchawi Saraw	0.037 Per 22 days	0.0047 Per 255days	24.1
Qalabo	0.02 Per 16 days	0.0043 Per 262 days	24.65
Qurena	0.023 Per 12 days	0.0026 Per 264 days	17.59
Total	0.026 Per 16.6 days	0.0038 Per 260.3 days	22.1 Per 276.9 days

- Reshen Spring

Reshen Spring pours out from slide debris of the Avroman Formation and it is fed mainly by this formation (TKA). This spring is one of the large karstic aquifers and represents the main source of irrigation for a wider area located to the east and northeast of Said Sadiq town, in the Sharazoor plain. Together with Reshen spring, another smaller spring (Shalm) contributes to the irrigation of the area.

Fig.4.52 Reshen spring, Feb.2003, FAO.

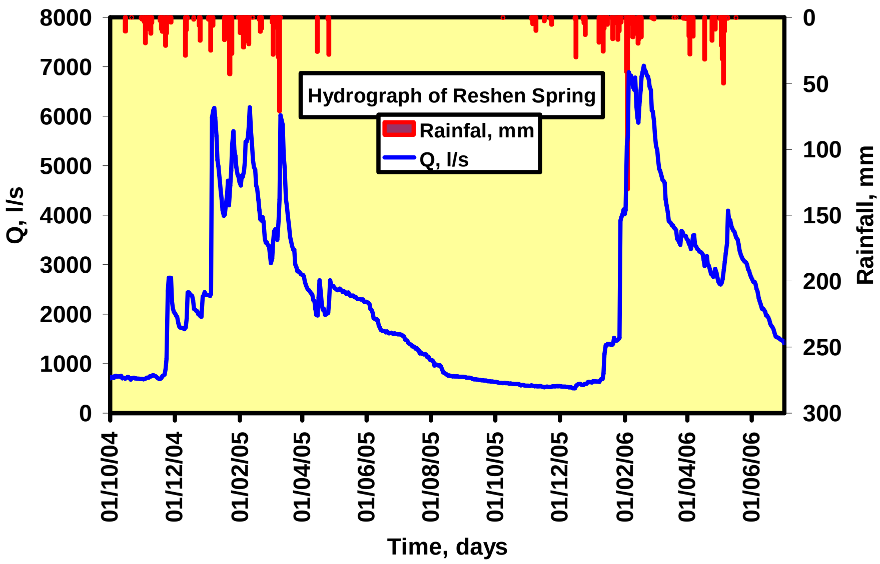

Fig.4.53 Reshen spring hydrograph for the period Oct 2004 – July 2006.

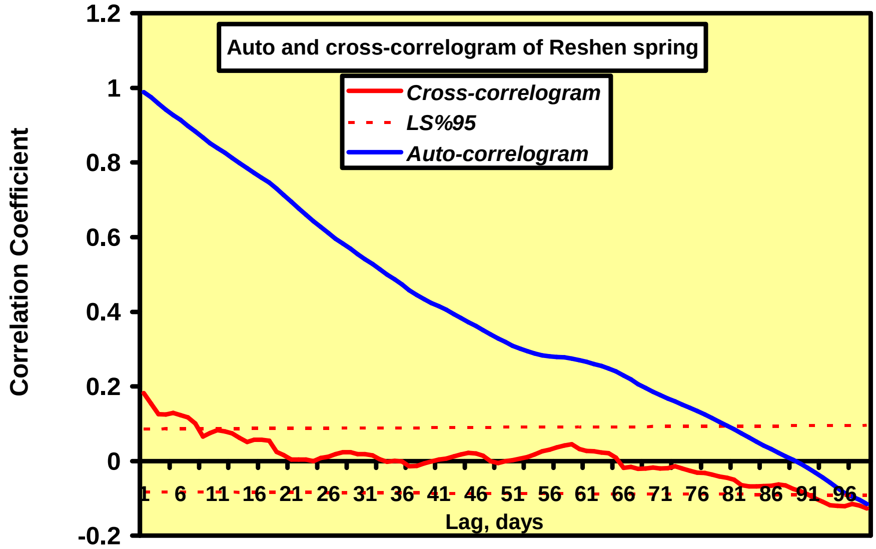

Fig.4.54 Auto and cross – correlogram of Reshen spring, Oct.2004 – July 2006.

As obvious from the hydrograph, this spring, comparable to the other mentioned, is under artesian pressure but with rather more developed karstification characteristics.

The auto-correlogram (Fig.4.54) shows a similar view to that of other previously mentioned springs. High interrelation of the discharge rate with a statistical significance of 80 days is noticeable, meaning that the system has a long memory, and that the aquifer storage is significant and releases water gradually. This may also indicate that the networks of fine fissures are the main constituents of effective porosity

The cross-correlogram shows different information in comparison to the previously mentioned springs. The cross correlation coefficients are statistically insignificant after 9 to11 days, which indicates that antecedent precipitation beyond this period has no direct influence on spring discharge.

Generally low values of the cross-correlogram show that the influence of infiltration from precipitation is significantly attenuated by the porous medium. For all the karstic springs mentioned, sudden reaction of the karst accumulation as a result of newly infiltered water could be considered the main characteristic. The vacillation in the correlation coefficient most likely resulted from the pressure increase as a consequence of ascending precipitation and adding up the karst accumulation.

The spectral density analysis curve (Fig.4.55) shows similar pictures to other springs, which again confirms an annual cyclicity of discharge and recharge.

Mailet recession coefficients

Recession coefficients are calculated in fig 4.56, and the results tabulated in table 4.20. Three recession coefficients were estimated. The dynamic reserve of this spring is calculated to be 40.96 x10^6 cubic meters for the period of 277 days (around 9 months) which is equivalent to 1.7 m^3/s. Accordingly, in case no replenishment occurs, theoretically more than six years are required for the spring to be exhausted.

Table 4.19 Reshen Spring Discharge characteristics for the years 2004-2006.

Spring Name	Q max (l/s)	Qmin (l/s)	Qav (l/s)	Qmax/Qmin
Reshen	7020	505	2282	13.9

Table 4.20 Recession coefficients and dynamic reserves of Reshen spring.

Spring Name	α_1	α_2	α_3	V_{total} x 10^6 m^3
Reshen	0.048 Per 9 days	0.008 Per 176 days	0.0027 Per 92 days	40.96 Per 277 days

- Zalim Spring

The geological and hydrogeological setting of this spring has been studied in detail by Ali and Ameen (2005). This spring is located at the lower slope of Avroman Mountain in the SB4. It is considered one of the most beautiful karstic springs in the region, when directly after the spring it pours out from a large cave and from high cliff, making a very inspiring waterfall (Fig.4.67). This gives the area great merit as a very nice tourist area.

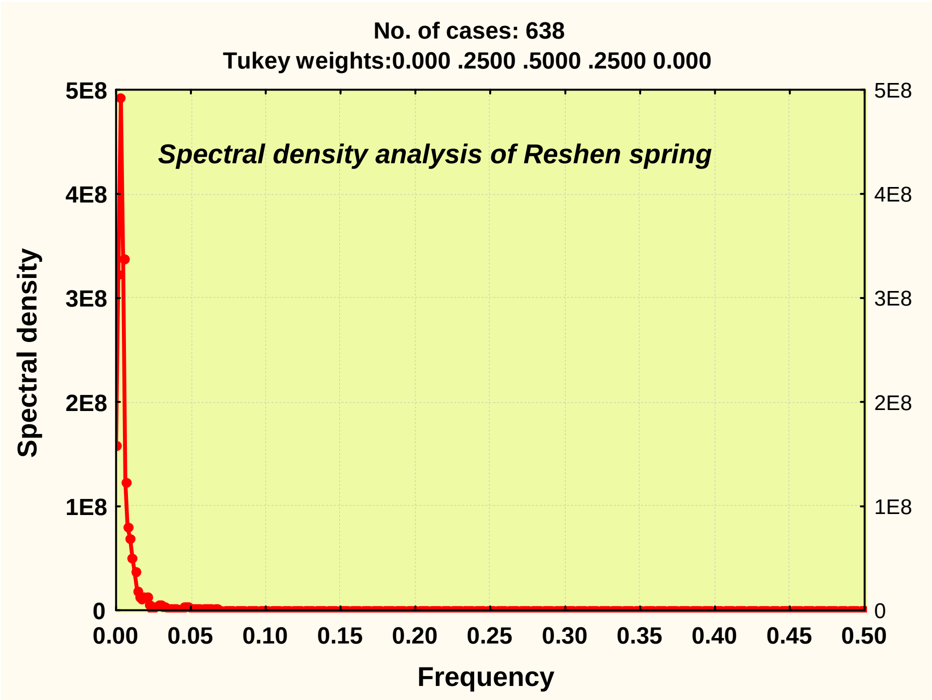

Fig.4.55 Spectral density analysis of Reshen spring, Oct.2004 – July 2006.

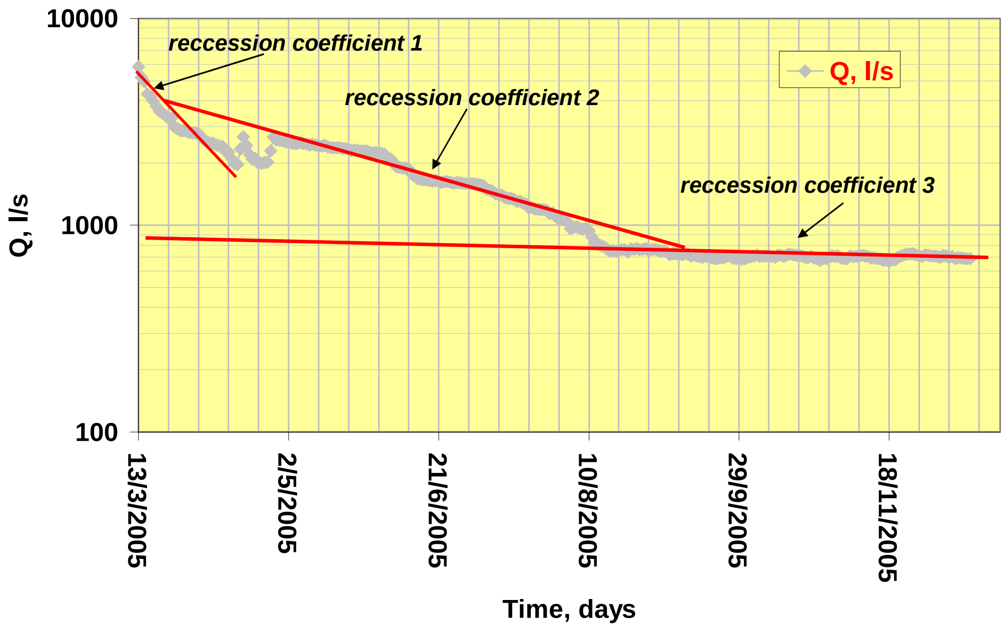

Fig 4.56 Recession coefficient estimation of Reshen spring.

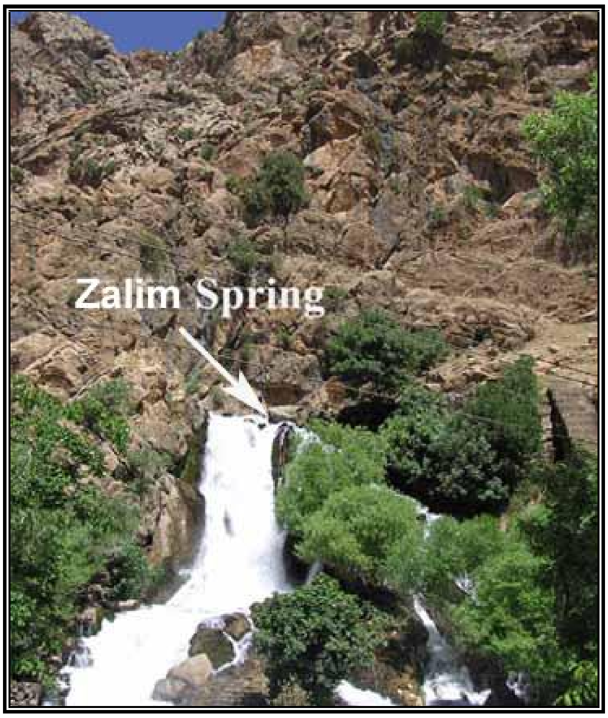

Fig.4.57 Zalim spring, May 2005.

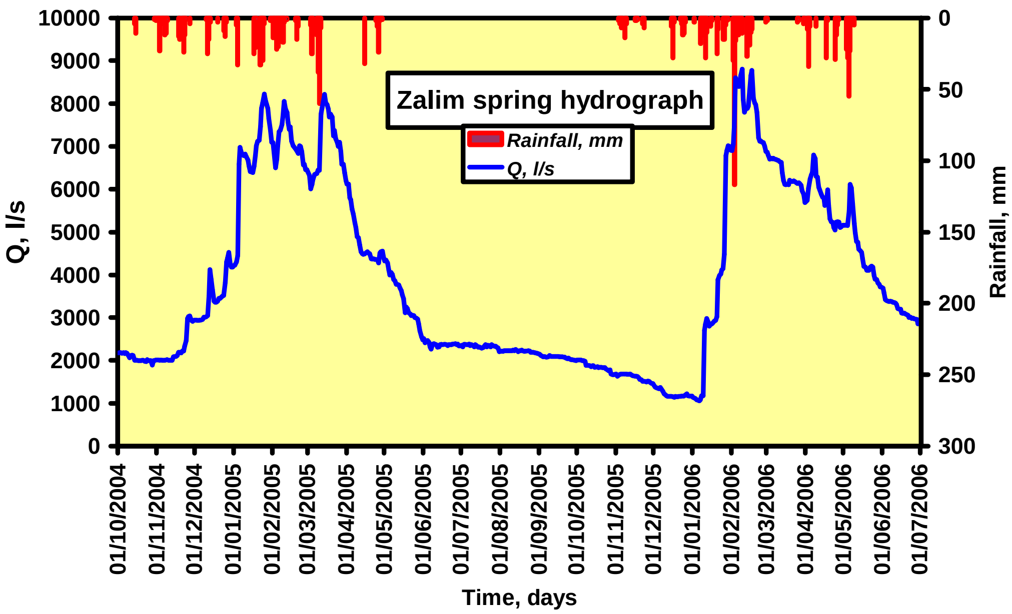

Fig.4.58 Zalim spring hydrograph for the period, Oct 2004 – July 2006.

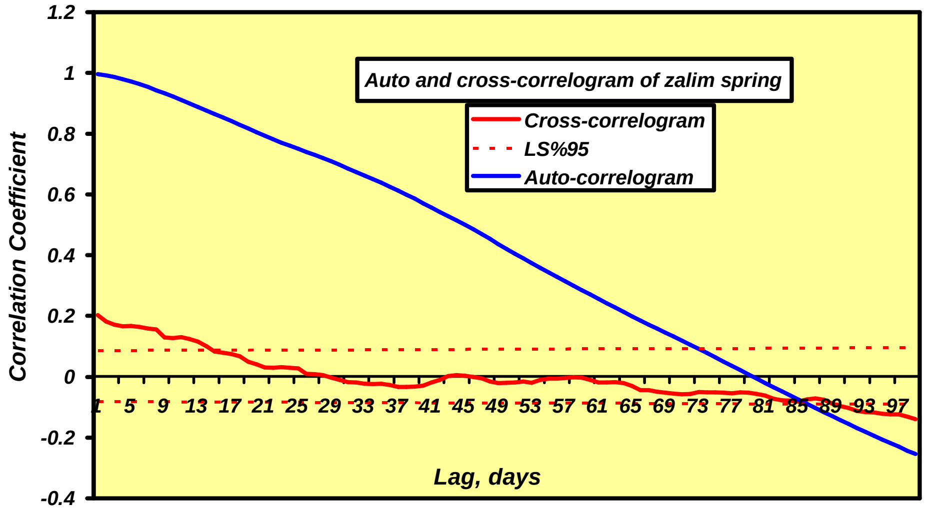

Fig.4.59 Auto and cross – correlogram of Zalim spring, Oct.2004 – July 2006.

It is obvious from the spring hydrograph (Fig.4.58) that this spring reacts strongly to the first rainfall events within the period of the first steps continuing to 15 days. The existence of relatively large channel routes within the aquifer directly connected to the discharge point is confirmed by:

1. The visible fluctuation of the discharge with the fluctuation of the rainfall.

2. The Cross-correlogram, which shows a relatively high correlation coefficient within the statistically significant level of 15 days.

3. The relatively long 79-day period of rapid discharging during the wet season with a steep recession (α_1=0.015), followed by a gentle gradual discharging of the reserve from the fissures with limited dimensions of non-karstic aquifer, represented most probably by the highly deformed shale and phyllite inside Iran. Fig.4.59 shows the auto-correlogram and cross-correlogram of this spring.

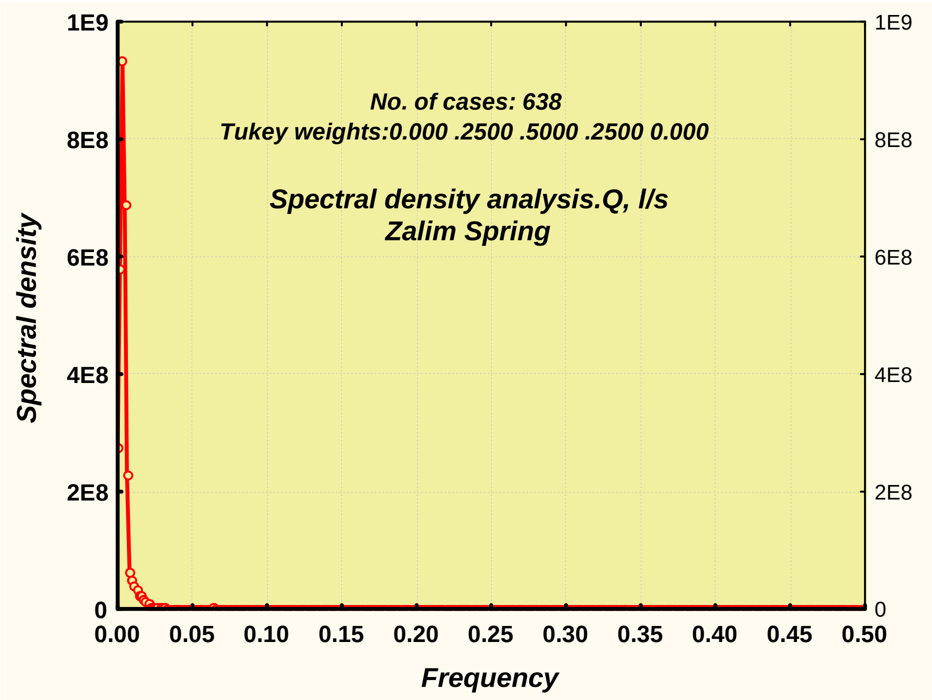

Fig.4.60 Spectral density analysis of Zalim spring, Oct.2004 – July 2006

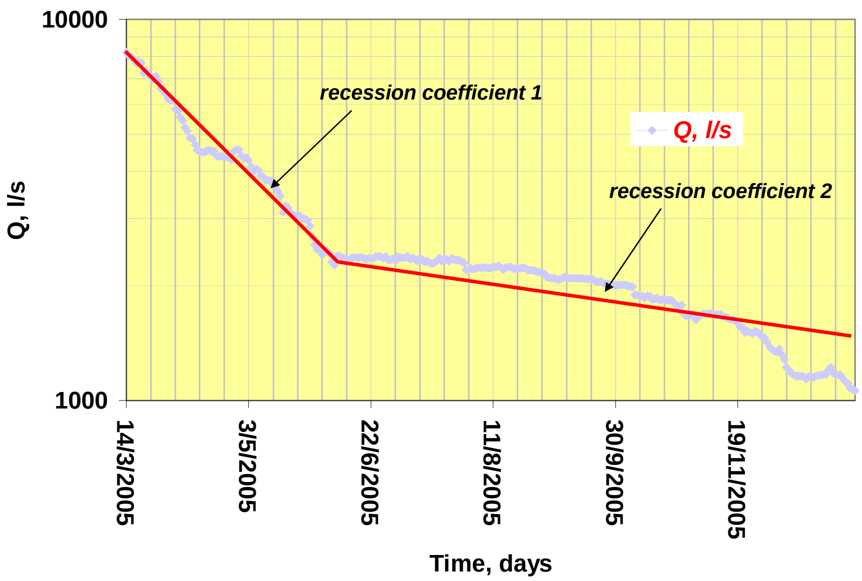

Fig.4.61 Recession coefficient estimation of Zalim spring.

Table 4.21 Zalim spring discharge characteristics for 2004-2006.

Spring Name	Q max (l/s)	Qmin (l/s)	Qav (l/s)	Qmax/Qmin
Zalim	8800	1060	3857	8.3

The auto-correlogram, like the other large karstic springs in the area, signifies a large storage with a high correlation coefficient and statistical significance of 73 days.

Annual cyclicity of the system recharging-discharging is verified by the spectral density analysis, (Fig 4.60).

Mailet recession coefficients

The dynamic reserves of the spring calculated by the Tarisman method are 62.73 million cubic meter per 277 days. This is equivalent to 2.62 m^3/s. The aquifer requires about five years to be exhausted if no replenishment occurs.

Table 4.22 Mailet recession coefficient and dynamic reserve of Zalim spring.

Spring Name	α_1	α_2	V total x 10^6 m^3
Zalim	0.014 Per 88 days	0.00397 Per 190 days	62.73 Per 9 month and 8 days

- Bestansur Spring:

This spring is considered one of the largest springs in the Arbat - Zarain sub-basin (SB2). It is also considered the main drinking source for the two large towns of Arbat and New Halabja in this sub-basin. In order to have a suitable plan for better management of this important resource, the detailed study of the discharging characteristics and the mechanism of flow are of vital importance.

Fig.4.62 Bestansur spring intake structure, May 2006.

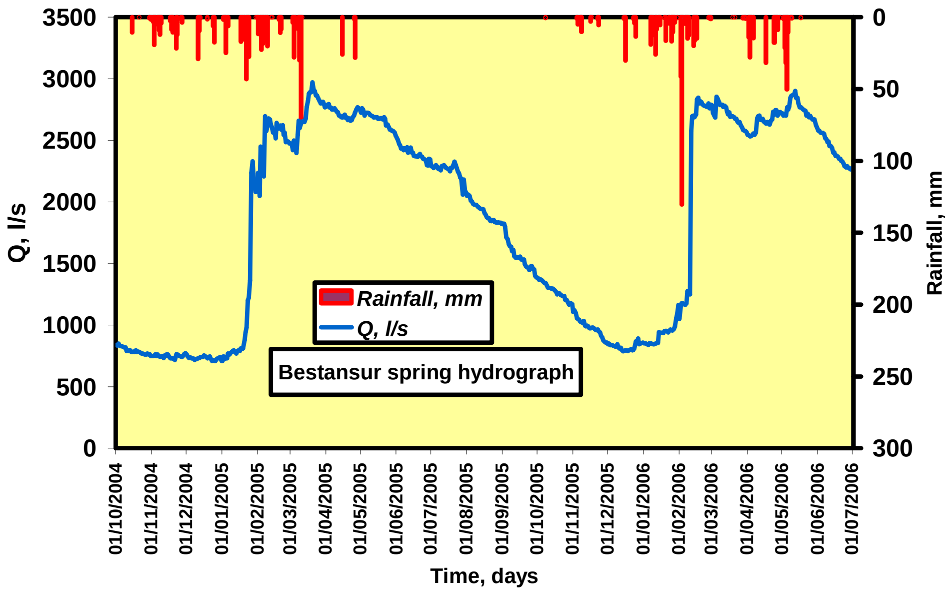

Fig.4.63 Bestansur spring hydrograph for the period Oct 2004 – July 2006.

The Kometan and Balambo Formation (CKFA) constitute the main aquifer and recharging area of the spring. The impermeable beds of the Shiranish and Tanjero Formations comprise the barrier which prevents groundwater from percolating into deeper areas. Spring hydrograph and the resulting time series analysis of the data are presented in figs 4.63, 4.64, and 4.65.

Table 4.23 The discharging characteristics of Bestansur spring.

Spring Name	Q max (l/s)	Qmin (l/s)	Qav (l/s)	Qmax/Qmin
Bestansur	**2970**	**710**	**1845**	**4.18**

As clear from table 4.23, this spring has the smallest discharge variation between maximum and minimum in comparison to other springs discussed previously, and has a weak response to instantaneous climatic changes. This is a good preliminary indicator of the nature of the aquifer pattern and stratigraphy of the spring which confirm a karstic fissured system of porosity. This is attributed to three points; the first is that the aquifer of the spring is located in land mostly lower than other springs and it therefore has a lower hydraulic head. The second reason is that there is no massive limestone for the development of karstic aquifer as both the area of recharge and discharge are composed only of Kometan and Balambo Formation which have well-bedded limestone and contain some interbeds of marl.

The spring discharge hydrograph (Fig.4.63) shows a relatively minor reaction between daily rainfall events and daily spring discharge. Because the aquifer reservoir completely floods after the accumulation of infiltrated water from more than 250mm rainfall, a sudden increase in the spring discharge is recorded; this is about three times the discharge magnitude of those two to three days earlier. The spring has a more or less stable discharge until the end of July when gradual decreasing of pressure materializes.

The auto-correlogram of the spring discharge shows a very statistically significant relation of up to 81 days (Fig.4.64), which points to both a great storage and to long term reserve of the aquifer gradually draining. The majority of the infiltrated water serves the purpose of adding up to the fissured porosity accumulation. The cross-correlogram, unlike the other previously mentioned springs, does not show any significant quick response to and interrelation with the daily rainfall events. This behavior supports the fissured nature as the main secondary porosity of the Bestansur aquifer reservoir. No surface open connected channels to the discharging point are found.

The spectral density analysis curve (Fig.4.65) similar to that of other springs confirms the annual cyclicity nature of the discharge recharge system of the spring.

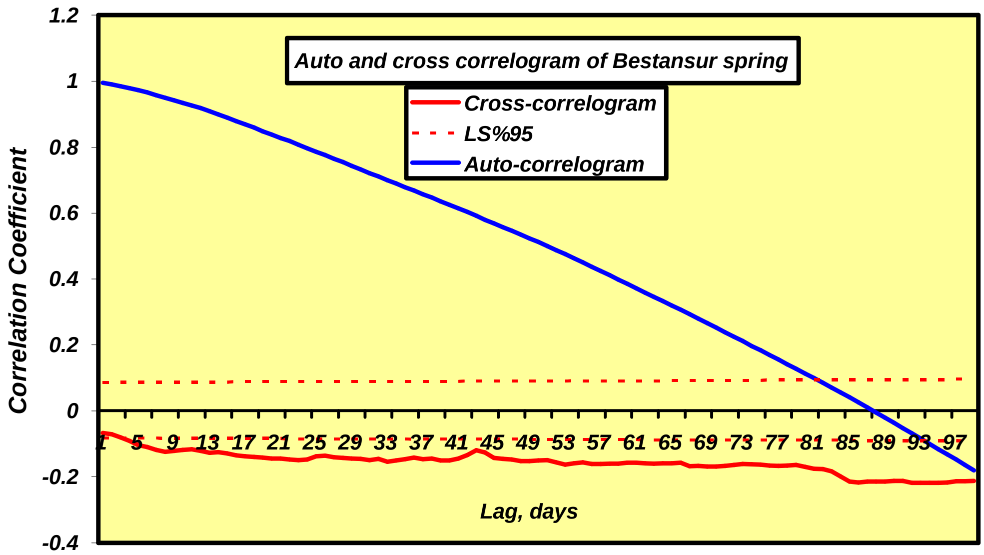

Fig.4.64 Auto and cross – correlogram of Bestansur spring, Oct. 2004 – July 2006.

Mailet recession coefficients

The Mailet recession curve shows that the spring discharge gradually drains in a gentle mode. As one recession coefficient determined, the groundwater flows through fissures which comprise the effective porosity of the aquifer without any dual pattern of flow. The dynamic reserve is calculated to be about 13.93 x 10^6 m^3 which is equivalent to 0.59 m^3/s. Theoretically, the springs are supposed to be sustainable for at least three years without any new recharge.

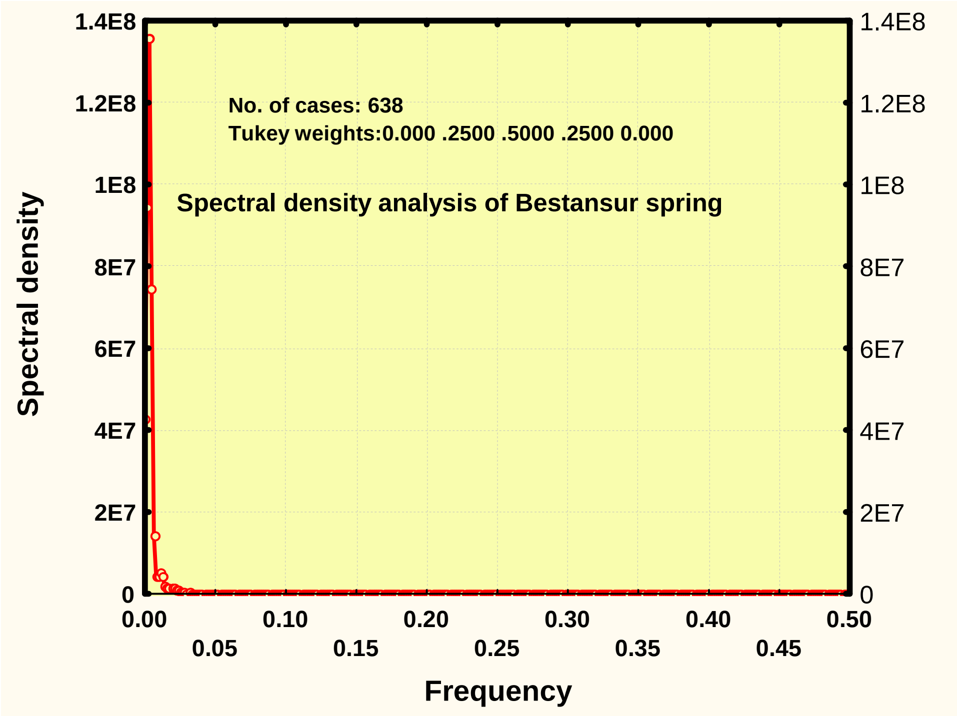

Fig.4.65 Spectral density analysis of Bestansur spring.Oct.2004 –July 2006.

Table 4.24 Mailet recession coefficients and dynamic reserve of Bestansur spring.

Spring Name	α_1	V total $_{x\,10^6}$ m^3
Bestansur	0.0049 Per 270 days	13.93 Per 9 month =0.59 m^3/sec

Estimation of groundwater recharge from spring hydrograph

Yongxin and Hans (2003) are authors of the book containing several published papers on all the applied methods for groundwater recharge estimation: spring discharge hydrograph and catchment water balance were two frequently used methods. Castany (1968), Mijatovic (1970), Bredenkamp et al (1995, 2002) and many others also attempted to find recharge amount through different methods.

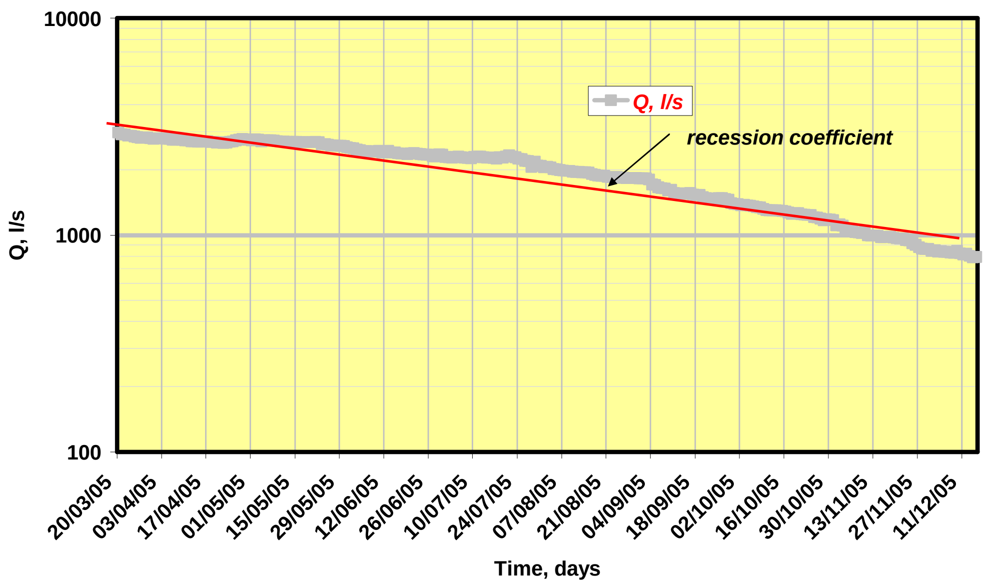

Fig.4.66 Recession coefficient estimation of Bestansur spring.

Korkmaz (1990) estimated the recharge rate of the Kirkgoz springs area in the Mediterranean region in Turkey based on the spring discharge recession coefficient, and by the changes in the dynamic reserves of the spring throughout a year.

The climate of Iraqi Kurdistan is characterized by a clear distribution of rainfall throughout the seasons. No effective rainfall contributing to groundwater recharge could be expected from June to the end of September. Thus, the recession curve of the hydrograph of the springs recesses until new replenishment starts to reach the aquifer. Therefore, the difference in spring discharges from the beginning of the water year (1st October) to that of the end of the water year (30th September of the next year) could approximate a change in dynamic reserves throughout that year.

Accordingly, the annual recharge of any spring could be estimated by adding or subtracting the amount of change in the dynamic reserve to the total drained water throughout the year. Such an approach is most convenient for areas with long periods without rainfall, like Iraq. The table below clarifies the means of calculations and the resulting recharge values.

Comparing the annual recharge values obtained by this method (R1) and that estimated from water balance equations and SCS method (R2), differences could be observed. The differences for each spring are discussed hereunder:

For ***Sarchinar Spring***: The amount of annual recharge to CKFA which supplies this spring as estimated by the water balance equation is equal to 90.4 x 10^6 m^3. This is higher than that calculated by the spring discharge method. This difference is attributed to the fact that the recharged karstified aquifer is distributed in SB1 and a major part of this aquifer discharges through the Sarchinar springs while the rest, comprising storage of the other part of aquifer inside Kometan and which is discharged either by small springs or through deep wells, penetrates this aquifer inside the city of Sulaimani. The two deep wells in Reaya and Kadam Kher School are the most productive among the wells penetrating CKFA-Kometan, both of which function at least 10 hr/day with an average discharge of 10 l/s. Therefore, the estimated annual recharge of CKFA which supplies Sarchinar spring could be considered to be reliable and dependable.

For ***Bestansur Spring***: The annual recharge volume of water (R2) to fissured-karstified aquifers in SB2 was found to be equal to 76.5 x 10^6 m^3 by the water balance method, while for Bestansur spring (R1) it was found to be equal to 75 x 10^6 m^3. This means that the estimated difference of 1.5 x10^6 m^3 is supposed to be the rest of the reserves which drain from the springs of Kani Panka, Greza and small Bestansur.

If the total average discharge of Kani Panka and Greza which most likely have a hydraulic connection with CKFA aquifer of SB2 (based on the data of FAO, 2002) as 0.7 m^3/s, at least an additional 22 x 10^6 m^3 per year of recharge volume must be available to quarantine this amount of discharges.

The CN numbers which were proposed for the outcrops of the rocks of CKFA, were supposed to be the maximum possible values according to the nature and pattern of the discontinuities of these rocks which are observed in the field. Therefore, the resulting deficiency in the amount of recharge which could not be less than 22 x 10^6 m^3 must be due to the missed assessment of the contributing area and not to the CN estimate. This conclusion is more visible in the field. This volume is equivalent to an area of at least 50 km^2; accordingly, an additional 50 km^2 from the adjacent northern catchment should have contributed to the supply CKFA aquifers of SB2.

Table 4.25 Estimation of annual recharge of the main springs in the study basin using spring discharge values.

Spring Name	Catchment area	Spring discharge		Difference in discharges per year	Equivalent reserves Change within one year	Bulk volume of spring discharge (Q) per year based on daily measurement	Annual recharge of the springs	Annual recharge of spring aquifer estimated by SCS method	Equivalent annual volume of rainfall	% of recharge per annual volume of rainfall
	(1)	(1) 1st Oct. 2004	(2) 1st Oct. 2005	(3) = (2)- (1)	(4) = (3)x 86400x 365	(5) $\sum_{1}^{365} Q \times 86400$	(6) = (5) ± (4)	(7) From tables 4.8, 4.10, 4.12, 4. 14	(9) = (1)x 780	(10) =6/9
	A km^2	Q_1 (m^3/s)	Q_2 (m^3/s)	ΔQ m^3/s	Δv X 10^6 m^3	Vtotal X 10^6 m^3	R1 X 10^6 m^3	R2 X 10^6 m^3	Vp X 10^6 m^3	%
Sarchinar	187.6	1.119	1.047	- 0.072	-2.27	86.2	83.93	90.4	146.3	57
Bestansur	159.2	0.842	1.385	0.543	17.12	57.98	75.1	76.5	124.17	46
Reshen	135.1	0.706	0.690	-0.016	-0.50	68.85	68.35	73.3	105.37	65
Sarchawai Saraw(a)	-	0.650	0.640	-0.010	-0.31	34.23	33.92			
Qurena(b)	-	0.632	0.538	-0.094	-2.96	23.84	20.88			
Qalabo(c)	-	0.860	0.744	-0.116	-3.65	37.91	34.26			
Saraw All (a+b+c)	245.91	2.142	1.922	-0.22	-6.92	95.98	89.06	114.3	191.8	46
Zalim	165.54	2.180	2.010	-0.17	-5.36	120.264	114.9	89.8	129.12	93

The area north of the spring, (Barzinja), extending to Kura Kazhaw Mountain is the most aspirant one. It is worth mentioning here that no large spring was found in this latter area, and this increases the probability of feeding the springs in the study basin.

The delineation and separation of the groundwater divide between Bestansur, Kani Panka, Greza and even the Saraw group spring is a complex and very difficult task. For ***Saraw group springs*** - The annual recharge volume (R1) of Saraw group springs (89.06 x 10^6 m^3) was found to be reliable and compatible with the amount calculated for both CKFA and JKA aquifers (which are supposed to be the main feeding source of Saraw springs) (R2 114.3 x 10^6 m^3). The difference could be considered as the amount of water discharging Said Sadiq, Komash, and Kani Zard springs. The average discharge of the Said Sadiq spring is estimated by the Energoprojekt authors (1980) to be 0.4 m^3/s i.e. 12.6 x10^6 m^3/ year. The average discharge of the Komash spring is measured to be 0.3 m^3/s, i.e. 9.5 x 10^6 m^3/year. Hence, the annual recharge volume of CKFA and JKA which supplies the Saraw group springs could be considered reliable and dependable also.

For ***Reshen Spring:*** The annual volume of recharge (R1) for this spring is estimated to be 68.35 x 10^6 m^3.

In this sub-basin and from the same aquifer at least two other large springs drain. One is the Jomarase spring with an average Q=1.2 m^3/s, and the other is Shalm, with an average Q=0.3 m^3/s. This is equivalent to 47x10^6 m^3 volume of water per year. Accordingly, the total annual recharge should be in the range of (68+47) x$10^6$$m^3$; i.e, 39 x10^6 m^3/year is the deficit the annual recharge calculated by SCS method.

This difference could be calibrated based on two assumptions:

The first assumption is a mis-assessment of the catchment area. This above deficit volume is equivalent to about 71 km^2 surface area, i.e. the contributing area from Iran becomes 171 km^2.

The second assumption is a higher amount of precipitation and snowfall than estimated for the entire basin (780mm) and therefore a greater annual recharge volume is possible.

The greater part of the catchment area of TKA for both territories of Iraq and Iran are meridian locations with a high annual rate of precipitation (rainfall and snowfall). According to Polservice (1980), the annual average rainfall of the metrological station nearby Penjween is 1059mm, and 50% of the annual averages for 38 years of measurements were below 1000mm, while the other 50% is more than 1000mm. Accordingly, if 220mm difference is added to the annual rainfall average upon which the calculations in this study are based, it means 220mm/780mm x100 = 28% of the annual calculated recharge could be added i.e. %28 of R2 = %28 x 76.5 x 10^6 m^3 /year = 21.4 x10^6 m^3 /year. This volume is equivalent to about 38 km^2 surface area. Still a catchment deficit exists. Thus, even if the best cases of precipitation contribution are taken into account, 33 km^2 is still the least the additional recharge area inside Iran, in addition to the already calculated 100 $km^{2.}$

The most difficult part of the hydrogeological investigation in the region is to delineate the groundwater boundary, particularly when no tracer tests have ever been performed for that area.

For ***Zalim Spring***: The amount of discharge (R1) was about 120 x 10^6 m^3 per year, while the estimated recharge volume (R2) to the aquifer comprising the source of this spring was estimated by the water balance method as only 92 x 10^6 m^3. If the amount of another 20x $10^6 m^3$ is added for the other springs which pour from this aquifer, (like Sargat and Shiramar springs), it means at least 50x$10^6 m^3$ of water also must be recharged from a source extending more to inside Iranian territory. This volume is equivalent to at least 90 km^2 surface area.

If the same assumption which was applied to the Reshen spring is applied to this spring, 28% of excess precipitation is added, meaning 24x 10^6 m^3 annually is added which is equivalent to about 45 km^2 surface area. Hence, the additional contributing area becomes 45 km^2 instead of 90 km^2. Accordingly, the most probable range of contributing area for TKA in SB4 becomes 145 km^2 in the best case of high average rainfall. The overall conclusion is that the majority of the area contributing to Zalim, Shiramar and Sargat springs is located inside Iran; accordingly, trans-boundary detailed studies are required to define this aquifer more precisely and it may be that tracing is the best method in this area.

Table 4.26 Estimation of runoff based on water balance for major springs

Spring , the related aquifer, and Sub-basin	Catchment area km^2	Annual rainfall $\sum p$ mm	Annual equivalent volume of rainfall $X10^6 m^3$	Total discharged volume of the spring $X\ 10^6\ m^3$	P-Q Rs +AE ± Error	Equivalent annual volume of 173.2 mm of AE	Rs Total annual volume of runoff
	1	2	3=2x1	4	5=3-4	6=AE x 1	7=5-6
Sarchinar CKFA-SB1	187.6	780	146.3	86.2	60.1	35.0	25.1
Bestansur CKFA-SB2	159.2	780	124.17	57.98	55.32	27.57	27.75
Reshen TKA-SB3	135.1	780	105.37	68.85	36.52	23.4	13.12
Saraw All CKFA+JKA SB3	245.91	780	191.8	95.98	95.82	42.6	53.22
Zalim TKA- SB4	165.54	780	129.12	120.26	8.86	28.61	Error -19.76

According to the water balance based on rainfall–spring discharge analysis as shown in table 4.26 the resulting volume of runoff in the Sarchinar catchment is 25.1 x 10^6 m^3 which is equivalent to 1.3 m^3/s for 7 rainy months. This value, with about 0.7 m^3/s of runoff which forms from the TAT and covers about 45 km^2 inside the same catchment, was found to be close to the real measurement of the Chaqchaq stream during the six months of 2005-2006. This again confirms some reliability of the first assessment done for this area. The rest of the springs could not be compared as no complete data was available about the discharge of the relating streams or valleys. However, establishment of a continual monitoring system for surface / groundwater is required in this hydrogeologically very important basin.

4.6.2. Groundwater level fluctuation

The seasonal and annual fluctuations of the groundwater level are the mirror image of the recharge and discharge processes (Hassan, 1996).

The regular monitoring of the groundwater level fluctuation through drilled deep wells was one of the essential tasks of the FAO Groundwater monitoring network program in Iraqi Kurdistan from 2000-2003. The program covered 176 monitoring wells distributed in different aquifer systems. This program helped to define the hydrogeologic characteristics and depletion indicators of each aquifer and their response to rainfall events and climatological fluctuations (Stevanovic & Iurkiewicz, 2004). Some of these FAO wells are located in the study basin. For the current study few of these wells could be used for monitoring, but unfortunately in some others the piezometers were damaged and could not be used. Thus, new piezometers have been installed for some other wells.

Weekly measurements of static water level in 17 deep wells in the study basin were achieved for the period of December 2004 to February 2006, as follows:

For SB1: Seven deep wells monitored, four of them penetrating TAT, two wells penetrating CKFA of the Kometan Formation and the other drilled within AIA.

For SB2: Four deep wells monitored two in AIA, one in TAT and the other CKFA.

For SB3: Five deep wells monitored, three of them in AIA, the other two penetrating CKFA.

For SB4: Two wells monitored, both penetrating AIA.

The groundwater level observation data are presented in the figures (4.76-4.82) for all four sub-basins.

As is illustrated in the graphs, considerable fluctuations of the groundwater level took place during the observation period 2004-2006.

For SB1 - The AIA in this sub-basin declined 7.7m during the maximum recession period, while for TAT it is in the range of 4.12 - 8.7 m. Deep wells penetrating CKFA show a maximum decline in head, ranging from 5.5 - 12.3m. The reaction of the aquifers to recharge was recorded generally at the end of December, and the highest water level reached either at the end of April or beginning of May of each water year, but for one karstic-fissured aquifer the maximum water elevation was recorded in mid- March and then started to decline again.

The travel time is found to be different from one type of aquifer to another. For intergranular aquifer, 3-5 days of travel time was observed while for karstic-fissured aquifers it sometimes reached more than 5 days.

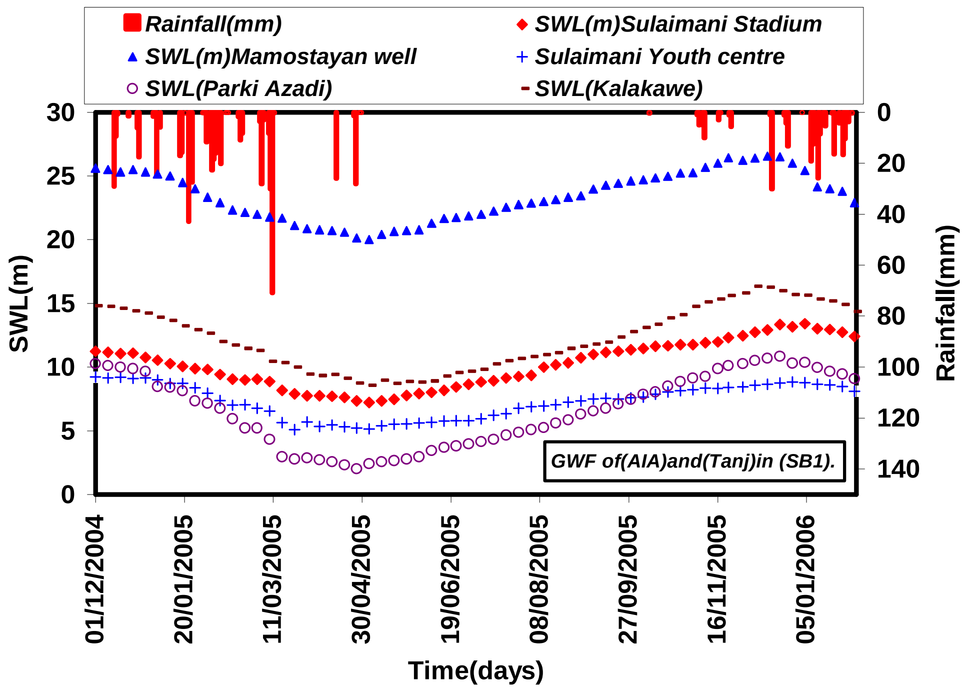

Fig.4.66 Groundwater level fluctuation of AIA and TAT in SB1.

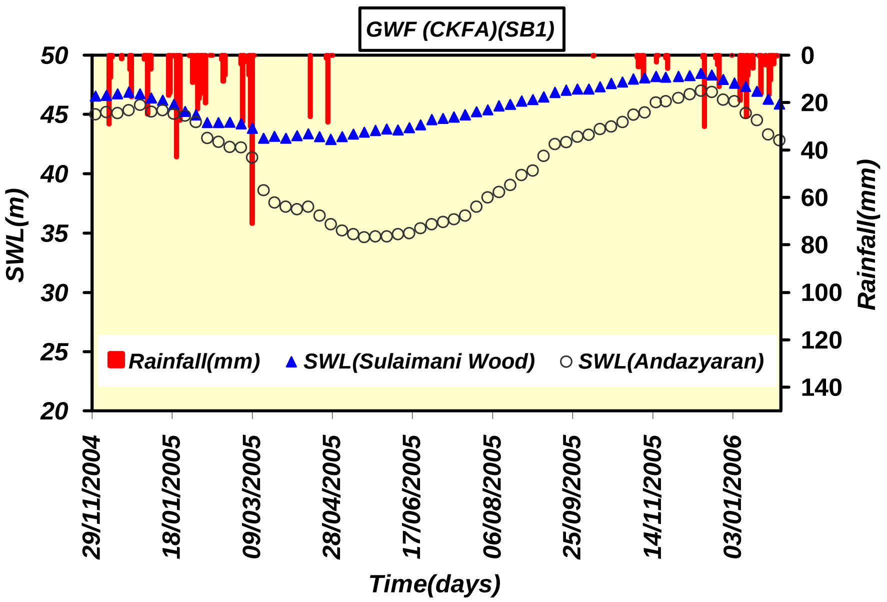

Fig.4.67 Groundwater level fluctuation for CKFA in SB1.

For SB2- A decline in the static water level of the range 2.73-5.24m is recorded for the wells penetrating AIA, while for the wells penetrating CKFA a higher decline of 6.1m is recorded. The Arbat well which penetrates TAT with a few meters of surfacial deposits declined during the recession period to an amount of 7.9m.

The maximum reaction to recharge remains active to the maximum elevation until the 1st of June, while the minimum elevation recorded was in the third week of December.

Travel time recorded for karstic aquifers was about 2-3 days with a 0.70m rise in the static water level after an 80mm rainfall. For intergranular aquifer, this amount of rainfall has a limited impact on the rising static water level of only 20cm.

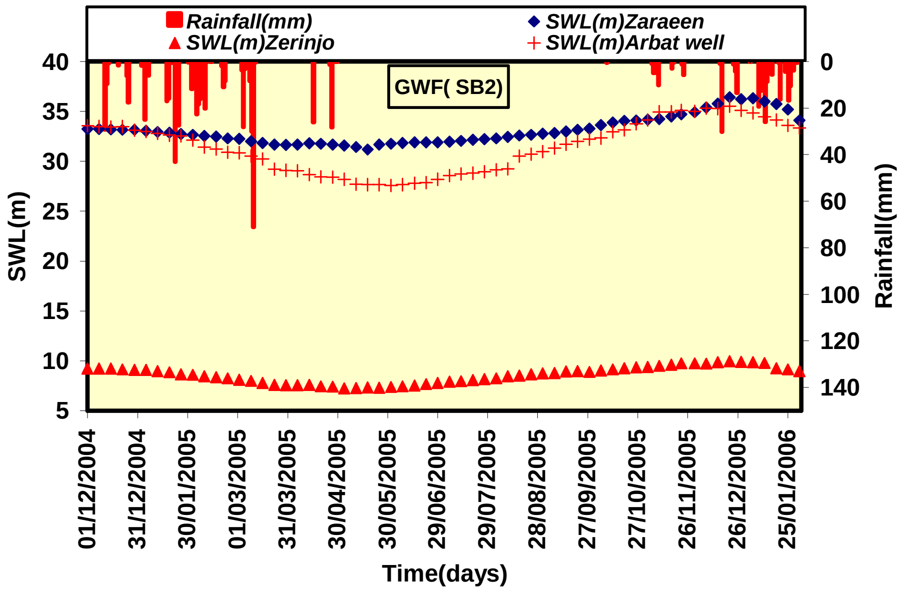

Fig.4.68 Fluctuation of groundwater level for deep wells penetrating AIA and TAT in SB2.

For SB3 : For AIA, the range of decline of the static water level recorded was 2.85 - 5.0 m, the reaction to more than 100mm rainfall result only a 1m rise in the water table, and travel time was found to be more than 6 days .

Two deep wells in this sub-basin penetrate CKFA. The recorded decline was 5.87 - 11.75 m. The reaction of this aquifer to 80 -100 mm rainfall was only a 0.45 m rise in water level which appeared with a travel time of 5-6 days.

In SB3, during a study performed by Energoprojekt (1980), great amplitudes of the water level oscillations were observed in the piezometers tapping the Jurassic karstic aquifers. In fact, the amplitudes of the water level fluctuations reached a range of 20-26m. On the other hand, the amplitude of the water level fluctuations in the piezometers situated downstream appears to be a rather limited amount of up to 5m. The minimum water levels were measured at the very end of December 1979. The maximum water levels were observed either in May or exceptionally in June 1980. The minimum water level representing the hydrological year 1980/81 was not established until the end of November 1980. The Energoprojekt report (1980) mentioned that the piezometers installed in the Shanadari plain north of Said Sadiq (SB3) and situated near the valley beds were subjected to the most conspicuous water level rise during the rainy season in 1980, which confirms recharging from connecting valleys.

The recharge zone seems, however, to be limited immediately downstream of the Shenedari village since the aquifer becomes confined.

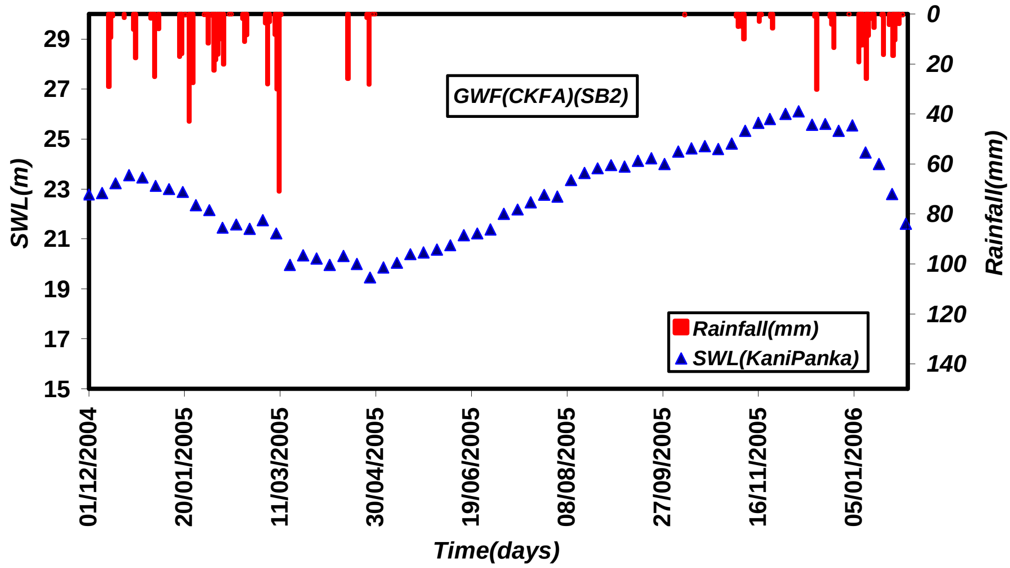

Fig. 4.69 Groundwater level fluctuation for deep well penetrating CKFA in SB2.

For the piezometers installed in the Khargellan well (AIA) in (SB4), a decline of about 4.5m is recorded between the maximum recharge period to the lower recession period. Cumulative rainfall of 130mm resulted in a rise in the groundwater level of only

1m. Before this amount of rainfall no influence of any rainstorm was recorded even for 10 days of travel time, but the six days' continuous rainfall of about 90mm resulted in another 0.75 m rise within a travel time of five days. Most likely, this rise might have been under the influence of a previous three days' heavy rainfall (felt about 70mm).

The travel time was generally longer than 5 days and the aquifer's reaction started in December and the beginning of January.

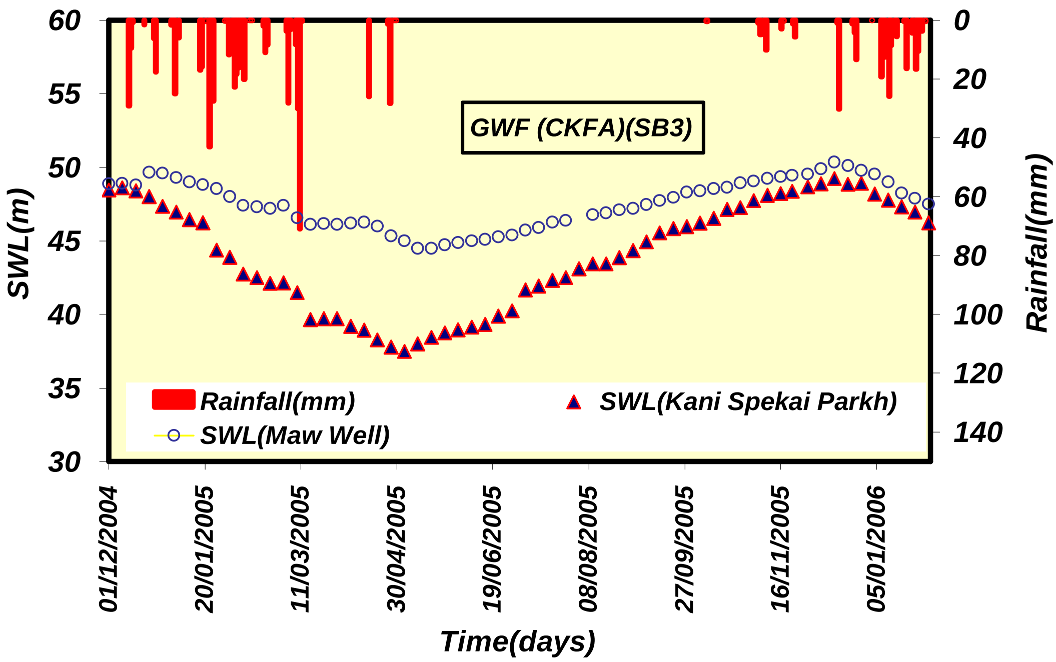

Fig. 4.70 Groundwater level fluctuation for deep wells penetrating (CKFA) in SB3.

Obviously, the great amplitudes of the ground water level fluctuations are caused by an intense recharge into the upstream part of the alluvium aquifer. Presumably, groundwater recharge into the aquifer comes predominantly from percolation of water along the connecting streams such as Chaqan and Surajo Zamaki, Hasanawa and Darashesh valley beds.

The groundwater regime can, however, be used for further analyses of the aquifer parameters by assuming the value of the storage coefficients.

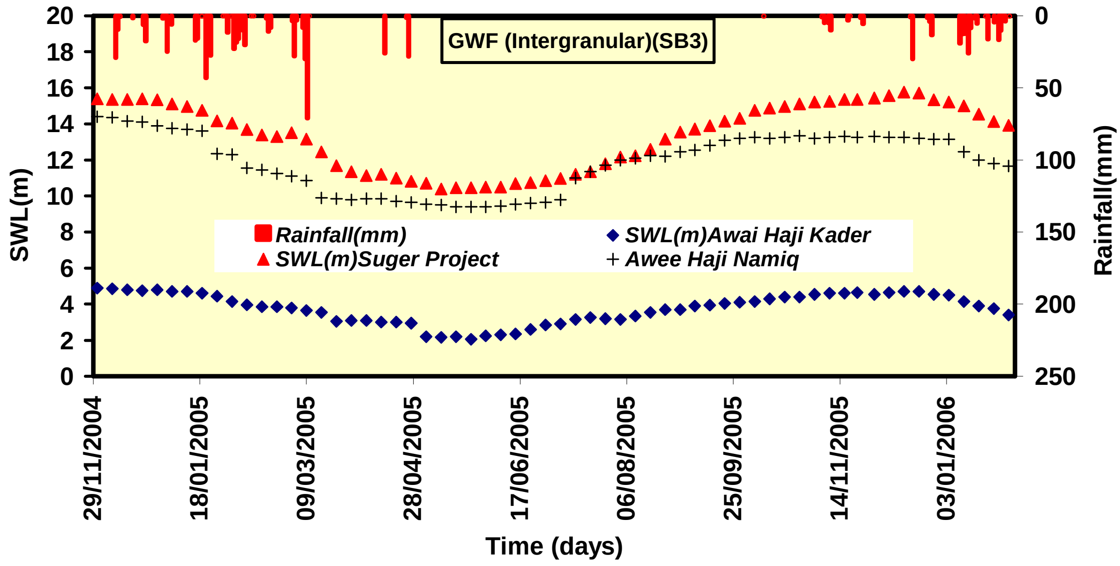

Fig. 4.71 Groundwater fluctuation for deep wells penetrating (AIA) in SB3.

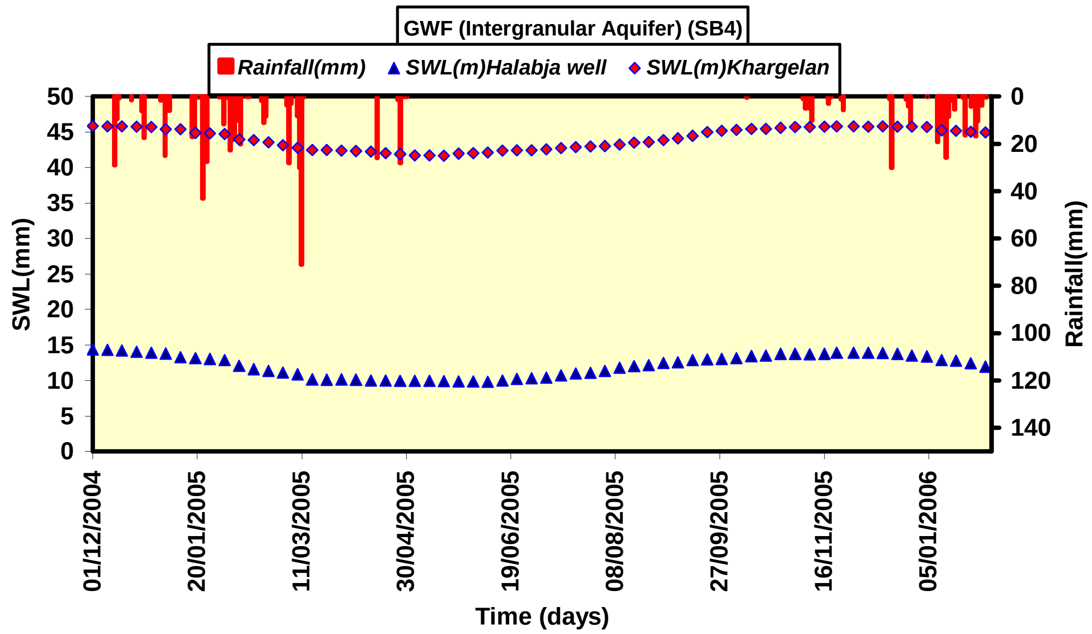

Fig. 4.72 Groundwater level fluctuation in deep wells penetrating AIA in SB4.

Chapter Five

Hydrochemistry

In groundwater evaluation, quality is often of greater importance than quantity. The chemical, physical, and bacterial characteristics of groundwater determine its usefulness for municipal, commercial, industrial, agricultural, and domestic water supplies. The fast development of the Iraqi Kurdistan region provides opportunities for easier pollution of groundwater and great consideration must be given to the protection of its quality. A water with certain physical and chemical characteristics may be suitable for agricultural uses, but not as a domestic water supply. Therefore, the study of water quality is of great importance to define the prime mode of use.

The study of groundwater quality involves a description of the occurrence of the various constituents and the relationship of these constituents to the aquifer material. In addition, groundwater quality data give important clues to the geologic history of rocks and indications of groundwater recharges, discharge, movement and storage.

Chemical analysis of groundwater includes the determination of the concentrations of basic inorganic constituents, and expressed as ions comprise the cations, including calcium ,magnesium, sodium and potassium, and the anions, including sulfate, chloride, nitrate and those contributing to alkalinity which are usually expressed in terms of an equivalent amount of carbonate and bicarbonate (Walton,1970).

Examination of water in the field to determine its approximate chemical and physical characters includes determination of specific electrical conductivity, pH, color, temperature and turbidity.

The concentration of the ions differs from place to place and with time, because the concentration of the different ions increases along the course of the flow and the duration of water contact with the rocks through which it flows, in addition to the fact that the chemical quality of the groundwater at any point inside the system is a function of the rock facies at that point and the quality of the ancient water (Dominico, 1972). The incidence of CO_2 gas in the unsaturated sediments which overlies an aquifer affects the chemistry of the percolated water that reaches the water table, because this gas affects the alkalinity or the pH of the water together with the bicarbonates (Fetter, 1980).

The hydrochemical work for this thesis involves the major, minor and traces of ionic concentrations in the groundwater in the basin. As well, this study also involves the salinity in terms of total dissolved solids (TDS), electrical conductivity (Ec), and reactivity in terms of pH. Laboratory and field chemical tests were conducted.

All the samples collected within the period of field work (October, 2005) were analyzed in the analytical laboratory of the Department of Chemistry of Sulaimani University. A total of 211 samples were collected from different wells, springs and kahrezes. The distribution of the samples points in the area were selected according to the field information, variation in the aquifers, scale of utilization of the source, and accessibility for sampling.

The average results of chemical analysis are shown in the tables in the following sections. During sample collection in the field, additional samples were collected for accuracy and precision assessments of the tests. The accuracy of the results of water samples analysis indicated from the results of reaction error test (Appelo et al, 1999; Mazor, 1990) and analytical accuracy classes of Stoodely et al. (1980).

Reaction error was between minimum values of %2 to a maximum value of 9.4%. About 84.37% of the samples analysis results were within an acceptable limit, and about 15.63% were acceptable with some risk. Therefore, the results of the analysis can be used with certainty for interpretation purposes.

5.1. Interpretation of the physical, chemical and bacteriological analysis results

The results of the physical, chemical and bacteriological analysis of groundwater samples are interpreted in the following sections.

-Temperature and PH

Temperature is one of the conservative properties of groundwater. It affects the density and viscosity properties of water (Todd, 1980). Also temperature will impact on the acceptability of a number of other inorganic constituents and chemical contaminants that may affect taste, odor, color, and corrosion problems (WHO, 2006). The averages of the measured temperatures for the springs, deep and shallow well water samples, are tabulated in table 5.1.

Table 5.1 Range of temperature values of water samples in Sharazoor - Piramagroon basin, October, 2005.

Item	Average T (C^o)	Max. T (C^O)	Min. T (C^o)	Homogeneity Index(IH)
Springs	20.06	29	16	0.74
Deep wells	20.43	22	19	0.86
Shallow wells	23.17	25	21	0.84

The difference in the temperature of water samples may be related to the chemical processes that occur between the rocks of the aquifer and the water of the aquifer. Minimum temperature values were $16C^0$ for the main large springs of Zalim and Sarchinar with very low variability, while a relatively constant temperature of $29C^o$ is recorded for Khurmal acidic spring. A comparatively low homogeneity index (HI) indicates low spatial variation in the temperature of water samples. This is due to the variation of groundwater table depth.

The pH values of the water samples were in the range of 6.6 to 8.4 and the mean pH value was 7.4. Moderately high pH values are commonly associated with waters high in bicarbonates (Davis and DeWiest, 1966); this relation is more or less clear in the results of the present study, and the homogeneity index of pH indicates low spatial variation.

Table 5.2 Range of pH values of water samples in Sharazoor - Piramagroon basin.

Item	Average pH	Max. pH	Min. pH	(HI)
Springs	7.49	8	6.6	0.825
Deep wells	7.72	8.35	6.7	0.8
Shallow wells	7.56	8.25	6.8	0.82

- Total Dissolved Solids (TDS)

Total dissolved solids were determined for the entire water samples. Sometimes the tests were repeated for confirmation. The mean values considered, the maximum TDS value was 1300 ppm for the acidic spring of Khurmal (most probably Jurassic aquifer), and 530ppm in the Chinara spring (JKA). The minimum TDS values were recorded in the Qleja spring (EIA) south of SB2.

Maximum TDS values (700, 750 and 755 ppm) were measured for the deep wells of Awal, Bakrajo and Kani Goma respectively, which penetrate AIA. These three wells are located in the discharging area south of SB1 which is probably influenced by the infiltration of the sewage water from the sewage open channels close to them. Minimum TDS values were in the Halabja wells (SB4) drilled in AIA. These wells are relatively closer to the recharge area, so limited hydrochemical processes might have been taking place and the residency time is not sufficient for more solution of the carbonate rocks into the groundwater.

For shallow wells, the maximum TDS value was 885ppm for the Wulluba well which was drilled in AIA southeast of SB1. An undeveloped sewage system in this area also is most likely responsible for these high values, as is the location of this well far from a recharging area. The minimum measured TDS value was 154ppm for the Damirkan shallow wells drilled in TAT in SB2 west of Arbat town. Due to exposing low permeable rocks of the Tanjero formation, the limited catchment area and low density population in the recharging area total dissolved solids are relatively low.

$$IH.TDS = \frac{Min.TDS}{Max.TDS} x100 = \frac{189*}{1300} x100 = 14.5\% \qquad \text{For springs}$$

$$IH.TDS = \frac{Min.TDS}{Max.TDS} x100 = \frac{177}{755} x100 = 23.4\% \qquad \text{For deep wells}$$

$$IH.TDS = \frac{Min.TDS}{Max.TDS} x100 = \frac{154}{885} x100 = 17.4\% \qquad \text{For shallow wells}$$

$*$ *TDS values are in ppm.*

The high *homogeneity index of TDS* values indicates a wide range of variation in the tested wells and springs. Since TDS represents the total sum of cations and anions generally, in addition to the rare and secondary elements (Mathees, 1982), a wide variation in the cation and anion concentrations exists within the area of study.

Any change in the pH values creates changes in TDS values. When the pH values of the percolated waste waters decreases due to bacterial activity, it causes an increase in the TDS value, mainly due to the mobilization of calcium carbonate as the effluent moves through the vadose zone (Bower, 1991).

All water samples are considered to be a fresh water type (TDS<1000ppm), except the sample from the Khurmal acidic spring in SB4, which is considered to be slightly brackish water according to the classification of Todd (1980).

- Electrical Conductivity (EC)

The conductivity of groundwater is a function of temperature, the type of ions present and the concentration of various ions. All conductivity readings are calibrated to 25 °C to eliminate the influence of temperature on the real Ec values.

The highest EC value of 2200 µs/cm recorded was for the Khurmal acidic spring (Jurassic aquifer) and the lowest EC was 310 µs/cm for Kahreze Naqib (TAT) with an average of 512 µs/cm.

Good correlation coefficients (0.7 to 0.89) were found between TDS and EC values for all water samples.

5.1.1 Cations

- Calcium Ca^{2+}

Groundwater contents of cations generally reflect the aquifer lithology (Alsawaf, 1977). Therefore, the calcium ion is the dominant cation in the water samples of the studied area. This is logical given the fact that limestone rocks comprise most of the recharging area and forming most of the karstic aquifers. Moreover, the grain particles of the alluvium aquifers are composed mostly of fragments of limestone as the source rock.

The solubility of the carbonate rocks increases in the presence of solutions rich in dissolved carbon dioxides. Therefore, the percolated waters that are enriched with CO_2 (from the atmosphere and due to anaerobic activity in the soil) dissolve greater amounts of calcium carbonates.

In the studied area the Ca ions are the major cations in the water samples. For the springs Ca ions concentration ranged between 32 ppm for the Kahrezi Naqib (TAT) and Qleja spring (EIA) and 215ppm for the Khurmal sulfuric spring. In general, the concentration of Ca increases in the southward direction towards Sulaimani city, Said Sadiq and towards Zarain and Arbat towns (Fig.5.3).

For deep wells the minimum content of Ca cations is detected in water samples from the Halabja well (W9) from (AIA) aquifer, and the maximum was for the Reaya well from CKFA (Kometan). The concentration of calcium in normal potable groundwater generally ranges between 10-100 ppm. Calcium in these concentrations has no obvious effect on the health of humans or animals. Indeed, as much as 1000 ppm of calcium may be harmless.

- Magnesium (Mg^{2+})

Magnesium ion concentrations in the water samples of the studied area ranged between 2.3 ppm for the Sargat spring (TKA) and 30 and 38 ppm for the Chinara spring (JKA) and Khurmal sulfuric spring (Jurassic rocks) respectively.

For deep wells the minimum was 4.4 ppm for the Halabja well (AIA), and the maximum was 44 ppm for a well drilled in the industrial area (AIA) south of Sulaimani city

For shallow wells the minimum concentration of Mg ion was 2.4 ppm in Majeed Beg in the north part of Sulaimani city, and the maximum was 45 ppm in Dolash south of Said Sadiq town. The impact of urbanization on magnesium ion concentrations is observed when samples from the north and northeastern part of the city of Sulaimani are compared with those located in the south and south east part of it (Fig.5.4)

- Sodium (Na^{+})

Concentration of sodium ions in the water samples of the studied area ranged between 1.7 and 22 ppm for spring water samples; the minimum concentration was for the Zalim Spring (TKA) and the maximum was for the Nawe spring (CFA), but an exceptionally high concentration of Na of 84 ppm was recorded for the Khurmal acidic spring.

The highest concentration of Na ion in deep wells was 95 ppm recorded for the Kani Goma well (AIA) (south east of Sulaimani, which is a more vulnerable area for the impact of sewage infiltration and agricultural activities). The lowest concentration was for the Hozekhwaja well (JKA) in the Galal valley (SB4), which is more likely attributable to the lithology of Jurassic rocks which comprise the main aquifer. Relatively, the high hydraulic gradient in that area might minimize the residence time of groundwater and consequently decrease the hydrochemical reactions.

For shallow wells, a relatively high concentration in the range of 40-50 ppm was recorded for wells more affected by agricultural activities particularly in the areas of SB3 and SB4, while the lowest concentration clustered in recharging areas and rural areas.

More than 50ppm sodium in the presence of suspended matter causes foaming which accelerates scale formation and corrosion in boilers. Moreover, high sodium concentration in drinking water may be a health hazard to those suffering from high blood pressure or cardiovascular or kidney diseases. (Household water Quality, 2002).

- Potassium (K^+)

The concentration of potassium in the water samples of the studied area ranged between 0-1 ppm; its highest values of 6 ppm appeared in the Khurmal sulfuric spring. For deep wells the range was 0 to 2.1 ppm. In addition, a high concentration of K ions was recorded in wells drilled in JKA in the Galal valley; some wells drilled in AIA influenced by urbanization south of Sulaimani city presented a high concentration compared to of other wells.

5.1.2 Anions

- Bicarbonates (HCO_3^{2-})

Since the pH values of the groundwater samples of the study basin are more than 4.5 and less than 8.2, their alkalinity is due to bicarbonate only (Davis and De Weist (1966) and Abawi and Hasan (1990)).

Bicarbonate concentrations in the water samples of the studied area ranged between 55 and 380 ppm; the lowest concentration was for a well in Halabja (AIA) and the highest value was for the water sample of Awal well (AIA) south of Sulaimani.

For spring water samples the lowest concentration of bicarbonate is for the Qawella spring (JKA) in the Galal valley, while the Khurmal sulfuric spring contains 400 ppm of bicarbonate.

The lowest concentration of bicarbonate anion in the shallow wells samples was in Razianai Khwaroo which was drilled in TAT between Arbat and Sulaimani, while all the other shallow wells were drilled in AIA; the highest concentration of bicarbonate was in the sample taken from the Qumash shallow well south of Said Sadiq.

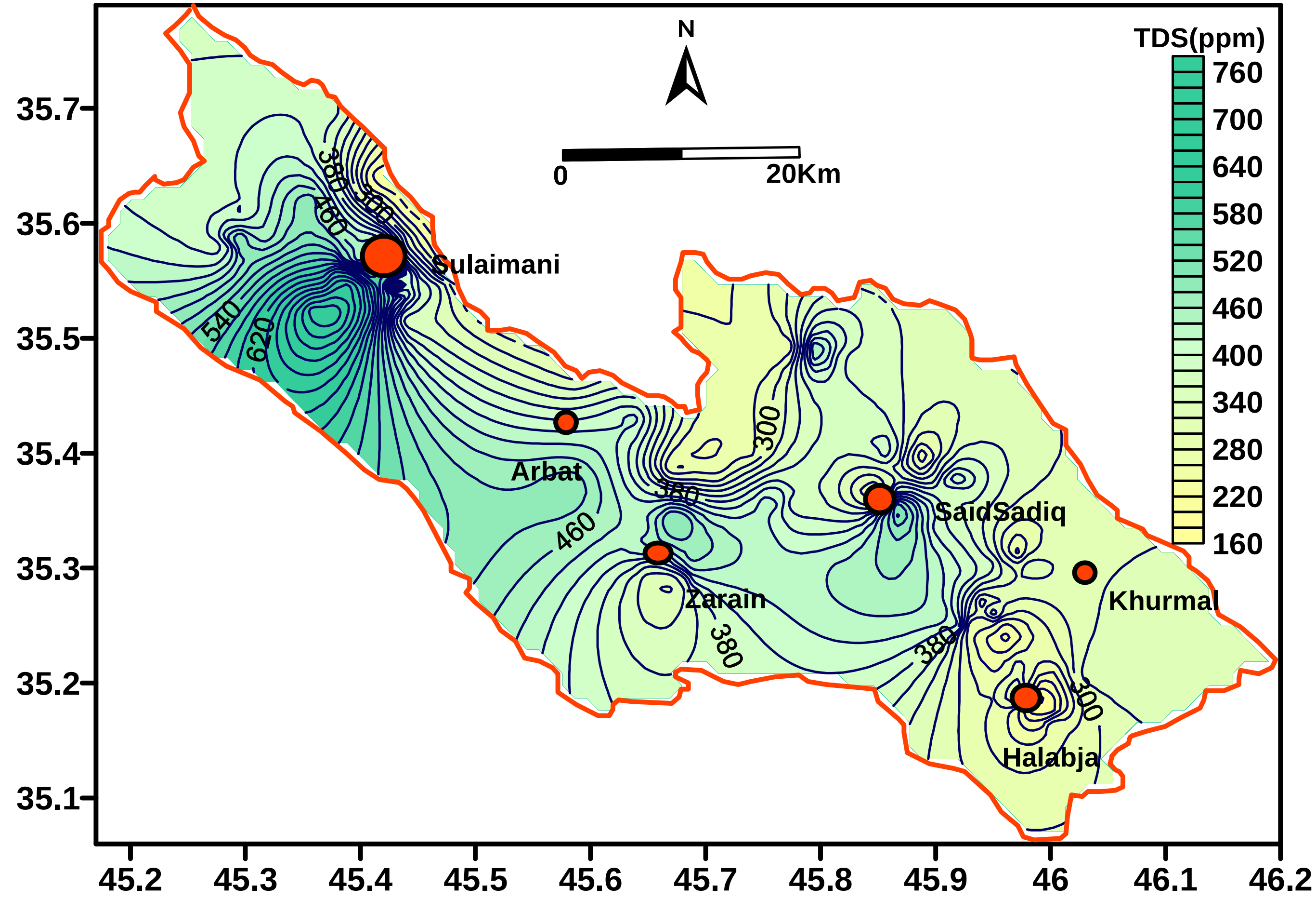

Fig.5.1 Iso-TDS map of water samples of deep wells in the basin

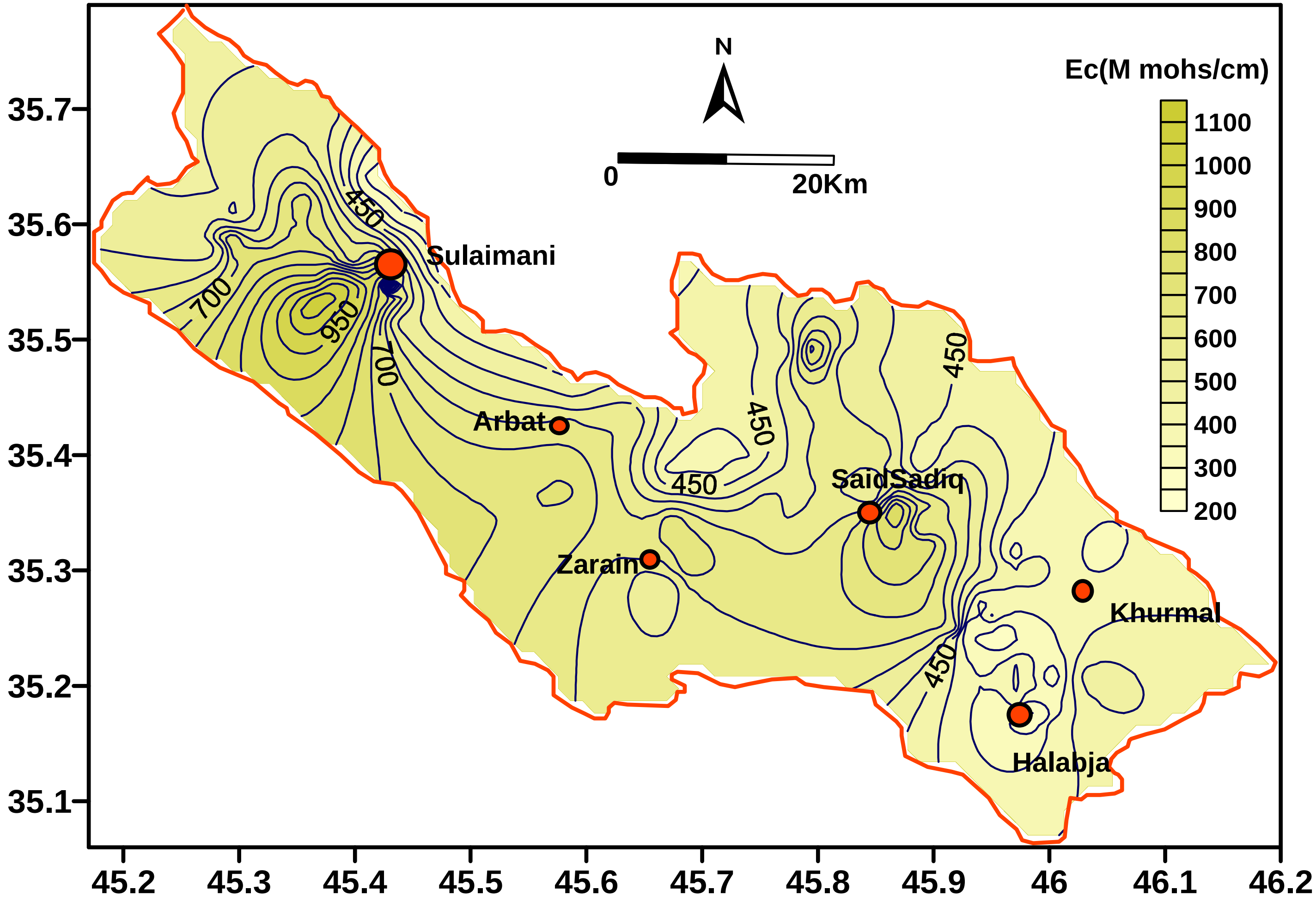

Fig.5.2 Iso-EC map of water samples of the deep wells in the studied basin.

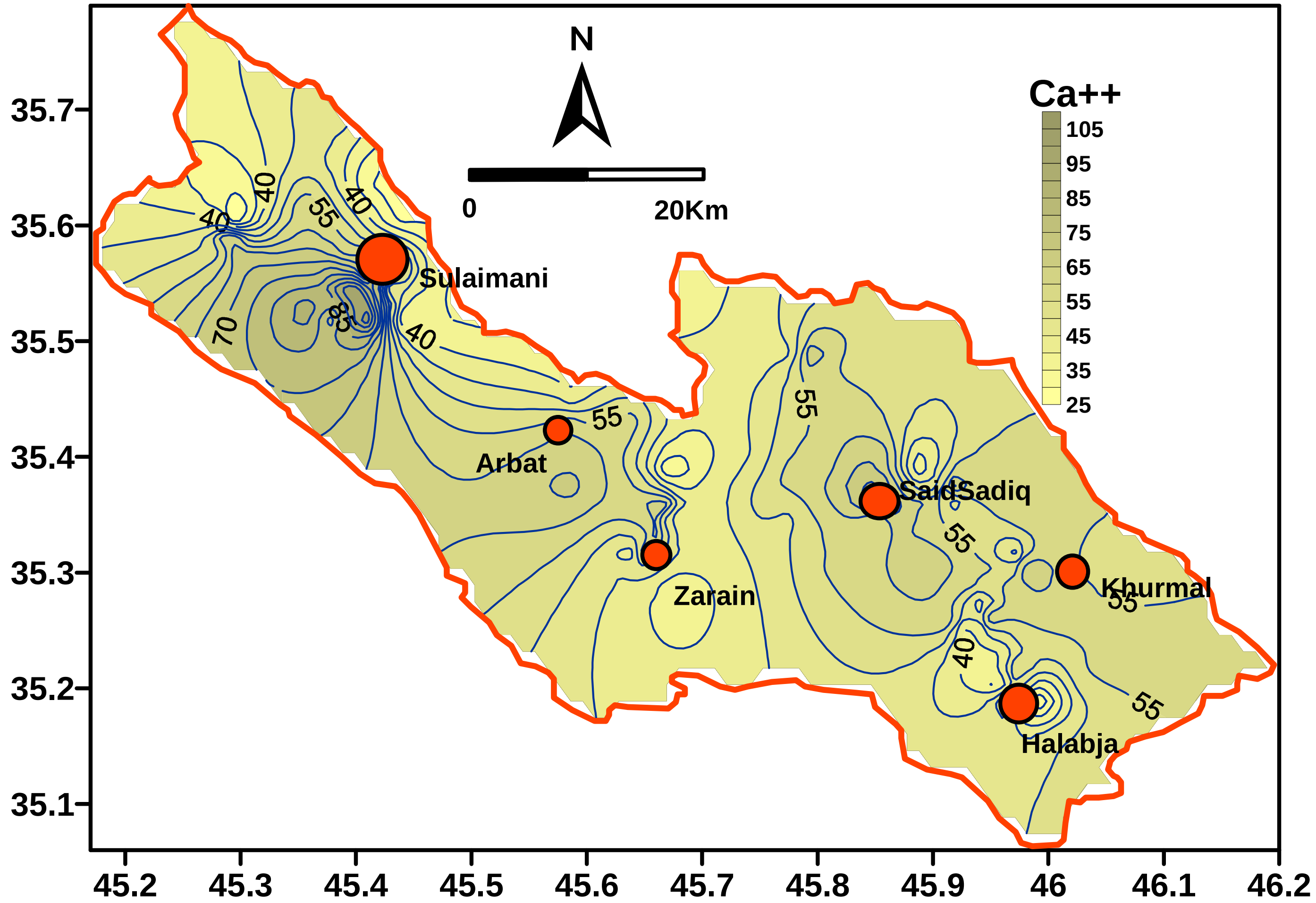

Fig.5.3 Iso-concentration map of calcium cation in deep wells in Sharazoor- Piramagroon basin.

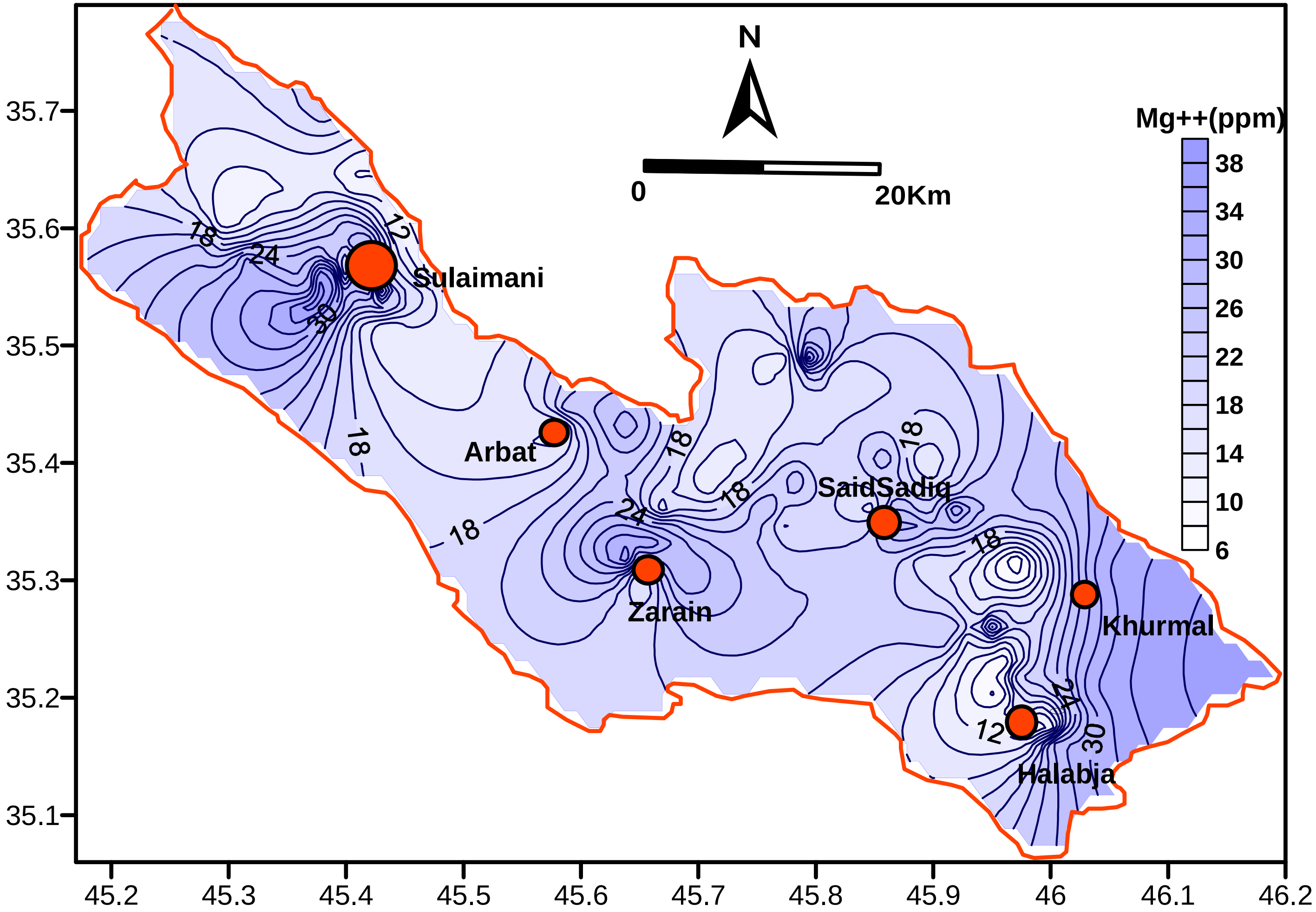

Fig.5.4 Iso-concentration map of Mg^{2+} in the Sharazoor - Piramagroon basin.

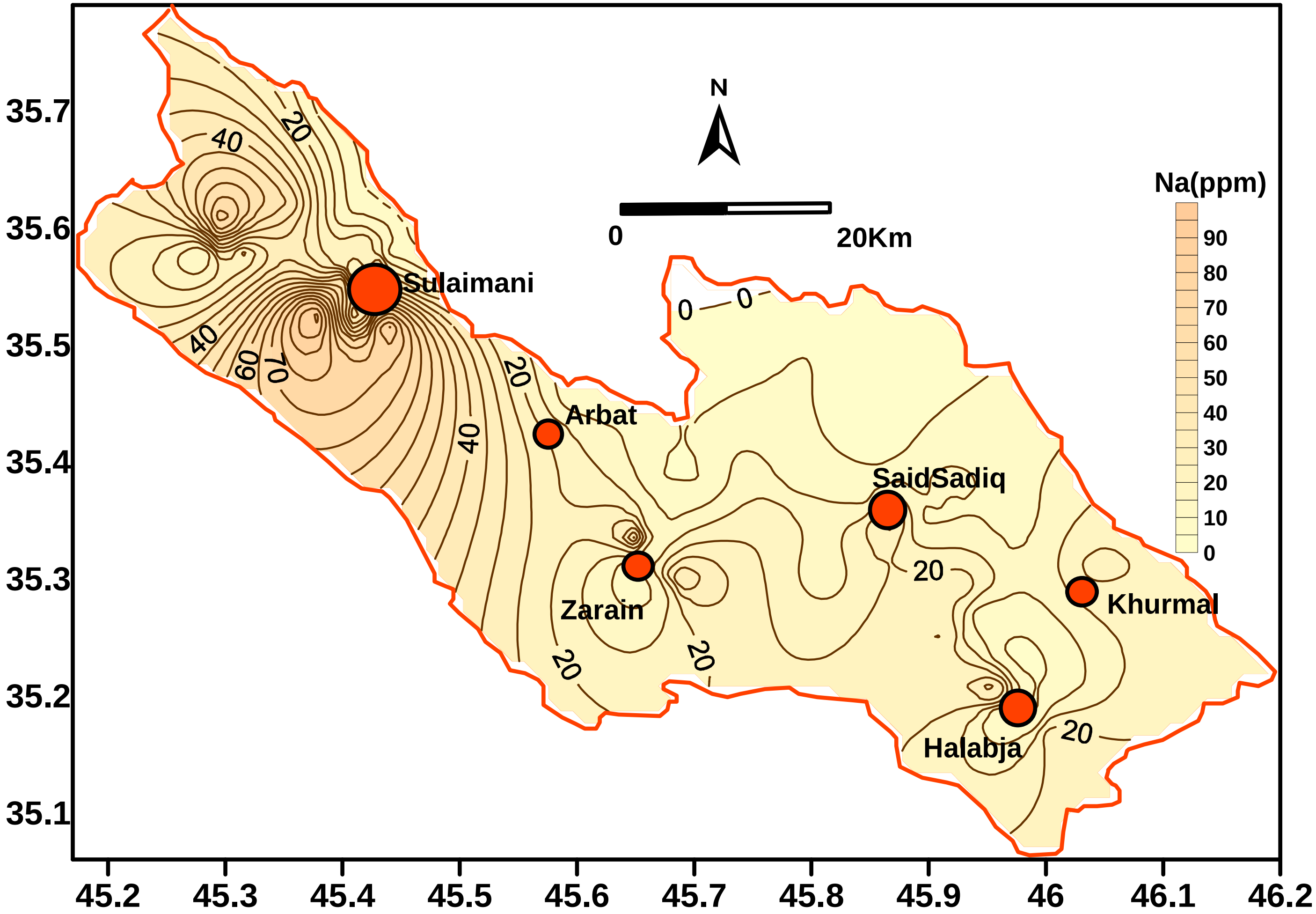

Fig.5.5 Iso-Concentration map of Na^{+} for deep wells in the studied are

It is obvious from Fig. 5.6 that the highest positive anomalies were in the south of the city of Sulaimani and around Arbat, Zarain and Said Sadiq towns. These high values clustered around the main sewage channel; also, the concentration of bicarbonate ion increases in the groundwater flow direction, which indicates the effect of urbanization on the water quality.

- Sulfates ($SO4^{2-}$)

Sulfate concentration in the spring water of the study area ranged between 10 and 110 ppm; the highest value was for the Qawella spring (SB3), which is a very low discharging one issuing from JKA in the Galal valley. The Khurmal sulfuric spring was excluded from this range as it has a sulfate concentration of 246 ppm. The lowest concentration was for water samples from the Jomarase spring issuing from TKA and the Kamalani Zhoro spring (SB2) issuing from SDA.

For the deep wells, sulfate concentration was in the range of 2 to 180 ppm; the highest concentration was in two wells and was most probably attained from agricultural fertilizers and sewage infiltration as they are located in the southern part of Sulaimani city where all sewage channels connecting to the Tanjero river and used as irrigation waters are. The wells drilled in JKA in the Galal valley show a relatively high concentration of $SO_{4.}$

For shallow wells the lowest concentration was recorded for AIA in Setalani Zhoro village (SB2) which is a rural area far from most human activities. The highest concentration of sulfate anion was in the shallow well in Mwani Kon (SB3) village; this high value was most probably gained from agricultural, human and livestock activities beside open sewage channels. Similar to this village, other shallow wells drilled in areas with similar factors as impacts gained relatively high sulfate concentrations.

In general, except for the relatively high concentration of SO_4 in JKA which most likely comes from the water bearing layers of Jurassic, the rest of the high content of this anion has been attained from external sources or anthropogenic sources.

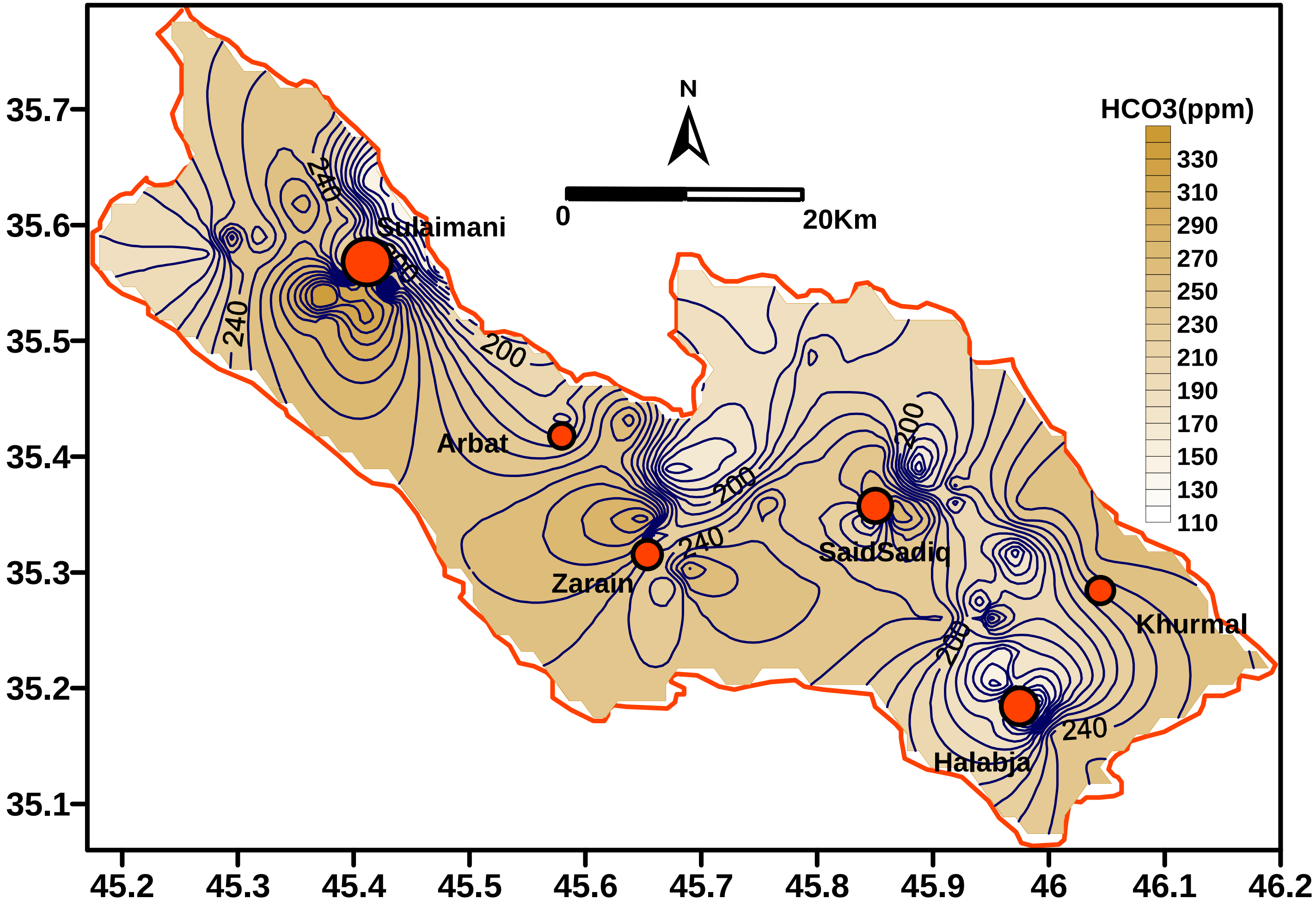

Fig.5.6 Iso-Concentration map of bicarbonate of deep wells in the study area

Table 5.3 The average, maximum and minimum concentrations of the major cations of the groundwater samples from the dominant type of aquifers, Oct. 2005- Sharazoor-Piramagroon basin.

		Average ,maximum and minimum values of hydrochemical cations of different aquifers in the basin												
Aquifer	Stat.Term	Ca++	Ca++	Ca++	Mg++	Mg++	Mg++	Na+	Na+	Na+	K+	K+	K+	SUM
		ppm	epm	epm%	ppm	epm	epm%	ppm	epm	epm%	ppm	epm	epm%	epm
TKA- Springs	Average	55.2	2.8	74.6	7.0	0.6	15.9	4.1	0.3	9.2	0.6	0.0	0.4	3.7
	Max	74.0	3.7	85.0	14.0	1.2	30.6	6.0	0.5	13.2	0.7	0.0	0.5	4.4
	Min	42.0	2.1	55.8	2.4	0.2	5.3	1.7	0.1	4.5	0.2	0.0	0.2	3.1
CKFA- Springs	Average	70.7	3.5	74.0	10.6	0.9	17.4	5.0	0.4	8.3	0.6	0.0	0.3	4.8
	Max	82.0	4.1	84.4	19.0	1.6	26.5	10.0	0.8	13.9	0.9	0.0	0.4	5.9
	Min	55.0	2.8	59.3	6.0	0.5	10.4	2.5	0.2	4.6	0.4	0.0	0.2	3.8
JKA- Springs	Average	73.5	3.7	66.8	17.0	1.4	25.2	5.9	0.4	7.8	0.6	0.0	0.2	5.5
	Max	95.0	4.8	81.4	30.0	2.5	36.3	8.0	0.6	9.7	1.0	0.0	0.4	6.8
	Min	52.0	2.6	57.4	6.0	0.5	10.0	3.6	0.3	6.1	0.0	0.0	0.0	4.2
CKFA- Deep wells- Balambo	Average	64.0	3.2	61.7	20.1	1.7	32.2	7.1	0.3	5.9	0.4	0.0	0.2	5.2
	Max	78.2	3.9	70.0	24.0	2.0	37.6	10.2	0.4	7.9	1.3	0.0	0.6	5.6
	Min	56.0	2.8	56.8	14.6	1.2	21.5	4.0	0.2	3.3	0.0	0.0	0.0	4.6
CKFA- Deep wells- Kometan	Average	61.6	3.1	57.1	17.7	1.5	28.3	18.3	0.8	14.3	0.9	0.0	0.4	5.4
	Max	110.0	5.5	69.2	25.0	2.1	42.4	45.0	2.0	32.7	1.8	0.0	0.6	7.9
	Min	42.0	2.1	48.3	12.0	1.0	16.6	5.0	0.2	6.6	0.0	0.0	0.0	3.3
JKA- Deep wells	Average	55.0	2.8	59.9	20.4	1.7	35.0	4.4	0.2	4.2	1.6	0.0	0.9	4.7
	Max	64.0	3.2	64.8	32.8	2.7	43.9	6.1	0.3	5.5	2.1	0.1	1.5	6.1
	Min	44.0	2.2	52.1	13.4	1.1	31.2	2.6	0.1	2.7	0.8	0.0	0.3	3.5
CFA- Springs	Average	52.3	2.6	63.2	14.8	1.2	27.7	8.9	0.4	8.8	0.4	0.0	0.3	4.2
	Max	76.0	3.8	83.5	33.0	2.7	42.2	22.0	1.0	14.9	0.7	0.0	0.5	6.4
	Min	39.0	2.0	42.7	7.0	0.6	12.7	3.8	0.2	3.6	0.0	0.0	0.0	3.4

AIA- Springs	Average	52.3	2.6	60.0	18.7	1.5	33.2	7.3	0.3	6.4	0.6	0.0	0.4	4.5
	Max	68.0	3.4	77.9	38.0	3.1	48.0	20.0	0.9	13.4	0.9	0.0	1.0	6.5
	Min	32.0	1.6	38.4	6.5	0.5	13.9	2.0	0.1	3.2	0.0	0.0	0.0	2.3
AIA-Deep Wells	Average	53.0	2.6	53.3	20.7	1.7	33.0	17.6	0.8	13.5	0.3	0.0	0.1	5.1
	Max	100.0	5.0	76.6	44.0	3.6	51.5	95.0	4.1	43.8	2.1	0.1	0.7	11.0
	Min	23.0	1.2	33.5	4.4	0.4	13.9	3.0	0.1	4.5	0.0	0.0	0.0	2.1
TAT Springs	Average	41.0	2.1	66.0	7.5	0.6	20.8	9.0	0.4	12.6	0.8	0.0	0.7	3.1
	Max	50.0	2.5	70.0	8.0	0.7	25.5	11.0	0.5	13.4	0.9	0.0	0.9	3.6
	Min	32.0	1.6	61.9	7.0	0.6	16.1	7.0	0.3	11.8	0.7	0.0	0.5	2.6
TAT -Deep Wells	Average	48.7	2.4	50.3	18.6	1.5	31.3	22.2	1.0	18.2	0.3	0.0	0.2	4.9
	Max	85.0	4.3	63.0	35.0	2.9	47.8	85.0	3.7	60.8	1.0	0.0	0.6	7.6
	Min	24.0	1.2	23.3	8.6	0.7	15.0	5.0	0.2	6.8	0.0	0.0	0.0	2.5
Shallow wells – SB1	Average	75.6	3.8	64.8	15.2	1.3	23.2	14.9	0.6	11.7	0.7	0.0	0.3	5.7
	Max	153.0	7.7	91.0	25.0	2.1	47.1	30.0	1.3	25.2	2.0	0.1	1.1	11.0
	Min	28.0	1.4	47.3	2.4	0.2	4.4	3.6	0.2	3.3	0.0	0.0	0.0	2.5
Shallow wells- SB2	Average	49.0	2.4	55.6	17.0	1.4	31.4	13.3	0.6	12.9	0.3	0.0	0.2	5.7
	Max	85.0	4.3	89.3	30.0	2.5	53.5	38.0	1.7	29.6	1.4	0.0	0.7	11.0
	Min	27.0	1.4	39.0	2.7	0.2	6.0	4.0	0.2	4.1	0.0	0.0	0.0	2.5
Shallow wells – SB3	Average	66.1	3.3	52.2	24.0	2.0	31.0	24.0	1.0	16.5	1.0	0.0	0.4	6.3
	Max	90.0	4.5	64.6	45.0	3.7	50.3	50.0	2.2	29.5	4.0	0.1	1.4	9.0
	Min	35.0	1.8	36.6	12.0	1.0	19.6	5.5	0.2	4.9	0.0	0.0	0.0	3.8
Shallow wells – SB4	Average	51.7	2.6	50.4	13.7	1.1	21.1	33.0	1.4	28.0	0.8	0.0	0.4	5.2
	Max	67.0	3.4	62.6	19.0	1.6	25.8	48.0	2.1	34.4	1.0	0.0	0.5	6.1
	Min	40.0	2.0	39.6	8.0	0.7	16.2	19.0	0.8	15.4	0.7	0.0	0.3	4.1

Table 5.4 The average, maximum and minimum concentrations of the major anions for groundwater samples of the dominant aquifer types in Sharazoor –Piramagroon basin

		Average ,maximum and minimum values of hydrochemical anaions of different aquifers in the basin												
Aquifer	Statistical term	SO4=	SO4=	SO4=	Cl-	Cl-	Cl-	$HCO3^{=}$	$HCO3^{=}$	HCO3=	NO3=	NO3=	NO3=	SUM
		ppm	epm	%epm	ppm	epm	%epm	ppm	epm	%epm	ppm	epm	%epm	epm
TKA-Springs	Average	26.6	0.5	15.0	12.1	0.3	9.4	164.6	2.7	75.6	0.0	0.0	0.0	3.6
	Max	60.0	1.2	28.8	17.7	0.5	14.0	190.0	3.1	82.3	0.0	0.0	0.0	4.3
	Min	10.0	0.2	5.8	7.0	0.2	7.6	118.0	1.9	61.3	0.0	0.0	0.0	2.6
CKFA-Springs	Average	27.6	0.6	11.2	16.5	0.5	9.6	230.6	3.8	79.2	0.0	0.0	0.0	4.8
	Max	56.0	1.2	20.2	24.0	0.7	13.4	265.0	4.3	86.3	0.0	0.0	0.0	5.9
	Min	14.0	0.3	7.0	8.0	0.2	5.2	177.0	2.9	70.9	0.0	0.0	0.0	3.5
JKA-Springs	Average	64.3	1.3	24.8	19.9	0.6	10.3	222.8	3.7	64.9	0.0	0.0	0.0	5.5
	Max	110.0	2.3	52.5	28.0	0.8	13.3	340.0	5.6	78.2	0.0	0.0	0.0	7.2
	Min	30.0	0.6	12.3	14.5	0.4	6.7	100.0	1.6	38.0	0.0	0.0	0.0	4.3
CKFA-Deep wells-Balambo	Average	31.8	0.7	12.5	18.1	0.5	9.6	244.5	4.0	76.5	4.5	0.1	1.3	5.2
	Max	33.0	0.7	14.4	24.0	0.7	12.8	265.0	4.3	80.2	8.0	0.1	2.3	5.6
	Min	30.0	0.6	11.7	9.0	0.3	5.4	230.0	3.8	74.0	0.0	0.0	0.0	4.7
CKFA-Deep wells-Kometan	Average	44.3	0.9	14.8	19.7	0.6	9.4	243.8	4.0	74.0	4.9	0.1	1.8	5.5
	Max	104.0	2.1	25.6	40.0	1.1	15.3	330.0	5.4	81.6	10.0	0.2	4.6	8.3
	Min	12.0	0.2	7.2	7.0	0.2	5.6	170.0	2.8	60.3	0.0	0.0	0.0	3.4
JKA-Deep wells	Average	80.6	1.7	29.1	14.0	0.4	8.0	199.8	3.3	62.9	0.0	0.0	0.0	5.3
	Max	148.0	3.0	44.7	19.5	0.5	11.4	213.0	3.5	71.8	0.0	0.0	0.0	6.8
	Min	34.1	0.7	17.1	9.9	0.3	4.1	180.0	3.0	51.2	0.0	0.0	0.0	4.1
CFA-Springs	Average	23.9	0.5	11.2	17.2	0.5	11.4	192.4	3.2	76.0	4.3	0.1	1.4	4.2
	Max	54.0	1.1	18.1	34.0	1.0	15.6	245.0	4.0	86.7	22.3	0.4	5.8	6.1
	Min	14.0	0.3	7.5	9.5	0.3	5.8	158.0	2.6	60.5	0.0	0.0	0.0	3.4
Al A-Spr ing	Average	31.4	0.6	13.8	20.9	0.6	12.6	207.9	3.4	73.5	0.5	0.0	0.2	4.7

	Max	72.0	1.5	33.2	42.0	1.2	25.3	310.0	5.1	86.3	6.0	0.1	2.0	6.9
	Min	10.0	0.2	4.4	7.0	0.2	4.9	105.0	1.7	58.8	0.0	0.0	0.0	2.4
AIA- Deep Wells	Average	44.0	0.9	15.9	21.8	0.6	10.5	214.6	3.5	69.3	13.6	0.2	4.3	5.3
	Max	180.0	3.7	34.9	72.0	2.0	25.4	380.0	6.2	88.9	43.1	0.7	15.2	10.7
	Min	2.0	0.0	1.5	3.6	0.1	2.7	88.5	1.5	43.3	0.0	0.0	0.0	2.4
TAT Springs	Average	36.0	0.7	22.7	27.0	0.8	22.7	110.0	1.8	54.6	0.0	0.0	0.0	3.3
	Max	37.0	0.8	25.4	33.0	0.9	25.7	120.0	2.0	54.8	0.0	0.0	0.0	3.6
	Min	35.0	0.7	19.9	21.0	0.6	19.8	100.0	1.6	54.4	0.0	0.0	0.0	3.0
TAT Deep Wells	Average	36.7	0.8	14.4	23.2	0.7	12.1	221.3	3.6	72.1	5.2	0.1	1.4	5.1
	Max	88.0	1.8	23.9	70.0	2.0	31.7	330.0	5.4	87.8	20.0	0.3	5.8	7.7
	Min	10.0	0.2	6.7	7.0	0.2	4.3	120.0	2.0	50.9	0.0	0.0	0.0	2.7
Shallow wells - SB1	Average	68.8	1.4	25.2	30.9	0.9	14.5	207.4	3.4	58.9	5.0	0.1	1.4	5.8
	Max	130.0	2.7	49.6	88.0	2.5	31.5	355.0	5.8	79.2	18.0	0.3	6.0	10.5
	Min	17.0	0.3	8.1	8.0	0.2	4.2	65.0	1.1	35.8	0.0	0.0	0.0	2.7
Shallow wells- SB2	Average	48.9	1.0	22.3	14.3	0.4	8.8	186.4	3.1	67.4	4.2	0.1	1.5	4.5
	Max	122.0	2.5	67.9	29.0	0.8	16.6	275.0	4.5	88.2	25.0	0.4	8.8	7.7
	Min	12.9	0.3	7.3	4.0	0.1	2.7	55.0	0.9	27.0	0.0	0.0	0.0	2.1
Shallow wells -SB3	Average	83.4	1.7	27.0	25.9	0.7	11.5	222.8	3.7	56.6	20.5	0.3	4.9	6.4
	Max	160.0	3.3	53.6	38.0	1.1	16.8	378.0	6.2	80.4	70.0	1.1	17.8	9.4
	Min	38.0	0.8	10.1	12.0	0.3	5.4	117.0	1.9	32.6	0.0	0.0	0.0	4.1
Shallow wells – SB4	Average	79.7	1.6	30.3	30.0	0.8	15.4	176.3	2.9	49.9	16.0	0.3	4.4	5.6
	Max	94.0	1.9	42.6	32.0	0.9	19.9	226.0	3.7	57.3	25.0	0.4	6.8	6.5
	Min	65.0	1.3	22.7	28.0	0.8	13.1	98.0	1.6	35.4	6.0	0.1	2.1	4.5

- Chloride (Cl^-)

Chloride concentration in the groundwater samples of the studied area ranged between 3.6 and 88 ppm. The highest concentration was for the Wulluba well (AIA), which most likely reached this concentration from sewage water as the sewage channels of Sulaimani pass close to this area. Mustafa (2006) mentioned that the source of chloride in the Wulluba area is domestic rather than agricultural. The lowest concentration was for the wells penetrating AIA in the Sirwan area (SB4). The highest anomalies appeared in the south part of the urban area in SB1 and SB3, (Fig.5.8).

The Khurmal sulfuric spring shows the highest value of chloride concentration (202ppm). This high value more likely attained through deep geo-hydrochemical processes which have been taking place in the related Jurassic aquifer. Due to the variation in geological formations and the degree of urbanization in the basin, no clear relationship between chloride change and the general flow direction of groundwater could be observed (Foster and Lawrence, 1995).

- Nitrate (NO_3)

The nitrate concentration in the studied area ranged between zero and 70 pp;, the highest concentration was for hand-dug wells through AIA in Malawais village .The majority of the spring, deep well and shallow well waters were relatively free from nitrate (or it was not detectable), which might be attributed to limited urbanization and human activities with regard to nitrate source, ,but most of the high nitrate concentrations were in the waters of shallow wells and in the areas of agricultural activities. The source most likely comes from fertilizer-amended farm lands. Therefore, the urbanization processes can cause radical changes in the groundwater quality, and pollution of groundwater, and high concentrations of nitrates can be used as an indicator of the impact of urbanization on groundwater quality (Wilkinson, 1993).

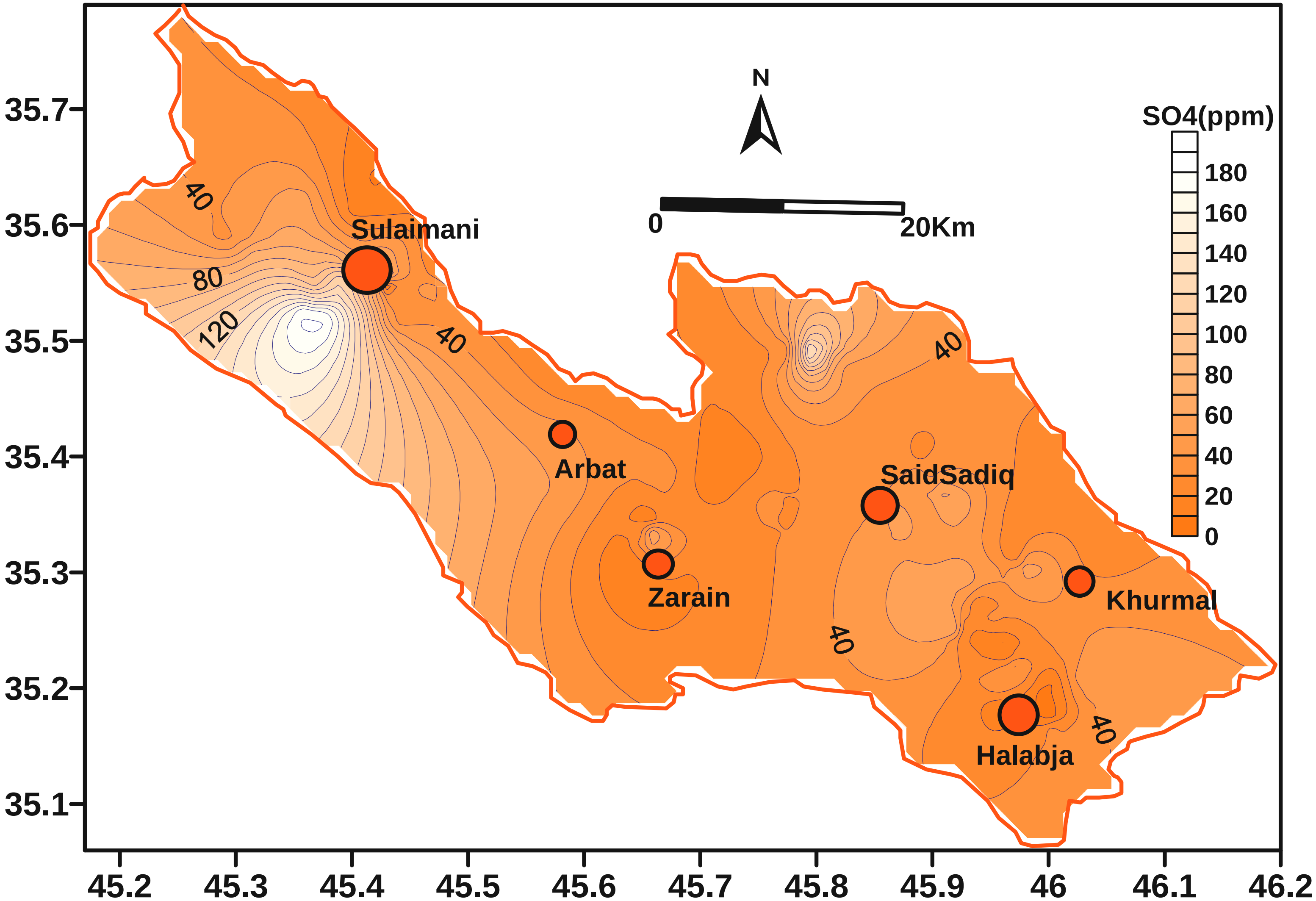

Fig.5.7. Iso-Concentration map of SO_4^{2-} in deep well water samples of the study area.

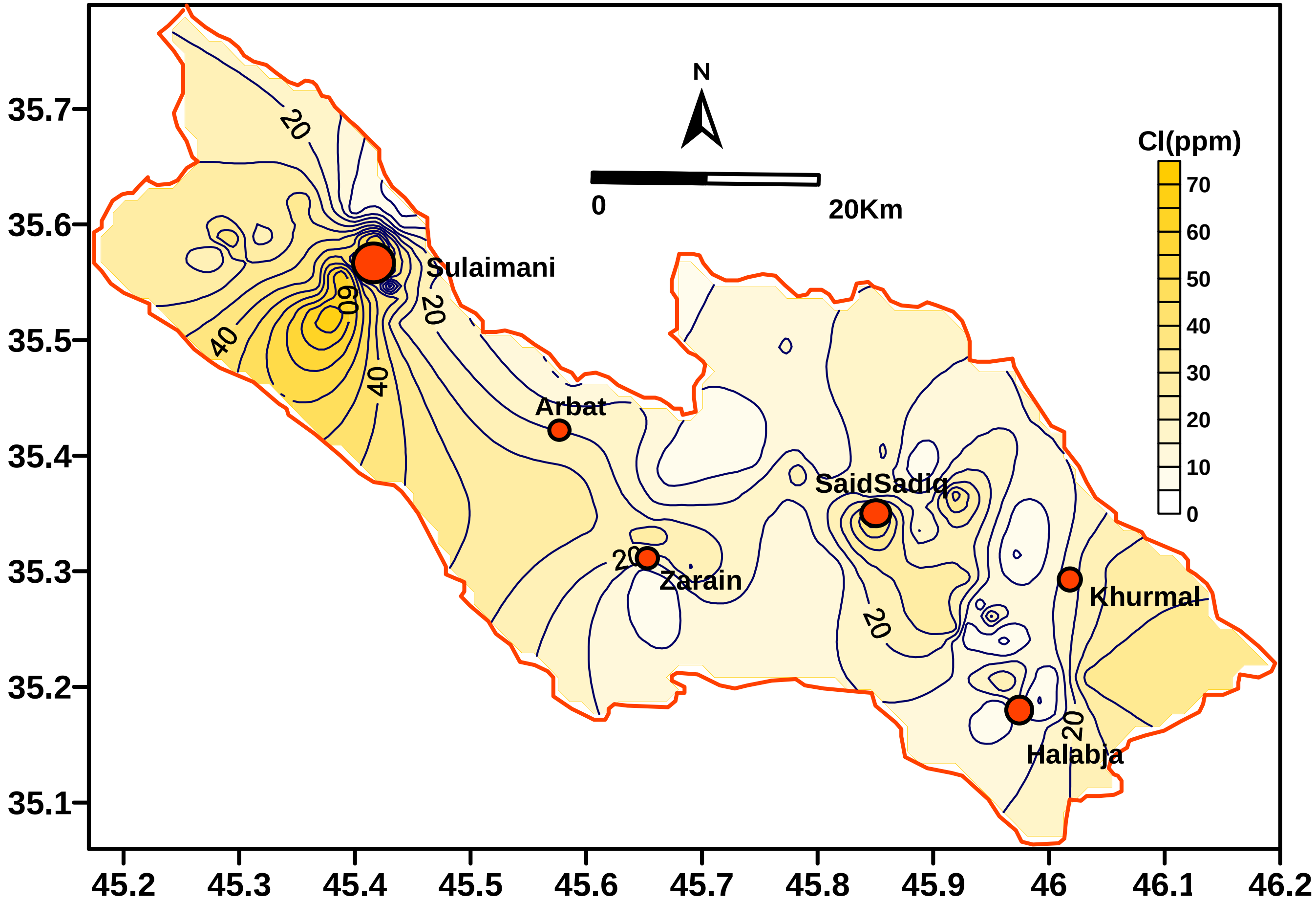

Fig.5.8. Iso-concentration map of chloride anion of deep well water samples

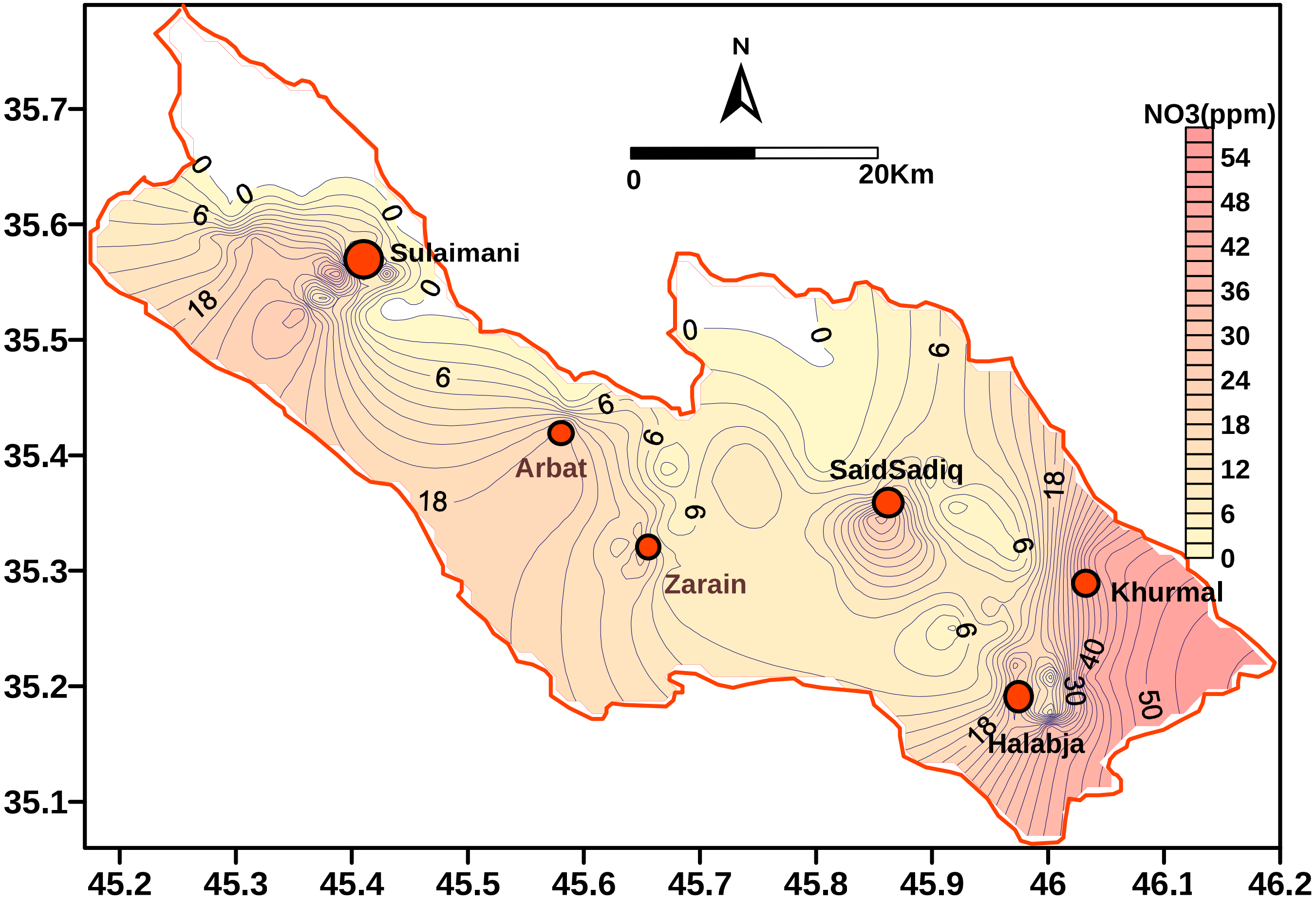

Fig.5.9. Iso-Concentration map of NO3⁼ for deep well water samples

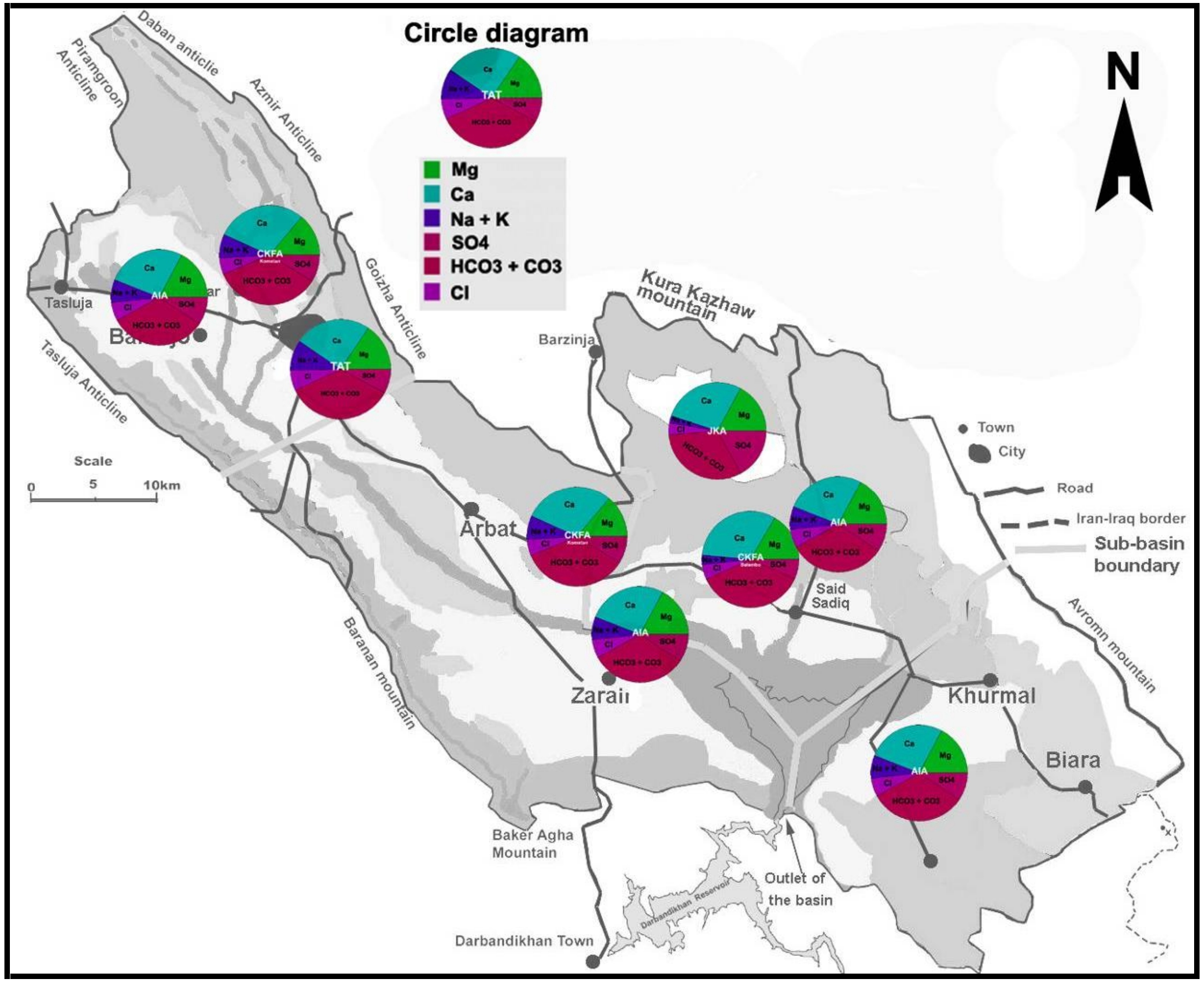

Fig.5.10. Circle diagram of the average values of groundwater chemistry of different types of aquifers in the Sharazoor - Piramagroon , October 2005, deep wells.

Table 5.5 The average, maximum and minimum values of some physical and hydrochemical parameters for the dominant aquifers in Sharazoor-Piramagroon basin.

Average, max. ,and minimum values of some physical and hydrochemical parameters for different aquifers in the basin								
Aquifer	Statistical term	Temp.ºC	Ec	TDS	pH	TH	SAR	%Na
TKA-Springs	Average	18.6	353.8	283.4	7.6	166.6	0.4	9.5
	Max	20.0	414.0	305.0	7.8	205.4	0.5	13.7
	Min	16.0	326.0	247.0	7.4	146.6	0.2	4.7
CKFA-Springs	Average	19.8	472.3	366.9	7.2	220.0	0.2	4.9
	Max	20.5	542.0	455.0	7.4	268.8	0.4	8.2
	Min	17.0	400.0	270.0	7.1	166.1	0.1	2.7
JKA-Springs	Average	20.5	553.3	420.7	7.5	253.5	0.2	5.1
	Max	21.0	663.0	530.0	8.0	318.2	0.3	7.8
	Min	20.0	455.0	295.0	7.1	195.7	0.2	3.5
CKFA-Deep wells-Balambo	Average	20.0	545.5	346.8	7.4	242.8	0.2	6.1
	Max	21.0	590.0	403.0	7.5	255.1	0.3	8.5
	Min	19.5	485.0	247.0	7.1	213.9	0.1	3.4
CKFA-Deep wells-Kometan	Average	20.5	593.4	425.0	7.4	226.6	0.5	14.6
	Max	21.0	845.0	620.0	7.6	340.5	1.4	33.3
	Min	20.0	400.0	275.0	7.1	154.3	0.2	6.6
JKA-Deep wells	Average	19.5	620.3	377.8	7.6	221.5	0.1	5.1
	Max	20.0	820.0	488.0	7.9	294.8	0.2	6.3
	Min	19.0	480.0	266.0	7.4	164.8	0.1	4.0
CFA-Springs	Average	20.0	478.1	324.6	7.2	191.4	0.4	9.1
	Max	21.0	597.0	426.0	7.8	273.1	0.8	15.1
	Min	19.0	391.0	270.0	6.9	146.8	0.2	3.8
AIA-Springs	Average	20.5	520.5	377.2	7.3	219.4	0.3	7.2
	Max	21.0	630.0	510.0	7.7	281.2	0.7	13.6
	Min	20.0	355.0	307.0	7.1	176.6	0.1	3.5
AIA-Deep Wells	Average	20.4	544.4	380.1	7.4	218.9	0.5	14.1
	Max	22.0	1100.0	755.0	8.4	395.8	2.4	43.8
	Min	19.0	215.0	177.0	6.8	100.0	0.1	4.5
TAT Springs	Average	21.3	335.0	239.0	7.6	118.4	0.6	18.5
	Max	21.5	360.0	260.0	7.8	153.7	0.7	23.1
	Min	21.0	310.0	218.0	7.5	83.2	0.5	13.9
TAT Deep Wells	Average	20.7	551.4	385.2	7.6	197.8	0.7	18.3
	Max	21.0	940.0	590.0	7.9	318.8	3.1	60.8
	Min	20.0	288.0	214.0	7.0	101.1	0.2	6.8
AIA Shallow wells -SB1	Average	23.6	657.3	451.8	7.4	251.2	0.4	12.0
	Max	25.0	1200.0	885.0	7.8	480.8	0.9	25.2
	Min	22.0	260.0	189.0	6.8	98.7	0.1	3.9

AIA Shallow wells-SB2	Average	22.8	484.0	340.7	7.5	192.2	0.4	13.0
	Max	24.0	850.0	590.0	8.0	266.0	1.1	29.6
	Min	21.0	220.0	154.0	6.8	108.6	0.1	4.3
AIA Shallow wells -SB3	Average	23.2	676.7	478.4	7.3	263.7	0.7	16.9
	Max	25.0	970.0	680.0	7.8	399.9	1.4	29.9
	Min	22.0	484.0	320.0	7.0	149.1	0.2	4.9
Shallow wells -SB4	Average	23.7	595.7	406.3	7.3	185.3	1.1	28.4
	Max	24.0	682.0	459.0	7.4	224.9	1.5	34.7
	Min	23.0	495.0	325.0	7.3	132.8	0.6	15.9

5.1.3 Trace elements

Water samples from 26 deep wells, 25 shallow wells, and 13 large springs were analyzed for the trace elements (Cd, Zn, Cu, Cr, Ni, and Pb). The average, maximum and minimum values of these results are shown in tables 5.6 and 5.7.

Cd - The concentration of cadmium in the analyzed water samples of the study basin ranged between 0.002 - 0.019 ppm, with an average of 0.008 for deep wells, 0.004 for springs and 0.01 ppm for shallow wells. The level of cadmium in most of the tested groundwater samples shows a slightly higher concentration than the permissible level of 0.003 ppm according to WHO (2006) and IQS (1996); this is so especially in samples from the two wells penetrating AIA in the industrial area and Wulluba south of Sulaimani city. Pollution of groundwater in the area may result from a leakage of sewage waste water (Priestley, 2002)**.** Shallow wells (AIA) generally show a higher concentration of Cd compared to deep wells. This is attributed to the fact that shallower aquifers are more vulnerable to the impact of surface water or sewages wastewater infiltration particularly, because most of these wells are not protected and covered properly.

In general, TKA and CKFA aquifers show a lower content of Cd, while AIA and TAT contain a higher one. This is because these two latter aquifers are located more in the lower land areas and can be more easily contaminated by surface sources.

Ni- The concentration of Ni in the water samples ranges between 0.002 and 0.08 ppm. In general, the majority of the water samples are not contaminated with Ni, except, those exceeded the permissible level of 0.02 ppm recommended by(WHO, 2006; EU, 2004 and IQS, 1996. Deep wells from the industrial area and Kani Goma (south of

Sulaimani), and some wells in and around Said Sadiq, show a higher concentration of this element. These contaminations are restricted to the wells located in the highly urbanized areas and/or agricultural areas. Some shallow wells (AIA) are also contaminated by Ni. In general, all waters from CKFA, TKA, and JKA show Ni concentration within the permissible limit. Pollution of groundwater with Ni may result from a leakage of sewages (Alloway and Ayres, 1997).

Pb- The concentration of Pb in the water sample is in the range of 0.003 to 0.05ppm. Waters from deep wells in Kawchktash in AIA (SB3), three wells in TAT(SB1), and one in AIA (SB1), and shallow wells (AIA) in the wells of, Wulluba, Rapareen, and those in the industrial area (SB1), are slightly polluted with Pb as its concentration in these samples exceeds the recommended value for drinking, 0.01ppm according to WHO, (2006), EU, (2004) and IQs (1996).

Except the Greza spring, which shows slight contamination with Pb, all other springs show a permissible concentration of Pb.

Cu- The concentration of Cu for the water sample of the study area was in the range of 0.003 to 0.026 ppm. This means all water samples fall under the permissible limit with regard to copper concentration.

Zn- Zinc concentration in groundwater samples was in the range of 0.004 to 0.45 ppm. The water samples exceeding the recommended value in groundwater of 0.05 ppm according to WHO (2006) are as follows: the deep wells penetrating AIA in Gamesh Tapa, Nawgrdan, Kawchktash (SB3), the deep wells penetrating TAT and AIA in the urbanized and industrial area of Sulaimani (SB1) and shallow wells in the same locations of the industrial area and Wulluba (SB1), and south of Said Sadiq AIA. A few springs show slight contamination with Zn; they are Sarchinar, Kanipanka and Bawa Kochak springs.

Sewage pollution may be responsible for zinc pollution in some of the well waters mentioned above (Baptista et al, 2006). Re-used sewages used for irrigation and as fertilizers, are responsible for zinc pollution in other groundwater samples (Krishna and Govil, 2005; Callender and Rice, 2000), especially in waters of the Kani-Goma well.

Cr- Chromium contamination of soil and groundwater is a significant problem worldwide. The extent of this problem is due primarily to its use in numerous industrial processes (i.e., metal plating and alloying, leather tanning, wood treatment, chemical manufacturing), but also to its natural presence in rocks enriched in chromium (Kresic, 2007). Compared to the results of the contamination of soil and groundwater by industrial and mining practices, the naturally occurring concentrations of Cr in soil and groundwater are low, commonly less than 10 µg/l (Hem, 1989).

If the concentration of chromium exceeds 50 µg/l in drinking water, it becomes toxic and leads to lung and kidney cancers (Camacho and Armienta, 2000).

The concentration of Cr in the water samples of the study area is in the range of 0.015 to 0.29 ppm. Some deep wells penetrate either AIA or (AIA and TAT) slightly contaminated with chromium. The source of this contamination is more probably from mixing sewage water with groundwater, particularly for some household wells drilled in the newly expanded part of the city of Sulaimani, beside some source of waste industrials.

Out of 25 shallow wells tested, more than 15 are slightly contaminated with chromium. It is noticeable that most of these wells show a similar case of contamination with regard to other elements. Locations of these contaminated shallow wells confirm that the source of the contamination comes either from agricultural fertilizers (which sometimes, according to Qaragholi (1987) contain more than 600 ppm of chromium) or from sewages or industrial wastes. The reason can simply be attributed to the carelessness of the villagers and well-owners, non-proper cover and protection of the wells, and to the shallow groundwater in these areas.

All spring water from TKA, CKFA and JKA tested show a permissible concentration of chromium, as none of the spring water samples have chromium concentration of more than 0.05 ppm.

Table 5.6 The average, maximum and minimum value of some trace elements in the water samples of the study area.

Water samples	Values	Cd (ppm)	Ni (ppm)	Pb (ppm)	Cu (ppm)	Zn (ppm)	Cr (ppm)
Deep Wells	Average	0.008	0.016	0.011	0.009	0.076	0.04
	Max	0.060	0.070	0.050	0.026	0.450	0.09
	Min	0.002	0.004	0.003	0.003	0.010	0.02
Shallow Wells	Average	0.010	0.009	0.008	0.007	0.056	0.06
	Max	0.019	0.021	0.019	0.012	0.290	0.12
	Min	0.004	0.005	0.004	0.003	0.015	0.03
Springs	Average	0.004	0.005	0.006	0.008	0.034	0.04
	Max.	0.008	0.009	0.012	0.019	0.140	0.05
	Min.	0.002	0.003	0.003	0.004	0.004	0.03

Table 5.7 Concentration of some trace elements in the water samples taken from deep wells in the study basin.(October-2005).

Values	Cd (ppm)	Ni (ppm)	Pb (ppm)	Cu (ppm)	Zn (ppm)	Cr (ppm)	Aquifer Type
Average	0.003	0.006	0.006	0.010	0.056	0.017	CKFA
Max.	0.005	0.009	0.012	0.019	0.140	0.021	
Min	0.002	0.004	0.004	0.006	0.016	0.011	
Average	0.006	0.007	0.007	0.006	0.013	0.016	JKA
Max.	0.008	0.009	0.008	0.008	0.024	0.019	
Min	0.004	0.005	0.006	0.005	0.007	0.013	
Average	0.003	0.004	0.004	0.005	0.005	0.014	TKA
Max.	0.004	0.005	0.005	0.006	0.007	0.016	
Min	0.002	0.003	0.003	0.004	0.004	0.009	
Average	0.008	0.017	0.012	0.010	0.099	0.022	TAT
Max.	0.012	0.025	0.016	0.013	0.180	0.046	
Min	0.003	0.008	0.007	0.007	0.016	0.014	
Average	0.009	0.018	0.012	0.009	0.083	0.004	AIA
Max.	0.060	0.070	0.050	0.026	0.450	0.009	
Min	0.003	0.006	0.003	0.003	0.010	0.002	

5.1.4 Total Hardness (TH)

Todd (1980) and Letterman (1999) classified water according to TH into four categories. The calculated values of (TH) are shown in table 5.8.

The average value of TH in the analyzed water samples of the study area was in the range of 83ppm to 480ppm. The lowest value was in the Kahrezes and springs in TAT in SB1, while the highest TH values were in the shallow wells in AIA.

The lowest values of TH indicated near the recharge area, and the highest value determined for the water samples of shallow wells and hand dug wells south of the main cities and towns particularly in SB1 and SB3, indicate that, in addition to the obvious effect of sewerage channel on the TH values, the TH values increase with the direction of flow and with the increase of the impact of human activities in the cities The high value of TH in the southern part of Sulaimani city may be due to percolation of sewage and waste water to the groundwater as detected in the Wulluba and Groundwater directory unit wells. An exceptionally high TH value was in the Khurmal sulfuric spring (Jurassic aquifer) which is 693ppm, as well as in the Chinara spring from JKA in the Galal valley which is equal to 318ppm.

According to the classification of Detay (1997), and based on the French degree scale, the water samples of the study area are classified as follows:

Table 5.10 Water classes of the samples of the study area based on TH values.

Water Class	**TH (ppm)**		**Classification**		
	Letterman (1999)	**Todd (1980)**	**Springs**	**Deep Wells**	**Shallow wells**
Soft	**7- 75**	**0 - 75**			
Moderately Hard	**75-150**	**75-150**	**%11 of springs Chawtan (CFA), Zalim, Jomarase (TKA) Kahrezi Naqib(TAT) Average is TAT**	**%21 AIA in SB4, SB3 + TAT in SB1**	**%9 TAT and AIA, in SB1**
Hard	**150-300**	**150-300**	***All other samples Average is TKA, CKFA, JKA, CFA and AIA.***	**All other samples** ***As average CKFA(Balambo), CKFA(Kometan), JKA, AIA, TAT***	**All other samples** ***Average AIA in SB1,SB2,SB3,SB4***
Very Hard	**>300**	**>300**	**Khurmal acidic spring**		

Table 5.11 Hardness Classification of water samples and percentage of each class based on Detay (1997) classification

Water class	Detay(1997) French degree	% of Water samples Average values		
		Springs	Deep wells	Shallow wells
Very fresh	0º-7º	0%	0%	0%
Fresh	7º-14º	6.97% TAT	16.83%	10.44%
Moderately hard	14º-20º	48.83% TKA	23.78% TAT	26.86% AIA in SB4, SB2
Low hardness	20º-30º	37.2% AIA,CKFA JKA	51.48% CKFA (Balambo), CKFA (Kometan) JKA,AIA	41.8% AIA in SB3, SB1
Hard	30º-50º	4.65%	7.9%	20.9%
Very hard	>50º	2.3%		

As is clear from the above table, the fresh water is restricted to TAT spring waters, and to deep wells in TAT and CKFA drilled in rural regions near recharge areas north and northeast of Sulaimani. Some water samples taken from deep wells penetrating AIA near Halabja were also found to be fresh.

Hard water tends to originate in areas where thick top soil overlies limestone formations. Generally, the relatively high TH values of the groundwater samples in the study area are attributed to the carbonate type of lithology of both the recharging area and the water bearing units.

5.1.5 Biochemical Oxygen Demand (BOD_5)

Biological oxygen demand is the most important parameter used to assess the quality of water in terms of organic matter present in both suspended and dissolved form (Ahipathy and Puttaiah, 2006).

Samples from 11 deep wells, 11 shallow wells and 5 major Springs of Zalim, Qalabo, Sarchawi Saraw, Bestansur, and Sarchinar springs were taken for BOD_5 test (table 5.12). All the values of the springs and deep wells were exclusively in the range of (0-1) mg/l.

The BOD values of the shallow wells were in the range of 0.8 to 3.6 mg/l. One shallow well in Qumash village with 4.2 mg/l, one shallow well in Said Sadiq and Nawgrdan have BOD_5 values of 3.3 and 3.5 mg/l respectively, a shallow well in the industrial area south of Sulaimani, and Wulluba show BOD_5 values of 3.6 and 3.5mg/l respectively. The rest of the shallow water tested for BOD_5 s were less than 1.0mg/l. All the shallow wells are drilled in AIA.

According to the classification of Hynes (1974), the type of waters having BOD ≤ 1 are considered as very clean, those of BOD=2 as clean, while those BOD≥3<5 are considered as fairly clean.

5.1.6 Chemical Oxygen Demand (COD)

Chemical oxygen demand (COD) is the important parameter used to assess the quality of water regarding organic matter. Contamination of water can be classified depending on chemical oxygen demand value, according to (Swedish EPA, 2000) as in table 5.13:

All water samples were found not to be contaminated except shallow wells in Glazarda Shanadari in SB3, the industrial area of Sulaimani and Wulluba (SB1) which drilled in AIA since the COD values are all below the lower level of contamination.

Table 5.12 BOD_5 and COD values of water samples in the study area.
**** V.clean - very clean, F.clean -fairly clean, N.C.- not contaminated, L.C.- low level of contamination.***

Well or Spring No.	Aquifer type	BOD_5 (mg/l)	COD (mg/l)	Water Class and level of contamination
Sp7	TKA	0.48	0.7	V.clean-N.C*
Sp15	JKA+CKFA	0.67	1.2	V.clean-N.C
Sp16	JKA+CKFA	0.72	2.2	V.clean-N.C
Sp22	CKFA	0.72	2.3	V.clean-N.C
Sp35	CKFA	0.56	1.8	V.clean-N.C
W9	AIA	0.33	1.6	V.clean-N.C
W19	AIA	0.42	1.1	V.clean-N.C
W25	AIA	0.85	1.9	V.clean-N.C
W33	AIA	0.76	2.0	V.clean-N.C

W37	JKA	0.58	1.1	V.clean-N.C
W45	AIA	0.77	2.4	V.clean-N.C
W50	AIA	0.34	1.6	V.clean-N.C
W61	CKFA	0.28	0.9	V.clean-N.C
W85	AIA	0.66	1.4	V.clean-N.C
W86	TAT	0.45	0.4	V.clean-N.C
W100	CKFA	0.21	0.5	V.clean-N.C
Sw1	AIA	3.3	3.8	F.clean-N.C
Sw3	AIA	0.8	2.3	V.clean-N.C
Sw5	AIA	3.5	4.2	F.clean-L.C
Sw7	AIA	4.2	3.7	F.clean-N.C
Sw19	AIA	1.2	2.5	clean-N.C
Sw23	AIA	2.2	3.4	clean-N.C
Sw30	AIA	0.9	1.3	V.clean-N.C
Sw51	AIA	1.0	1.0	V.clean-N.C
Sw59	AIA	3.6	4.3	F.clean-L.C
Sw62	AIA	0.9	2.3	V.clean-N.C
Sw63	AIA	3.5	4.1	F.clean L.C.

Table 5.13 Classification of water contamination depending on (COD) (Swedish EPA, 2000)

COD(mg/l)	Contamination level
4 -8	Low level
8 –12	Moderately high
12 -16	High
>16	Very high level

5.1.7 Bacteriology

Total coliform bacteria include a wide range of aerobics and facultatively anaerobic capable of growing in the presence of relatively high concentrations of bile salts with the fermentation of lactose and production of acid or aldehyde within 24 hours at 35-37°C.

Total coliform bacteria (excluding *Escherichia coli*) occur in both sewage and natural waters. Some of these bacteria are exerted in the faeces of human and animals, but many coliform are heterotrophic and able to multiply in water and soil environments. *E. coli* is considered the most suitable index of faecal contamination and pollution, WHO (2006).

According to WHO (2006), 100 ml of water must be free from total coliform and *E coli*, but according to Abawi and Hasan, (1990), the most probable number (MPN) of total coliform should not be more than 5/100 ml for each sample and 0/100 ml per couple of successive samples. (MPN) E coli must be less than 1/100 ml and the total count of bacteria must be not exceed 50 unit/ 1 ml. Samples were taken for bacteriological tests from the same locations where samples for BOD and COD tests were carried out.

Table 5.14 Bacteriological test results of the water samples of the study area.

Well or Spring No.	Aquifer type	MPN (100ml) Coliform	MPN (100ml) E.Coli
Sp7	TKA	0	0
Sp15	JKA+CKFA	2	2
Sp16	JKA+CKFA	3	3
Sp22	CKFA	2	2
Sp35	CKFA	3	2
W9	AIA	2	2
W19	AIA	6	3
W25	AIA	6	3
W33	AIA	2	1
W37	JKA	2	1
W45	AIA	2	2
W50	AIA	0	0
W61	CKFA	2	2
W85	AIA	4	4
W86	TAT	2	2
W100	CKFA	0	0
Sw1	AIA	18	11
Sw3	AIA	7	7
Sw5	AIA	12	12
Sw7	AIA	10	10
Sw19	AIA	11	5
Sw23	AIA	9	7
Sw30	AIA	6	6
Sw51	AIA	9	9
Sw59	AIA	108	60
Sw62	AIA	65	35
Sw63	AIA	85	50

From the above table it is clear that most of the water samples in the study area are polluted with bacteria at variable rates. Shallow wells show higher percentages of pollution which is actually attributed to the improper way of drilling and well completion and carelessness for making protective concrete zones against wastewaters. It was found that all shallow water samples are polluted bacteriologically. Even though deep wells and spring water samples show some degree of contamination by bacteria, according to Abawai and Hasan (1990) they could be considered as water suitable for drinking and as non-polluted on an Iraqi scale, but great care should be taken to protect those sources which comprise main water supplies for the large cities and towns.

5.2 Groundwater use

Whether a groundwater of a given quality is suitable for a particular purpose depends on the criteria or standards of acceptable quality for that use. Quality limits of water supplies for drinking water, industrial purposes, and irrigation apply to groundwater because of its extensive development for these purposes (Todd, 1980). Groundwater of the studied basin is utilized for different purposes; therefore it is necessary to check its suitability for the different purposes.

- Drinking

Water quality can be defined and standardized by means of indications expressing the limiting concentrations of relevant components and other water properties with regard to their health effect. Their values have to be derived from the character and intensity of the impact of the relevant components on the human organism Jermar, (1987). The relevant values can be standardized as:

A- Maximum permissible values--water which exceeds these values may not be considered as drinking water (Mandatory limits)

B- Recommended limits--the rate of their occasional or permanent excess has to be analyzed individually in consideration of local conditions (and officially approved).

Table.5.15 Evaluation of the groundwater samples of the study basin with respect to WHO, EU and IQS standards

Parameter	Range of water samples	WHO recommendations 2006		EU standard 2004	Iraqi Standard 1996	Suitability of taken samples
		R limits	Max. permissible	R limits	R limits	
Temp.(C^0)	16-29	8-25	-	-	-	Suitable except Khurmal acidic spring
PH	6.6 - 8.4	6.5- 9.5	6.5-9.2	6.9-9.5	6.5-8.5	Suitable
Ca	23 - 153	75	200	100-200	50	Suitable except Khurmal acidic spring
Mg	2.4 - 45	50	100	30-50	50	Suitable
Na	1.7 - 95	200	250	200	200	Suitable
K	0.0 - 6.0	10	12	10-12		Suitable
Cl	3.6 - 202	250	-	250	250	Suitable
SO_4	2.0 - 246	250	-	250	250	Suitable
NO_3	0.0 - 70	50	-	25-50	50	Suitable shallow wells in Dolash, Malawais
Ni	0.003-0.09	0.02	-	0.02	0.02	suitable except (Homara kwer, industrial, Kani goma) wells in TAT and AIA in SB1 Shallow wells in the same two last sites.
Cd	0.002-0.06	0.003		0.003	0.003	suitable except Six wells in AIA (SB4),seven wells in AIA(SB3), three wells in AIA(SB2), three well in TAT (SB1) and four wells in AIA in (SB1) and all shallow wells
Cu	0.003-0.026	2		2	1	all suitable
Zn	0.004-0.29	1.1	3	3	3	all suitable
Cr	0.02-0.12	0.05			0.05	suitable except 2 wells in AIA (SB4) and 2 wells in TAT and 2 well in AIA in (SB1) %25 of shallow wells (AIA), 8 well in SB3, 3 well in SB2, 4 well in SB1
TH	83.2 - 693	-			500	Suitable except Khurmal acidic spring
TDS	154 - 1300	1000		300	1000	Suitable except Khurmal acidic spring

Table 5.15 shows that the majority of the water samples are suitable for drinking, but some wells have Cd content slightly higher than the amount permissible by WHO, EU and IQS standards. In general it is concluded that except for some slight contamination of some water samples, the majority of the groundwater samples were found to be suitable for drinking, particularly those taken from large karstic springs and deep wells.

- Industry

It should be apparent that the quality requirements of waters used in different industrial processes vary widely. Sulaimani city contains only a few types of industries such as textile, cigarette, marble cuttings and steam laundering; therefore the groundwater suitability for these industries should be checked. Table 5.15 shows the requirements of water quality for different industry (Hem1985). Comparing the results of the analysis of the water samples with the proposed required quality values by Hem (1985), it is clear that the water samples of the study area are suitable for some industries but not for others. Whilst one parameter renders the water unsuitable, other parameters meet the required quality. The limited concentration of 10 ppm of NO_3 change 1/3 of deep water and shallow water samples from suitable to unsuitable for the freezing fruit industry. So some treatments are required on these water samples before they are used in such industries. The overall conclusion is that the majority of the deep groundwater and spring water qualities (except the Khurmal acidic spring) are suitable for all industries displayed in the table above except for the paper industry due to the low calcium concentration and TH requirements, while the majority of shallow wells were found not to be suitable for most of the mentioned industries. For most of them the slight differences in the range of required Ca or NO_3 concentrations with the study watr samples exist (± 2 -10 ppm).

- Building and construction

According to Altoviski (1962), all the groundwater in the studied area is considered to be suitable for building and construction purposes as shown in Table (5.16).

Table 5.17 Suitability of groundwater for building and construction (Altovisky,1962)

Ions	Allowable limit (ppm)
Na	1160
Ca	437
Mg	271
Cl	2187
SO4	1460
HCO3	350

- Livestock

Based on the suggested specifications of Altoviski (1962) and Ayers and Westcott (1989), the groundwater of the study area is considered to be very good to excellent for livestock use as shown in table 5.18.

Table 5.18 Groundwater utilization for livestock after Altoviski (1962)

Elements	Very good water	Good water	Allowable	Could be used	Max. permissible
Na	800	1500	2000	2500	4000
Ca	350	700	800	900	1000
Mg	150	350	500	600	700
Cl	900	2000	3000	4000	6000
SO4	1000	2500	3000	4000	6000
TDS	3000	5000	7000	10000	15000
TH	1500	3200	4000	4700	54000

Table 5.16 Water quality requirements for different industries, concentrations in ppm (Hem, 1985).

Type of Industry	Ca	Mg	Cl	HCO3	SO4	NO3	CU	Zn	TH	TDS	pH	Suitability Of water samples
Cement industry			250		250					600	6.5-8.5	All samples are suitable except seven deep wells in AIA located south of Sulaimani and Bakrajo.
Leather Industry	80	36	250		250				350		6.5-8.3	All samples are suitable except the same above wells. Khurmal acidic spring is not suitable
Bottling and drinks	100		500		500		500					All samples except Khurmal acidic spring
Freeze fruits			300		250	10			250	500	6.5-8.5	All samples are suitable, but due to the high rate of $NO3^{=}$ with regard to the recommended limit only %60 of deep well waters remain suitable
Oil product	75	30	300						350		6.5-8.3	All water samples except 7 deep well water samples with a slight higher Ca concentration, almost majority of shallow wells not suitable
Plastic industry	80	36							350		6.5-8.3	All samples almost suitable
Textile	100	50	500	250	100	5			900	1000	6.5-8	All samples almost suitable
Paper industry	20	12	200						100		6-10	Almost all samples are not suitable for paper industry because of high Ca content and high TH
Clothes	0	0	0	0	0		0.01		25	100	2.5-10.5	Almost not suitable

Table 5.19 Water specification requirements for livestocs and poultry after Ayers and Westcott (1989)

Ec(μmohs/cm)	Rank
<1500	Excellent
1500-5000	Very acceptable
5000-8000	Suitable for livestock but not for poultry
8000-11000	Suitable for livestock with restriction but not suitable for poultry
11000-16000	Very restricted use
>16000	Not recommended to be used

- Agriculture and irrigation

The groundwater quality of the Sharazoor-Piramagroon basin has also been evaluated for agricultural and irrigation purposes. Most of the personal and public lawns and gardens use groundwater for irrigation. Several factors must be taken into consideration when determining the suitability of water for irrigation such as quality of the water, soil, crop, climate, and irrigation management.

The quality of irrigation water may be considered an important factor, but it is only one of the factors, and no classification of irrigation water can be presented which may be utilized under all circumstances (Van Hoorn, 1970).

The suitability of water for irrigation depends upon its own quality as well as upon other factors. The same quality of water may be considered suitable for a certain type of soil or crop but unsuitable for others.

The quality of irrigation water considered the most important factor is determined by its soluble component which includes its total salt content, ionic composition, and presence of minor elements.

Groundwater is classified according to its salinity by USA salinity laboratory (Richards, 1954) as:

Table 5.20 Groundwater evaluation for irrigation purposes based on salt content and Ec (Richard, 1954)

Salt content ppm	Ec x 10^3 $ds.m^{-1}$	Evaluation
<200	<0.25	C1 low salinity water can be used for irrigation for most crops, most soils
200-500	0.25-0.75	C2 medium salinity, can be used if a moderate amount of leaching occurs
500-1500	0.75-2.25	C3 high salinity water, cannot be used on soils with restricted drainage
1500-3000	2.25-5.0	C4 very high salinity water, is not Suitable for irrigation under ordinary Conditions

FAO classification for irrigation water according to its salinity lies in (6) categories (Rhoades, 1992) as shown in table 5.21.

According to the classification of Richard (1954) 91% of water samples from the deep wells, 78% of the shallow wells and 96% of the spring water samples are of C2 type, and the rests are of C3, except one shallow and one deep well which fall into C1 class.

According to Rhoades' (1992) classification, 80% of water samples from the deep wells, 100% of the spring water samples (excluding the Khurmal acidic spring), and 75% of the shallow well water samples are classified as non-saline water suitable both for drinking and irrigation. The rest of the water samples are slightly saline and suitable for irrigation.

The ionic composition of water is important with respect to the sodium hazard, the bicarbonate hazard, and chloride hazard (Van Hoorn, 1970; Ayers and Westcott, 1985; pakshina and Rabochev, 1987).

The sodium hazard is determined by the absolute and relative concentrations of the cations and can be evaluated through the sodium adsorption ratio (SAR) because of its direct relation to the absorption of sodium by soil (Todd, 1980). It is defined by

Table 5.21 Classification of irrigation water depending on its salinity (Rhoades, 1992).

Water class	Ec $ds.m^{-1}$	Salinity concentration mg/l	Water type
Non-saline	<0.7	<500	Drinking and irrigation water
Slightly saline	0.7-2.0	500-1500	Irrigation water
Moderately saline	2.0-10	1500-7000	Primary drainage water and groundwater
Highly saline	10-25	7000-15000	Secondary drainage water and groundwater
Very highly saline	25-45	15000-35000	Very saline groundwater
Brine	>45	>35000	Sea water

$$SAR = \frac{r\,Na^{+}}{\sqrt{r(Ca^{++} + Mg^{++})/2}}$$

Sodium content is usually expressed in terms of percent sodium (also known as sodium percentage and soluble sodium percentage), defined by

$$\%Na = \frac{r\,(Na + K)100}{r(Ca + Mg + Na + K)}$$

where the concentrations are expressed in milliequivalent per liter.

A high concentration of bicarbonate in irrigation water may lead to the precipitation of calcium and magnesium in the soil and thus to a relative increase of sodium concentration. Consequently, the sodium hazard will increase (Van Hoorn, 1970).

The bicarbonate hazard expressed by residual sodium carbonate (RSC) which was introduced by Eaton (1950) is defined by

$$RSC = (CO3^{=} + HCO3^{=}) - (Ca^{++} + Mg^{++}) \qquad \text{in meq/l}$$

Water containing more than 2.5 meq/l of RSC is considered not suitable for irrigation with 1.25 to 2.5 meq/l as marginal, and water with less than 1.25 meq/l as safe. The chloride ion has generally not been included in the water classifications. However, excess of chloride may be of special importance for some tree and vine crops.

The groundwater was analyzed only for a few minor elements which may have some effect on different crops.

Wilcox (1955) proposed another classification which depends upon RSC values, but this classification is not well accepted (Esmail, 1992).

The most accepted classification of irrigation water is that proposed by Ayers and Westcott (1985) which depends upon EC values, and upon the permeability of the soil, as described in table 5.22.

Toxic effects of the ions and the side effects of some trace elements are described in table 5.23.

Table 5.22 Classification of irrigation water, Ayers and Westcott (1985)

Nature of the problem	Restriction limits		
	None	Slight- moderate	severe
1-Salinity (ds/m)	<0.7	0.7-3.0	>3.0
2-Permeability SAR	Electrical conductivity ds/m		
0-3	0.7	0.2-0.7	<0.2
3-6	>1.2	0.3-1.2	<0.3
6-12	>1.9	0.5-1.9	<0.5
12-20	>2.9	1.3-2.9	<1.3
20-40	>5.0	2.9-5.0	<2.9
3-specific ion toxicity			
a-Sodium (meq/l)			
SAR (epm) values for:-			
surface irrigation	<3	3-9	>9
Sprinkler irrigation	<3	>3	>10
b-Chloride (meq/l)			
Surface irrigation	<4		>3
Sprinkler irrigation	<3	4-10	>3
4-Other ions effect			
a-Nitrate(epm)	<5	5-30	>30
b-Bicarbonate meq/l	<1.5	1.5-8.5	>8.5

None- means that water is without problem, Slight-moderate - means water with increasing problems. Severe – means water with severe problems

According to this classification of Ayers and Westcott (1985) and because almost all water samples have a bicarbonate content more than 1.5 meq/l and most of Ec values are in the range of 0.2 to 0.7 ds/m, water samples are classified as slight-moderate for irrigation purposes.

Table 5.23 Phyto-toxicity and threshold levels of heavy trace metal for crop production. (1)*Skordas and Kelepertsis, 2005; (2)* Pettygrove and Asano, 1988.

Heavy metals	Phyto-toxicity (ppm) (1)*	Threshold level for crop production(ppm) (2)*	Damage to crops (2)*
Cd	-	0.01	toxic to beans and turnips at concentrations as low as 0.1 ppm in nutrient solutions conservative limits recommended due to its potential for accumulation in plants and soil to concentration that may be harmful to humans
Cu	60-125	0.2	.toxic to a number of plants at 0.1-1.0 ppm in nutrient solutions.
Ni	100	0.2	toxic to a number of plants at 0.5-1.0 ppm ; reduced toxicity at nutrient or alkaline pH
Pb	100-400	5	Can inhibit plant cell growth at very high concentration
Zn	70-400	2	Toxic to many plants at widely varying concentrations; reduced toxicity at pH>6 and in fine textured or organic soils.

- US Salinity Laboratory Classification

The United States (US) salinity diagram (Richards, 1954) classifies irrigation water into sixteen classes depending on electrical conductance (μS/cm) at 25°C and sodium adsorption ratio (SAR). Analytical data of the groundwater samples plotted on the US salinity diagram (Fig.5.11) illustrate that almost all samples fall into the field of (C2-S1), indicating medium salinity and low sodium hazard waters, except two samples which fall into the field of (C3-S1) indicating high salinity and low sodium hazard waters. All samples falling exclusively into the field of S1 implies that no alkali hazard is anticipated to the crops (Subramani et al, 2005).

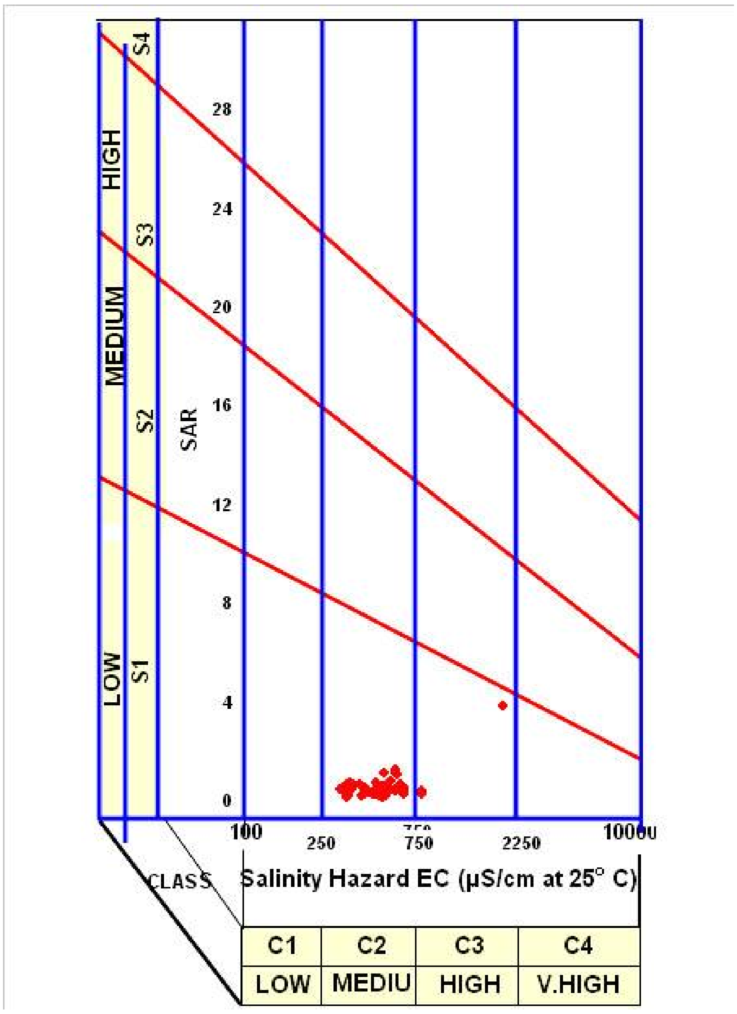

Fig. 5.11 Salinity hazard diagram (after Ayers and Westcott, 1985)

5.3 Hydrochemical formula and water types

The hydrochemical formula and the dominant type of groundwater of the study area are determined depending on the hydrochemical classification of Ivanov (1968) All geochemical processes which take place in the flow route of the groundwater are reflected in its chemistry, the resultant changes and produced type of groundwater depending on the area of recharging and discharging. Adams, et al (2001) presented in a schematic diagram all the possible chemical reactions and ionic replacements responsible for the appearance of different types of waters.

Table 5.24 The dominant average water type of the different aquifers in Sharazoor-Piramagroon basin

	Aquifer type	Average Water type
Springs	TKA	Ca-Mg-Bicarbonate
	CKFA	Ca-Bicarbonate + Ca-Mg-Bicarbonate
	JKA+C KFA	Ca-Mg-SO4-Bicarbonate
	JKA	Ca-SO4-Bicarbonate + Na-Mg-SO4-Cl-Bicarbonate*
	CFA	Ca-Mg-Bicarbonate
	EIA	Ca-Mg-SO4-Bicarbonate
	SDA	Ca-Mg-Bicarbonate + Ca-Mg-Cl-Bicarbonate
	TAT	Ca-Mg-SO4-Cl-Bicarbonate
Deep Wells	AIA	Ca-Mg-Bicarbonate + Ca-Mg-Na-SO4-Cl-Bicarbonate+ Ca-Mg-SO4-Bicarbonate
	CKFA	Ca-Mg-Bicarbonate
	JKA	Ca-Mg-SO4-Bicarbonate
	TAT	Ca-Mg-Na-Cl-SO4-Bicarbonate
Shallow wells	AIA	Ca-Mg-SO4-Bicarbonate(%38)+ Ca-Mg-Na-Cl-SO4-Bicarbonate(%30)+ Ca-Mg-Bicarbonate(%22) +Ca-Mg-Na-HCO3-Sulfate(%10)

In table 5.24 the most dominant hydrochemical type of water samples of the springs, shallow and deep wells for different aquifer types is shown. As is clear from the table, calcium and bicarbonates are respectively the most dominant cations and anions. Sulfate and chloride are the second most dominant. More than 97% of the samples are calcium bicarbonate type water with about 25.5% Ca-Mg-Bicarbonate and 30% Ca-Mg-SO_4 bicarbonate, while about 15% is of (Ca-bicarbonate) type. The only water within the spring samples which is calcium sulfate type is from Jurassic rocks of the Galal valley (SP33). In samples taken from deep wells, no sulfate water type is found; about 31.7% is Ca-Mg-Bicarbonate and 21% is Ca-Mg-SO_4-Bicarbonate type, and more than 20% is Ca-Mg-Na-Bicarbonate type with or without SO_4 erratically. For the shallow well water sample, the view of distribution is different: the Ca-Mg-SO_4-Bicarbonate water type comprises the majority of water samples with more than 38% with 30% Ca-Mg-Na-Cl-SO_4-Bicarbonate. Calcium sulfate water (Ca-Mg-HCO_3-Sulfate), unlike spring and deep well water samples, comprises 10% of water samples. This is most likely attributable to the degree of vulnerability of the shallow aquifers to contamination from surface contaminants in comparison to the deep aquifers.

With regard to the aquifer types, the groundwater hydrochemical formula for CKFA and TKA is almost Ca-Mg-Bicarbonate; with a profusion sometimes of Ca-Bicarbonate while for JKA is almost Ca-SO_4- Bicarbonate or Ca-Mg-SO_4-Bicarbonate. The Khurmal Sulfuric spring which issues from the deep Jurassic aquifer is found to have a specific hydrochemical formula rich in Sodium chloride and Sulfate compounds which have resulted from deep hydrochemical reactions.

In the rest of the aquifers AIA and TAT, clear interaction and the influence of contamination with SO_4 and Na and Cl ions could be sensed. The groundwater commonly attained such contents from anthropogenic sources due to the vulnerability of the aquifers of AIA and TAT to surface contamination.

5.3.1 Water Classification

Many researchers proposed various classification modes for water classification. The first attempt started by Hill, (1940) was followed by that of Piper, (1944), then Durov, (1948). In 1946, Sulen established a diagram for water classification followed by Scholler's (1962) diagram, and Scholler and Solen, (1981) and there is recently the proposed diagram of Chadha, (1999).

The water samples of the study area classified according to the Piper, Durov and Chadha classifications.

- Piper diagram:

Figure 5.12 presents the type and characteristics of water samples in each field of the combined triangles of the diagram.

The figure below demonstrates that most of the water types fall into the field of alkaline water with prevailing bicarbonate. Waters from the Tanjero aquitards deep wells(Fig.5.13), springs and shallow wells in SB1 and SB3 are classified as normal earth alkaline water with prevailing bicarbonate with sulfate and chloride, while water samples from shallow wells of SB4 is earth alkaline with increased portions of alkalis and prevailing bicarbonate with sulfate and chloride.

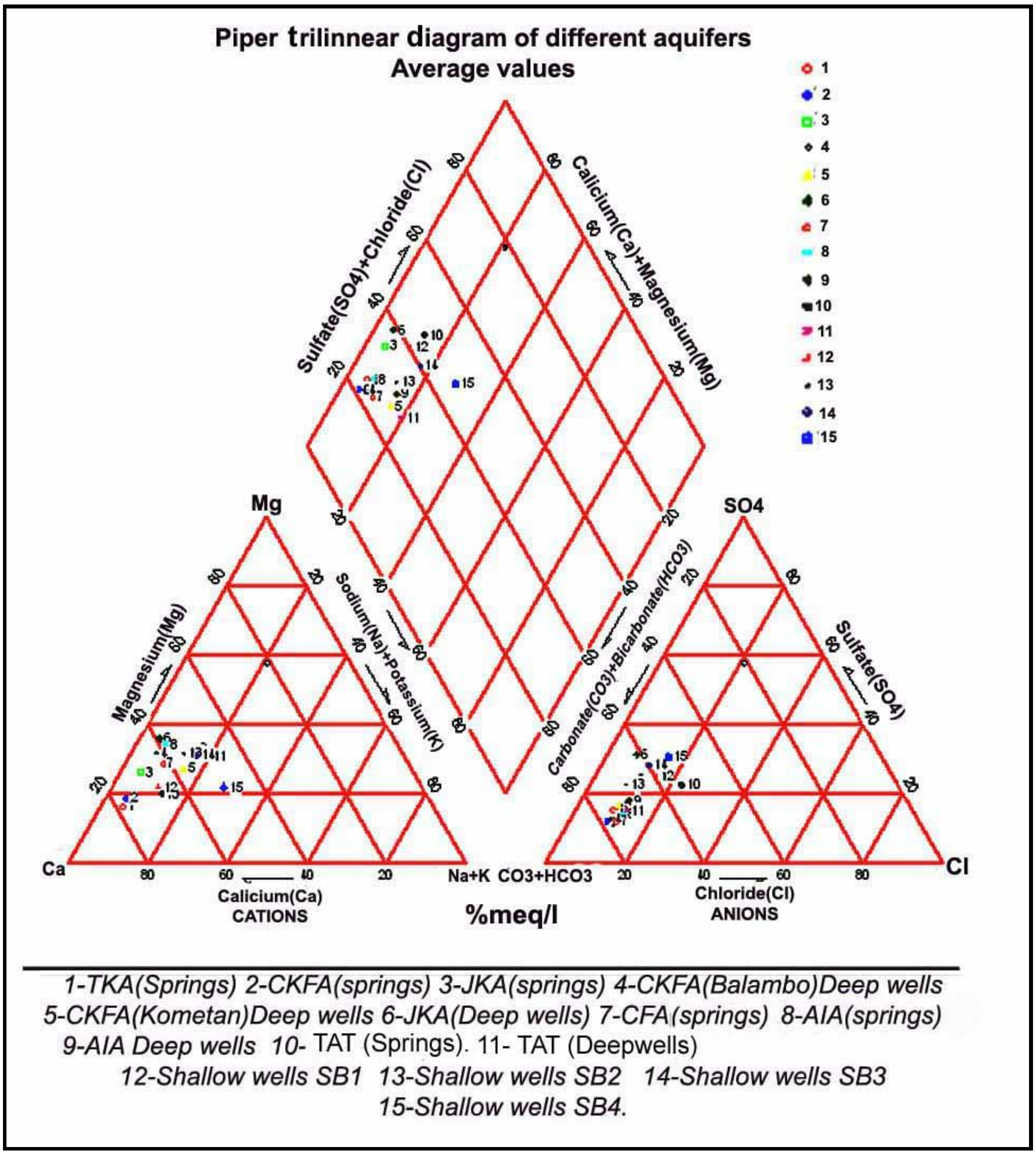

Fig5.12 Piper diagram for water types for different kind of aquifers based on average data.

-Durov diagram -

Figure 5.14 below shows the water classification according to Durov's classification and the complete similarities with the results of the Piper Classification.

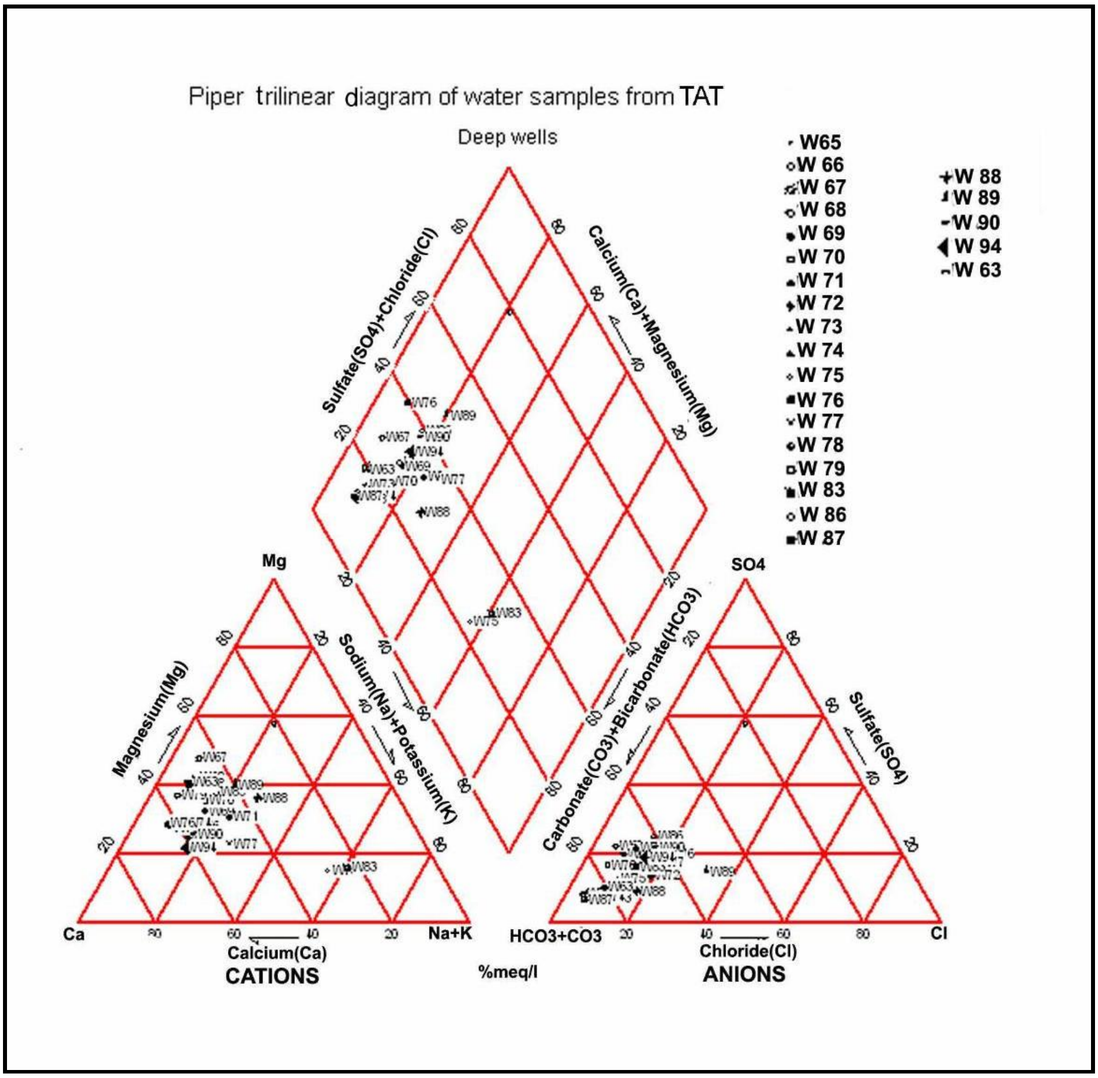

Fig.5. 13 Piper trilinear diagram for the water samples taken from deep wells in TAT,Oct.2005- Sharazoor-Piramagroon basin.

-Chadha Diagram (1999)

From figure 5.15, it is apparent that almost all water samples quality fall into field 5 which represents earth alkaline waters with prevailing weak acid anions. This type of water represents temporary hardness and this region was revealed to be Ca-Mg-HCO_3 water type. For shallow wells, as clear from figure 5.18, about ten water samples (AIA) fall into field 6, which means the earth alkaline water type is more prominent than metal alkaline, and strong acid ions are more prevalent than weak acid anions. This type of water has permanent hardness and the residual sodium carbonates remains during irrigation

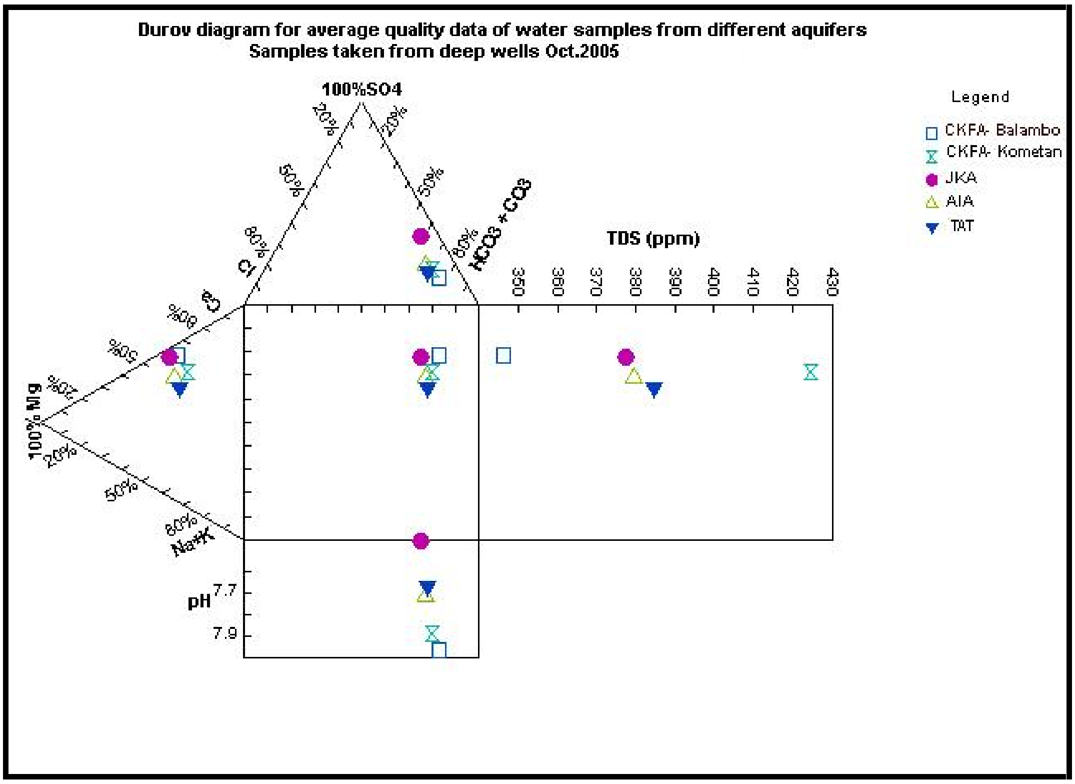

Fig.5.14 Durov diagram representing the average dominant chemistry of different types of the existing aquifers in Sharazoor-Piramagroon basin.

5.4 Water Origins

Hydrochemical indicators are of specific importance for the determination of the origin and the chemical changes which take place in major ions of water samples.

Hydrochemical indicators are determined for water samples of the study area and for different types of the existing aquifers, and the average ranges results are presented in tables 5.25, 5.26, 5.27 and 5.28, and compared with constant indicators of marine waters (Kushnir, 1982 Cited in Al-Bedawi and Al-Bassam, 1997), (Plamer and Cherry, 1985).

Based on the major indicator of rNa+rK/rCl, it is concluded that the majority of groundwater samples taken from deep wells of the study area are of the meteoric type: 88% of Kometan CKFA waters, 77.3% TAT waters, 71% AIA waters, 50% Balambo CKFA waters, and 25% of JKA waters appeared to be of meteoric origin type.

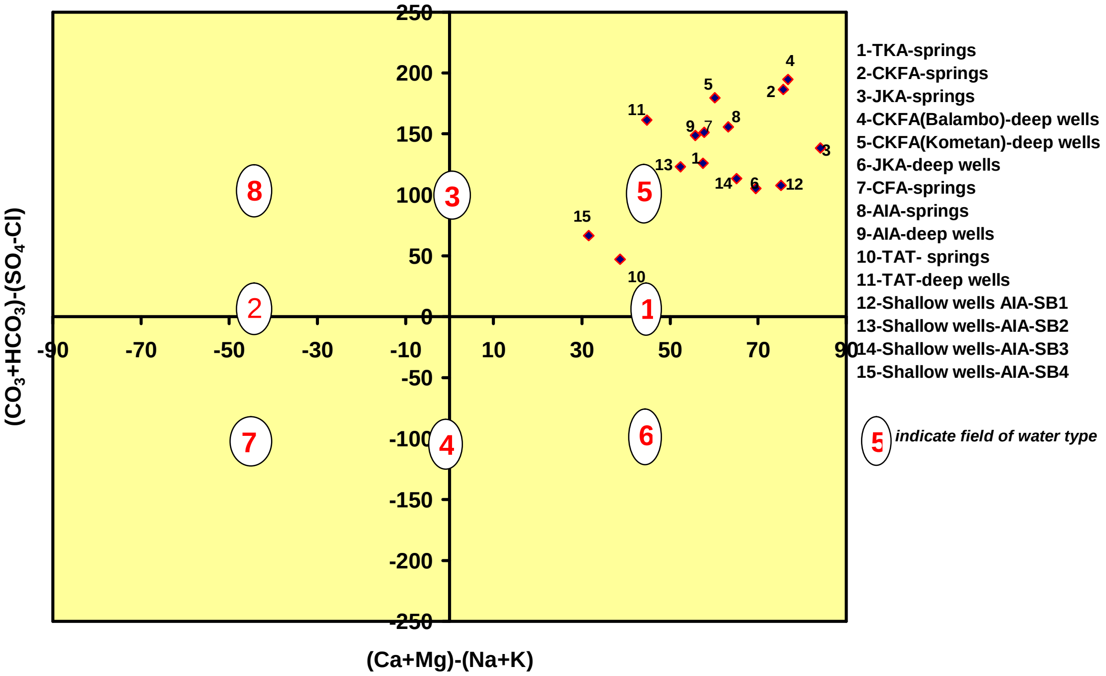

Fig 5.15 Chadha diagram for water samples of the study area, the data represent averages of different kinds of aquifers.

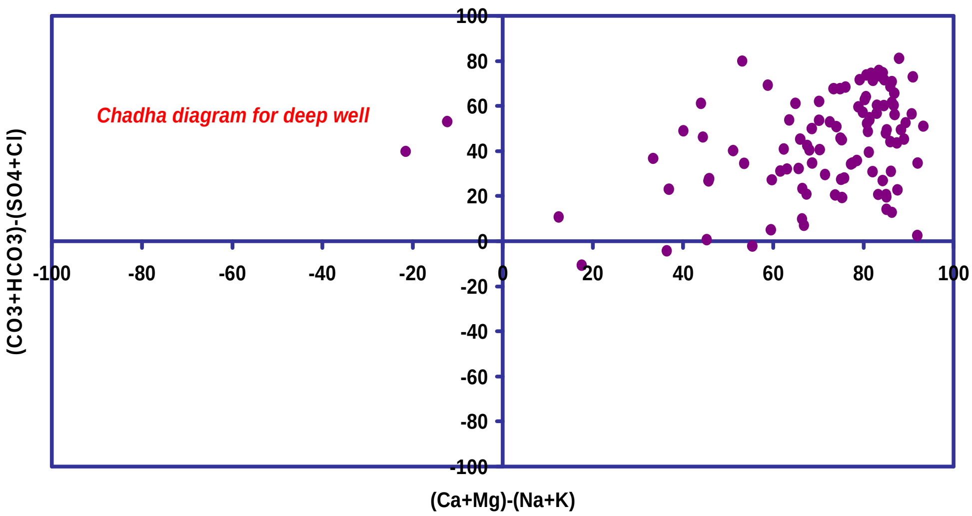

Fig 5.16 Chadha diagram for deep water samples

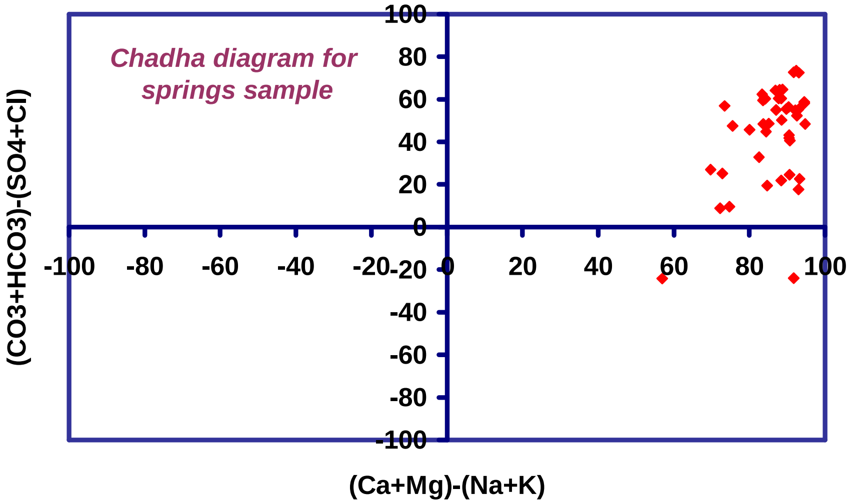

Fig.5.17 Chadha diagram for spring water samples.

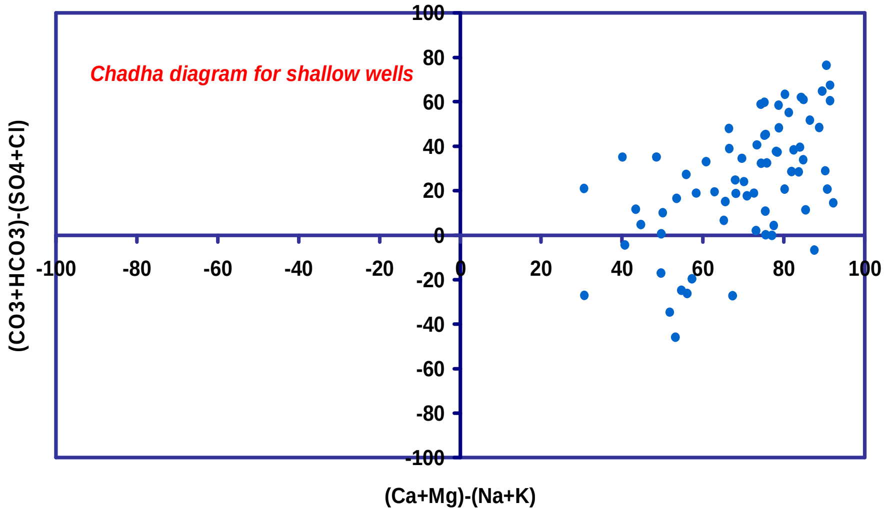

Fig.5.18 Chadha diagram for shallow well water samples.

For shallow water aquifers, meteoric water comprises 100% of water samples in shallow aquifers of SB4, while it constitutes 67%, 78%, and 83% for SB1, SB2 and SB3 respectively. Although the ratios could appear to be of marine origin, this is not the actual case as the shallow wells are subjected to contamination more from surface seepages which provide a consequently unreal view of the original constitution of the water.

The high values of rCa/rCl have more likely resulted from the intense weathering of carbonate rocks which constitute the majority of the aquifers material.

The indicator rSO_4/rCl is relatively high (as an average value); this is an indicator of the contamination that the groundwater might have been subjected to. This conclusion is drawn based on the fact that no natural sources of sulfate in the area (as evaporite rocks) exist, so the only probable source is from human activities.

The relatively high rMg/rCl indicator could be attributed to the existence of clay minerals (montmorillonite), particularly in the AIA shallow aquifers and (Tanjero and Kolosh rocks).

Table 5.25 The average, maximum, minimum, and range of the hydrochemical indicators for different aquifer types in the study basin

	rK/rCl	rNa/rCl	rMg/rCl	rCa/rCl	rSO4/rCl	r(Na+K)/rCl	r(Na+K)/rSO4	
Average	0.04	1.56	3.35	6.61	1.58	1.60	1.05	Kometan CKFA
Max	0.09	2.78	5.84	11.41	2.68	2.87	1.81	
Min	0.00	0.77	1.11	3.17	0.88	0.77	0.53	
Range	0.0-0.089	0.77-2.78	1.11-5.84	3.17-11.4	0.87-2.68	0.77-2.86	0.53-1.81	
Average	0.015	1.590	4.221	7.210	1.858	1.605	1.182	AIA
Max	0.152	6.847	12.164	23.667	6.052	6.847	8.875	
Min	0.000	0.309	0.757	1.726	0.365	0.309	0.273	
Range	0.0-0.15	0.31-6.84	0.75-12.16	1.72-23.66	0.36-6.0	0.31-6.84	0.27-8.87	
Average	0.013	1.561	3.284	4.934	1.388	1.575	1.331	TAT
Max	0.076	5.466	9.175	11.411	3.757	5.466	4.727	
Min	0.000	0.340	1.081	1.268	0.449	0.360	0.293	
Range	0.0-0.076	0.34-5.46	1.08-9.17	1.27-11.41	0.45-3.75	0.36-5.46	0.29-4.72	
Average	0.019	0.709	3.598	7.116	1.502	0.728	0.483	Balambo CKFA
Max	0.066	1.200	5.839	11.044	2.678	1.200	0.718	
Min	0.000	0.281	2.449	4.438	0.913	0.285	0.268	
Range	0-0.066	0.281-1.2	2.45-5.84	4.44-11.0	0.9-2.68	0.285-1.2	0.268-0.718	
Average	0.100	0.577	5.023	7.822	5.196	0.677	0.180	JKA
Max	0.122	0.923	9.672	11.475	10.920	1.045	0.315	
Min	0.072	0.208	2.364	4.786	1.526	0.301	0.081	
Range	0.072-0.122	0.208-0.923	2.364-9.672	4.78-11.47	1.526-10.92	0.301-1.045	0.081-0.315	

Table 5.26 Comparison of the hydrochemical indicators of shallow well water samples with normal sea water

Indicators	Shallow aquifers/Sub-basins								
	SB1	SB2	SB3	SB4	Deep GW	Shallow GW	GW With Oil	Marine origin GW	Normal Sea water
rK/rCl	0.0-0.13	0.0-0.15	0.0-0.18	0.02-0.03					0.018
rNa/rCl	0.11-2.47	0.37-4.41	0.34-3.08	0.98-2.64	1.056	5.09	0.606	0.855	0.854
rMg/rCl	0.14-8.39	1.17-11.68	1.4-6.32	0.73-1.98					0.119
rCa/rCl	3.03-17.75	2.32-24.85	3.12-8.58	2.22-3.96					0.039
rSO4/rCl	0.26-9.22	0.45-13.4	1.11-6.87	1.69-2.14					0.103
r(Na+K)/rCl	0.15-2.53	0.37-4.41	0.34-3.13	1.0-2.67					0.87
r(Na+K)/rSO4	0.09-0.99	0.26-1.12	0.15-1.34	0.51-1.57	0.076	1.473	-43.333	-1.444	1.33

Table 5.27 Comparison of the hydrochemical indicators of spring water samples with normal sea water

Indicators	Aquifer Type(Springs)												
	CFA	JKA	TKA	CKA Komean	AIA	SDA	EIA	TAT	Deep GW	Shallow GW	GW with Oil	Marine origin GW	Normal Sea water
rK/rCl	0.0-0.04	0.0-0.031	0.03-0.08	0.02-0.05	0.01-0.03	0.0-0.015	0.031 -0.11	0.02-0.04					0.018
rNa/rCl	0.44-1.28	0.38-0.59	0.31-0.92	0.17-0.91	0.51-1.09	0.14-0.37	0.34-0.66	0.51-0.51	1.056	5.092	0.606	0.855	0.854
rMg/rCl	1,112-4.622	1.03-5.15	0.66-4.09	0.77-3.65	1.36-3.4	1.39-2.31	2.27-5.84	0.62-1.11					0.119
rCa/rCl	2.87-14.2	4.73-8.35	4.81-12.17	6.06-13.98	2.1-7.6	1.86-4.01	4.98-12.17	2.7-2.7					0.039
rSO4/rCl	0.71-1.34	1.08-5.54	0.41-2.92	0.55-2.15	0.77-1.67	0.17-0.73	1.7-4.14	0.77-1.3					0.103
r(Na+K)/rCl	0.47-1.33	0.41-0.59	0.34-0.99	0.19-0.94	0.54-1.12	0.16-0.37	0.4-0.77	0.53-0.53					0.87
r(Na+K)/rSO4	0.50-1.37	0.07-0.54	0.11-1.25	0.27-0.82	0.4-0.78	0.51-0.91	0.09-0.43	0.43-0.7	0.076	1.473	-43.333	-1.444	1.333

Table 5.28 Comparison of the hydrochemical indicators of deep well water samples with normal sea water

Indicator	Aquifer Type/Deep Wells								
	JKA	CKFA Balambo	CKFA Kometan	AIA	TAT	Deep GW	Shallow GW	GW With Oil	Marine Origin GW	Normal Sea water
rK/rCl	0.072-0.122	0-0.066	0.0-0.089	0.0-0.15	0.0-0.076					0.018
rNa/rCl	0.208-0.923	0.281-1.2	0.77-2.78	0.31-6.84	0.34-5.46	1.056	5.092	0.606	0.855	0.854
rMg/rCl	2.364-9.672	2.45-5.84	1.11-5.84	0.75-12.16	1.08-9.17					0.119
rCa/rCl	4.78-11.47	4.44-11.0	3.17-11.4	1.72-23.66	1.27-11.41					0.039
rSO4/rCl	1.526-10.92	0.9-2.68	0.87-2.68	0.36-6.0	0.45-3.75					0.103
r(Na+K)/rCl	0.301-1.045	0.285-1.2	0.77-2.86	0.31-6.84	0.36-5.46					0.87
r(Na+K)/rSO4	0.081-0.315	0.268-0.718	0.53-1.81	0.27-8.87	0.29-4.72	0.076	1.473	-43.333	-1.444	1.333

CHAPTER SIX

TOWARDS GROUNDWATER MANAGEMENT

Many communities use groundwater as the main source for their public water supply system and many individual residences are totally dependent on groundwater for their supply. In addition, many agricultural operations are partly or entirely dependent on groundwater for their water supply, especially in times of drought. The amount of groundwater in storage in each basin is dependent on the precipitation, recharge and total extraction from all the wells. If a groundwater management plan is designed for the political, institutional, legal and technical specifics of any basin, it can help everyone maintain the quality and quantity of the groundwater supply.

Groundwater resource is now under severe stress in some cities of the Iraqi Kurdistan Region, particularly in the boundary of the study basin, because of the excessive groundwater abstraction in the course of socioeconomic development.

Problems such as water table drawdown, decreasing well yield and pollution of the groundwater that have emerged as the results of overexploitation of groundwater and improper well drilling may incur socioeconomic losses and disturb the development of the cities that face these problems. These problems are either irreversible in nature or require extended periods to abate. Therefore, we need to consider how we can conserve this precious resource while taking full advantage of it for the development of the region.

The overexploitation of groundwater which is most likely going to occur in the city of Sulaimani has already created problems. Although groundwater problems are not well-recognized, a city like Sulaimani experiencing rapid population and economic growth now depends more on groundwater to meet the growing demand for water, and thus experiences the subsequent problems with the groundwater. Therefore, avoiding the devastation of the aquifers and lands by proper groundwater management is the order of the day, and the only solution for the sustainable development of the entire region.

For municipal water supply, both the water quantity and quality are important. The variability of the quantity and quality in space and time is important, and should be considered and monitored. With regard to surface water quantity, designing and planning for a water supply source is usually based on the maximum daily, monthly, seasonal, or annual demand versus the minimum flow available at the source during the peak demand period. However, where the water demand is far less than the minimum available yield of a water source, the design of the intake will be based mainly on the maximum demand rates. On the other hand, for groundwater supplies, the water availability assessment should be based on the following criteria:

-The annual sustainable yield of an aquifer.

-The maximum yield of a well or well field during the period of maximum demand

-The relative volume of the available aquifer storage

The last of these criteria is necessary to balance the offset between the periods of recharge/replenishment, and the period of maximum withdrawal to meet the demand. The long-term sustainable yield of an aquifer, groundwater basin, well field, individual well, or even a surface water source is the rate of consumption (daily, monthly, seasonally, or annually) that can be physically, environmentally, economically, legally, and politically withdrawn without causing significant irreversible impacts (source depletion, quality deterioration, environmental impacts, etc.).

Alley et al. (1999) defined groundwater sustainability as the development and use of ground water in a manner that can be maintained for an indefinite time without causing unacceptable environmental, economic, or social consequences. The definition of "unacceptable" is largely subjective, depending on the individual situation. For instance, what may be established as an acceptable rate of groundwater withdrawal with respect to changes in groundwater level may reduce the availability of surface water, locally or regionally, to an unacceptable level.

According to Alley et al. (1999), the term “safe yield" should be used with respect to specific effects of pumping, such as water level declines or reduced stream flow. Thus, safe yield is the maximum pumpage for which the consequences are considered acceptable.

Sophocleous (2000) pointed out that the traditional concept of safe yield ignores the fact that over the long term natural recharge is balanced by discharge from the aquifers by evapotranspiration and/or ex-filtration into streams, springs, and seeps. Consequently, if pumping equals recharge, eventually streams, marshes, and springs may dry up. Additionally, continued pumping in excess of recharge may eventually deplete the aquifer.

Seward et al. (2006) found serious problems with the simplistic assumption that sustainable yield should equal recharge. In many cases, sustainable yield will be considerably less than average annual recharge; therefore, the general statement that sustainable or "safe" yield equals recharge is incorrect. Natural recharge does not determine sustainable yield; rather, the latter is determined by the amount of capture that it is permissible to abstract without causing undesirable or unacceptable consequences.

Sustainable yield can also be expressed as a percentage of recharge. Globally, if recharge can be assumed to be approximately 20% of precipitation, then deep percolation would be about 10% of recharge. Thus, a reasonably conservative estimate of sustainable yield would be 10% of recharge. Limited experience indicates that average values of this percentage may be around 40%, while less conservative percentages may exceed 70% (Miles and Chambet, 1995; Hahn et al., 1997). The current concept of sustainable yield represents a compromise between theory and practice. In theory, a reasonably conservative estimate of sustainable yield would be about 10% of recharge. In practice, values higher than 10% may reflect the need to consider other factors besides conservation.

6.1 Water demand

Sharazoor-Piramagroon basin occupies an area of 2680Km^2; one main large city and seven relatively large and highly populated towns exist within this basin. The types of the main demands vary from place to place and the water resources are distributed over the basin irregularly. For instance, the center of the second largest city in Kurdistan located in SB1 with a population of more than 700,000 inhabitants has only one main large karstic spring of Sarchinar. The majority of the area of this sub-basin is distorted to residential, industrial or general services areas. So for this sub-basin, assessing and managing potable water supply is the priority. However, because the other three sub-basins are formed largely by extensive plain fertile land, in addition to the importance of potable water supply in the required plan, managing irrigation water is also an essential aspect of the plan. Currently, the existing water resources in these last three sub-basins are relatively more than both the demand and the sort of demand. Accordingly, it is found to be more reasonable to assess the current demand and available water resources for each sub-basin separately in order to have a proper plan for sustainable groundwater management.

-Current and future water demand of SB1

-Population and population growth

The center of Sulaimani governorate has 650,000 inhabitants according to the data of Directory of Statistics of Sulaimani in 2005, but the population is currently higher than this number because more than 50,000 people from the middle and south of Iraq have left their home cities and transferred to Sulaimani to seek a safe and secure life.

To set proper sustainable groundwater management, the population growth for the next twenty five years is accounted for and the demand and availability sources are assessed on that basis.

According to the standard equations for the calculation of water demand based on the life standards and the degree of developments and improvement of services, the water demand per capital per day is estimated and shown in Table 6.1, and the current demand with population growth is shown in Tables 6.2.and 6.4.

The required water demand is calculated according to the Jovanovic (1972, cited in Filipovic, 1982) equation

Q= St. Pt. K. G

Where

Q: required water demand l/c/d

St: number of customers (population)

Pt: specific demand l/c/d

K: coefficient of variation of water use, without variation is 1; with maximum standard variation is 1.4, for this area is considered to be 1 as most of the water system is distributed through storages.

G: losses are considered to be 1.2

Table 6.1 Estimated water demand criteria l/c/d .

Parameter	Quantity	units
Domestic use- Urban area	300	l/c/d
Domestic use- rural area	200	l/c/d
Commercial use	30	l/c/d
Industrial use	30	l/c/d
Losses	20	%

Based on the equation of Keeler (2000), population of the next twenty five years is estimated, as

$$N=N_o e^{kt}$$

Where: N= number of future population, N_o is the present population number, e is a constant 2.71828; k is equal to the rate of increase (a decimal representing a percentage); and t is the number of years over which the growth is to be calculated.

The growth rate assessed by the Ministry of Planning–Iraq is 2.25% until 2010 and 2% after 2010. Accordingly, the expected population for the city of Sulaimani and the outskirts is as in Table 6.2.

Table 6.2 Population growth of SB1 area.

District	Sub-district	2005	2010	2015	2020	2025	2030
Sulaimani	Center-Urban	650.000	729.300	818.274	905.829	1002.753	1110.047
Sulaimani	Center-rural	8.230	9.234	10360	11.469	12.696	14.054

The potable water demand for both urban and rural areas is supposed to be as shown in Table 6.3 both for the present and until 2030.

Table 6.3 Water demand criteria for SB1.

District	Sub-district	Domestic l/c/d	Commercial l/c/d	Industrial l/c/d	Losses l/c/d	Total l/c/d
Sulaimani	Center-Urban	300	30	30	66	426
Sulaimani	Center-rural	200	0	0	40	240

Table 6.4 Total water demand for the projected years for SB1. ($x10^6$ l/d)

District	Sub-district	2005	2010	2015	2020	2025	2030
Sulaimani	Center-Urban	276.900	310.681	348.584	385.883	427.172	472.880
Sulaimani	Center-rural	1.975	2.216	2.486	2.752	3.047	3.372
Sulaimani	Total	278.875	312.897	351.07	388.635	430.219	476.252

Water demand for irrigation - SB1

In this sub-basin agricultural activities are declining sharply as most of the previous agricultural lands have distorted to residential, industrial or commercial areas. The current area of arable land is estimated to be about 5000 hectares of which %10 is irrigated and the rest is rain-fed. More than 20% of this land is expected to distort in the very near future to residential areas. Accordingly, the demand for irrigation water is calculated for 500 hectares, and because most of the landowners use water-saving technology for irrigation, 1 l/s/hectare is depended for the calculations.

The total estimated demand for water for irrigation is 500l/s meaning that for five months the required water for different types of cropping is about 6.48 x 10^6 m^3.

6.2 Present water practice, management and responsibilities for SB1

The main water supply of the city of Sulaimani and some outskirts comes from two main sources; the first is the water which pumps from Sarchinar karstic spring. Due to the variability of the Sarchinar spring yield during the wet and the dry seasons, the water cannot be pumped at the same capacity throughout the year. From November to June about 1.6 m^3/s will be pumped to the distribution tanks inside Sulaimani with a daily average of 5900 m^3/hr, this amount will be reduced to 0.9 m^3/s during recession period.

The second main source supplying the city of Sulaimani is from Small Zab River downstream of Dokan Lake. The difference in static levels between the water source and the delivery points is in the order of 400 m, and the length of conveyance mains is about 85 kms (Fig.6.1). Hence a number of pumping stations and a treatment plant are established. This also helps to keep maintenance at lower levels. This Dokan line supplies water to Sulaimani from July to the end of October with an average yield of 0.75 m^3/s.

Besides these two sources, there are a number of wells and kahrezes upon which small distribution projects exist inside the city of Sulaimani. Any of these projects supply water to about 50-100 houses. The estimated rate of supply from this source amounts to 0.1 m^3/s.

Table 6.5 represents the regular municipal water supply by the government. After 2003, when a rapid development and expansion of the city started, more than 50% of the area of the city expanded and continues to do so to the outskirts as shown in Fig.6.2

Table 6.5 Current water supply amount with the current deficit for Sulaimani city and the outskirts.

Season	Supply from Sarchinar X 10^6 l/d	Supply from Dokan X 10^6 l/d	Supply from Karez projects with distribution system X 10^6 l/d	Total X 10^6 l/d	Current demand X 10^6 l/d	Current deficit X 10^6 l/d
Wet	135	0	8.6	143.6	278.8	135.3
Dry	85	64	8.6	157.6	278.8	121.3

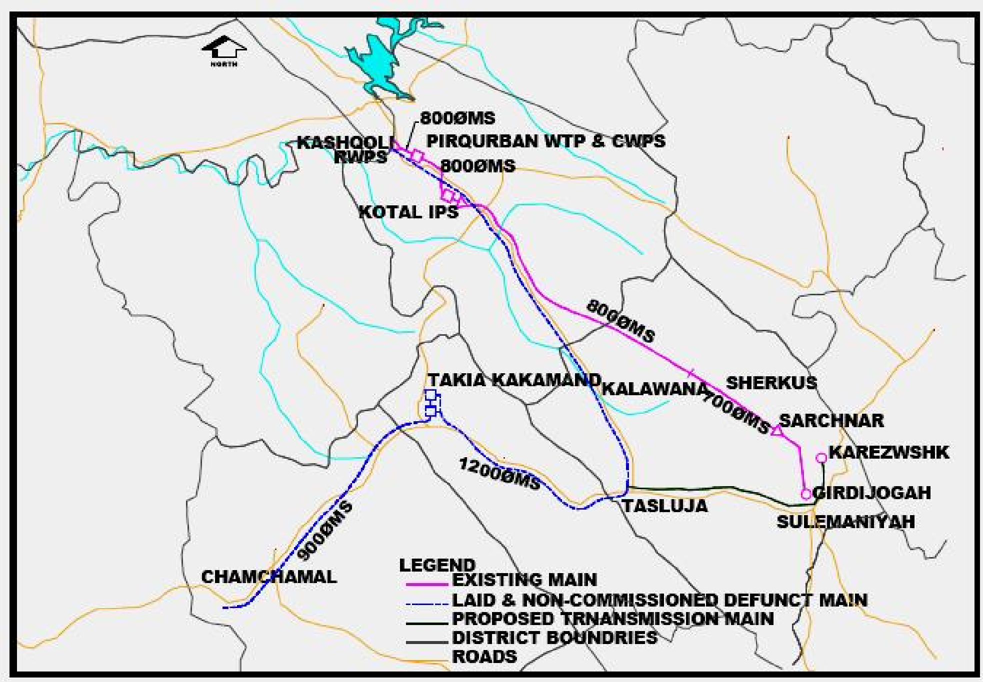

Fig.6.1 Dokan (downstream)-Sulaimani project water supply. After Nabar, 2002

All these areas became densely residential areas without any system of water distribution or sewage draining system. This forced the people to start drilling wells up to depths of 60-100m in their backyards with no control by the government. From 2003 to the present,,more than 8000-12000 deep wells have been drilled without licence from the related governmental offices and by cheap traditional machines of percaution tools (known as Syrian machines, as they came from Syria). The very cheap cost of drilling per meter (total cost of 100m deep well with submerge pumps not exceeding 1000US$) encouraged owners of even the older houses to drill wells inside their backyards because the municipal tap water could not satisfy their real demand, particularly during summer season.

This was the start of the problem of overexploitation and pollution risk in this major city and the outskirts, particularly because most of these wells are neither properly drilled nor protected. Consequently they are gravely vulnerable to contamination and pollution by sewage waters from the first few surface meters.

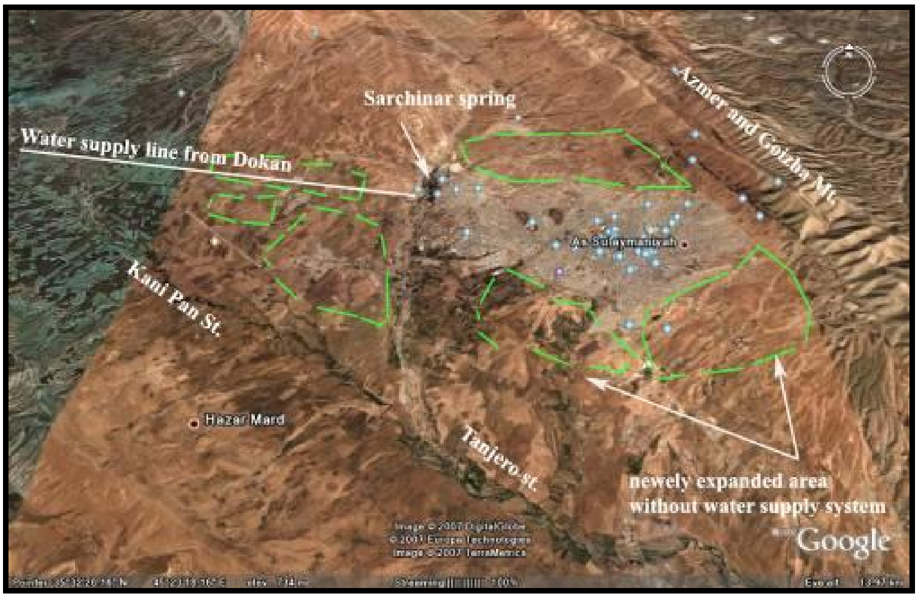

Fig.6.2 Sulaimani city and the outskirts show the sources of water supply and the newly expanded areas (green dashed lines) for residential settlements. (The image is taken from Google Earth web site and returned to 2003)

The very rapid spread of this phenomenon of drilling wells inside backyards causes the estimation and even registration and documentation of these wells to be uncontrollable. However, according to the Groundwater directory of Sulaimani, the registered number of these wells is approaching 10000.

Fortunately, 85% of these wells penetrate TAT or a few meters from AIA then TAT. As mentioned in chapter four of this thesis these types of rocks rarely act as aquifers. The yield of most of the wells drilled within these rocks is limited to between 1-2 l/s but with a limited capacity of supply i.e. the well will dry after discharging the column of the water inside the well and pumps should be switched off for a few hours to allow the wells to recover.

Comparing the projected water demand for the next 25 years with the current water supply projects as shown in Tables 6.4 and 6.5, it is obvious that the annual water demand of the city of the Sulaimani and outskirts is 173.83 x 10^6 m^3 which is equivalent to 5.5 m^3/s, while the existing water supply for a normal rainy year for Sarchinar spring and Little Zab river is only 3 m^3/s. This means that 2.5 m^3/s is the deficit in a normal case, without taking into consideration any abnormal or un-expected cycle of drought and future depletion in groundwater.

A new water supply project for Sulaimani city studied by the Ministry of Municipality and currently being implemented aims to increase the current supply of water from Dokan Lake to Sulaimani City by another 2.2m^3/s. In this proposed new system, a 1200 mm MS pipeline, which was laid in 1984 but never commissioned, is utilized fully. An additional 1500 mm MS pipeline is proposed between IPS-3 and Tasluja Reservoir, and a new 1200/900 mm MS pipeline is proposed between Tasluja and Sulaimani. The principal components of the new Dokan water supply project are an intake and raw water pumping station on Lower Zab River at Kashkoli with vertical turbine pumps; a 280000m^3/d water treatment plant WTP at Pirqurban; a 36 km long MS clear water transmission main 1500/1200 mm in diameter, running parallel to the existing line, internally mortar-lined for reducing frictional losses and externally gunited for protection against corrosion; intermediate pumping stations along the Dokan-Tasluja Road; a break pressure tank near Kotal a reservoir and bifurcation pumping station at Tasluja; a reservoir and pumping station at Halabja Memorial on the outskirts of Sulaimani; MBR at Karezwshk (part of Sulaimani city) with provision for a pumping station, and rehabilitation and commissioning of existing 1200 mm dia. 68 km long MS pipeline along the Dokan-Tasluja-Chamchamal road up to the existing master balance reservoir at Takia Kakamand.

To meet the power requirement of 50 MVA for the existing and proposed systems, a 132/33 kV substation is proposed at a location between IPS-1 and IPS-2. This will also improve the reliability of supply.

As shown above, the projected water demand for the entire Sulaimani Governorate will almost double during the 25-year planning period. To meet the 2030 plan, the existing supplies and associated infrastructure will have to more than double the current systems supply less than the need projected for 2005.

As clear from the comparison of this new projected supply system, even this new line of supply could not meet the real demand of the next 30 years. That is why looking for additional alternatives and solutions with sustainable conjunctive use of both surface and groundwater resources is the great challenge.

The operations factor for supply, treatment, and distribution should be to ensure service 24 h/d. When moving to actual design, the safety factors, redundancy, and reliability aspects should be reviewed in relation to this requirement. There should be sufficient facilities to provide for reasonable maintenance down time. The projected water demand is determined based on population and level of water service.

The UNJHC (2002, cited in Parson, 2006) reported that potable water is available for about 90 percent of the population in the district of Sulaimani and the drinking water is good in quality and quantity, but the distribution systems have problems such as contamination of the drinking water by sewage due to breakdowns in both piping systems. Some areas have no distribution systems for clean water.

The Sulaimani Water Department in the City is responsible for operating and maintaining the water system in the district center. This is financed by the Ministry of Municipalities. In the sub districts, the Water and Sanitary Department is responsible for the operation and maintenance of the individual sub district systems, financed directly by the Ministry of Municipalities. The villages in the district are under the General Directorate of Reconstruction and Public Works, which provides funding for various village projects.

In addition to the above-mentioned ministries, other authorities are involved in the water functions in the district: The Ministry of Health carries out water quality testing, and the Ministry of Water Resources constructs wells and monitors groundwater.

6.3 Current and future demand of SB2

Besides being the center of three relatively highly populated sub-districts (Zarain, Arbat and New Halabja collection town) a large extensive agricultural plain occupies a great part of this sub- basin. One large karstic-fissured spring (Bestansur spring), two other medium karstic-fissured (Greza and Kani Panka) springs, tens of smaller springs and a relatively highly productive alluvial aquifer (AIA) are the main groundwater sources of this basin; as well, the Tanjero stream crosses the middle of this sub basin.

Population and population growth-

According to the data of the Directory of Statistics of Sulaimani, the population of this sub-basin is as shown in Table 6.6.

Table 6.6 Population growth of SB2 area.

District	Sub-district	2005	2010	2015	2020	2025	2030
Sulaimani	Tanjero- Urban	16000	17920	20070	22217	24594	27226
Sulaimani	Tanjero - rural	12000	13464	15106	16723	18512	20493
Sharazoor	Warmawa- urban	22000	24684	27695	30658	33939	37570
Sharazoor	Warmawa- rural	4870	5464	6130	6786	7513	8317
Sharazoor	New Halabja- urban	36000	40392	45320	50169	55537	61479
Sharazoor	New Halabja- rural	0	0	0	0	0	0
Total	SB2	90870	103934	116336	128573	142120	157115

Table 6.7 Total water demand for the projected years for SB2. ($x10^6$l/d)

District	Sub-district	2005	2010	2015	2020	2025	2030
Sulaimani	Tanjero- Urban	6.3	7.1	7.9	8.8	9.7	10.8
Sharazoor	Tanjero - rural	2.9	3.2	3.6	4.0	4.4	5.0
Sharazoor	Warmawa- urban	8.7	9.8	11.0	12.1	13.4	14.8
Sharazoor	Warmawa- rural	1.2	1.3	1.5	1.6	1.8	2.0
Sharazoor	New Halabja- urban	14.2	16.0	17.9	19.8	22.0	24.3
Sharazoor	New Halabja- rural	0	0	0	0	0	0
Total	SB2	33.3	37.4	41.9	46.3	51.3	56.9

According to Table 6.7, the current potable water demand is estimated to be 0.38 m^3/s, while for the year 2030 it increases to 0.65 m^3/s.

-Water demand for irrigation

Table 6.8 shows the distribution of the land in hectares for agricultural rain-fed, irrigated and non-cultivated areas.

Table 6.8 The agricultural lands in hectares in SB2.

District	Sub-district	Rainfed	Irrigated	Natural Orchard	Forestation	Non-cultivated
Sulaimani	Tanjero	23484	4366	7286	72	7085
Sharazoor	Warmawa	13655	4074	1915	114	2560
	Total	37139	8440	9201	186	9645

If the estimation is done on the basis of 1l/s/hectare, the current water demand for the irrigation of the irrigated land is (2.77 m^3/s or 87.5x106 m^3/year). Expanding the irrigated land with additional non-cultivated land nearly doubles the value, meaning (5.6 m^3/s or 175x10^6 m^3/year) will be the demand for additional and future developing irrigation lands.

6.4 Present water practice, management and responsibilities for SB2

The main water supply for Arbat and New Halabja town is the Bestansur water pumping project, which pumps water from the Karstic-Fissured spring of Bestansur beside two deep wells. A location map of the water supply to New Halabja is shown in Figure 14.2.

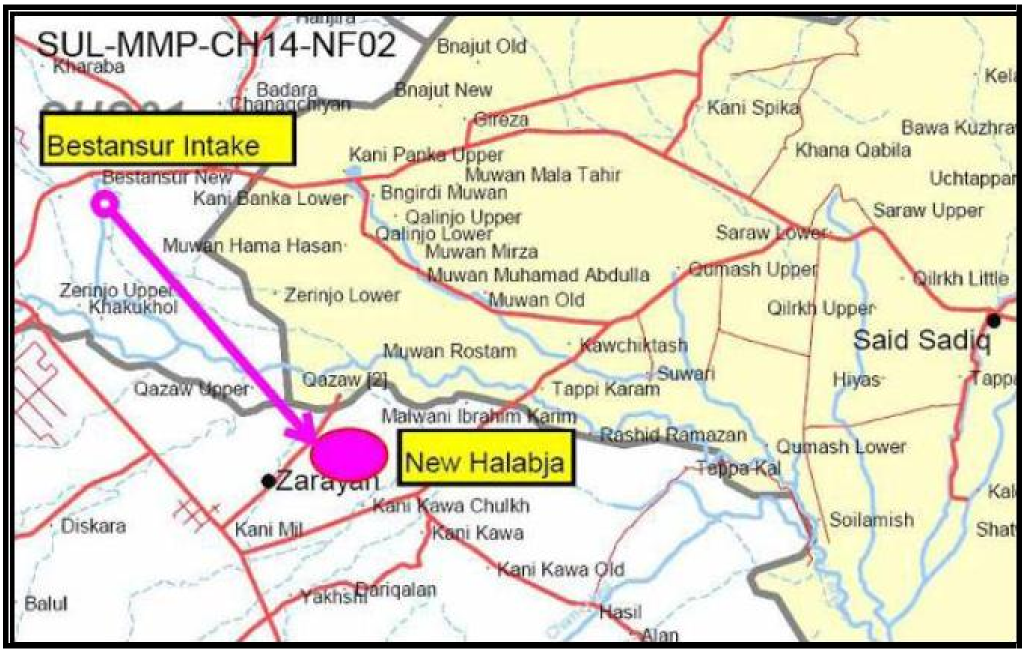

Fig.6.3 Location of the water supply source for New Halabja, after (Parson,2006)

The water from the Bestansur Spring is conveyed to New Halabja via the Bestansur intake and pump stations. This system is depicted schematically in Figure 6.4. As illustrated in the figure, the water is collected from two springs and pumped in two directions. In one direction, a pipeline feeds both the Arbat (Tanjero) Sub district and Barika Village. In the other direction, a pipeline conveys the water to New Halabja and the Warmawa (Zarain) Sub district.

The 13 pump units (depicted schematically in Figure 6.4) are used to deliver the Bestansur water to the service areas in the two districts. It is reported that the supply source has a high potential yield estimated at 4000 m^3/h (Parson, 2006). The intake is operated for about 16 h/d, and the reported actual capacity of the pumps to Zarain and New Halabja towns is approximately 900 m^3/h.

There is no treatment for the New Halabja water supply system other than chlorination which takes place at the Bestansur collection reservoir.

There are three storage facilities that serve New Halabja: a 2500 m^3 ground collection

Reservoir at Bestansur intake (designated as T1); a 4670 m^3 terminal storage reservoir on the south side of town; and a 100 m^3 elevated steel tank inside the town (Parson, 2006)

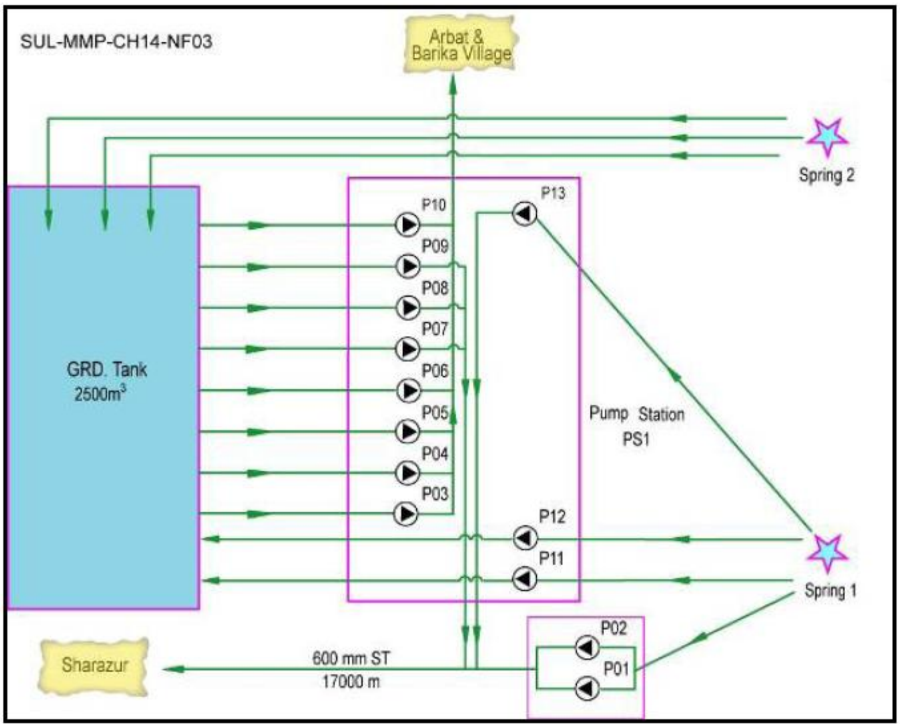

Fig.6.4 Scheme of intake pump station and reservoir – Bestansur Springs

The urban area of New Halabja is approximately 5 km^2. It is estimated that about 4.5km^2 of the city is covered by the distribution network which serves approximately 90 percent of the population. The remaining population obtains their water by tankers.

The Water Department in the Sharazoor (SaidSadiq) Municipality is responsible for operating and maintaining the water system in the district center and is financed by the Ministry of Municipalities. In the sub districts, the Water and Sanitary Departments of the respective municipalities are responsible for the water systems operation and maintenance in the individual sub districts, financed directly by the Ministry of Municipalities. The villages in the district are under the General Directorate of Reconstruction and Public Works which provides funding for the various projects in the villages, including water supply.

In addition to the Bestansur source, the old Zarain village depends on deep productive wells connected to the distribution system of the town which is estimated to supply the town with 1000 m^3/day. Water is collected in a 100m^3 storage tank and conveyed to public taps by a water distribution network. Villagers store water at their homes in barrels.

The share of Arbat (Tanjero) town from the Bestansur pump station is 2120 m^3/day which is in addition to the 640 m^3/day from the two existing wells connected to the network.

Accordingly, the total water supply for SB2 from the regular governmental water distribution network is 18160 m^3/day, equivalent to 0.21 m^3/s, meaning there are currently about 0.17 m^3/s deficits.

The design capacity of Bestansur Pump Station is significantly larger than this figure (reported to be 3,100 m^3/h) but operation is limited to only one or two of the six pumping units due to the inadequacy of the generator and transformer at the site. Therefore, as far as constraints to the supply are concerned, the intake and pumping system would not be a limiting factor in this case. In addition, based on the expected demands of New Halabja, Warmawa and Arbat, the supply source, the Bestansur Springs, should not be a constraint either. As such, the design capacity of the existing supply system has been estimated based on the capacity of the conveyance pipeline from Bestansur to Sharazoor. Based on a velocity of 1.5 m/s in the 600 mm conveyance pipeline, it is estimated that the system could deliver approximately 36,000 m^3/d (Parson, 2006).

Most of the southern rural villages spread along the foothill of Baranan Mountain depend mainly on small springs discharging from SDA. Most of these springs are regulated by the construction of intake collecting structures and distribution by taps to the houses either directly by gravity or by pumping to storage elevated tanks. For some villages, where the spring water was insufficient for their survival, deep wells were drilled. FAO, UNICEF, KLA and some other national and NGOs made a great contribution to the rehabilitation and regulation of water supply projects in these villages from 1998-2003. Due to the scattered nature and low population density of the rural settlements, assistance will be expensive (relative to the district center) on a per capita basis.

Regarding irrigation projects practice in SB2, a number of irrigation canals exist in the area, some of them built during the eighties and others constructed during 2000 or recently rehabilitated. The main irrigation canals are shown in Table 6.9.

Table 6.9 Irrigation canals in SB2

Name of the canal	Irrigated area, hectares
Mwan-Kanipanka	1440
Greza	75
Bestansur	1250
Qaragol	438
Hasil	335

These projects are built on the existing spring waters outlets of Kanipanka, Greza, Bestansur, Alan and Hasil, while Qaragol is built on Tanjero stream.

Most of the farmers in this area depend on their own wells drilled inside their farm and operate these wells during the demand seasons (June-Sept) by operating their diesel pump for about 5hrs/day, with a discharge rate of 8-10 l/s, and spreading the water by ordinary traditional small earth canals.

6.5 Current and future demand of SB3

The center of Sharazoor district is located in this sub basin; SaidSadiq is the largest town within this district, and many relatively highly populated villages and collection towns such as Qlrkh, Gamesh Tapa, Saraw, Shanadari, and Grda Naze surround this center.

This sub-basin is the most fertile area from an agricultural point of view. Besides many large karstic springs such as the Saraw group, Reshen, Hasar, and Jomarase being located in the mountainous part of this area, the plain is characterized as the richest intergranular groundwater aquifer AIA.

However, the current status of this basin should be clarified from the point of view of water supply and irrigation projects. This clarification will provide better insight into the types of problems and the future forecasted risks which, as a result of bad management, might surface in the groundwater and environmental resources of this sub basin.

Population and population growth

According to the data of the Directory of Statistics-Sulaimani and according to the estimated rate of growth, the current and the population growth of this sub basin during next 25 years are shown in Table 6.10.

Table 6.10 Population growth of SB3.

District	Sub-district	2005	2010	2015	2020	2025	2030
Sharazoor	SaidSadiq- urban	48000	53856	60426	66892	74050	81973
Sharazoor	SaidSadiq- rural	20350	22833	25618	28359	31394	34753
	Total	68350	76689	86044	95251	108803	116726

Table 6.11 Total water demand for the projected years for SB3. ($x10^6$l/d)

District	Sub-district	2005	2010	2015	2020	2025	2030
Sharazoor	SaidSadiq- urban	19.0	21.3	23.9	26.5	29.3	32.4
Sharazoor	SaidSadiq- rural	4.9	5.5	6.1	6.8	7.5	8.3
	Total	23.9	26.8	30	33.3	36.8	42.7

According to Table 6.11 the current potable water demand is 0.21 for urban and 0.27 m^3/s for all SB3, and the expected demand for 2030 is 0.5 m^3/s.

Water demand for irrigation

Table 6.12 shows the area of agricultural land of SB3

Table 6.12 The agricultural lands of SB3

District	Sub-district	Rain fed	Irrigated	Natural Orchard	Forestation	Non-cultivated
Sharazoor	Said Sadiq	13058	6562	-	77	955

The rough estimation of the amount of water demanded for irrigation is 68 $x10^6$ m^3/year which is equivalent to 2.15 m^3/s. This amount will increase to about 2.5 m^3/s if additional non-cultivated land planned is put into the irrigated programs.

Adding 0.02m^3/s for livestock watering, the bulk water demand for this sub basin for human consumption, irrigation and livestock is 2.8 m^3/s currently and will be 3.0 m^3/s in 2030.

6.6 Present water practice, management and responsibilities for SB3

The existing water supply capacity of SaidSadiq is 3000m^3/d. The supply is regulated through Hasar (SaidSadiq) spring and 11 deep wells inside the city from which water is pumped to elevated tanks and distributed through the water network of the town.

The water supply project studied by Parson (2006) proposed an improvement in the system to increase the water supply to 18360 m^3/day, which is equivalent to 0.21 m^3/s. This amount will meet the current demand of the town. As a result, more than 60% of the houses in Said Sadiq town drilled shallow wells inside their backyards and use this water for their daily needs, even for drinking. According to the data of water availability in this sub basin, it is clear that the available water is greater than the current demand, but the problem which faces their function is with the deficiency in the existing projects and constraints such as shortages in electricity.

Despite the great surplus in the available water resources in this sub basin, improper or, more precisely, absence of management has led to great losses in this important resource. Many flowing artesian wells such as Perashka well and Nawgrdan well south of SaidSadiq (Fig. 6.5) were drilled in this sub basin and have been left flowing without use for years

Regarding the irrigation practice in this sub basin, many irrigation canals exist, some of them constructed during the eighties or earlier and some constructed recently during the FAO mission.

Table 6.13 Irrigation canals in the area of SB3.

Name of the canal	Irrigated area, hectares
Qurena	818
Sarachawi Saraw	500
Qalabo	375
Malwan	725
Hasar	650
Qumash-Swelamesh	251
Kanikawa-Chogh	175
Shatwan	625
Qalejo saroo	200
Dargolan	275

6.7 Water demand for SB4

This sub basin includes four relatively densely populated towns: Halabja, which is the center of the district, Sirwan, Khurmal and Biara. Extensive fertile plain constitutes the majority of this sub basin and is considered to be excellent agriculture land in the area. Two large Karstic springs (Zalim and Shiramar), springs with medium discharge such as Bawa Kochak, Sargat, and Khurmal, and tens of smaller springs are located in this sub basin. The intergranular aquifer is also considered a highly productive groundwater source in the area.

Population and population growth

According to the data of the Directory of Statistics in Sulaimani, and based on the growth rate estimated by the Ministry of Planning, the current and future populations of this sub basin are shown in Table 6.14

Fig.6.5 A flowing artesian well in Perashka village south of SaidSadiq. (Left as it is now since drilled in 2002)

Table 6.14 Population growth in the area of SB4

District	Sub-district	2005	2010	2015	2020	2025	2030
Halabja	Municipal center-urban	50000	56100	62944	69679	77134	85388
Halabja	Municipal center-rural	0	0	0	0	0	0
Halabja	Khurmal- urban	9740	10928	12261	13573	15025	16633
Halabja	Khurmal- rural	13720	15393	17271	19120	21166	23430
Halabja	Biara- urban	3700	4151	4657	5156	5708	6319
Halabja	Biara- rural	6800	7629	8560	9476	10490	11613
Halabja	Serwan-urban	6677	7491	8405	9305	10300	11402
Halabja	Serwan-rural	0	0	0	0	0	0
	Total	90637	101692	114098	126306	139821	154782

Table 6.15 Total water demand for the projected years for SB3. ($x10^6$ l/d)

District	Sub-district	2005	2010	2015	2020	2025	2030
Halabja	Municipal center-urban	19.8	22.21	24.92	27.59	30.54	33.81
Halabja	Municipal center-rural	0	0	0	0	0	0
Halabja	Khurmal- urban	3.85	4.32	4.85	5.37	5.95	6.58
Halabja	Khurmal- rural	3.29	3.69	4.14	4.58	5.0	5.62
Halabja	Biara- urban	1.46	1.64	1.84	2.0	2.26	2.5
Halabja	Biara- rural	1.6	1.83	2.0	2.27	2.51	2.78
Halabja	Serwan-urban	2.64	2.96	3.3	3.68	4.08	4.51
Halabja	Serwan-rural	0	0	0	0	0	0
	Total	32.64	36.65	41.05	45.49	50.34	55.8

The current demand for the urban area of this sub basin is 0.32 m^3/s; for the year 2030 this amount becomes 0.54 m^3/s. For the rural area the current demand is 0.05 m^3/s, and for the year 2030 becomes about 0.1 m^3/s.

Water demand for irrigation

The current water demand for irrigation is estimated to be in the range of 4.6 m^3/s for the whole sub basin, and if non-cultivated lands are added, in the future the demand becomes 7.7 m^3/s. The roughly estimated current water demand for livestock and poultry in the area is 0.002 m^3/s.

Table 6.16 shows the area of the agricultural land in SB4

District	Sub-district	Rain fed	Irrigated	Natural Orchard	Forestation	Non-cultivated
Halabja	Sirwan	7731	6241	3133	379	7549
Halabja	Khurmal	9060	6740	23896	45	7805
Halabja	Biara	3123	998	50	2	3313
	Total	19914	13979	27079	426	18667

Accordingly, the total current demand for human consumption, irrigation and livestock watering is estimated to be 4.97 m^3/s, while this demand becomes 5.24 m^3/s for the year 2030 and becomes 8.34 m^3/s if non-cultivated lands are developed and changed to irrigated lands.

6.8 Present water practice, management and responsibilities for SB4

Sources of potable water in the Halabja District include Darbandikhan Lake, artesian wells, springs and streams. It is reported that potable water in Halabja is available for about 75 percent of the population (UNJHC, 2002, cited in Parson, 2006).

In the rural areas, about 80 percent of the villages rely on springs for their potable water, while the remaining villages have constructed wells with an average depth of 100 m.

Halabja's water supply source includes 26 wells distributed throughout the city, and four springs. The current Halabja wells have an average depth of approximately 120 m, and their average yield is about 35 m^3/h. The maximum daily production of the 26 wells was computed to be 5871 m^3/d. It was limited by various factors such as generator outages, well yield, pump condition and electrical service (Parson, 2006).

In addition to the well sources, there are six springs in Halabja. Two of these springs do not supply the domestic water system in the city. The flow of the springs fluctuates based on the season, with increased flow in the winter and decreased flow in the summer. All the springs discharge water 24 h/d. The Hama Amin, Haji Hasan, and Pasha Springs, combined, produce a minimum of 900 m^3/d. The Ahmed Awa Spring produces 6000 m^3/d. The Mosque and Kani Sheik springs are not used for the Halabja water system (Parson, 2006)

There is currently no treatment to water in the Halabja system beyond disinfection using chlorine. At present, the Halabja water system has 14 tanks for storage. There is a new one being built to replace the existing Gulan tank. The current capacity of the tanks combined is approximately 2144 m^3. With the completion of the new Gulan tank, the capacity will become approximately 2410 m^3. The tank sizes range from 20 m^3 to 750 m^3. Each of these tanks is fed by a combination of well and springs.

The current production capacity of the Halabja water supply system with the combined sources is 5871 m^3/day, while Khurmal town depends on Zalim Spring with a production capacity of only 200m^3/day. For Biara and Sirwan the current production capacities are 500 and 1000m^3/day respectively. Biara depends on spring sources, while five deep wells are currently the main municipal source of water distribution in Sirwan town.

Similar to Halabja town, no water treatment exists for the Biara, Khurmal and Sirwan water supply systems, sometimes resulting in problems of mass infections among the population of Khurmal because the pipes which supply the town directly extend not from the spring but from the middle of Zalim stream which is often contaminated with the wastes of tourists and the sewages of Zalim village upstream.

To a certain extent the phenomenon of uncontrolled drilling of wells by the people is relatively widespread throughout the area of Halabja, but the majority of these wells are used for agriculture and not for human consumption. Power shortages and relatively expensive fuel prices have a positive role in minimizing the over-pumping and abstraction of more water than required; otherwise people would be careless in their practices.

It is worth mentioning here that a new project of developing a water supply system for Halabja town is currently under study and implementation. This project will be funded by the Japanese government. The proposed new supply system will pump water from the Darbandikhan reservoir and Sirwan River, establish a water treatment plant, as well as rehabilitate and improve all the distribution networks and pumps inside the town.

Farming and irrigation in this area is relatively high. Many farmers practice regular cultivation and crop cycling during different seasons. There are many irrigation canals in this sub-basin which were constructed by NGOs, UN organizations or the Directory of Irrigation in Sulaimani, as shown in Table 6.17

Table 6.13 Irrigation canals in the area of SB4.

Name of the canal	Irrigated area, hectares
Sargat	125
Sargat-2	125
Khalan u Majol	95
Sheramar	475
Kani Shex	350
Biara	1150
Glijan u Mawami	75
Wulusenan	300

In addition, few farmers have started to use new mechanical irrigation technology for irrigating their farms, particularly drip irrigation technology.

6.9 Annual groundwater production

- SB1

The calculation of annual groundwater production is based on the daily discharges of the shallow and deep wells and on spring discharges in each sub basin. Average daily discharges of the shallow and deep wells are obtained through the field survey done on all the drilled or dug wells possible for survey. For those drilled during the period of the study the estimated number of these wells obtained from different sources is multiplied by an average discharge rate and daily operation hours.

Table 6.14 Annual groundwater production in SB1 based on data of the year 2005-2006.

Type of Aquifer	Type of discharge	No. of wells	Average daily operation hours	Estimated discharge rate l/s	Total annual production X 10^6 m^3/year	Total normal estimated recharge X10^6 m^3/year
CKFA	Deep wells	20	7	10	1.84	90.4
	Deep wells	50	2	3	0.40	
	Springs	Sarchinar + 20 small springs			86.7	
	Total annual production				88.94	
AIA	Deep wells	600	5	6	23.6	52.2
	Deep wells	1750	2	3	13.8	
	Shallow wells	150	6	2	2.4	
	Total annual production				39.8	
TAT	Deep wells	50	6	3	1.2	15.9
	Deep wells	8000	1	2	21.0	
	Springs and Kahrezes	50	24	1.2	1.8	
	Total annual				24.0	
	Bulk total				152.74	158.5

The following conclusions can be drawn from Table 6.14 and summarized as follows:

1. In a normal average year such as that of 2005-2006, TAT aquitard is the predominant hydrogeological unit subjected to overexploitation as it covers the majority of the city of Sulaimani and the newly expanded part of it. This leads to appreciable drawdown in a great number of the wells inside the city. In addition, during the late summer some of the Kahrezes on which water distribution system is established are dried out.
2. As is clear, the total annual amount of discharged and exploited groundwater is 152.74 x 10^6 m^3, while the current annual real demand of the area does not exceed 105x10^6 m^3. If the annual supply from Sarchinar spring water is accounted at 45 x 10^6 m^3, about 118 x10^6 m^3 is the real consumption of the city. These figures show that people in SB1 deal in an irresponsible and offensive way with these groundwater resources and more than 3 x 10^6 m^3 /year is exploited excessively on account of the impact on the aquifers in the area. The amount of water consumed

from the small springs of SDA south of the basin is excluded in these comparison figures.

-SB2

The rate of groundwater exploitation is low compared to SB1. The main source of water supply is from Bestansur spring. During wet seasons, a great amount of discharged water flows without appreciable use while during dry seasons, when the demand increases, the discharge rate of the springs will barely cover part of this demand.

Table 6.15 Annual groundwater production in SB2 based on data of 2005-2006.

Type of Aquifer	Type of discharge	No. of wells or springs	Average daily operation hours	Estimated discharge rate l/s	Total annual production X 10^6 m^3/year	Total normal estimated recharge X10^6 m^3/year
CKFA	Deep wells	12	4	7	0.44	>80
	Springs	Bestansur + KaniPanka + Greza and 20 small springs			58+22	
	Total annual production				80.4	
AIA	Deep wells	70	6	10	5.5	74.0
	Deep wells	600	1	5	3.9	
	Shallow wells	80	1	2	0.2	
	Total annual production				9.6	
TAT	Deep wells	100	1	2	0.26	15
	Springs and Kahrezes	50	24	0.8	1.26	
					1.52	
					91.52	169

The other main source of groundwater production is through deep wells in AIA. Many deep wells up to 140m deep in these aquifers yield a good quantity of potable water. Besides deep wells drilled by the government to supply water in the area, many other deep wells have been drilled by the people recently, as shown in Table 6.15. It is clear from this table that in this sub basin the present ground water withdrawal from the existing wells is quite limited. If 45% of annual recharge is considered the safe yield, the maximum current exploited volume comprises only 30% of the safe yield.

Accordingly, this area could be considered the area of low population stress compared to existing water resources.

-SB3

The groundwater exploitation in this sub-basin in comparison to the existing reserve is low. The annual estimated recharge of AIA is much higher than the estimated exploited amount.

If the safe yield considered is 45% of the total annual recharge, exploitation of AIA in this sub-basin is only 40% of the safe yield. Table 6.16 shows the figures of the current maximum possible exploitation in the SB3.

Table 6.16 Annual groundwater production in SB3 based on the year 2005-2006.

Type of Aquifer	Type of discharge	No. of wells or springs	Average daily operation hours	Estimated discharge rate l/s	Total annual production X 10^6 m^3/year.	Total estimated recharge X10^6 m^3/year
TKA	**Spring**	**Reshen + Jomarase**	**24**		**69+47**	**?**
JKA + CKFA	**Spring**	**Saraw group+Hasar +Qumash+Kanizard**	**24**		**96+22**	**114.3**
	Deep well	**20**	**4**	**7**	**0.7**	
	Total annual discharge				**118.7**	
AIA	**Deep well**	**40**	**8**	**12**	**5.0**	**89.3**
	Deep well	**300**	**2**	**8**	**6.3**	
	Shallow well	**520**	**2**	**5**	**5.2**	
	Total annual exploitation				**16.5**	

Improper use of groundwater by the people is clear in this sub-basin; as mentioned in previous sections the real water demand of this sub-basin for human consumption is only 0.27 m^3/s, while 0.52 m^3/s water will be pumped from the AIA. Even though this figure is still below the safe yield limit, it is expected to be more than the real demand. Based on the estimated area which is far from surface water resources and the irrigation projects, it is supposed that only 25% of this amount is used for irrigation purposes.

-SB4

In this sub-basin the stress on the groundwater resources is relatively more than in SB2 and SB3.

Table 6.17 Annual groundwater production in SB4 based on data for the year 2005-2006.

Type of Aquifer	Type of discharge	No. of wells	Average daily operation hours	Estimated discharge rate l/s	Total annual production X 10^6 m^3/year	Total normal estimated recharge X10^6 m^3/year
TKA	Spring	Zalim, Sheramar, Sargat +smallers springs	24		140	unknown
AIA	Deep well	60	7	10	5.5	57
	Deep well	800	2	5	10.5	
	Shallow wells	230	2	3	1.8	
	Total annual exploitation				17.8	
CKFA	Spring	Bawakochak			17.0	61.8
					174.8	260

In SB4, because of their location, the TKA and CKFA aquifers could not be exploited by drilling wells, and the only benefit from these aquifers is through the natural discharge springs. Accordingly, the only potentially exploitable reserve of groundwater in the area is through AIA. The investigated part which the drilling of wells could so far reach is AIA to a maximum depth of 160m; beyond this it is not clear yet to what depth this aquifer extends, but it is predicted to be deeper than the explored one. However, the AIA could be still in the safe yield range and more wells could be drilled without any harmful impact on the aquifer.

6.10 Potential and the development of the groundwater resources

In the Sharazoor–Piramagroon basin the most potential groundwater resources are Karstic, Karstic-Fissured and intergranular aquifers. These aquifers conjointly play a great role in supplying the main water sources for the purposes of human consumption and irrigation.

-Karstic and Karstic-Fissured aquifers developments and regulations

The main karstic and karstic-fissured aquifer in the basin of Sulaimani (SB1) is CKFA. This aquifer drains Sarchinar spring which supplies 60% of Sulaimani city through its natural discharge and the two intake pools and pumping stations constructed on the discharging mouth of the spring. The discharge of this spring decreases to the minimum value during the recession period which makes pumping from the spring mouth at the same rate as that of the wet season not feasible. The questions which need to be answered for the development of this karstic aquifer are these: Is any additional water available from the karstic aquifer for developing this beside the quantity yielded by the spring during the maximum demand period? In the rainy season is it possible to regulate the karstic springs' discharge using the storage water from the karstic aquifer resulting from water surplus from the spring? To answer these questions additional information about the water-bearing character of the karstic aquifer feeding Sarchinar spring is necessary.

The main aquifer of Sarchinar spring is 120m thick Kometan rocks underlain by more than 150m thick Qamchuqa karstic rocks which probably holds an appreciable amount of groundwater. These Qamchuga karstic rocks have not been investigated yet, which is why additional investigation is required to get the evidence for this assumption.

A similar approach could be taken to the Saraw group springs in SB3 and perhaps to Bestansur spring in SB2.

It is obvious from the spring discharge and Mailet recession analysis that these karstic springs show high storage reserves of groundwater at the end of the recession period. Storage of a magnitude of 20-37 $x10^6$ m^3 is of practical interest, but the question is what the amount is that could be used during dry periods when the requirements for irrigation and human consumption are larger and the discharge of springs is moderate or low.

In principle there are two options to get larger amounts of water from the karstic aquifers than those yielded by the springs during the dry season:

- Either by over-pumping the springs from the lower water table (static reserve).
- Or by drilling wells to a greater depth to pump groundwater to a limit so as not to harm the aquifer sustainability.

In both cases, residual storage of water is to be used in the season of maximum demand and would be replenished during the rainy season.

For this approach to be successful without having any negative impact on the level of the annual replenishment of the aquifer, additional detailed study and assessment are highly recommended before any practical steps are taken.

Stevanovic (2001) used the term “control of aquifer” which applies to all technical structures and measures aimed to enhance aquifer recharge and groundwater conservation (balancing the regime, i.e. stabilizing quantitative and qualitative groundwater characteristics). Thus, nearly any water structure which influences the modification of the natural regime may be considered to control and regulate the aquifer. If successful, aquifer control has effects analogous to managing surface accumulation water resource. The purpose is to extract the necessary water quantities for a limited time, and rely on natural replenishment during a future high water period (Fig.6.5).

As explained in chapter four, for Saraw springs the water source represented by the Jurassic aquifers lies at a considerable depth beneath the springs. Groundwater flows upward through the karstic channels in the overlying cretaceous confining sediments, as far as Saraw and Hasar springs are concerned. Thus, pumping and lowering of the groundwater level in these springs is expected to bring about some increase in the spring discharge, especially from the Saraw springs, since their residual storage is considerable.

The water-bearing character of the karstic and the karstic-fissured aquifers is quantitatively not known at all, except in the vicinity of the springs in particular. Therefore, any quantitative estimation of possible effects is not reliable.

From the practical point of view, over-pumping might be a more favorable solution than drilling of water wells. Drilling and pumping from the wells would be more expensive. A great number of relatively deep wells would probably be needed. On the other hand, it is generally risky to approach the groundwater development from the karstic aquifers through the wells. Due to an exceptional heterogeneity of the karstic aquifers, a great number of the wells may fail to discover the channels and other karstic openings yielding a practically interesting amount of water. Consequently, the most favorable option concerning the exploitation of the karstic aquifers appears to be over-pumping of the karstic springs, providing it would have satisfactory effects.

When spring discharge dramatically reduces and no other solution exists, the expansion of drilling and pumping activities might be the only response to the basic water demand of the population, livestock and orchards. However, this always requires careful selection of the well site, correct water management (with optimization of pumping), reduction of losses through different types of intervention, etc.

Tabular channels through which the springs are supplied may allow for pumping and achieving certain drawdown without undertaking any technical measures. If not, a corresponding intake structure would have to be built. For instance, it could be a shaft with a gallery. This idea is applied by Avias (1984) on Lez karstic spring in Montpellier, France and similarly by Stevanovic et al (2005) on several karstic springs in eastern Serbia and Montenegro.

A comprehensive program of investigation is necessary to prove or disprove the feasibility of this idea, including a large rate pumping from the springs during their low yield, drilling and testing of the wells, submersible survey of the spring channels and other similar activities.

AIA aquifers development and regulations

There are numerous technical solutions for aquifer control and regulation. They do not only imply intervention in the discharge zone, but in the whole catchment area where the objective is to change the natural conditions of recharge and storage in the aquifer system. The types of interventions are riverbed regulation, by diverting the surface or by closing sinkholes, building weirs, impermeable barriers and the like (Stevanovic and Iurkiewicz, 2004). *Aquifer control* includes *artificial recharge*, which regulates groundwater percolation to the areas having greater potential for recharge.

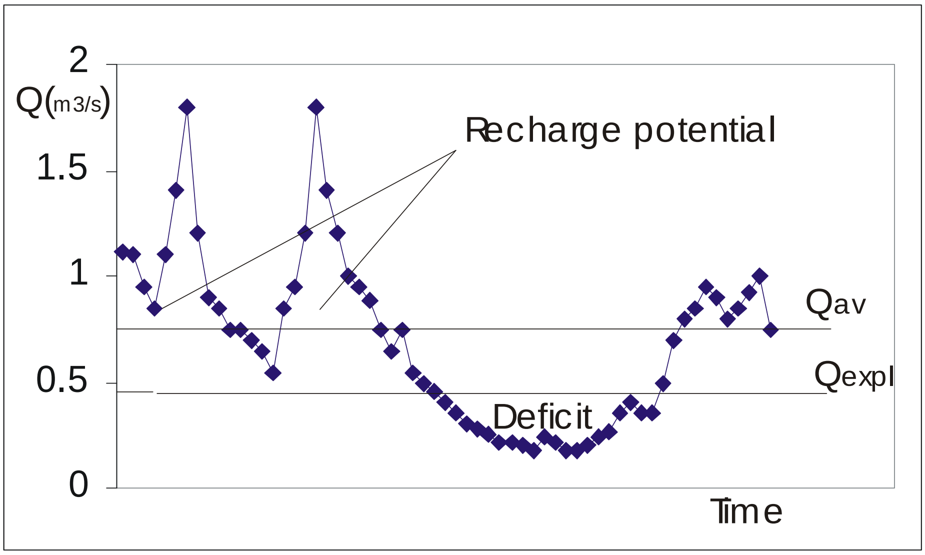

Fig. 6.6 - An example of spring hydrogram with defined optimal exploitation rate higher than natural spring flow in recession period (Stevanovic, 2001)

Artificial recharge in hydrogeological practice is the term used to describe different kinds of interventions. In fact it represents only direct infiltration (injection) of water into an aquifer system. It is a technical solution that is frequently applied in arid regions. The introduction and storage of temporarily available surface (runoff) water into an aquifer in support of a normal water supply during the recession period is the chief reason for application. The application of artificial recharge requires the building of a storage reservoir for surface water and the drilling of wells through which water needs to be recharged. The recharge could be achieved in two ways:

1. Gravity recharge,
2. Water injection under enough pressure to facilitate the process.

This latter technique was first used in Iraqi Kurdistan by Stevanovic and Iurkiewicz (2004) and applied to the Kasnazan area in Erbil city. The results show that the injection method is more efficient than the gravity method. By applying 8 bar pressure, continuous 6 l /s recharge could be achieved.

There are feasible locations in the study basin where artificial recharge of AIA could be achieved. As mentioned in chapter two of this thesis, an appreciable volume of runoff water flows through the intermittent valleys without taking benefit from them. Topographically there are convenient locations to decrease the velocity of these runoff waters and to harvest them for infiltration or to spread them over the small channels for gradual infiltration.

In SB1 the following locations are found to be suitable for artificial recharge of AIA:

- ***Qamartle site***: This site is located in the area between Sulaimani and Tasluja. Three tributaries conjugate at this location where surface runoff could be harvested by the construction of a small embankment with a maximum height of 10m, and water could be pumped into injection wells and recharge the AIA which covers the whole downstream area with variable thicknesses, in some places reaching 100m.
- ***Surtka site***: close to Qamartle where Tanjero rocks crop out and the surface runoff in the valley could be harvested and injected down to AIA aquifers through wells.

Artificial recharge could be applied also to the area near Zarain and Merade where water from Merade springs and Qleja could be harvested in a small reservoir and diverted to spread over the plain area for gravity recharge.

South of Halabja in SB4 a similar idea could be applied through the harvesting of waters in Khazena and Zamaqi valleys by diverting the surface runoff and spreading it over the plain area of Zamaqi for gravity infiltration. If runoff water is captured in Biara and Darashesh valleys, successful artificial recharge through injection wells is expected.

Artificial recharge could also be applied on Surajo and Chaqan streams in SB3 also by the spreading method. All these sites are shown in Annex 2.

A technique called aquifer storage and recovery (ASR) where the same wells are used for injection and recovery to reduce operational problems such as well clogging now offers viable ways in which water can be stored subsurface in deeper aquifer systems.

Sub-surface dams

Due to climate change worldwide, groundwater bearing sediments fall considerably short of sufficient replenishment. In this respect calls for the development and construction of subsurface dams arise, to challenge the effect of erosion and desertification. Sub-surface dams are easy to build and economical to generate, use and process new water cycles in rural areas (Thomas, 2005). Such dams stop erosion, restore river sediments and vegetation, and generate bank storage. In short, they create artificial aquifers. They are considered to be a sustainable anti-erosion device which retards runoff and diverts it into the sediments, and prevents evaporation. The construction of subsurface dams often takes place in countries having arid and semi-arid climatic conditions. The purpose is to collect water in valleys alluvium and to ensure water availability for upstream/downstream consumers throughout the year. Short periods of valleys flow, high variability of the hydrologic regime, and fast propagation through river bed permeable deposits are the main reasons why such systems should be applied (Stevanovic, 2001).

Construction of an impermeable barrier either of concrete or earth clay core from the base of the valley bedrock rising to a certain height would result in the formation of a subsurface reservoir. This reservoir could be used during high water periods as a surface reservoir and during low water periods through large diameter shallow wells. Wherever the bedrock or riverbanks are fully impermeable, the benefit of the dam is a new subsurface reservoir in the upstream zone, which is filled during flooding. In the case of permeable rocks at the bottom/bank contact with alluvium, this type of structure may have a multifunctional character:

1. Groundwater storage in upstream alluvial and riverbed deposits;
2. Longer period of recharge of the underlying aquifer (Stevanovic 2001).

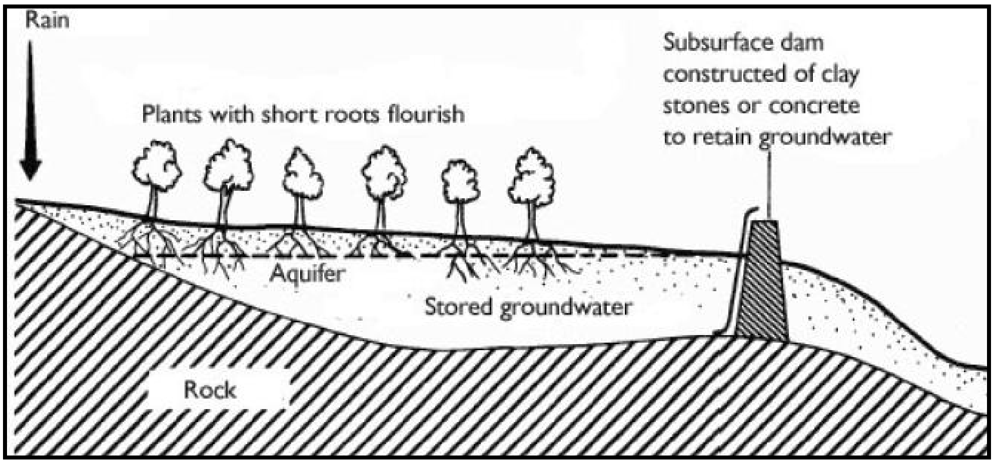

Fig.6.7 Subsurface dam and the reserved water.(Kenya Rainwater Association, Erik Nissen-Petersen,1987)

Construction of subsurface dams across streams in the upland areas is relatively easy as the thickness of sand encountered is quite low. In order to ensure that flows through or around a subsurface dam are blocked, the dam is keyed into the impervious formation both at the bottom and the sides. If the height of the subsurface dam coincides with the bed level, groundwater flows downstream as surface runoff after the entire upstream sand is saturated with groundwater. If there is need to let more water than this flow for the benefit of downstream users, the height of the dam can be kept below the bed level so that some upstream groundwater can also flow downstream. As a subsurface dam only blocks the groundwater that was flowing earlier and any surplus water after saturating the upstream sand freely flows downstream, there will be practically no additional load in the upstream of the subsurface dam (Rao, 2007).

The first subsurface dam in northern Iraq was implemented by Stevanovic in Gali Basera near Dohuk (2001). Appreciable positive hydrogeological and environmental changes appeared after the completion of this very low cost project.

A subsurface dam could be constructed on one of the streams in SB1, theYakhyan stream or Dole Nader valley. This valley is covered by about 5m of gravel and boulders; surface runoff in most periods of the year flows under these layers and feeds groundwater but due to a relatively high hydraulic gradient recharge process it might not get sufficient opportunity to do so. This could have a multifunction character as mentioned above, particularly for increasing the recharge volume of the surface runoff into the AIA aquifers. The water so saved could be diverted into some canal networks for enhancing canal flows.

It is worth mentioning here that such types of developments require continuous monitoring of the water quality from contamination by nitrates and other contaminants. Satoshi et.al, (2003) found after ten years' monitoring there was no appreciable impact on the nitrate content of groundwater when the subsurface dam construction technique is used.

Preliminary feasibility of these types of development was obtained during a detailed field study period but additional study is recommended for the potential areas mentioned.

6.11 Main risks, and challenges facing the water availability in the area

As mentioned in the previous sections, the perplexity and absence of management are parallel to the visible growth in population and the expansion of the city of Sulaimani and other surrounding districts and leads both to the appearance of more problems and to greater vulnerability to devastation and environmental impacts in the area.

Moreover, global warming which is starting to ring the risk alarm will have to force all decision makers to think much more deeply and seriously about facing future risks of losing sources for fulfilling water demands. The obvious principal current and future risks in the basin could be summarized as followings.

- ***Overexploitation***

This is practiced in the city of Sulaimani and might expand to other highly populated surrounding districts. If this phenomenon is allowed to continue without control by the government it might devastate the existing aquifers. One of the aquifers subjected to the impact is AIA in the four sub basins, particularly in SB1 and SB4.

- ***Drying up*** of some of the Karstic aquifers when probable drought appears again in the near future.

Drying up of most of the wells drilled by the basin dwellers for their daily needs, both because of the improper way of drilling, and because most of these wells dried up often when the neighbour drilled another deeper well. As a majority of these wells are filled with gravel packing, re-deepening of the wells is not possible.

- ***Severe environmental degradation and pollution*** appears to be threatening the long-term development prospects. Careful management of water as a resource is essential for meeting the major demand created by accelerated urbanization, industrialization and agricultural development. This development highlights the threat of increased possibilities of ground and surface water pollution. In the study basin there are many locations which are very close and vulnerable to contamination and pollution.

For SB1 - Expansion of the city of Sulaimani towards the catchment area of Sarchinar spring threatens the alleviate pollution of the source area.

The absence of regular sewage systems in most of the newly expanded parts of Sulaimani city and the rapid increase of industrialization activities west of SB1 (in the area between Tasluja- Sulaimani) increase degradation impact opportunities.

For SB2 - The catchment area of Bestansur spring is vulnerable to pollution because from a few meters up to about one kilometer upstream and north of the spring, groundwater is at a shallow depth and directly connected to the surface through highly jointed outcrops of Kometan rocks. Any future urbanization, industrialization and even agricultural activities will easily transfer pollutants into the aquifer, so urbanization, industrialization and agricultural activities should be prohibited and a protection zone must be delineated.

For SB3 and SB4 - The main possible degradation and contamination source of groundwater is the mixing of sewage water through the shallow wells and deep wells in SaidSadiq town and the surrounding area. Using fertilizers in the agricultural lands could also have a great impact on the degradation of AIA.

As mentioned previously, upstream consumers pollute the water which flows to the downstream consumers. An example of this case is the frequent pollution of Zalim water supplied to Khurmal town and the pollution of the water of Saraw springs to the downstream consumers.

This study posits that water pollution control needs to be supported by coordinated policy, and adequate legal and institutional framework which are essential tools for sustainable development.

Scenario of possible drought

The possible impacts of climate change induced by global warming on the aquifers of the study basin require comprehensive study and research. Under different scenarios of possible drought, taking into account population growth and water demand increase, the management plans should be considered. The last drought cycle of 1999-2001 dramatically affected groundwater resources in the region. The yield of many important springs was reduced, many shallow wells dried out, and the groundwater table in some areas was significantly depleted. Fortunately, this evidence increased the awareness of the local authorities and local and international experts of the importance of the sustainable use of groundwater and aquifer control. This pushed the international experts in FAO to implement some projects and experiments and put the basic policy for controlling the drilling of deep wells into practice (Stevanovic and Iurkiewicz 2004).

If at least and as the worse case the drought of 1999 is considered, the annual expected recharge upon which the management plan should be drawn could be re-estimated. A rough estimation of the rate of depletion in the annual recharge of different aquifers will be at least 50%. Accordingly, if a drought lasts more than three years many large springs might dry up, and the groundwater will deplete at such a rate that the majority of the wells drilled inside Sulaimani will be abandoned entirely.

Paul (2002) studied the impact of global warming on groundwater in highly permeable unconfined aquifers of eastern Massachusetts in the US. He calibrated the groundwater model MODFLOW to analyze the influence of global warming for a scenario extending between the years 2030 and 2100. Since he found the impact is most severe under drought scenarios, he recommended that wise management of the aquifer should be advocated with a particular focus on limiting the expansion of water supply from the aquifer and increasing the present amount of groundwater recharge.

6.12 Recommendations for better future sustainable management

Groundwater management should be implemented in accordance with the local hydrogeological, social, economic and cultural conditions. Therefore, the recommendations listed below may not be universally applicable. Instead, they should be interpreted and optimized according to local contexts.

Combination of different policy actions could have great impact on groundwater management.

The very limited existing policy measures in Iraq and the Iraqi Kurdistan region should be reviewed, improved and adjusted to meet the changes in the socio-economic and environmental background of the region. Adjustments should take four major elements into consideration in order to obtain the optimum effective management design. They are: (a) regulations governing groundwater abstraction, (b) provision of economic encouragements/discouragements to reduce groundwater abstraction (e.g. charges for groundwater usage and wastewater discharge), (c) provision of alternative water resources to groundwater, and (d) support for the major groundwater users in their water-saving activities. Successful groundwater management is a function of how optimally the different policy measures are integrated according to the local situations.

Resolution number 408 issued on 14/4/1976 states that spring water is considered a public resource owned by the government regardless of what is registered in its documents, and the supreme agricultural council organizes the way of benefiting from this water by some specific instructions.

Instructions number 109 / clause 4-Act 11 issued in 1975 by the high Iraqi agricultural committee regulates the beneficiaries of the natural springs, and how they could be distributed and maintained. These resolutions followed by a regulation issued from M.O.A is Act.No.1 for the year 1978 which puts restrictions on drilling deep wells and how it could be used. Even though this act includes some restrictions on drilling and the pumping hours and the type of uses of groundwater wells, it is found that improvement to meet the changes in socioeconomic and hydrogeological changes is essential.

- No effective charges are found in these regulations to be able to stop illegal actions by people impacting environments and the natural state resources. Recently, the Ministry of Water Resources of the Iraqi Kurdistan region has been trying to put into effect some new regulations and course of actions to educate the people about the values of natural water resources. These new regulations are not approved yet but if applied are supposed to restrict the over-abstraction of the groundwater resources.

Local conflicts are possible between water end-users even in the case of sufficient water sources or the existence of highly productive wells (Stevanovic et al. 2005). There are still different opinions regarding the manner in which the water management (including the control of exploitation) should be applied at the local level. Acquired experience suggests that a flexible strategy would be the best solution - gradually introducing “modern”, more restrictive principles, in combination with local traditional systems of water delivery and sharing.

In Erbil city, the capital of Kurdistan region, the drinking water supply system is comprised largely of groundwater through deep wells. Now, the local government has decided to close 100 deep wells and to depend on the Greater Zab River through the

Efraz water supply project for that portion on the water supply. This decision was made as a fast reaction to the great depletion of the groundwater level resulting from over-exploitation in the city during the last two years.

- It may be that some water demands can be reduced by providing alternatives. Flush toilets (water borne sanitation) require a large volume of water (up to 70L per person per day). Pit latrines or simple pour-flush toilets should be the first choice. Some water requirements may be met by using lower quality (untreated) water or by recycling water. Not all water has to come from the same source: people may be provided with bottled drinking water, but use a stream to wash their clothes in. As demand for water increases, generally the quality needed for each use can be reduced. Water for cleaning a floor does not have to be of drinking water standard and water for growing subsistence crops can be of a lower quality still.
- The installation of water-saving technology stipulated in the building code (e.g. recycled water for flushing toilets) is another action which is recommended for the municipality affairs.

Instead of using fresh water, surface water to industrial sectors and public gardens is another recommended plan the government should think about. This could be achieved by new water supply schemes for industrial and public parks.

- The government of Iraqi Kurdistan should think about and plan to hand over the abstraction of fresh unpolluted groundwater for daily human consumption (excluding drinking purposes) and watering the public parks. Future plans should be made for recycling the waste and sewage waters for some domestic uses and watering farm lands and public gardens. Many deep wells have been drilled recently by the government inside and around the city of Sulaimani for watering the public parks and gardens. These all should be changed to depend on surface water resources. Construction of small dams along the existing convenient valleys to harvest surface runoff waters during rainy seasons and to use them for such purposes is expected to have positive appreciable results.
- Encouraging drought resistant crops or keeping livestock that can survive on less water can reduce demands, as can the provision of alternative livelihoods that require less water. Regardless of the importance of agriculture in the economy of every country, reserving water for basic human demands must have priority in the future strategic plan of the region. Additional agricultural projects based only on water-saving technology must be encouraged and must be supported only in case of water availability.

- Groundwater management should be designed within the framework of the whole urban water management policy. It is a well-established fact that both groundwater and surface water are interlinked and have an interdependent relationship through the water cycle. Therefore, it is essential to look at these two water sources more generally rather than individually. This approach not only optimizes management costs but is also very useful in minimizing risks during extreme situations such as droughts or incidents of contamination. The conjunctive use of groundwater and surface water provides a flexible approach to water management. With the increased environmental constraints in siting surface reservoirs, conjunctive use for "banking" surplus surface water in aquifers in times of plenty for use in times of scarcity assumes increasing importance. Developed countries are not immune to fresh water problems either. Researchers found a six-fold increase in water use for only a two-fold increase in population size in the United States since 1900. Such a trend reflects the connection between higher living standards and increased water usage, and underscores the need for more sustainable management and use of water supplies even in more developed societies.
- Another recommended action that should be in the strategic water management plan for the Iraqi Kurdistan government is the transfer of waters from other watersheds. As mentioned in previous sections in this chapter, SB1 is currently under greater water demand stress; accordingly, thinking of bringing water from other nearby basins is crucial for facing any future worse cases.

For the construction of a 60m high earth dam on the Khewata stream (Chwarta-Penjween basin) north of SB1, a proposal (with a feasibility study report) was submitted to the local government by a consulting team of which the author of this thesis was a member. This proposed dam will lead to the harvest of more than 250 million m^3 of water, will supply 900000 inhabitants of Sulaimani and the surrounding villages based on 200 l/c/d, and in addition will irrigate 1000 hectares of land northwest of Sulaimani which is planned to be a large park under the name of (Hawari Shar). Then, this water could be transferred to SB1 through a 4Km length tunnel and to an elevation of 1250m a.s.l which could be easily distributed by gravity to the city of Sulaimani after passing through treatment processes. This project, if implemented, will quarantine the water demand to the area for the next 30 years without any impact on the original watershed and with a very comparable low cost and energy.

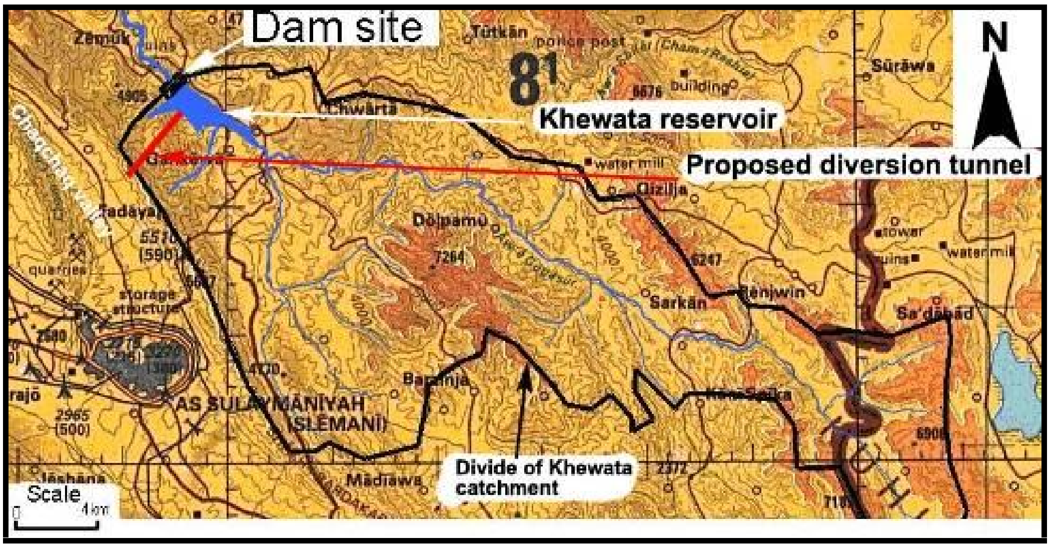

Fig 6.8 The proposed transferring water project from Chwarta-Penjween basin.

- Groundwater abstraction rights should be stipulated in a statutory form and a public entity (in principle, the national government) should be entitled to have overall responsibility of groundwater management for the effective control of groundwater abstraction. The groundwater use rights are not clearly defined by law, thus it is difficult for governments to take proactive responses to groundwater management, including the allocation of groundwater usage rights by the government and groundwater charges. Therefore, the right to control groundwater resources should be assigned to governments by law to ensure the effective allocation of groundwater resources to the respective beneficial applications.
- A panel of different stakeholders including experts and groundwater users should be established to monitor the groundwater management policy regularly, because sometimes government permits more groundwater abstraction through municipalities for more revenue (IGES, 2006). Moreover, dialogues among relevant stakeholders should be incorporated in the policymaking and review process as a tool for promoting efforts in groundwater conservation.
- Groundwater control regulations should be implemented with the provision of technical guidance and modest financial support for the introduction of water-saving technologies. Improving water pollution control measures, such as enforcing effluent standards, can also encourage industry to minimize its water inputs to reduce the volume of wastewater.
- Many of the water shortages emerging around the world stem from the widespread failure to value water at anything close to its worth (Postel, 1992). Groundwater

usage charges, wastewater treatment charges and other economic disincentives for groundwater usage can effectively control the demand for groundwater. Charging for groundwater usage can be an effective tool when properly applied.

Raising water prices can often be politically difficult to do. But if accompanied by public outreach explaining the need for the price hike and the steps consumers can take to keep their water bill down, they can have a strong positive effect (Postel, 1992).

In particular, for the industrial sector, the system of charges works well because industries are more sensitive to increases in the cost of water in their production process (IGES, 2006).

The effectiveness of groundwater user charges is clear in the success of Bangkok and the inefficiency of Bandung in introducing the charging system in the Bangkok study are, groundwater charge rates rapidly increased from 0.09 USD/m^3 to 0.22 USD/m^3 from 2000 to 2003, and the number of private wells began to decrease after 2001. In addition to groundwater charges, groundwater preservation charges were introduced in 2004 (IGES, 2006).

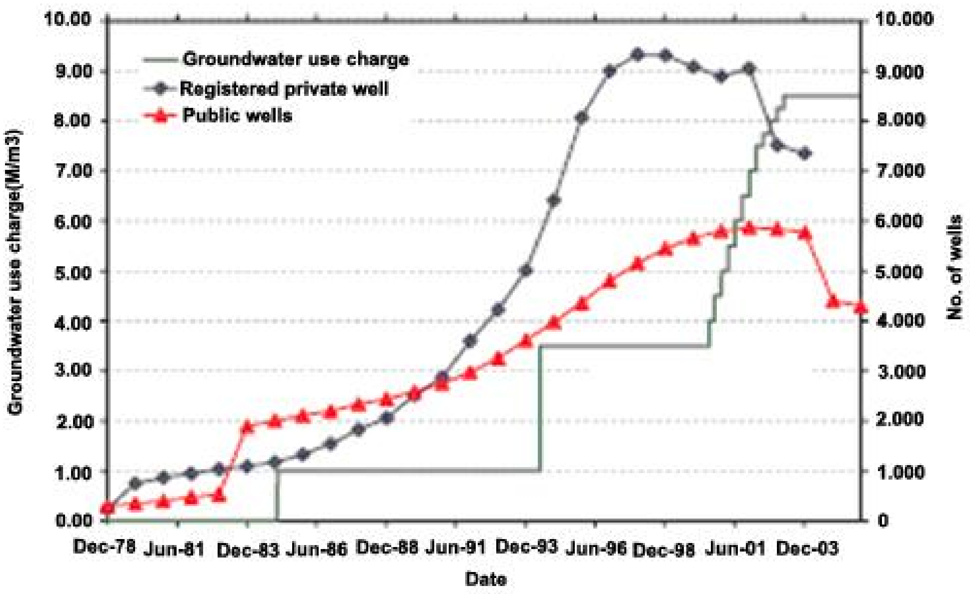

Figure 6.9 Variations in groundwater usage charges and number of private and public wells in Bangkok. (IGES, 2006).

- Fertilizer inputs should be capped to reduce the nitrate contamination of groundwater. It is critical for farmers to become aware that an appropriate amount of fertilizer should be consumed in the farming, avoiding the overuse of fertilizers. In this regard, public awareness is essential in promoting an appropriate volume of fertilizer use in farming.

- Scientific research and monitoring should be promoted by governments and research institutes to obtain reliable information for groundwater policy-making. Reliable information is essential for effective policymaking and implementation. However, the groundwater resources in the region are often poorly understood by both the decision-makers and the users of the groundwater. Even if there is available information, it is not well-organized and not properly shared among relevant stakeholders.
- The final link in the chain of preserving and protecting water resources involves educating the public about the connection between unseen groundwater and the water that comes out of the kitchen tap. In this way, the public can make the connection between everyday activities and the potential that water pollution has to affect their daily lives. Contamination is hard to address once it occurs; Postel (1992) said: "Pollution prevention is the only viable strategy for groundwater."

Chapter Seven
Conclusions and recommendations

7.1 Conclusions

The present investigation of the Sharazoor-Piramagroon basin has led to the overall conclusion that this basin is a very important one in the Iraqi Kurdistan region. Hydrogeologically, different types of aquifers (from karstic to karstic-fissured to intergranular) exist within different tectonic locations ranging from the Thrust zone to the boundary of the Low folded zone; accordingly, the results of this study could be considered as a general frame for additional investigations. Below are the summary conclusions of the present study:

1. ***Water surplus*** comprises 73.6%-77.8% of the annual rainfall in this region. These relatively high percentages of surplus are attributed to the concentration of the rainfall within five months of relatively low average temperatures and low PE values.
2. ***From a morphometrical point of view***, the basin surface drainage is sub-divided into three main sub-watersheds: the Tanjero, Chaqan and Zalim watersheds. These sub-watersheds vary in shape from longitudinal to circular to rectangular. Based on the relative relief values factor, according to the classification of Enin (1990) all the study watersheds can be categorized as very high class, All values of the hypsometric intervals are indicative of small drainage areas and an early stage of development. The drainage density values of the existing watersheds are relatively low. This is an indication of a less-developed network and a modest runoff due to the high permeability of the terrain. The relatively low values of the stream frequency of the watersheds indicate that these watersheds are situated in the arid to semi-arid region.
3. ***The aquifers*** of the basin consist of sedimentary rocks or sediments of either chemically deposited rocks (marine origin), or clastic rocks and sediments (continental origin). In this thesis, the stratigraphic units (formations and recent sediments) are grouped as karstic for Triassic and Jurassic rocks (TKA and JKA); karstic-fissured aquifers for Cretaceous and Eocene rocks (CKFA and EKFA) respectively; fissured aquifers for Cretaceous Qulqula Fn. (CFA); intergranular aquifers (AIA) and (EIA) for alluvium and Eocene

conglomerates respectively; aquitard of Tanjero rocks (TAT); and finally complex aquifers of slide debris (SDA).

4. High ***groundwater levels*** occur in the areas surrounding the basin on all sides, with higher elevation in the eastern, northeastern and northwestern parts. Almost all the groundwater flow is more or less in the same direction as the surface flow which is oriented towards the Darbandikhan reservoir. The regional geology shows that the basin (according to the suggested groundwater divide) is surrounded on all sides by impervious rocks; accordingly, a conceptual model has been drawn and named the "Oasis model".
5. Great variation was found in the ***transimissivity (T)*** values as it was in the range of 0.2×10^{-4} to 62×10^{-4} m^2/s. The storage capacity of the aquifers shows a great variation. CKFA aquifer in SB1 shows the highest value (49×10^{-2} m^2/min) due to the very limited drawdown in comparison to the high yield of the well, while at the same sub-basin TAT shows the lowest storage capacity (0.7×10^{-2} m^2/min).
6. In general, it is concluded that the relatively ***thick aquifers of AIA*** in SB3, SB2, and SB4 sequentially could be considered the most promising area for drilling successful and productive wells, while AIA in SB1 comes second to them because of the relatively limited thickness of the alluvial sediments.
7. The field observation of the valleys, streams and springs in these terrains showed that the surrounding mountainous terrains have a relatively high ***infiltration coefficient*** (low runoff coefficient). For CKFA the percentages of recharge were 56.6% for precipitation, while for TKA and JKA which comprise the mountainous recharging area of SB3 and SB4, it is estimated to be 69.9%. The estimated recharge percent of intergranular aquifers was variable from as low as 27.1 % for fine texture sediments to as high as 53.8 % for coarse gravely sediments.
8. ***For SB1*** the annual directly infiltrated ***recharge volume*** to CKFA was estimated to be 82.9×10^6 m^3, with 7.5×10^6 m^3 percolating from the Chaqchaq intermittent stream. The annual recharge volume of water to the groundwater system of AIA from direct infiltration and percolation from streams is estimated to be 52.2×10^6 m^3. Tanjero aquitard which covers the larger outcrop of SB1 is estimated to get 15.9×10^6 m^3 recharged water annually.

9. ***For SB2*** the annual groundwater ***recharge volume*** of CKFA is estimated to be 76.5 x 10^6 m^3, while AIA receives 74 x 10^6 m^3 and TAT 15 x10^6 m^3.
10. ***For SB3***, an estimation of ***annual recharge*** was more difficult, especially for TKA as the majority of the outcrops are located in Iran. A preliminary estimation of the total annual recharge of the three aquifers was 187.6 x 10^6 m^3. The annual recharge of AIA was estimated to be 89.3 x 10^6 m^3 of which 18.5 x 10^6 m^3 is obtained from percolation through the Chaqan valley and 8.7 x 10^6 m^3 percolates as subsurface recharge from Jurassic connected karstic channels.
11. ***For SB4***, similar to SB3, the Triassic rocks comprise the majority of the recharging area; with only one third of its surface area located inside Iraq, it was difficult to estimate the annual volume of groundwater recharge for TKA. Supposing 100Km^2 is the contributing recharge area inside Iran, the annual ***recharge volume*** was found to be 89.9 x10^6 m^3 for TKA and 61.8 x 10^6 m^3 for CKFA. The annual estimated groundwater recharge to AIA was estimated to be 57 x10^6 m^3.
12. ***Time series analysis*** of the five large springs in the basin (Sarchinar, Bestansur, Saraw group, Reshen and Zalim) was found to be a very useful tool for the general characterization of the karst aquifer system. The results of the auto-correlation revealed that these springs have large storage which drains gradually. The cross-correlation of spring discharge and precipitation data shows that all the springs except Bestansur have the duality of the groundwater flow. The first represents the channel-networks of great transmissibility and the second consists of voluminous media with poor permeability in block matrixes.
13. The ***spectral density function*** of the spring discharges confirms the presence of an annual recharge – discharge cycle.
14. The complete exhaustion of the ***dynamic reserve*** of all the spring reservoirs was relatively high. For Sarchinar, it is estimated to be about 37.58x10^6 m^3 (1.19 m^3/s); for Saraw, 22.1 x 10^6 m^3 (0.92 m^3/s); for Reshen, 40.96 x10^6 (1.7 m^3/s); for Zalim, 62.73 x10^6 (2.62 m^3/s); and for Bestansur spring, 13.93 x 10^6 m^3 (0.59 m^3/s). These different values would theoretically enable a period of almost two to six years for the different aquifers to be exhausted without any additional recharge.

15. Based on water balance and the concept of annual spring discharge the estimated catchment area of the karstic and karstic fissured aquifers is re-estimated and adjusted. Accordingly, a tentative ***groundwater divide*** has been drawn.
16. The decline in head for intergranular aquifers was in the range of 2.7 m – 7.7 m, with the maximum decline recorded in SB1 and the minimum in SB2. A higher decline range of groundwater level in the wells penetrating CKFA was recorded at 5.5 m – 12.3 m. Obviously, the great amplitudes of the ***ground water level fluctuations*** are caused by an intense recharge into the upstream part of the alluvium aquifer. Presumably, groundwater recharge into the aquifer comes predominantly from percolation of water along the connecting streams such as Chaqan, Surajo, Zamaki, Hasanawa and Darashesh valley beds.
17. ***The pH*** values of the water samples were in the range of 6.6 to 8.4 and the mean pH value was 7.4. ***TDS*** values for the water samples were in the range of 142 ppm - 885 ppm; the exceptional high TDS is recorded for the Khurmal Sulfuric spring.
18. All water samples are considered to be a fresh ***water type*** (TDS<1000 ppm), except the sample from the Khurmal acidic spring in SB4 which is considered to be slightly brackish water.
19. The ***calcium ion*** is the dominant cation in the water samples of the studied area. Ca^{2+} concentrations ranged between 23 ppm and 110 ppm. Khurmal sulfuric spring exceptionally shows 215 ppm of Ca^{2+}. In general, the concentration of Ca^{2+} increases in the southward direction towards Sulaimani city, Said Sadiq and towards Zarain and Arbat towns.
20. ***Bicarbonate concentrations*** in the water samples of the studied area ranged between 55 and 380 ppm. The highest positive anomalies of bicarbonates were in the south of the city of Sulaimani and around Arbat, Zarain and Said Sadiq towns. These high values clustered around the main sewage channel which indicates the effect of urbanization on the water quality. Also, the concentration of bicarbonate ion increases in the groundwater flow direction.
21. ***Sulfate concentration*** in the water samples of the study area ranged between 2 ppm to 180 ppm; the highest concentration was thought to be from agricultural fertilizers and sewage infiltration as they are located in the

southern part of Sulaimani city where all sewage channels are connected to the Tanjero River and used as irrigation waters.

22. The ***nitrate concentration*** in the studied area ranged between zero and 70 ppm. The majority of the spring, deep well and shallow well waters were relatively free of nitrate (or it was not detectable)
23. The level of ***cadmium*** in most of the tested groundwater samples shows a slightly higher concentration than the permissible level of 0.003 ppm according to WHO (2006) and IQS (1996). In general, the majority of the water samples are not contaminated with ***Ni, Pb and Cu***. Sewage may be responsible for zinc pollution in some of the well waters. Re-used sewages water for irrigation and as fertilizers are responsible for ***zinc*** pollution in other groundwater samples. Of 25 shallow wells tested, more than 15 are slightly contaminated with ***chromium***.
24. The average value of ***TH*** in the analyzed water samples of the study area was in the range of 83 ppm to 480 ppm. The high value of TH in the southern part of Sulaimani city may be due to the percolation of sewage and waste water to the groundwater as detected in the Wulluba and Groundwater directory unit wells. The fresh water is restricted to TAT spring waters, and to deep wells in TAT and CKFA drilled in rural regions near recharge areas north and northeast of Sulaimani.
25. All the values of ***BOD_5*** tests of the springs and deep wells were exclusively in the range of (0-1) mg/l. All water samples were found to be uncontaminated except for some shallow wells which were drilled in AIA. The ***COD*** values are all below the lower level of contamination.
26. ***Bacteriological tests*** showed that in the study area most water samples are polluted with bacteria at variable rates. Shallow wells show higher percentages of pollution, a condition which can actually be attributed to the improper way of drilling and well completion and carelessness in making protective concrete zones against wastewaters.
27. Calcium and bicarbonates are respectively the most ***dominant cations and anions.*** Sulfate and chloride are the second most dominant. More than 97% of the samples are calcium bicarbonate type water with about 25.5% Ca-Mg-Bicarbonate and 30% Ca-Mg-SO4 bicarbonate.

28. Based on the ***major indicator of rNa+rK/rCl***, it is concluded that the majority of groundwater samples taken from deep wells of the study area are of the meteoric type.
29. In chapter six of this thesis the main problems regarding ***sustainability of the groundwater resources*** are exposed. The current water demand and that of 25 years in the future of all the four sub basins are determined. It was found that in comparison to other sub basins SB1 is under stress due to the greatest population.
30. The current exploitation in SB1 is more than the ***safe yield*** while in the other three sub- basins it is still below the safe yield. For SB2 the maximum current exploited volume comprises only 30% of the safe yield and for SB3 is 40% of the safe yield, while in SB4 the stress on the groundwater resources is more than the SB2 and SB3.
31. There is currently a 2.5 m^3/s deficit in the normal water supply in SB1 without taking into consideration any abnormal or expected cycle of drought and future depletion in groundwater. Even if the new supply line of Dokan Lake is completed there will still be a deficit for the next 30 years.
32. Two options to get larger amounts of water from the karstic aquifers than those yielded by the springs during the dry season are recommended particularly for Saraw and Sarchinar springs. These options are either to over-pump the springs from the lower water table, or drill wells to greater depths to pump groundwater to a limit so as not to harm the aquifer sustainability. Over-pumping is recommended as the more successful option.
33. A number of feasible sites are recommended for ***artificial recharge*** and one site in SB1 for construction of a ***sub surface dam***.
34. The ***main risks*** and problems which currently have an impact on the basin and if not controlled are, in future, expected to cause greater harm to the groundwater resources are overexploitation, probable drought and the drying up of Karstic springs and wells, and severe environmental degradation and pollution.
35. Accordingly, for better sustainable groundwater management a number of ***recommendations*** are presented for the decision and policy makers as a combination of different policy actions which could have great impact on groundwater management.

7.2 Recommendations

In the light of this study the following are recommended:

1. Additional detailed study and investigation of each sub basin is required to assess the real groundwater reserve. This could be achieved through:
    - Geophysical prospecting for the subsurface deeper parts where no wells have hit them yet.
    - Drilling deep investigation boreholes not to be shallower than 500m.
    - Installation of piezometers in different aquifer types and of a continuous monitoring program.
    - Pumping tests of long duration and recording drawdown through observation wells.
    - Installation of gauging stations on the major relating streams to measure continuous runoff.
    - Conducting infiltration tests on all the possible sites.
    - Periodical water quality measurements to control pollution.
    - Isotopic analysis to define the route of groundwater flow and defining the recharge areas.
    - Conducting tracer tests for the karstic aquifers wherever possible.
    - Groundwater transboundary study for the sharing of aquifers with Iran is crucial.
2. To assess the recommended regulations and aquifer control proposals, the following actions should be taken: ***A- drilling exploratory wells*** upstream of the karstic springs to discover the karstification nature and dimensions of the subsurface channels ***B- application of geophysical methods*** such as electrical receptivity or microgravity method to detect the subsurface channel dimensions. ***C-artificial recharge tests*** in the recommended sites and other sites particularly in the areas covered by AIA. Recharge by injection under different applied injection pressures and/or under normal gravity and spreading methods should be done.
3. Installation of piezometers upstream and downstream of the main streams which have potential for construction of subsurface dams and the measurement of the rate of interflow through gravely river bed layers.
4. For better management, future program conceptual and numerical modeling should be prepared for different types of scenarios and should be applied to

all the aquifer types. The model should take into consideration the probable conjunctive use of surface and groundwater resources.

5. Additional urgent detailed investigation should be undertaken in the site which is proposed for transferring water from adjacent Chwarta-Penjween watershed.
6. Detailed investigation for finding feasible sites for the construction of small reservoirs (small dams, embankments, ponds, subsurface dams, etc...), particularly for the rural areas.
7. Continuous research into the impact of the industrialization, urbanization, and waste sewage landfills, agricultural activities on the environment of soil, surface and groundwater resources is highly recommended.
8. Identifying the more sensitive areas for groundwater water contamination. The preparation of a vulnerability map is essential to achieve this goal. Defining the detailed properties of the unsaturated zone beside the previously mentioned hydrogeological studies becomes a priority.

Poglavlje sedam
Zaključci i preporuke

7.1 Zaključci

Izvedena straživanja su potvrdila da je basen Šarazur-Piramagrun jedan od najvažnijih u okviru Iračkog Kurdistana. Hidrogeloški gledano, u okviru basena postoji nekoliko tipova izdani (od karstne preko karstno-pukotinske do intergranularne) u okviru različitih tektonskih zona: od Zone Navlačenja do Slabo nabrane zone; u skladu sa tim rezultati disertacije mogu da se posmatraju kao okvir za naknadna detaljna istraživanja:

1. **Suficit vode** iznosi 73.6%-77.8% godišnjih padavina u regionu. Ovaj relativno visok procenat suficita se dobija zahvaljujući koncentraciji padavina u toku pet kišnih meseci u toku kojih je relativno niska temperatura i niska vrednost potencijalne evapotranspiracije (PE).
2. **Posmatrano iz ugla morfometrije,** površina basena sa koje se voda drenira može se podeliti u tri velika slivna područja: sliv Tandžira, sliv Čakana i sliv Zalima. Ova tri slivna područja imaju različit izgled i oblik od izduženog do približno ovalnog. Na osnovu vrednosti faktora reljefa, a prema klasifikaciji Enina (1990) sva tri slivna područja se mogu okarakterisati kao vrlo visoka klasa. Sve vrednosti hipsometrijskih intervala nagoveštavaju postojanje malih drenažnih sistema i njihovu ranu fazu nastanka. Vrednost indeksa gustine drenaže postojećih slivnih područja je relativno niska. Ovo ukazuje na slabije razvijenu mrežu i skroman oticaj površinskih voda zbog velike vodopropusnosti terena. Relativno niske vrednosti učestalosti tokova u slivnom području potvrđuju da se slivna područja nalaze u aridnim i semi-aridnim oblastima.
3. **Izdani** u basenu su formirane u okviru sedimentnih stena koje su nastale hemijskim istaložavanjem (morsko poreklo) ili taloženjem fragmenata drugih stena (kontinetnalno poreklo). U ovoj disertaciji, stratigrafske jedinice (stenske formacije i nevezani sedimenti kvartara) grupisane su u okviru: karstne izdani trijaskih i jurskih sedimenata (TKA i JKA); karstno-pukotinske izdani, stena kredne i eocenske starosti (CFKA i EFKA); pukotinske izdani kredne Kulkula formacije (CFA); intergranularne izdani aluvijona i eocenskih konglomerata (AIA i EIA); uslovno bezvodnih terena (TAT); i složene izdani u okviru sipara (SDA).
4. **Visok nivo podzemnih voda** javlja se u oblastima koje okružuju basen naročito u višim, istočnim, severoistočnim i severozapadnim predelima. Skoro sva podzemna voda se kreće, u manje-više, istom pravcu kao i površinska, ka veštačkom jezeru Darbandikan. Regionalna geologija je pokazala da je basen, shodno hidrogeološkoj analizi basena, sa svih strana okružen vodonepropusnim stenama; na osnovu toga je usvojen i izrađen model basena koji je nazvan "Oaza".

5. Uočena je velika promenljivost vrednosti **transmisivnosti (T)** od 0.2 x 10^{-4} do 62 x 10^{-4} m^2/s. Specifična izdašnost izdani takođe pokazuje velike promene vrednosti. Najveće vrednosti su uočene u okviru izdani CFKA u podbasenu SB1 (81.67 x 10^{-4} m^2/s) zahvaljujući malim vrednostima depresije u bunaru u odnosu na veliku izdašnost bunara, dok su najmanje vrednosti zabeležene u istom podbasenu u okviru uslovno bezvodne TAT formacije (11.6 x 10^{-5} m^2/s).
6. Zaključeno je da relativno **moćna izdan AIA** u podbasenima SB3, SB2 i SB4 može biti posmatrana kao optimalna za izradu visokoproduktivnih bunara, dok je izdan AIA u podbasenu SB1 druga po redosledu, zbog ograničene debljine aluvijalnih sedimenata.
7. Terenska osmatranja rečnih dolina, rečnih tokova i izvora u okviru basena pokazala su da okolni planinski masivi imaju prilično velike vrednosti koeficijenta infiltracije (mali koeficijent površinskog oticaja). Za CFKA izdan procenat infiltrirane vode u odnosu na padavine je 56.6%, dok je za TKA i JKA čiju oblast prihranjivanja čini planinski predeo podbasena SB3 i SB4 procenjeno da infiltracija iznosi 69.9% padavina. Procenjena vrednost prihranjivanja intergranularnih izdani varira od 27.1% za sitnozrne sedimente do 53.8% za krupnozrne sedimente.
8. **Za podbasen SB1** godišnja direktna **zapremina infiltrirane vode** u izdan CFKA je procenjena na 82.9 x 10^6 m^3, sa dodatnih 7.5 x 10^6 m^3 infiltrirane vode iz povremenog rečnog toka Čakčak. Godišnja zapremina infiltrirane vode u podzemni sistem AIA izdani kao suma direktne infiltracije padavina i infiltracije iz rečnih tokova procenjena je na 52.2 x 10^6 m^3. Uslovno bezvodna TAT formacija zahvata veći deo podbasena SB1 i akumulira oko 15.9 x 10^6 m^3 infiltrirane vode godišnje.
9. U okviru **podbasena SB2** procenjeno je da se u izdan CFKA **infiltrira** 76.5 x 10^6 m^3, u izdan AIA 74 x 10^6 m^3 i u izdan TAT 15 x 10^6 m^3 vode.
10. Što se tiče **podbasena SB3**, procena **godišnje infiltracije** za ovaj podbasen bila je otežana, posebno za izdan TKA čiji je veći deo u Iranu. Ukupna godišnja infiltracija za sve tri izdani je preliminarno procenjena na 187.6 x 10^6 m^3. Godišnja infiltracija izdani AIA je procenjena na 89.3 x 10^6 m^3 od čega 18.5 x 10^6 m^3 dolazi od infiltriranja iz Čakan doline, a 8.7 x 10^6 m^3 od podzemne infiltracije iz jurske karstne izdani.
11. Oblast prihranjivanja **podbasena SB4**, slično podbasenu SB3, čine stene trijaske starosti od kojih je samo trećina površine u okviru granica Iraka. Stoga je bilo teško proceniti **godišnji priliv** vode kojom se prihranjuje izdan TKA. U skladu sa procenom da oblast prihranjivanja u Iranu iznosi približno 100 km^2, došlo se do veličine od 89.9 x 10^6 m^3 za izdan TKA i 61.8 x 10^6 m^3 za CFKA. Godišnja infiltracija za izdan AIA je procenjena na 57 x 10^6 m^3.

12. Analiza vremenskih serija za pet najvećih karstnih vrela u basenu (Sarčinar, Bestansur, grupu Sarav, Rešen i Zalim) je poslužila za određivanje opštih osobina karstnih sistema. Rezultati primene auto-korelacije pokazuju da sva vrela imaju veliki kapacitet i da se njihovo pražnjenje vrši postepeno. Kroskorelacija izdašnosti vrela i padavina pokazuje da sva vrela osim Bestansura imaju dvojak način filtracije podzemnog toka. Jedan je predstavljen brzim tokom kroz karstne kanale velike vodoprovodnosti, dok se drugi obavlja kroz različite sredine slabije propusnosti u okviru krečnjačkih stena.
13. **Spektralna gustina funkcije** isticanja vrela potvrđuje postojanje godišnjeg ciklusa događaja: prihranjivanje-isticanje.
14. Vrednosti **dinamičkih rezervi** za izdani svih posmatranih vrela su očekivano visoke. Za Sarčinar su procenjene na oko 37.58 x 10^6 m^3 (Q_{sr}≈1 .19 m^3/s), za Sarav 22.1 x 10^6 m^3 (Q_{sr}≈0.92 m^3/s), za Rešen 40.96 x 10^6 m^3 (Q_{sr}≈1.7 m^3/s), za Zalim 62,73 x 10^6 m^3 (Q_{sr}≈2.62 m^3/s) i za Bestansur 13.93 x 10^6 m^3 (Q_{sr}≈0.59 m^3/s). Ove vrednosti teoretski znače da se za period od dve do šest godina može vršiti isticanje vode iz izdani bez bilo kakvog dodatnog prihranjivanja.
15. Na osnovu bilansa voda i koncepta godišnjeg prolećnog isticanja procenjena površina oblasti prihranjivanja karstne i karstno-pukotinske izdani je ponovo procenjena i prilagođena. Na osnovu toga, je predpostavljena **podzemna vododelnica.**
16. Opadanje nivoa podzemnih voda kod intergranularne izdani bilo je u opsegu od 2.7 m do 7.7 m, sa maksimalnim sniženjem zabeleženim u SB1 i minimalnim u SB2 podbasenu. Veće sniženje nivoa podzemnih voda zabeleženo je u bunarima koji kaptiraju izdan CFKA i iznosi od 5.5 m do 12.3 m. Očigledno je da je najveća amplituda **kolebanja nivoa podzemnih voda** uzrokovana intezivnom infiltracijom u uzvodnim delovima aluvijalnih izdani. Po svoj prilici, prihranjivanje podzemnih voda se u najvećoj meri vrši infiltracijom vode iz rečnih korita Čakana, Surajoa, Zamakija, Hasanave i Darašeša.
17. **Vrednosti pH** izmerene u uzorcima vode kreću se od 6.6 do 8.4, dok je srednja vrednost pH podzemnih voda 7.4. **Koncentracija ukupnih rastvorenih soli (TDS)** u uzorcima voda je u opsegu od 142 ppm do 885 ppm; izuzetno velika vrednost TDS je zabeležena na sulfatnom izvoru Kurmal.
18. Svi uzorci vode su **malomineralizovani** (TDS<1000ppm), osim uzorka sa "kiselog" izvora Kurmal u podbasenu SB4.
19. **Jon kalcijuma** je preovlađujući katjon u skoro svim uzorcima vode uzetih na istraživanom terenu. Koncentracija Ca^{2+} jona varira u opsegu od 23 ppm do 110 ppm, izuzetno je zabeleženo da na Kurmal sulfidnom izvoru ona iznosi 215 ppm. Uopšteno gledano koncentracija Ca^{2+} raste prema jugu, prema gradovima Sulejmanija, Said Sadik, Zarain i Arbat.

20. **Koncentracija bikarbonata** u uzorcima vode varira od 55 ppm do 380 ppm. Najveća zabeležena pozitivna anomalija bikarbonata bila je južno od grada Sulejmanija i u okolini gradova Zarain, Arbat i Said Sadik. Ove visoke vrednosti grupisane su u okolini glavnih kanalizacionih kanala, što ukazuje na značajni uticaj urbanizacije na kvalitet podzemnih voda. Koncentracija bikarbonata, se takođe, uvećava u pravcu kretanja podzemnih voda.
21. **Koncentracija sulfata** u uzorcima vode istraživane oblasti kreće se od 2 ppm do 180 ppm; najveća koncentracija verovatno potiče od veštačkih đubriva i infiltracije otpadnih voda, s obzirom da su izlazni kanalizacioni kanali locirani južno od grada Sulejmanija gde se ulivaju u reku Tandžero i kasnije koriste kao vode za navodnjavanje.
22. **Koncentracija nitrata** u istraživanoj oblasti varira od 0 do 70 ppm. U većini izvora, dubokih i plitkih bunara, nisu zabeleženi nitrati (ili su ispod granice detekcije).
23. **Koncentracije kadmijuma** u većini testiranih uzoraka podzemnih voda, pokazuju neznatno veće vrednosti od one preporučene od 0.003 ppm, na osnovu propisa Svetske Zdravstvene Organizacije (WHO-2006) i Iračkog Standarda Kvaliteta Voda (IQS-1996). Uglavnom, u većini uzoraka nisu zabeležene koncentracije **Ni, Pb i Cu.** Otpadne vode mogu biti uzrok zagađenja **cinkom** u nekim uzorcima bunarskih voda. Korišćenje otpadnih voda za navodnjavanje i đubrenje je, takođe, odgovorno za zagađenje i u drugih uzorak voda. Od 25 plitkih bunara čija je voda testirana, 15 je zagađeno **hromom.**
24. Srednja vrednost **TH (ukupna tvrdoća)** u analiziranoj vodi u okviru oblasti istraživanja je u opsegu od 83 ppm do 480 ppm. Visoke vrednosti TH u južnim delovima grada Sulejmanija mogu biti uzrok infiltracije kanalizacionih i otpadnih voda u podzemne vode, kao što je i detektovano u Vulubi. Malomineralizovana voda je ograničena na izvore u okviru izdani TAT, i duboke bunare koji zahvataju vodu iz TAT i CFKA izdani u ruralnim oblastima severno i severoistočno od grada Sulejmanija.
25. Sve vrednosti **BOD_5** (biološka potrošnja kiseonika) na testiranim izvorima i bunarima ne prelaze 1 mg/l. U skoro svim uzorcima nisu zabeležene veće vrednosti organskih materija osim u nekoliko plitkih bunara koji su izbušeni u izdani AIA. Vrednosti **COD** (hemijska potrošnja kiseonika) su ispod nivoa dozvoljenog pravilnikom za pijaću vodu.
26. **Bakteriološka istraživanja** su pokazala da je većina uzoraka vode zagađeno bakterijama u različitim koncentracijama. U plitkim bunarima zabeležen je veći procenat zagađenja, što je posledica nepravilnog načina izrade i opremanja bunara, kao i nemara prilikom izrade zaštitnog betonskog bloka (uticaj otpadnih voda).
27. Kalcijum i bikarbonati predstavljaju **dominantne jone** u podzemnim vodama ove oblasti. Sulfati i hloridi su sledeći po zastupljenosti. Više

od 97% uzoraka je hidrokarbonatno-kalcijumskog tipa sa oko 25.5% hidrokarbonatno-kalcijumsko-magnezijumskog tipa i 30% sulfatno-kalcijsko-magnezijumskog tipa.

28. Na osnovu **koeficijenta rNa+rK/rCl**, zaključeno je da većina uzoraka podzemnih voda uzetih iz dubokih bunara pripada meteorskom tipu.

29. U okviru poglavlja koje se bavi menadžmentom podzemnih voda izložen je osnovni problem koji se tiče **održivog razvoja resursa podzemnih voda**. Trenutni zahtevi za vodom, kao i projektovani zahtevi za narednih 25 godina određeni su za sva četiri podbasena. Utvrđeno je da u poređenju sa ostalim podbasenima, SB1 trpi najveći pritisak usled najvećeg broja stanovnika.

30. Trenutna eksploatacija vode u podbasenu SB1 prelazi **garantovani minimum (potzencijal prihranjivanja izdani)**, dok je u ostala tri podbasena ta vrednost i dalje u okviru garantovanog minimuma. Za podbasen SB2 maksimalna zapremina vode koja se eksploatiše iznosi samo 30% garantovanog minimuma, a u podbasenu SB3 40%, dok je u podbasenu SB4 pritisak na podzemni vodni resurs veći nego u SB2 i SB3.

31. Trenutno postoji deficit od 2.5 m^3/s vode u podbasenu SB1 bez uzimanja u obzir mogućeg sušnog ciklusa i daljeg povećanog korišćenja podzemnih voda. Čak i sa uzimanjem u obzir novog izvora vodosnabdevanja u vidu jezera Dokan, postojaće deficit u narednih 30 godina.

32. Predložene su dve opcije za zahvatanje većih količina vode iz karstne izdani nego one koja ističe prirodno preko vrela, posebno kod izvorišta Sarav i Sarčinar. Mogućnosti se svode na precrpljivanje vrela uz sniženje nivoa podzemnih voda ili bušenje dubokih bunara koji bi zahvatili vodu do granica koje ne bi naškodile održivom razvoju izdani.

33. Preporučen je i veći broj lokaliteta gde je moguće sprovesti **veštačko prihranjivanje** izdani, a jedna od mogućnosti je izrada **podzemne brane** na jednom lokalitetu u podbasenu SB1.

34. Najveći **rizik** i problem, koji trenutno ima najveći uticaj naŠarazur-Piramagrun basen, a koji ako se ne bude kontrolisao, može da izazove veću štetu podzemnom vodnom resursu predstavlja nadeksploatacija podzemnih voda, moguća suša i isušivanje karstnih vrela i bunara, ali i ozbiljna degradacija životne sredine i njeno zagađivanje.

35. Shodno tome, veći broj **preporuka** za bolji menadžment podzemnih voda predstavljen je donosiocima odluka kao kombinacija različitih akcija.

7.2 Preporuke

Istraživanje je dovelo do sledećih predloga:

1. Treba uraditi dodatna detaljna istraživanja svakog podbasena da bi se sa još većim stepenom preciznosti definisao podzemni vodni resurs. To se može postići kroz:
    - geofizičku prospekciju dubljih delova terena u koje se bunarima još uvek nije ušlo.
    - bušenje dubokih istražnih bušotina ne plićih od 500 m.
    - ugradnju pijezometara u različite tipove izdani za kontinualno osmatranje nivoa izdani (monitoring).
    - dugotrajne testove crpenja, uz osmatranje sniženja nivoa podzemnih voda u svim okolnim pijezometrima.
    - instaliranje mernih stanica na svim većim rečnim tokovima za kontinuirano merenje proticaja.
    - sprovođenje testova infiltracije na većem broju lokacija.
    - povremeno određivanje kvaliteta podzemnih voda radi kontrolisanja zagađenja.
    - izotopske analize kojima bi se utvrdila geneza i pravci kretanja podzemnih voda, kao i granice oblasti prihranjivanja.
    - provođenje testova obeležavanja u okviru karstnih izdani, gde god je to moguće.
    - izradu studije o međugraničnim izdanima koje koriste Irački Kurdistan i Iran.
2. Da bi se procenila predložena regulacija i kontrola izdani, treba preduzeti sledeće korake: A - bušenje istražno-eksplatacionih bunara u zoni karstnih izvora i vrela da bi se ustanovio način karstifikacije i dimenzije karstnih kanala; B - primena geofizičkih metoda, kao što su elektroprovodljivost i metoda mikrogravimetrije da bi se utvrdile dimenzije karstnih kanala; C - testovi veštačkog prihranjivanja izdani na već pomenutim lokalitetima i drugim mestima, pogotovu u oblastima koje obuhvata izdan AIA. Takođe, treba primeniti i metode prihranjivanja izdani putem nalivanja vode u bunare, bilo pod pritiskom ili slobodnim nivoom.
3. Instaliranje pijezometara na rečnim tokovima, uzvodno i nizvodno, od lokacija koje su potencijalne za izradu podzemnih brana, radi merenja protekle količine podzemnih voda kroz šljunkoviti rečni nanos.
4. Za bolji menadžment podzemnih voda, treba pripremiti nekoliko različitih koncepcija i numeričkih modela, koji su primenjivi na sve tipove izdani. Model treba da uzme u obzir moguću zajedničku upotrebu površinskih i podzemnih vodnih resursa.

5. Dodatna hitna detaljna istraživanja treba sprovesti na lokalitetu koji je predložen za transfer vode iz susednog Čvarta-Pendžven slivnog područja.
6. Detaljna istraživanja za pronalaženje mogućih lokaliteta za izgradnju malih sistema i veštačkih intervencija (malih brana, nasipa, jezeraca, podzemnih brana itd.) posebno u ruralnim oblastima.
7. Preporučuju se neprekidna osmatranja uticaja industrijalizacije, urbanizacije i deponovanja otpadnih materija, poljoprivrednih aktivnosti na površinske i podzemne vodne resurse.
8. Treba posebno definisati oblasti osetljive na zagađenje podzemnih voda. Izrada karata ugroženosti je neophodna za postizanje tog cilja. Osim predhodno pomenutog, prioritet predstavlja i određivanje osobina nezasićene zone.

REFERENCES

Abawi S. A., and Hassan M. S., 1990: Environmental engineering water analysis, Dar Al-Hikma press, 296p.

Adams S., Titus R., Petersen K., Tredoux G. and Harris C. 2001: Hydrochemical characteristics of aquifers near Sutherland in the Western Karoo, South Africa. J. of Hydrology 24: 91-103.

Ahipathy M.V. and Puttaiah E.T., 2006: Ecological characteristics of Vrishabhavthy River in Bangalore, India. Environmental Geol, 49:1217-1222.

Al-Bedawi A. and Al-Bassam Kh. 1997: Hydrochemistry of groundwater surface water samples in Razzaza- Najaf area. 1st Scientific Conference-Univ.of Babel, 11-12 Nov.1997. (In Arabic).

Al-Fadhli I., Janardan Rao Y., Oweiss G., and Takla M.A., 1980: Superimposed folding in SaidSadiq area near the Zagros suture zone, Iraq. Geoviews, Vol. 8, No.3, 127-147.

Al-Hassani F., and Al-Sahaf M., 1990: Principle of applied climatology, Dar Al-Hikma press, Baghdad Univ., 248 p.

Ali S.S., 2005: Effect of slide masses on groundwater occurrence in some areas of Sharazoor Plain, NE-Iraq. In Water resources and environmental problems in karst, Proceedings of IAH Intern. Conf. KARST 2005 (Eds. Z. Stevanovic & P. Milanovic) Belgrade. 215-222.

Ali S. S. and Ameen D. A. 2005: Geological and hydrogeological study of Zalim spring, Sharazoor- Sulaimanyia, Iraq., Iraqi Journal of Erath Science, Vol. 5, No.1, 45-57.

Ali S.S., Stevanovic Z. and Jemcov I., 2007: The mechanism and influence on karstic spring flow: Sarchinar spring case example NE Iraq, 4th Conference on hydrogeology, ecology, monitoring, and management of groundwater in karst terrains, Feb.27-28, 2007, Florida, USA.

Al-Kubaise Q.Y., 1996: Hydrogeological study of Dibdiba basin in Safwan-Zubair area. Ph.D. thesis, coll. of science, Univ.of Baghdad, 174 p.

Alley W. M., Reilly T. E. and. Franke O. E. 1999: Sustainability of groundwater resources. U.S. Geological Survey Circular 1186, Denver, Colorado, 79 p.

Alloway B. and Ayres D.C., 1997: Chemical principles of environmental pollution. 2nd ed., Chapman & Hall, London, 395p.

Al-Manmi D. A. M., 2002: Chemical and environmental study of groundwater in Sulaimanyia city and its outskirts. Msc. Thesis, University of Baghdad. (In Arabic)

Al-Manharawi S. and Hafiz A., 1997: Fresh water .resources and quality. Arabic press. Cairo. 181p. (In Arabic).

Al-Rawi D.Y., Ali S.S., and Abdel Fattah, Th., 1990: Geological study of Sarchinar springs NE- Iraq., Int. Rept., Salahaddin Univ.(Unpublished).

Al-Rawi I.K. 1981: Sedimentology and petrology of the Tanjero Clastic Formation in north and northeastern Iraq. Ph.D. thesis, Coll. of science, univ. of Baghdad, 295p. (Unpublished).

Al-Sawaf F.D.S., 1977: Hydrogeology of Sinjar plain, Northwest Iraq. Unpublished PhD Thesis, University of London. 307p.

Al-Sayab A., Al-Ansari N., Al-Rawi D, Al-Jassim J., Al-Omari F. and Al-Shaikh Z., 1982: Geology of Iraq. Univ.of Mosul press, 277 p.

Al-Shalash A.H., 1981: Climatic regions. Basra univ. press, 298p.

Al-Tamimi O.S.I., 2007: Water resource assessments of Middle part of Diala River Basin, Ph.D. Thesis, Univ.of Baghdad.190 p. (In Arabic)

Altoviski M.E., 1962: Hand book of Hydrogeology. Gosgeolitzdat, Moscow, USSR (In Russian), 614p.

Al-Qaragholli N. 1987: Plant influent elements content in Al-Qa'am's fertilizer products-Iraq. Iraqi J. of agricultural Sciences, Zanko, 5(3): 57-69. (In Arabic).

Al-Qayim B. 2000: Sedimentation and tectonic environment of the Suwais Red Beds, NE-Margin of the Arabian plate- 5th international on the geology of the Arab world, Egypt. Abstract book, 112 p.

Ameen B. M., 2006: Sequence stratigraphy of Gercus Formation (Middle Eocene) In Sulaimanyia area, Northeast Iraq. Iraqi Jour. of earth science, Vol.6, No.2, 23-32.

American Public Health Association (APHA), 1975: Standard methods for the examination of water and waste water. 14th ed. Washington DC. 759p.

American Public Health Association (APHA), 1995: Standard methods for the examination of water and waste water. 19th ed. Washington DC.

American Public Health Association (APHA) 1998: Standard methods for the examination of water, sewage and waste water. 20th ed. Washington DC.

Appelo C.A.J. and Postma, D. 1999: Geochemistry, groundwater and pollution .Rotterdam: A.A. Balkama, 536p.

Aqrawi Z.A.K., 2003: Hydrological and hydrogeological study of the Etot-Aloka basin-Dohuk-Northern Iraq, PhD Thesis, Univ.of Salahaddin –Iraq.

Arthur N.P., 2003: Pattern of dissolution porosity in carbonate rocks. Speleogenesis and Evolution of Karst Aquifers. 1-7.

Atkinson T.C., 1977: Diffuse flow and conduit flow in limestone terrain in the Mendip Hills, Somerset (Great Britain), J.Hydrol, 35: 93-103.

Avias J., 1984: Captage des sources karstiques avec pompage en periode detiage. L'example de la source du Lez. In: Hydrogeology of Karstic Terrains, Case Histories. ed. Burger A. & Dubertet L., Intern. Contrib. to Hydrogeol, IAH, Vol.1, Heise, Hanover, 117-119.

Ayers R.S., and Westcott, D.W., 1985: Water quality for agriculture, irrigation and drainage .paper No.29 Rome, Italy, 174P.

Baalousha H., 2005: Using CRD method for quantification of groundwater recharge in the Gaza strip, Palestine. Environ Geol, 48:889-900.

Baptista N.J.A., Gingele F.X., Leipe T. and Brehme I., 2006: Spatial distribution of heavy metals in surfacial sediments from Guanabara Bay Riode Janeiro, Brazil. Environ Geol, 49: 1051-1063.

Bartram J. and Ballance R., 1996: Water Quality Monitoring. A practical guide to the design and implementation of fresh water quality studies and monitoring programs. UNEP/ WHO. Chapman & Hall, 383 p.

Barzinji Kh.T. 2003: Hydrologic studies for Goizha-Dabashan and other watersheds in Sulaimani governorate. Msc. Thesis, College of Agriculture, Univ.of Sulaimani.224 p.

Barzinji S, T., 2005: Stratigraphy and basin analysis of Red Bed Series in NE- Iraq, Kurdistan Region, Unpublished Ph.D. Thesis , University of Sulaimani.

Baziany M.M.Q., 2006: Stratigraphy and sedimentology of former Qulqula Conglomerate Formation, Kurdistan region, NE- Iraq. Msc thesis, Sulaimani University, 98p.

Baziany M.M.Q. and Karim K. H. 2007: A new concept for the origin of accumulated conglomerates, previously known as Qulqula Conglomerate Formation at Avroman- Halabja area, NE-Iraq., Iraqi Bulletin of Geology and Mining, Vol.3, No.2, 33-41.

Bellen R.C., Dunnington H.V., Wetzel R., and Morton D., 1959: Lexique Stratigraphique International. Asie, Iraq. Vol. 3C, 10a, 333p.

Berding F., 2002: Soil management consultancy, FAO Agricultural Rehabilitation Programme, Mission Report, No. 1, Erbil, Iraq

Berding F., 2003: Agro-ecological zoning of the three northern governorates of Iraq, FAO Agricultural Rehabilitation Programme, Plant production SS, Erbil, Iraq

Bolton, C.M.G., 1958: The geology of Ranya area. Site inv co. upubl. Rept., Vol IX B SOM Library, Baghdad. p117

Bonnacci, O., 1993: Karst spring hydrographs as indicators of karst aquifers. J. Hydrol. Sci., 38: 51-62.

Boonstra, J., De Ridder, N.A., 1981: Numerical modeling of groundwater basins. II. RI. Publication 29, II. RI, Netherlands, 226p.

Bouwer, H., 1991: Groundwater recharge with sewage effluent, Water science Tech., Vol.23, and 2099-2108.

Buday T., 1980: Regional Geology of Iraq: Vol. 1, Stratigraphy, I.I. Kassab and S.Z. Jassim (Eds) D. G. Geo Survey. Min. Invest. Publication. 445p.

Buday T., and Jassim S.Z. 1987: The Regional geology of Iraq: Tectonis, Magmatism, and metamorphism. I.I. Kassab and M.J. Abbas (Eds), Baghdad, 445 p

Bredenkamp Db, Botha Lj, Tonder GjVan, Rensburg Hj Van, 1995: Manual on quantitative estimation of groundwater recharge and aquifer storativity, WRC report no. tt 73/95, Water Resources Commission, South Africa, Pretoria 899

Bredenkamp Db. and Yongxin X., 2002: Perspectives on recharge estimation in dolomitic aquifers in South Africa., Cited in (Yongxin, X and Hans, E. B., 2003).

Brickle P., Rodrigues V.T., and Partida E.G., 1995: Effect of evapotranspiration on the water balance of the valley of Mexico .Geofisica Int.35 (1).63-72.

Callender E. and Rice K.C., 2000: The urban environmental gradient; Anthropogenic influences on the spatial and temporal distributions of Lead and Zinc in sediments. Environmental Science and Technology, 34: 232-238.

Camacho J.R. and Armienta M.A. 2000: Natural Chromium contamination of groundwater at Lean Valley, Mexico. J. Geochem. Expl. 68: 167-181.

Castany G., 1968: Prospection et exploitation des eaux souterraines. DUNOT, paris.

Chadha D.K., 1999: A proposed new diagram for geochemical classification and interpretation of chemical data. Hydrogeology J. 7:431-439.

Chnaray M.A.H. 2003: Hydrogeology and hydrochemistry of Kapran basin, Erbil, N-of Iraq., PhD thesis, Coll.of Science, Univ. of Baghdad, Iraq.172p (Unpubl.).

Chow V.T., 1964: Handbook of applied hydrology, .McGraw Hill book co. New York.

Conrad J., Nel J. and Wentzel J., 2004: The challenges and implications of assessing groundwater recharge: A case study – northern Sandveld, Western Cape, South Africa Water SA Vol. 30 No. 5 (Special edition).

Cwiertniewski C., 1961: Water supply report, Sulaimania: Baghdad, Directorate of water, Underground water section, 29 p.

Daoud H.S. and Karim K.H. (in press): The Laminitic limestone from Jurassic limestone of Basarine Formation, Barzinja area, NE. Iraq. Submitted to: Studia Universitatis Babeş-Bolyai, Geologia.

Davis S.N., and Dewiest R.J.M., 1966: Hydrogeology. John Wiley &Sons .Inc, NewYork.463p

Detay M., 1997: Water wells –Implementation, maintenance and restoration. John Wiley and Sons, London, 379p.

Dominico P.A., 1972: Concepts and models in groundwater hydrology., McGraw Hill Co., New York, 405p.

Drogue C., 1980: Essai d' identification d' un type de structure de magasions caranates, fissures. Application a l' imterpretation de certains aspects de fonctionnement hydrogeologique. Mem Soc Geol France, Paris, 101-108.

Dunnington H.V., 1958: Generation, accumulation, and dissipation of oil in Northern Iraq. In Weeks, L.G.(ed.)Habitat of Oil, AAPG, Tulsa, Oklahoma, USA, 1194-1251.

Eaton F.M., 1950: Significance of carbonate in irrigation waters. Soil Science 69:123-126.

El-Enin H.A., 1990: The physical geography of the basin of Wadi Dibba in U.A.E and its effect on agricultural development. Dept. of geography, Kuwait.

El-Yousif, F.Y. and Al-Najim, M.A., 1977: Sarchinar spring hydrological and water quality studies, Zanko Series A, 3(2):195-213.

Energoprojekt (Beograd), 1981: Kaolos dam project .Definite planning report. Vol.2, Book 2, Part 2. Min.of Irrigation, State organization of dams, Iraq.70p.

Esmail A.O. 1992: Effect of ion composition and ion pair in irrigation water on soil and plant, Ph.D. Thesis, College of agriculture ,Univ.of Baghdad,262p.

European standards (EU), 2004: EU's Drinking-Water Standards. http://www.lenntech.com.

Falcon N.L., 1961: Major earth flexturing in the Zagros Mountains of southwest Iran.Quart.Journ.of Geol.Soc., London, Vol. CXVII,No.468,Pt.4. 367-376.

Fetter C.W., 1980: Applied hydrogeology, Charles E. Merrill Publishing Company, Ohio, 448p.

Fikos I., Ziankas G., Rizopulou A. and Famellos S., 2005: Water balance estimation in Anthemountas river Basin and correlation with underground water level", Global NEST Journal, Vol.7, No.3, .354-359.

Foster S., and Lawrence A., 1995: Groundwater quality concerns in Asian cities, UNEP-UNESCO scope groundwater contamination workshop. Beijing -China.

Gill R., 1997: Modern analytical geochemistry. An introduction to quantitative chemical analysis for earth, environmental and material scientists. Longman, London, 329p.

Gorden N. D., Thomas A. M. and Brain L. F., 1993: Stream Hydrology. Center for Environmental applied Hydrology. University of Melbourne, John Wiley and Sons, New York, 526p

Grischek T., Nestler W., Piechniezek D., and Fisher T., 1996: Urban ground water in Dresden, Germany. Hydr. Jour. Vol.4, 48-63.

Hahn J., Lee Y., Kim N., Hahn C., and Lee S. 1997: The groundwater resources and sustainable yield of Cheju volcanic island, Korea. Environmental Geology,33(1), December, 43-52.

Hasan A. H. 1981: Hydrogeological conditions of the central part of the Erbil basin, Ph.D. Thesis, Baghdad University, 179 p.

Hassan I.O., 1998: Urban Hydrology of Erbil city region. PhD. Thesis, Univ.of Salahaddin. Erbil, Iraq, 120 p.

Hamil L. and Bill F.G., 1986: Groundwater resource development. London, 344p.

Household water quality series 52. 2002: Evaluation of household water quality in Hanover and Henrico counties- Virginia. Department of biological systems engineering. Virginia Polytechnic Institute and State University., publication 442-942.

Hem, J.D., 1985: Study and interpretation of the chemical characteristics of natural water, 3rd edition, U.S.G.S. water supply paper 2254, 263p.

Heron. A.M., and Lees, G.M., 1943: The zone of nappes in Iraqi Kurdistan. Min. of Development. Unpubl. Reports , Library, No. 133.

Hynes H.B.N., 1974: The biology of polluted water. Liverpool Uni. Press, 202p.

Ibrahim A.M.K., 1981: A study on the algal ecology of springs in Sulaimanyia province .Msc. Thesis, Univ.of Sulaimani, 218 p (Unpubl.)

IGES. 2006: Sustainable groundwater management in Asian Cities: A final report of research on sustainable water management policy. IGES Freshwater Resources Management Project Publisher: IGES (Hayama, Japan). 157p.

IQS 1996: Iraqi standards for drinking water. Draft of improving standards No. 417 /1996. (In Arabic).

Ivanov V.V. Barvanov L.N. and Plotnika G.N., 1968: The main genetic type of the earths crust mineral water and their distribution in the USSR. Inter. Geol. Cong. of 23rd session, Czechoslovakia, Vol.12, 33p.

Jazza I.M., 1993: Sedimentary facies analysis of Tanjero Formation, Sulaimani district, NE Iraq, M Sc. Thesis, unpublished, Univ. of Salahaddin, 123p.

Jemcov I, Ristić V, Stevanovic Z, and Prohaska S, 1998: Application of autocross-regression model on analysis and discharge simulation of some karst springs*.* Theoretical and Applied Karstology. Vol. 11-12/1998-1999. Academia Romana, 125-132

Jemcov I., 2007: Water supply potential and optimal exploitation capacity of karst aquifer systems.Environ.Geol.51:767-783.

Jermar M.K., 1987: Development in Water Science, Water Resources and Water Management, Elsevier publ.Inc. 385p.

Jones J.A.A., 1997: Global hydrology: processes, resources, and environmental management. Longman Limited, England, 399 p.

Jovanovic B, 1972, IN: Filipovic B, 1982: Hydrogeological survey for water supply (in Serbian), Spec. ed FMG, Belgrade

Jovanovic O. and Gabre R. 1979: Results of sedimentological examination of specimens from the area of Kaolos Dam project – Iraq. GEOZAVOD, Belgrade. 120p.

Karim K.H. 2004: Basin analysis of Tanjero Formation in Sulaimanyia area, NE-Iraq. Unpublished Ph.D. thesis, University of Sulaimani, 135p.

Karim K.H. and Ali S.S., 2004: Origin of dislocated blocks on the slope side of Baranan (Zergoez) homocline: An attempt to outlook the development of western part of Sharazoor plain. KAJ, 3(1), part (A) (5-21).

Karim K.H. Surdashy A. M., 2005a: Paleocurrent analysis of Upper Cretaceous foreland basin: a case study for Tanjero Formation in Sulaimanyia area, NE Iraq, Journal of Iraqi Science, Vol. 5, No.1, pp.30-44.

Karim K. H. and Surdashy A. M., 2005b: Tectonic and depositional history of Upper Cretaceous Tanjero Formation in Sulaimanyia area NE-Iraq. JZS, Vol.8, No.1.

Karim K.H., 2006: Environment of Tanjero Formation as inferred from sedimentary structures, Sulaimanyia area, NE-Iraq. KAJ, Vol.4, No.1.

Karim K.H. and Surdashy A. M., 2006b: Sequence stratigraphy of Upper Cretaceous Tanjero Formation in Sulaimanyia area, NE-Iraq. KAJ, Vol.4. No.1.

Keller E. A., 2000: Environmental Geology, Prentice Hall, Upper Saddle River, New Jersey, 562 p.

Kenya Rainwater Association, 1987: Water Resources and Agricultural Development in the Tropics. Erik Nissen-Petersen and the book by C. Burrow.

Kiraly L., Perrochet P., and Rossier Y., 1995: Effect of the epikarst on the hydrograph of karst springs: a number approach. Bul d' Hydrogeologie, 14:199-220.

Komac B. 2001: The karst springs of the Kanin massif. Geografski zbornik, XII.

Korkmaz N., 1990: The estimation of groundwater recharge from spring hydrographs. Hydrological Sciences – Journal-des Sciences Hydrologues, 35, 2, 4.209-217.

Kresic N., 1991: Quantitative hydrogeology of karst. Ed.Naucna Knjiga, Belgrade, 192p.

Kresic N 1997: Quantitative solutions in hydrogeology and groundwater modeling. Lewis publishers. CRC. 461p.

Kresic N. 2007: Hydrogeology and groundwater modeling. 2nd edition, CRC.press, 807p.

Krishna A.K. and Govil P.K., 2005: Heavy metal distribution and contamination in soils of Thane-Belapur industrial development area, Mumbai, Western India. Environ Geol, 47: 1054-1061.

Langmuir D., 1997: Aqueous environmental geochemistry. Prentice Hall, USA, 600p.

Letterman R. D., 1999: Water quality and treatment. A handbook of community water supplies. American water work association, 5th ed., McGraw-Hill, New York, ISBN 007-001659-3, 1194p.

Mam Rassol G.A., 2000: Study of water quality and its effect on nutrients availability for corn in Sulaimania region. Msc.Thesis, College of Agriculture, Univ.of Sulaimani, 120p.

Mangin A., 1984: Pour ine meilleure connaisance des systemes hydrogeologiques a' partir des analyses correlatoire et spectrale., J. Hydrol. 67: 25-43.

Maulood B.K. and Hinton G.C.F., 1978: An ecological study on Sarchinar water – chemical and physical aspects. Zanko Series, A 4(1):93-117.

Maulood B.K. and Hinton G.C.F., 1980: A study of the pollution ecology of Kiliasan River with particular reference to Sulaimania Sugar Factory. Zanko Series A 6(1):97-124.

Maran A. and Stevanovic Z., (Under press): Iraqi Kurdistan environment "The manual for the beginners." ITSC, Belgrade.

Mathess G., 1982: The properties of groundwater .Department of environmental science .England, John Wiley and sons Inc., NY, U.S.A., 406 p.

Mazor M. 1990: Applied chemical and isotopic groundwater hydrology, Open University press, NY, 274 p.

Meigs P. 1953: World distribution of arid and semiarid zones homoclimates. In Arid Zone Hydrology, UNESCO Arid Zone Research Series. 1: 203-209.

Mijatovic B. 1970: A method of studying the hydrodynamic regime of karst aquifers by analysis of the discharge curve and level fluctuation during recession. Institute for geological and geophysical research, Beograd.

Milenic D., 2004: Evaluation of groundwater resources of the Cork city and Harbour area. PhD thesis, National univ of Ireland, Univ. College Cork, 486p. (Unpublished).

Mondal N. and Singh V., 2004: Analysis of unconfined aquifer response to delineate potential groundwater recharge zone in hard rock terrain. Water resource research center, DPRI, Kyoto university http://www.wrrc.dpri.kyoto-u.ac.jp/ APHW2004.

Mohammed F.M., Najib F.M. and Baban Sh.O., 1980: Pollution effect of Sulaimaniyah sugar factory on Kiliasan water (Trace heavy metal consideration). Zanko J. Series A, 6(4):141-160.

Miles J. C. and Chambet D. t. 1995: Safe yield of aquifers. Journal of Water Resources Planning and Management, American Society of Civil Engineers, Vol. 121, No. 1, January/February, Paper No. 5381, 1-8.

Muhammad Sh.A. 2004: An ecological study on the aquatic life of Sarchinar spring, Chaqchaq and Kiliasan streams, Sulaimani, Kurdistan region of Iraq. Unpublished Msc. Thesis, Coll. Of Science, Univ. of Sulaimani, 142p.

Mustafa O.M., 2006: Impact of sewage wastewater on the environment of Tanjero River and its basin within Sulaimani city/NE-Iraq., Msc. Thesis, University of Baghdad, 142p.

Numan N.M.S. 1997: A plate tectonic scenario for the Phanerozoic Succession in Iraq. Iraqi, Geol. Jour. Vol.30, No. 2, 85–110.

Numan N.M.S., and Ameen, M.S., 1983: Regional Alpine Geoflextures in the folded zone of Iraq. Second geological congress of the Middle East, GEOCOM II, Baghdad.

Nunna R. R., Karim M. K. and Hamza R. 1981: Geological study of the Kaolos dam project. ZANKO (Scientific J. of University of Sulaimanyia) vol.7, No.2, 43-66.

Pakshina S.M. and Rabochev G.I. 1987: Calculation of ion activities in soil solutions and mineralized water. Sovi. Soil Science, No.9, 115-124.

Palmer C. D. and Cherry J. A. 1985: Geochemical evolution of groundwater in sequence of sedimentary rocks. J. of Hydrology, 75: 27-65.

Parson CH2MHILL, 2006: Mini master plan for the public water supplies for the governorate of Sulaimanyia., Iraq public works- water sector. Projects and contracting office- United States missions to Iraq. Iraq- Baghdad, 122p.

Parsons M. Ralph, 1957: Groundwater resource of Iraq, Sulaimanyia Liwa and area of north of Khaniqin. Engineering Company, Ministry of Development Board, Govt. of Iraq, V. 12, 93 p.

Paul H., Kirshen M. ASCE. 2002: Potential impacts of global warming on groundwater in Eastern Massachusetts., J. Water Resour. Plng. and Mgmt., Volume 128, Issue 3, 216-226.

Pettygrove G. and Asano T., 1988: Irrigation with reclaimed municipal wastewater. A guideline manual. 3rd ed., Michigan, Lewis Pub., 345p.

Polservice. 1980: Sharazoor irrigation project. Feasibility report, Annex 1, Climate and water resources, Ministry of Irrigation, Baghdad, 76 p.

Postel S. 1992: Last Oasis: Facing water scarcity. New York: W. W. Norton & Co., forth coming, 240p.

Priestley A.J. 2002: Report on sewage sludge treatment and disposal. Environmental problems and research needs from an Australian prospective CSIRO**.** Division of Chemical and Polymers, 48p.

Raeisi E, and Karimi G., 1997: Hydrochemographs of Berghan karst spring as indicators of aquifer characteristics. J. of Cave and Karst studies (59) (3):112-118.

Rao J. 2004: Unseen waters. India together. /www.indiatogether.org/

Rhoades J.D., Kandiash A., and Mashali A.M., 1992: The use of saline water for crop production. Irrigation and drainage paper, No.48, FAO, Rome, Italy.

Richard L.A., 1954: Diagnosis and improvement of saline and alkali soils, Agric. Handbook No.60, U.S.Dept.Agric., Washington.D.C., D.C., 160p.

Salar S.Gh. 2006: Hydrogeology and Hydrogeochemistry of Kifri Area (North of Iraq).Unpublished Msc Thesis, Univ.of Baghdad, 105 p.

Samani N., 2001: Response of karst aquifers to rainfall and evaporation, Maharlu Basin, Iran. J. of Cave and Karst studies (63) (1):33-40.

Sasowsky I.D., 1999: Structural effects on carbonate aquifers Karst modeling, Proc. of the symposium held February 24 through 27, 1999 sp. Publication.

Satoshi I., Motoi K., Eiichi A., Fazal M., Takio T. and Masayuki I., 2003: Construction of subsurface dams and their impact on the environment. RMZ, Materials and geo-environment, Vol. 50, No.1, 149-152.

Serrano S.E., 1997: Hydrology for engineers, geologists, and environmental professionals. Hydro science Inc. U.S.A., 452p.

Seward P., Y. Xu., and Brendock L., 2006: Sustainable groundwater use, the capture principle, and adaptive management. Water SA, Vol. 32, No. 4, October, 473-482.

Sharma M.L., Herne D.E., Byrne J.D., and Kin P.G., 1996: Nutrient discharge beneath Urban lawns to a sandy coastal aquifer, Perth, WA, Jour.of hydro., Vol.4,No.1, 103-117

Sharma P.D., 1998: Microbiology: A text book for university studens., 2nd ed. Rastogi Publ., India, 539p.

Sissakian V. K., 2000: Geological map of Iraq. Sheets No.1, Scale1:1000000 , State establishment of geological survey and mining. GEOSURV, Baghdad, Iraq.

Skordas K. and Kelepertsis A., 2005: Soil contamination by toxic metals in the cultivated region of Agia, Thessaly, Greece; Identification of source of contamination. Environ Geol, 48: 615-624.

Smirnov A.V. and Nelidov V.P., 1962: Report on 1: 200000 Prospecting correlation of Choarta - Sulaimaniya and Penjuin areas. Unpubl. Report, SOM Library, No. 290.

Sophocleous M., 2000: From safe yield to sustainable development of water resources - The Kansas experience. Journal of Hydrology, Volume 235, Issues 1-2, August, 27-43.

Stevanovic Z., 2001: Subsurface Dams – Efficient groundwater regulation scheme. Brayatti Press. 18. Erbil. 145-150

Stevanovic Z., Ali S., Iurkiewicz A., Lowa F., Andjelic M., and Motasam E., A., 2005: Tapping and managing a highly productive semi-confined karstic aquifer – Swerawa near Sulaimaniyah (Iraq). In. Water resources and environmental problems in karst, Proceedings of IAH Intern. Conf. KARST 2005 (Eds. Z.Stevanovic & P. Milanovic) Belgrade. 327-334

Stevanovic Z., Jemcov I., Milanovic S, Dokmanovic P., and Hajdin B. B., 2005: Management of karst aquifers in Serbia for water supply - achievements and perspective. In. Water resources and environmental problems in karst, Proceedings of IAH Intern. Conf. KARST 2005 (Eds. Z. .Stevanovic & P. Milanovic) Belgrade. 283-290.

Stevanovic Z and, Iurkiewicz A., 2004: Hydrogeology of Northern Iraq, General hydrogeology and aquifer system. Vol.2, 1st edition, FAO.

Stevanovic Z and Markovic, M, 2004: Hydrogeology of Northern Iraq, Climate, Hydrology, Geomorphology & Geology., Vol.1, 2nd edition, FAO.

Stocklin J. 1974: Possible ancient continental margins in Iran. In Bruke, L.D.(Editor) Geology of continental margins, 873-887.

Stoodely K.D., Lewis T. and Santon C.L., 1980: Applied statistical technique. John Wiley and Sons, London.

Subramanya K., 1992: Engineering hydrology, translated by Mosul University by Hassan M.S., Dawood B.K., and Al-Rawi S.M., 464p.

Subramani T., Elango L., and Damodarasamy S.R., 2005: Groundwater quality and its suitability for drinking and agricultural use in Chithar River Basin, Tamil Nadu, India .Environ Geol, 40:1209-1213.

Swedish Environmental Protection Agency, 2000: Metals in lakes and water courses. http://www.internat.environ.se.

Thomas EK. D., 2005: Artificial groundwater recharge by means of sub-surface dams. www.brainworker.ch/reports/Somaliland/10p.

Todd D. K., 1980: Groundwater hydrology, 2nd ed., John Wiley, NY, 535p.

USDA NRCS, 2004: National engineering handbook, Part 630 hydrology, Chapters 9 20p, and Chapter 10, 79p.

Van Hoorn J.W., 1970: Quality of irrigation water, limits of use and prediction of long term effects, Salinity seminar Baghdad, Irrigation and drainage .Paper No.7, FAO, 117-135.

Walton C.W., 1970: Groundwater resource evaluation, McGraw Hill Co., 664p.

White W.B., 1969: Conceptual models for carbonate aquifers. Groundwater, 7(3): 15-21

WHO, 2006: Guidelines for drinking–water quality .2nd ed., Vol.1, Recommendations, Geneva, 515 p.

Wilkinson W.B., 1993: Groundwater problems in urban areas, Proceedings of the international conference organized by the institution of civil engineers and held in Thomas Telford, London.

Yongxin X and Hans E. B., 2003: Groundwater recharge estimation in Southern Africa, UNESCO IHP Series No. 64, 206p.

Zurawska G. 2003: A hydrogeological study of springs in the western part of the Pieniny Klippen belt, southern Poland. Geological Quarterly, 47 (1); 107-110. Warszawa.

Summery

The Sharazoor-Piramagroon basin is located in northeastern Iraq (Kurdistan Region), and comprises a large area of the eastern part of the Sulaimani Governorate. It extends between the latitude 35º 04' 00" and 35" 47' 24" to the north and the longitude 45º 10'12" and 46º 12' 00" to the east. The studied area is a mountain-encircled basin and located in the Iraqi side of the Zagros mountain belt.

The entire surface and groundwater of the basin is discharged to the Darbandikhan reservoir through three main and several smaller streams. The area, relatively large at 2680 $km^{2,}$ is surrounded on all sides by high mountains while the central part of the basin consists of gently dipping flat plains with sporadic hills.

The basin can be recognized as three large branched valleys. The main one is Tanjero from northwest direction; the second is Chaqan from north where north of SaidSadiq town form as conjoining of Galal valley in the western direction and Chawtan valley in the eastern direction. The third branch is flowing from the northeast and east as Zalim and Biara valleys respectively.

Because of the great length and extensive surface area of the basin, in addition to differences in stratigraphy and lithology, the study area sub divided into four sub-basins. They are namely Sulaimani (SB1), Arbat-Zarain (SB2), SaidSadiq (SB3) and Halabja-Khurmal sub basin (SB4).

This dissertation intends to contribute to framing a relevant hydrogeological base for more detailed analysis, considering the importance of groundwater use for water supply and irrigation, and focuses on the following goals:

1- Performance of regional geological and hydrogeological investigation of the basin.

2- Assessment of groundwater resources quantitatively and qualitatively.

3- Provision of recommendation of the best possible groundwater practice and proposals for groundwater control projects in the area.

The Iraqi Kurdistan Region has a distinct continental interior climate with hot summers and cold winters of the Mediterranean type. The hottest months are June, July and August while the coldest months are December, January and February. During summer, the region falls under the influence of Mediterranean anticyclones and sub-tropical high pressure belts. In winter, the region is invaded by Mediterranean cyclones moving east to north-east through the region. The study area is a part of the region influenced by the Mediterranean climatological system, so rainfall occurs exclusively

during winter and spring season. The maximum monthly rainfall recorded was 354 mm in December of 1991-1992. The maximum average monthly rainfall for the years 1980-2006 is 131mm in December. The mean annual rainfall was 741mm during the period of 1980/1981-2005/2006. Most of the annual rainfall occurs in the eight months from October to May. The four remaining months are regularly dry. During the winter season, snow falls on the upper part of the surrounding mountains.

The average annual temperature was 19.4^{o}C. The maximum monthly temperature recorded was 38.6^{o} C in July 2000, while the minimum was 1.4^{o} C in January 1983.

The mean monthly PET values, calculated by the Thornthwait method were used to determine the mean monthly water surplus and water deficit. The water surplus for the years 1980-2006 calculated based on the data of Sulaimani metrological station for the area lower than 1200m a.s.l was found to be 73.6%, while for the mountainous area (higher than 1200m a.s.l) was 77.8%.

For morphometrical analysis of the basin, the surface drainage is sub-divided into three main sub-watersheds they are Tanjero, Chaqan and Zalim watershed. Each of these further sub-divided into smaller watersheds.

Geologically, according to the tectonic classification of Buday (1980) and Buday and Jassim (1987), the area is located mainly in the High Folded Zone and partly in the Thrust and Imbricated Zones. Both SB1 and SB2 are located in the High Folded Zone while part of both SB3 and SB4 are located in the Imbricated and Thrust zones.

The basin is included in the Western Zagros Fold-Thrusted Belt which was deformed by Laramide and post Laramide orogenies.

In this basin, the anticlines and synclines are high in amplitude and tight; in most cases, they are turned toward the southwest due to the stress of the overriding Iranian plate. Nearly all the rocks of the basin are sedimentary and range in the age from Triassic to Recent.

In all four sub-basins, the wider distribution is of Cretaceous age rocks, which consist mostly of pelagic limestone and clastic rocks. The Clastic rocks belong to the Tanjero and Kolosh Formations (Upper Cretaceous and Paleocene) which are exposed in the synclines, while the resistive limestone is exposed along axes and limbs of anticlines These rocks are covered, sporadically, by thick layers of recent sediments in the low lands (plains and valleys). In general, the age of the bedrocks in the area becomes progressively younger toward the southwest.

The Sharazoor - Piramagroon basin has a relatively complex geological and hydrogeological setting since its development is attributed to 1) geomorphology, 2) stratigraphy, and 3) structure. The basin is considered as one of the most important basins in Iraq from the point view of the availability of groundwater and fertility of the land.

The aquifers of the basin consist of sedimentary rocks or sediments of either chemically deposited rocks (marine origin), or clastic rocks and sediments (continental origin). In this thesis, the stratigraphic units (formations and recent sediments) are grouped as Karstic for Triassic and Jurassic rocks (TKA and JKA), Karstic-fissured aquifers for Cretaceous and Eocene rocks (CKFA and EKFA) receptively, Fissured aquifers for cretaceous Qulqula Fn. (CFA), Intergranular aquifers (AIA) and (EIA) for alluvium and Eocene conglomerates respectively, aquitard of Tanjero rocks (TAT) and finally complex aquifers of slide debris (SDA).

A flow net map is constructed from the collected data of static water level for the wells that could not be measured during October 2005. It is clear from the map that high groundwater levels occur in the areas surrounding the basin from all sides, with higher elevation in the eastern, northeastern and northwestern parts.

The SaidSadiq, Sirwan and Zarain plains are evidently the most important potential area for groundwater accumulation, with the lowest hydraulic gradient and higher hydraulic conductivities respectively.

The regional geology showed that the basin (according to the suggested groundwater divide) is surrounded from all sides by impervious rocks, accordingly a conceptual model is drawn and named as **”Oasis model“** since the basin is analogous to a desert oasis which collects water from all sides and at the time of a flood may escape in one passage.

For the current study, pumping tests on 22 productive wells were carried out covering all four sub-basins and penetrating different types of the aquifers. Great variation was found in the transimissivity (T) values as it was at the range of 0.2×10^{-4} to 62×10^{-4} m^2/s.

The storage capacity of the aquifers shows a great variation. CKFA aquifer in SB1 shows the highest value due to the very limited drawdown (only 1.1m) in comparison to the high yield of the well (9.0 l/s), while in the same sub-basin TAT shows the lowest storage capacity.

In general, it is concluded that the relatively thick aquifers of AIA in SB3, SB2, and SB4 sequentially, could be considered the most promising area for drilling successful and productive wells, while AIA in SB1 comes second to them because of the relatively limited thickness of the alluvial sediments.

For the estimation of the annual volume of runoff in the study basin, the SCS (Soil Conservation Service) method is applied.

The basin is divided according to the natural surface materials by using the tables of American Soil Conservation Service USDA, 2004. Due to the absence of suitable surface maps for the basin, detailed field study is achieved for dividing the basin into different zones with different curve numbers. This is done by comparing the characteristics of each curve number with the closest counterpart in the basin under study.

The field observation of the streams and springs in these terrains showed that the surrounding mountainous terrains have a relatively high infiltration coefficient (low runoff coefficient).

For SB1 the annual directly infiltrated recharge volume to CKFA estimated to be 82.9x 10^6 m^3, with 7.5 x10^6 m^3 percolating from Chaqchaq intermittent stream. The annual recharge volume of water to the groundwater system of AIA from direct infiltration and percolation from streams estimated to be 52.2 x 10^6 m^3. Tanjero aquitard which cover the larger outcrop of SB1 estimated to get 15.9 x 10^6 m^3 recharged water annually.

For SB2 the annual groundwater recharge volume of CKFA is estimated to be 76.5 x 10^6 m^3, while AIA receives 74 x 10^6 m^3 and TAT 15 x10^6 m^3.

For SB3, the mountainous recharging area is composed not only of Cretaceous rocks but Jurassic and Triassic rocks also comprising larger recharging area particularly the latter extending to the Iranian territory. Estimation of annual recharge for this sub basin was more difficult especially for TKA which majority of the outcrops locates in Iran. The total annual recharge of the three aquifers estimated preliminarily as 187.6 x 10^6 m^3. The annual recharge of AIA estimated to be 89.3 x 10^6 m^3 of which 18.5 x 10^6 m^3 estimated to be obtained from percolation through Chaqan valley and 8.7 x 10^6 m^3 percolating from subsurface recharge from Jurassic connected karstic channels.

For SB4, similar to SB3 the Triassic rocks comprising the majority of the recharging area of which only one third of its surface area locating inside Iraq. It was difficult to estimate the annual volume of groundwater recharge TKA but according to the proposed estimation based on rough estimate of the 100 Km^2 to be the probable contributing area the annual estimated recharge volume was found to be 89.9 x10^6 m^3 for TKA and 61.8 x 10^6 m^3 for CKFA. The annual estimated groundwater recharge to AIA found to be 57 x10^6 m^3.

The mechanism of the flow of five large karstic springs is discussed based on time series analysis and spectral Fourier analysis. The springs are Sarchinar, Saraw, Reshen, Zalim and Bestansur. In addition, the dynamic reserves of these springs are estimated based on the Mailet equation for the recession portion of the spring hydrographs. The daily spring's discharges for the period from Oct.2004 – Oct.2006 were depended for this analysis.

The auto-correlogram of all the analyzed springs shows almost similarity in hydraulic properties. The auto- correlogram of discharge rates exceeded the confidence limits of 79-88 days, which confirm gradual releasing of significantly large aquifer storage. Similarities for a certain extent were found also in cross-correlogram for all the springs flow and precipitation except Bestansur spring. A very minor level of significance from 2 to 15 days, but after that is insignificant. Low cross-correlation values show that the influence of infiltration is significantly attenuated by the karst hydrogeological system. While the cross-correlogram, for Bestansur spring, unlike the other springs, does not show any significant quick response to and interrelation with the daily rainfall events. This behavior supports the fissured nature as the main secondary porosity of the Bestansur aquifer reservoir. No surface open connected channels to the discharging point are found.

The spectral density function of the spring discharges shows high peaks at a low frequency of 0.003135 (319 days), which confirms the presence of an annual cycle.

By using the Mailet recession curve, two recession coefficients were obtained for Sarchinar, Saraw and Zalim springs , while three is obtained for Reshen and only for Bestansur spring.

The complete exhaustion of the dynamic resources of all the spring reservoirs was relatively high. For Sarchinar, it is estimated to be about 37.58x10^6 m^3 (1.19 m^3/s), for Saraw 22.1 x 10^6 m^3 (0.92 m^3/s), for Reshen 40.96 x10^6 (1.7 m^3/s), for Zalim 62.73 x10^6 (2.62 m^3/s) and for Bestansur spring 13.93 x 10^6 m^3 (0.59 m^3/s). These different values would theoretically enable a period of almost two to six years for the different aquifers to be exhausted without any additional recharge.

For all mentioned large karstic springs, the estimated volume of aquifer annual recharge by SCS curve method is compared with that estimated from the annual discharge of each spring during the time of measurements. For Sarchinar spring some agreements was found between the estimated recharge by the two different methods, while for the rest of the springs contradictions found which mostly related to the miss-estimation of the recharge contributing areas outside the basin or even outside the country.

Weekly measurements of static water level in 17 deep wells in the study basin were achieved for the period of December 2004 to February 2006.

The decline in head for intergranular aquifers was at the range of 2.7m – 7.7m, with maximum decline recorded in SB1 and the minimum was for SB2. Higher decline range of groundwater level in the wells penetrating CKFA was recorded it was 5.5m – 12.3m. Obviously, the great amplitudes of the ground water level fluctuations are caused by an intense recharge into the upstream part of the alluvium aquifer. Presumably, groundwater recharge into the aquifer comes predominantly from percolation of water along the connecting streams such as Chaqan and Surajo Zamaki, Hasanawa and Darashesh valley beds.

The hydrochemical work for this thesis involves the major, minor and traces of ionic concentrations in the groundwater in the basin. As well, this study also involves the salinity in terms of total dissolved solids (TDS), electrical conductivity (Ec), and reactivity in terms of pH. Laboratory and field chemical tests were conducted.

A total of 211 samples were collected from different wells, springs and kahrezes during October-2004.

The pH values of the water samples were in the range of 6.6 to 8.4 and the mean pH value was 7.4. The mean values considered, the maximum TDS value was 1300 ppm and the minimum TDS values were recorded in the Qleja spring (EIA) south of SB2.

All water samples are considered to be a fresh water type (TDS<1000ppm), except the sample from the Khurmal acidic spring in SB4, which is considered to be slightly brackish water.

In the studied area the Ca ions are the major cations in the water samples. For the springs Ca ions concentration ranged between 32 ppm and 215ppm. In general, the concentration of Ca increases in the southward direction towards Sulaimani city, Said Sadiq and towards Zarain and Arbat towns.

Bicarbonate concentrations in the water samples of the studied area ranged between 55 and 380 ppm.

Highest positive anomalies of bicarbonates were in the south of the city of Sulaimani and around Arbat, Zarain and Said Sadiq towns. These high values clustered around the main sewage channel; also, the concentration of bicarbonate ion increases in the groundwater flow direction, which indicates the effect of urbanization on the water quality.

Sulfate concentration in the spring water of the study area ranged between 10 and 110 ppm. For the deep wells, sulfate concentration was in the range of 2 to 180 ppm; the highest concentration was in two wells and was most probably attained from agricultural fertilizers and sewage infiltration as they are located in the southern part of Sulaimani city where all sewage channels connecting to the Tanjero River and used as irrigation waters are.

The nitrate concentration in the studied area ranged between zero and 70 pp .The majority of the spring, deep well and shallow well waters were relatively free from nitrate (or it was not detectable).

Water samples from 26 deep wells, 25 shallow wells, and 13 large springs were analyzed for the trace elements (Cd, Zn, Cu, Cr, Ni, and Pb).

The level of cadmium in most of the tested groundwater samples shows a slightly higher concentration than the permissible level of 0.003 ppm according to WHO (2006) and IQS (1996).

. In general, the majority of the water samples are not contaminated with Ni, Pb and Cu.

Sewage pollution may be responsible for zinc pollution in some of the well waters. Re-used sewages used for irrigation and as fertilizers, are responsible for zinc pollution in other groundwater samples

Out of 25 shallow wells tested, more than 15 are slightly contaminated with chromium. It is noticeable that most of these wells show a similar case of contamination with regard to other elements. Locations of these contaminated shallow wells confirm that the source of the contamination comes either from agricultural fertilizers or from sewages or industrial wastes.

The average value of TH in the analyzed water samples of the study area was in the range of 83ppm to 480ppm. The high value of TH in the southern part of Sulaimani city may be due to percolation of sewage and waste water to the groundwater as detected in the Wulluba and Groundwater directory unit wells. The fresh water is restricted to TAT spring waters, and to deep wells in TAT and CKFA drilled in rural regions near recharge areas north and northeast of Sulaimani.

Samples from 11 deep wells, 11 shallow wells and 5 major Springs of Zalim, Qalabo, Sarchawi Saraw, Bestansur, and Sarchinar springs were taken for BOD_5 test. All the values of the springs and deep wells were exclusively in the range of (0-1) mg/l.

All water samples were found not to be contaminated except some shallow wells which drilled in AIA since the COD values are all below the lower level of contamination.

Bacteriological tests showed that in the study area most water samples are polluted with bacteria at variable rates. Shallow wells show higher percentages of pollution which is actually attributed to the improper way of drilling and well completion and carelessness for making protective concrete zones against wastewaters.

Calcium and bicarbonates are respectively the most dominant cations and anions. Sulfate and chloride are the second most dominant. More than 97% of the samples are calcium bicarbonate type water with about 25.5% Ca-Mg-Bicarbonate and 30% Ca-Mg-SO_4 bicarbonate, while about 15% is of (Ca-bicarbonate) type.

Based on the major indicator of rNa+rK/rCl, it is concluded that the majority of groundwater samples taken from deep wells of the study area are of the meteoric type.

In chapter six of this thesis the main problems regarding sustainability of the groundwater resources are exposed. The current and the 25 years future water demand of all the four sub basins are determined. It was found that SB1 is under stress due to the greatest population in compare to other sub basins.

All these areas were totally became densely residential area without any system of water distribution and sewage draining system. This forced the people to start drilling deep wells up to depths 60-100m in their backyard houses without any control of the government. Since 2003 to present time more than 8000-12000 deep wells drilled without any license from the related governmental offices and by cheap traditional machines. This was the beginning of arising the problem of overexploitation and pollution risk in this major city and the outskirts, particularly most of these wells are not properly drilled and neither protected. Consequently they are gravely vulnerable to contamination and pollution by sewage waters from the first few top meters.

Fortunately, 85% of these wells are penetrating TAT or a few meters from AIA then TAT, which is not considered as aquifer. Comparing the projected water demand for the next 25 years with the current water supply, it is obvious that the annual water demand of the city of the Sulaimani and out skirt is 173.83 x 10^6 m^3 which is equivalent to 5.5

m^3/s, while the existing water supply with normal rainy year of Sarchinar spring and Little Zab river is only 3 m^3/s. This means that 2.5 m^3/s is the deficit in normal case without taking into consideration any abnormal or expected cycle of draught and future depletion in groundwater. A new water supply project, which is now under implementation, for Sulaimani city from Dokan Lake will increase supply by another 2.2 m^3/s

As clear from the comparison of this new projected supply system, even this new line of supply could not meet the real demand of the next 30 years. That is why looking for additional alternatives and solutions with sustainable conjunctive use of both surface and groundwater resources is the great challenge.

Even though, the available water reserve in the other three sub basins are more than the actual demand but bad dealing with the resource is clear.

The rate of groundwater exploitation is low in compare to SB1. The main source of water supply is from Bestansur spring. During wet seasons great amount of discharged water flows without appreciable use while during dry season when the demand increases the discharge rate of the springs will hardly cover part of this demand. The present ground water withdrawal from the existing wells in SB2 is quite limited. If 45% of annual recharge considered being the safe yield, it means the maximum current exploited volume comprises only 30% of safe yield. Accordingly, this area could be considered as the area of low population stress in compare to the existing water resources.

For SB3, If the safe yield considered being 45% of the total annual recharge, so exploitation of AIA in this sub-basin is only 40% of the safe yield.

In SB4 the stress on the groundwater resources is relatively more than the SB2 and SB3. AIA could be still in safe yield range and more wells could be drilled without any harmful impact to the aquifer.

Two options to get larger amounts of water from the karstic aquifers than those yielded by the springs during the dry season are clarified in this chapter;

- Either by over pumping the springs from the lower water table or (static reserve).
- Or drilling wells to greater depth to pump groundwater to a limit not to harm the aquifer sustainability.

In both cases, residual storage of water is to be used in the season of maximum demand that would be replenished during rainy season.

For Sarchinar and Saraw springs water sources, pumping and lowering of the groundwater level is expected to bring about some increase in the spring discharge, since their residual storage is considerable.

From the practical point of view, over pumping might be more favorable solution than drilling of water wells. This is due to relatively higher expense for drilling wells and the risk of well failures to detect the karst channels because of an exceptional heterogeneity of the karstic aquifers. Tabular channels through which the springs are supplied may allow for pumping and achieving certain drawdown without undertaking any technical measures. If not, a corresponding intake structure would have to be built. For instance, it could be a shaft with a gallery

There are feasible locations in the study basin where artificial recharge of AIA could be achieved. Appreciable volume of runoff water flows through the intermittent valleys during wet seasons, without taking benefit from them. Topographically there are convenient locations to decrease the velocity of these runoff waters and to harvest them for infiltration or to spread them over the small channels for gradual infiltration.

Many locations mentioned to be suitable for achieving artificial recharge among these, are Qamartle site: and Surtka in SB1, Merade and Qleja in SB2, Chaqan and Surajo in SB3, and finally Khazena, Zamaki, Biara and Darashesh in SB4.

Subsurface dam as another technical solutions for recharge and water saving is proposed. It could be constructed on one of the streams in SB1 which is Yakhyan stream or Dole Nader valley.

The main risks and problems which are currently impact the basin and expected to have greater harm impact on the groundwater resources in the future if not controlled are clarified in this chapter. The main problems are Overexploitation, probable draught and drying up Karstic springs and wells, and severe environmental degradation and pollution. Accordingly, for a better sustainable groundwater management a number of recommendations are presented for the decision and policy makers as combination of different policy actions could have great impact on groundwater management. Below are some of these recommendations.

- The government of Iraqi Kurdistan should think and plan to handover abstracting the fresh unpolluted groundwater for daily human consumptions (excluding drinking purposes) and watering the public parks. Future plans should be put for recycling the waste and sewage waters for some domestic uses and watering farm lands and public gardens. Construction of small dams along the existing convenient valleys to harvest surface runoff waters during rainy seasons and to use them for such purposes is expected to have positive appreciable results.

This approach not only optimizes management costs but is also very useful in minimizing risks during extreme situations such as droughts or incidents of contamination. The conjunctive use of groundwater and surface water provides a flexible approach to water management.

- Groundwater usage charges, wastewater treatment charges and other economic disincentives for groundwater usage can effectively control the demand for groundwater. Charging for groundwater usage can be an effective tool when properly applied. No effective charges are found in the existing regulations to be able stopping illegal actions by the people to those impacting environments and the natural state resources. It may be that some water demands can be reduced by providing alternatives. Flush toilets (water borne sanitation) require a large volume of water (up to 70L per person per day). Pit latrines or simple pour-flush toilets should be the first choice. Some water requirements may be met by using lower quality (untreated) water or by recycling water.
- The installation of water-saving technology stipulated in the building code (e.g. recycled water for flushing toilets) is another action which is recommended for the municipality affairs.
- Another recommended action that should be put in the strategic water management plan for the Iraqi Kurdistan government is transferring waters from other watersheds. Construction of a 60m height earth dam on the Khewata stream (Chwarta-Penjween basin) north of SB1 is proposed. This proposed dam will lead to harvest more than 250 million m^3 of water, and supply 900000 inhabitants of Sulaimani and the surrounding villages based on 200 l/c/d, in addition to irrigating 1000 hectares of land northwest of Sulaimani which is planned to be a large park under the name of (Hawari Shar). Then, this water could be transferred to SB1 through a 4Km length tunnel and to an elevation of 1250m a.s.l which could be easily distributed by gravity to the city of Sulaimani after passing through treatment processes.
- Groundwater abstraction rights should be stipulated in a statutory form and a public entity (in principle, the national government) should be entitled to have overall responsibility of groundwater management for the effective control of groundwater abstraction.

- A panel of different stakeholders including experts and groundwater users should be established to regularly monitor the groundwater management policy, because some time government permitting more groundwater abstraction through municipalities for more revenue (IGES, 2006). More over than that, dialogues among relevant stakeholders should be incorporated in the policymaking and review process as a tool for promoting efforts in groundwater conservation.
- Fertilizer inputs should be capped to reduce the nitrate contamination of groundwater. It is critical for farmers to become aware that an appropriate amount of fertilizer should be consumed in the farming, avoiding the overuse of fertilizers. In this regard, public awareness is essential in promoting an appropriate volume of fertilizer use in farming.
- Scientific research and monitoring should be promoted by governments and research institutes to obtain reliable information for groundwater policy-making.
- Educating the public about the connection between unseen groundwater and the water that comes out of the kitchen tap. This way, the public can make the connection between everyday activities and the potential that water pollution has to affect their daily lives. Contamination is hard to address once it occurs