HYDROGEOLOGICAL ASSESSMENT OF THE CRETACEOUS STRATIGRAPHIC UNITS EXPOSED ALONG THE NORTH-EASTERN LIMB OF AZMAR ANTICLINORIUM, SULAIMANY, NE IRAQ

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Abstract

Cretaceous stratigraphic water bearing units were evaluated hydrogeologically in combination with hydraulic parameters derived from single (productive) well test. The main recharge of water bearing units comes from percolation of precipitation. Generally all the tested wells taping water bearing units are productive wells and partially penetrating. The transmissivity values obtained by recovery test methods both by INFINITE EXTENT and AQTESOLVE 4.02 software programs reveal as high as double values calculated by constant pumping test methods, particularly for the Balambo aquifer, thus constant pumping test results were employed. While results for the Tanjero Formation are close and similar, therefore both methods were considered in calculating aquifer parameters. Some new hydrogeologic classification for those stratigraphic units was proposed and outlined under the section of hydrogeology. The groundwater flows from the NE limb of Azmar towards the east and north east directions. The hydraulic gradient is steeper within the Balambo aquifer, while it is gentler within the Tanjero aquitard. Drawdown of about 60m will be expected by the discharge of 432m^3/day in the first 4 hours of pumping after which the Tanjero aquitard may approach the steady state and the drawdown may be minor. The groundwater storage in the Balambo aquifer indicates considerable volume that sustained water for long period in the region. Moreover, increasing drilling wells that associated with growing tourist activity and irrigation projects in the recent years, may affect most of the area within the Tanjero Formation, while this effect is limited within the Balambo aquifer system.

التقييم الهيدروجيولوجي للوحدات الطباقية العائدة الى زمن كريتاسي والمنكشفة على طول الجناح الشمالي الشرقي لطية ازمر سليمانية شمال شرق العراق.

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الخلاصة

تم تقيم الوحدات الطباقية الحاملة للمياه للعصر الطباشيري هيدروجيولوجيا مع المعاملات الهيدروليكية المشتقة من إختبار البئر المنفرد. ان التغذية الرئيسية لهذه الوحدات تاتي من عملية ترشيح الساقط المطري. بشكل عام جميع الآبار المختبرة والخارقة للوحدات الحاملة للمياه الجوفية هي آبار منتجة والخارقة جزئيا. إن قيم معامل الناقلية المحصلة بطرق فحص الإستعواض بإستخدام برنامجي (INFINITE EXTENT 4.02

and AQTESOLVE) اظهرت قيم مضاعفة قياسا للقيم المحسوبة بطريقة اختبار الضخ الثابت، وخصوصا لخزان بالامبو، لذلك اعتمدت على نتائج اختبار الضخ الثابت لهذا الخزان، بينما في تكوين تانجيرو كانت النتائج متقاربة، لذا فالطريقتين (الإستعواض و اختبار الضخ الثابت) قد اخذتا بنظر الإعتبار في عملية حساب معاملات الخزان. اقترح الباحث بعض التصانيف الجديدة لهذه الوحدات الحاملة للمياه الجوفية تحت موضوع الهيدروجيولوجي. تتدفق المياه الجوفية من طرف أزمر باتجاه الشرق والشمال الشرقي لمنطقة الدراسة. ان الإنحدار الهيدروليكي لتكوين بالامبو اشد منه لتكوين التانجيرو. يتوقع ان تحصل انخفاض في منسوب المياه الجوفية بمقدار 60م في الساعات الأربعة الاولى من الضخ عندما يضخ البئر بمقدار 432م3/يوم، بعد ذلك قد يصل تكوين التانجيرو الى الحالة المستقرة والإنخفاض في المنسوب المائي قد يكون اقل. ان المخزون المائي لتكوين بالامبو يشير الى وجود كميات معتبرة من المياه الجوفية كافية لسد حاجيات المنطقة لفترات طويلة. فضلا عن ذلك، ان الزيادة في حفر الآبار مقترنا بازدياد نشاطات الحركة السياحية والمشاريع الاروائية في السنوات الاخيرة في منطقة الدراسة، قد يؤثر سلبا على معظم مناطق تكوين تانجيرو، في حين ان هذا التاثير قد يكون محدودا على نظام خزان بالامبو

Introduction

1. Location

The area under investigation lies in north-eastern Iraq (NE of Sulaimany city), covering an area of approximately $65km^2$ (Figure 1), it is bounded by longitudes 45^0 27^- and 45^0 32^- E, and latitudes 35^0 37^- and 35^0 41^- N. It covers part of northeastern limb of Azmar anticlinorium and south west of Chuarta-Penjwen basin which is considered as one of the 15 sub-basins in the Iraqi Kurdistan region.

2. Previous work

The first comprehensive study on groundwater resources of Iraq was conducted by Parsons Company [1], published in 13 volumes from 1955 to 1957 containing hydrogeological study and water resources of Sulaimany and surrounding areas, included analysis of meteorological data and preparing a location map of springs and drilled wells in addition to hydrochemical studies of the Sulaimany and surrounding areas.

Regional hydrogeological investigation was conducted under SCR 986 and FAO agricultural program in Iraqi Kurdistan Region from 2000-2003 "under supervising of Stevanovic & Markovic"[2]. They prepared three volumes under the title of "Hydrogeology of northern Iraq". Vol.1 included studies of climate, hydrology, geomorphology and geology of the Kurdistan Region, Vol.2 was concerned with regional hydrogeology and aquifer systems, while Vol.3 deals with groundwater resources and sustainable exploitation.

(Ma'ala, 2006) [3], evaluate hydrochemical properties of the water springs flowing on the western side of the Tagaran River (close to the studied area).

3. Methods of research

Hydrogeological information, vertical electrical sounding data and well reports have been collected at the beginning of this study. They have been provided from the archive of Directorate of Groundwater and from the owner private drilling wells in the field. Field trip was conducted during the period March-April 2007. General hydrological and geological observations were taken. Measurements of the static water level in the open hand dug and deep wells were recorded. In addition to previous tested wells, five single (productive) wells were tested from the field in different localities to cover the whole area. The analysis of pumping test was conducted using several software programs, such as: INFINITE EXTENT and AQTESOLVE 4.02. These software implemented several analytical methods assigned by different authors [4-10]for the computation of aquifer hydrological properties

4. Geology of the area:

I- Tectonic setting:

According to[11] the study area comprises part of the Balambo-Tanjero zone, which is considered as one of the four zones within the unstable shelf in Iraq. Surface folds are a characteristic feature of the unit. The Balambo-Tanjero zone is intensely folded and faulted throughout. Folded pre-Tethonian sediments have a structural style similar to the high folded zone; Cretaceous strata are isoclinally folded. Both Cretaceous and earlier units are traversed by reverse faults dislocating the anticlines into imbricates, the anticlines often overrides the synclines.

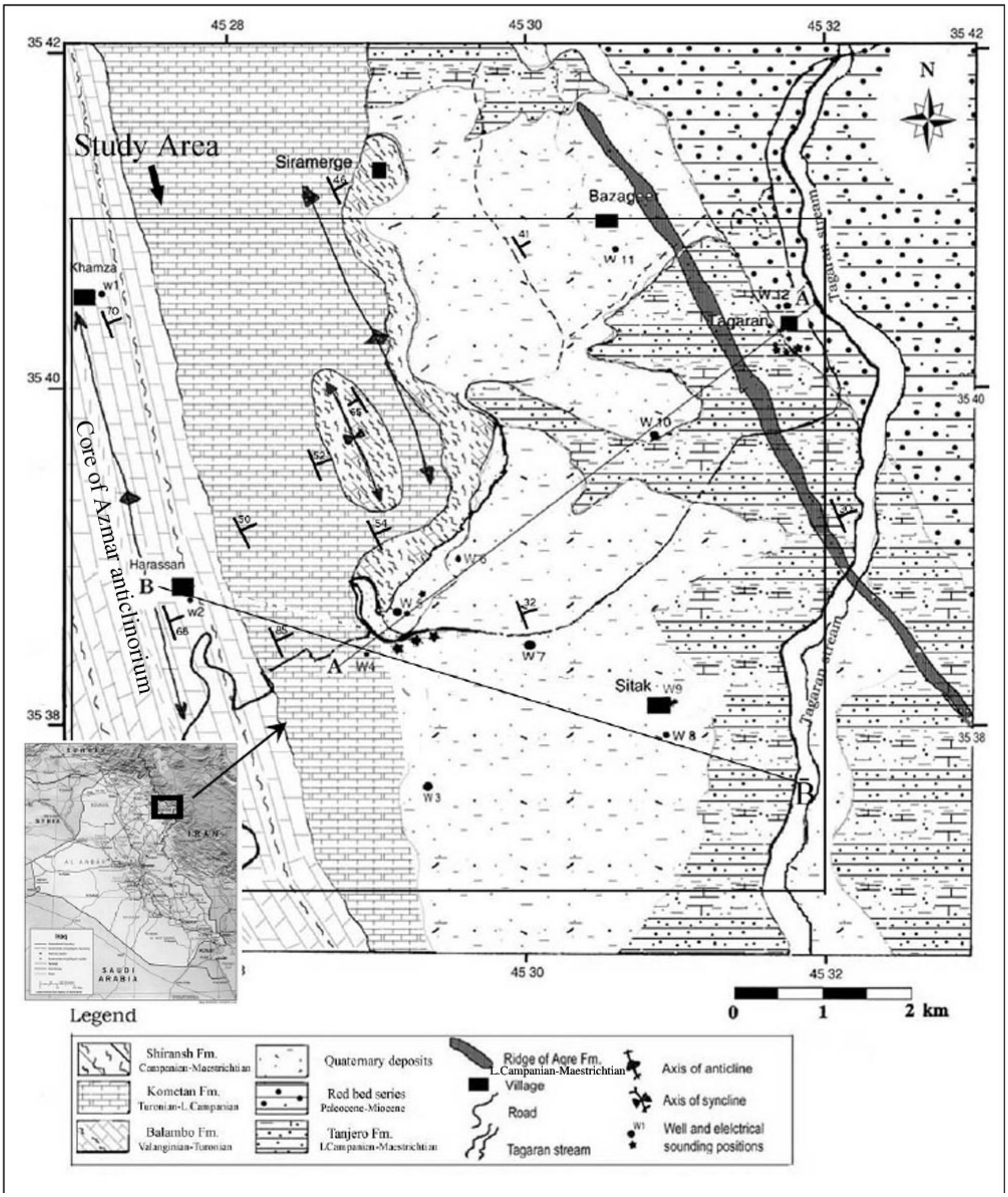


Figure 1: Map showing location, well test sites and vertical electrical sounding (VES) positions, as well as geological units of the study area. Modified after (Aziz and Lawa, 2001) and (Maala, et al. 2004)

Stratigraphy

Several stratigraphic units are encountered in the area (Figure 1); they are briefly summarized from the older to the younger:

A- Balambo Formation

Is the oldest formation exposed in the area, it occupies the core of Azmar anticlinorium. According to [12] Balambo Formation has been formed in bathyal deposition area, during U.Valanginain-Turonian. It is composed of two parts (upper part and lower part), the lower part mainly consists of thin bedded, blue amoniferous limestone with intercalations of olive green marls and dark blue shale (Figure 2), while the upper part consists of thin bedded globigernal, passing downward to radiolarian limestone.

Total thickness reaches more than 700m in the typical section, but in the studied area it was not recorded because no wells reach the lower contact of this formation.

B- Kometan Formation

Bellen et al,[12] described its lithology as "white weathering, light grey, thin bedded limestone, locally silicified with flattened ramulose chert concretions in occasional beds and glauconitic, especially at the base. It was deposited during Touronian- L.Campanian age. Kometan Formation has two unconformity surfaces; the lower contact overlies the Balambo Formation unconformably {contact shown an errosional unconformity
but without angular discordance, [12], while the upper contact is overlain unconformably by Shiransh Formation. According to the drilled well descriptions and preparation of cross sections in the area, the total thickness of the Kometan Formation is around 200m.

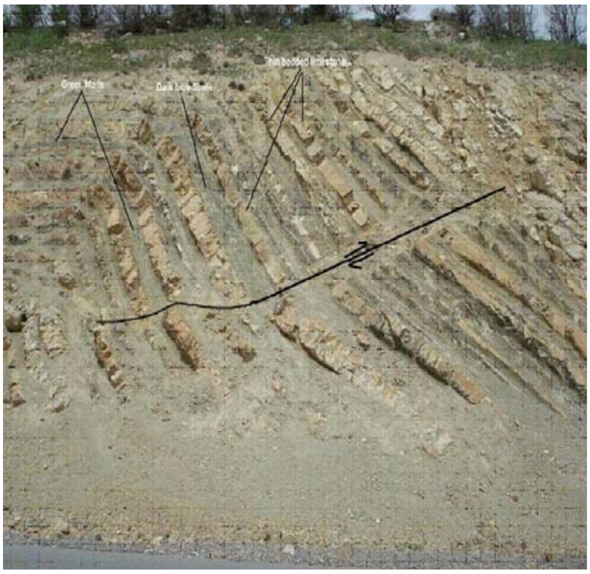


Figure 2: Lithological units and tectonic effects on the Balambo Formation (lower part), the photo direction is (N300E), taken at the core of Azmar anticlinorium (close to the checkpoint).

C- Shiransh Formation

According to Buday [13], this formation is composed of thin bedded limestone and marly limestone in the lower part, and blue marl in the upper part. The thickness of the formation is highly variable depending on the degree of subsidence of the basin. The average thickness within the study area may approach 200m (according to cross sections prepared in the area). It is believed to be of Upper Campanian age at the base and Maestrichtian at the top.

D- Tanjero Formation

Tanjero Formation is considered as the same age as the Shiransh Formation, the contact between them is gradational and conformable.
According to [14] the Tanjero Formation is divided into three parts (Lower, Middle and Upper parts) on the basis of main lithological distribution. He gave the following description and thickness around the study area:

- Lower regressive part: is mainly composed of thick succession of conglomerate and coarse sandstone. Thickness of this part is 50-100m.
- Middle transgressive part: The lithology of this part in Chuarta area consists of dark green calcareous shale with inter-bedded marly limestone. Thickness reaches 300m in the area.
- Upper regressive part: This part consists of sediments, which occur as succession of thick alternation of fossiliferous limestone and black silty calcareous shale or marl. Thickness may reach 100m around the area.

E- Quaternary Deposits

Sediments of fluvial, delluvial, elluvial origin were deposited during Pleistocene and Holocene ages [2], most of the study area is covered by the Quaternary deposits which are composed of various sizes of clastic and carbonate deposits (Figure 1). Thickness varies from few meters close to the limb of Azmar anticlinorium and 10m around Sitak village.

Geomorphology and Topography

Generally, Azmar anticlinorium is characterized by long and asymmetrical fold containing several minor anticlines and synclines. Many intermountain valleys were formed under the effect of fluvial erosion. The main types of drainage are of dendritic and some times parallel patterns. Gravitational movements of rock masses are evident on a wide scale. The structural hill and slopes are strongly affected by denudation; flank the cores of the major anticline structures, representing the anticline limbs and most parts of syncline valleys. These landform surfaces were severely dissected by fluvial erosion during the Alpine Orogeny in the Late Pliocene, forming Questa and Hogback ridges with dip ranging between 11-35 degree at the gentle side and 35-90 degrees at the steeper ones (This feature mainly found in the Tanjero Formation in the area). The Tagaran stream which flows throughout the year can be considered as effluent stream where it mainly recharged by aquifers in the area.

5. Climate

As a whole, the study area is located in a semi-arid climatic condition; it is characterized by cold, rainy winters and long, hot and dry summer. According to [11], during the summer, the region falls under the influence of Mediterranean anticyclones and sub-tropical high pressure belts moving from the west, south west to north. In the winter, the region is invaded by Mediterranean anticyclones moving east to north east over the region. In the view of Isoheytal contour map of Iraqi Kurdistan region, which was prepared by ([2], the study area has annual rainfall between 750-800 mm/year. The mean annual temperature is around 31C0. Depending on the data recorded at Mawat automatic station in 2002 (nearly 30km northwest of study area), the annual relative humidity was 51.66; Annual evapotrnspiration varies from 24.8 mm on January and 241mm on July.

B- Hydrogeology

Water bearing beds in the studied area can be generally categorized into several subdivisions on the basis of hydrogeological and stratigraphical characteristics, they outlines as follows:

I- Classification of the Hydrogeological units:

- **Aquifer**

Hydrogeologically, this type of water bearing beds is represented by the Balambo Formation.

Balambo Formation

In the core of the Azmar anticlinorium, groundwater flows preferentially through a complex system of discontinuities. These discontinuities intersect what would otherwise be an inter-bedded fissured limestone. This complex system made the Balambo Formation to consider as an aquifer system, the later term is used to indicate multi-layered aquifer including permeable and impermeable units within the same aquifer. As a result of highly repetition of compressed, relatively thin inter-bedded, impermeable shale and marl (thickness ranged from 20 to 60cm) within well bedded limestone, make the condition of this aquifer system to classify within semi-confined aquifer for the lower part (Figure 2), But due to the absence of shale and marl in the upper part, it may be considered as unconfined aquifer. These conditions are true for areas where the rocks of the Balambo aquifer system are cropped out around the core of the Azmar anticlinorium, but it becomes confined aquifer towards the north east of the study area, when it descends below the Shiransh Formation underlain by the Kometan Formation. It is clear that, intense tectonic activities in the area deformed rock units which often dip very steeply (dip angle of the Balambo is ranged from 68^0 to 85^0 degrees as shown in Figure.1), as well as complex fracture system and geomorphic activities, all have affected the depth, flow and accumulation of groundwater. Groundwater levels of this aquifer vary considerably; it ranges from 1235m (a.s.l) to 1351m (a.s.l) at the Khamza and the Harassan villages respectively, while the depth to groundwater at the same locations ranges between 5m to 24.5m. Generally, the groundwater flows away from the core of the Azmar anticlinorium towards the east and north east direction (Figure 4), however some other local directions appear due to tectonic and stratigraphic effects. In some locations, especially within the exposed lower part of this aquifer, some intermittent and perennial fissured and contact springs types of good quality flow throughout the year. Some of them particularly at the Harassan village supply most domestic, irrigation and other consumption for people living there.

- **Aquitard**

Referring to the low transmissivity obtained by pumping tests (around $2m^2$/day), and the new stratigraphic division of the Tanjero Formation by [14], Tanjero Formation can be classified hydrogeologically as an aquitard especially for the Upper and Middle parts, while the Lower part has a characteristic of aquifer. According to the lithologic description of the drilled wells (archives of the directorate of groundwater-Sulaimany), and results of pumping tests, most of drilled wells are penetrating the Upper and Middle parts, however other wells (W.7) reveals high transmissivity which may tapping the Lower part of the Tanjero Formation. Unsuitable locations for drilling wells close to the contact with Shiransh Formation, as well as low thickness of the lower part in the area, may be reasons for limited drilling wells in this part.

The static water level varies from 1002m (a.s.l) at W10 "Orchard area-Sitak" to 1098m (a.s.l) at

W5 "Sitak- sec.56". The depth to the groundwater at the same locations ranges the core of the Azmar anticlinorium towards the north east direction.

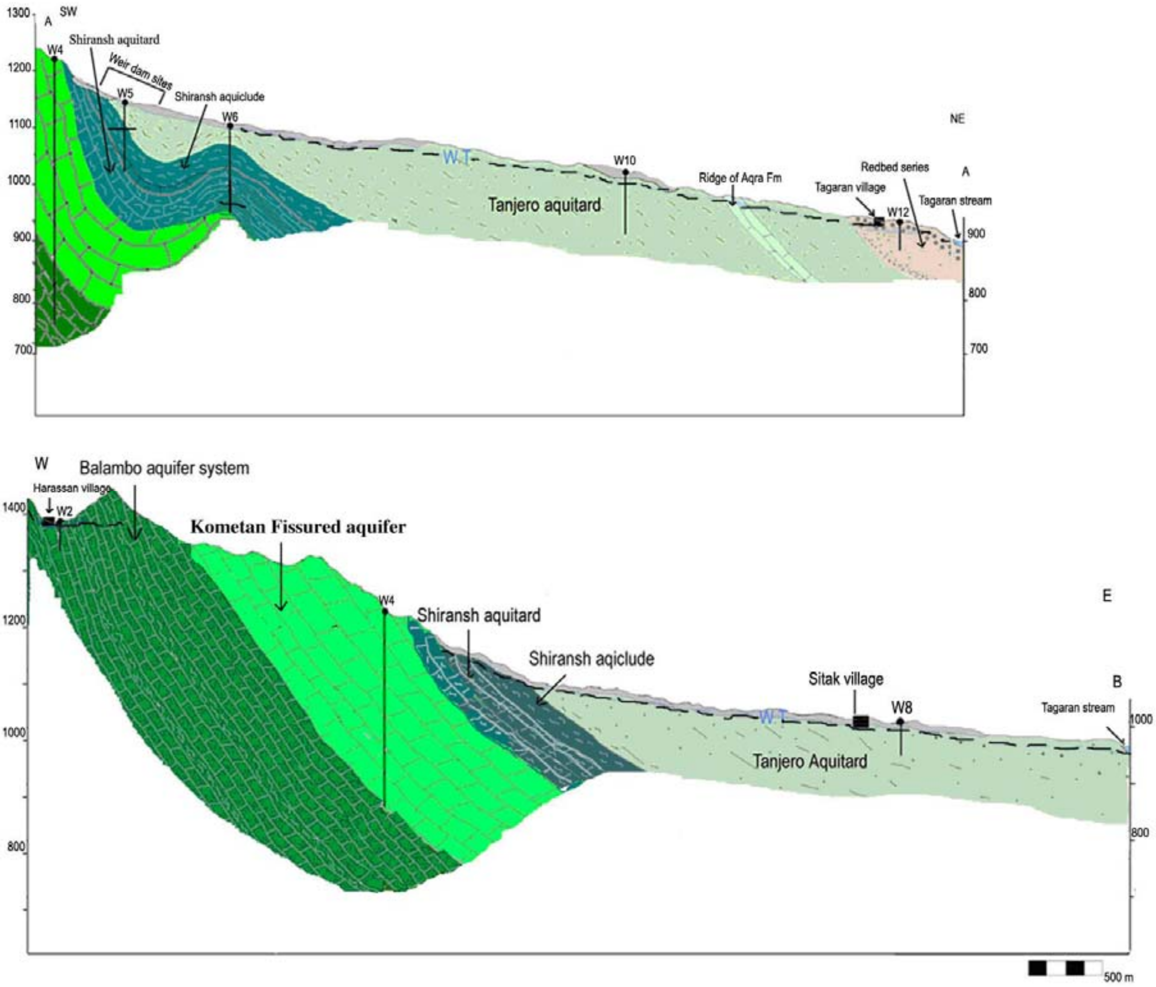


Figure 3: Simplified hydrogeological cross sections along AA and BB (vertical and horizontal scale exaggerated)

- **Aquicludes**

Since, relatively large thickness of marlstone and marly limestone (about 200m) within the Shiransh Formation would tend to impede flow downward, it might seem more appropriate to classify this unit as an aquiclude. However the lower part of this formation which is composed mainly of marly limestone, in some cases may act as an aquitard, such as (W3) in "Badir army" which has low Transmissivity of 5m2/day. As a whole, aquiclude beds of Shiransh separate the Tanjero aquitard from the underlying carbonate aquifers. These aquiclude beds vary considerably in their thickness and compaction due to the degree of subsidence and effects of between 28m to 48m respectively. Groundwater movement took place in the same direction as the Balambo aquifer system; it flows away from weathering. Finally they create lithostatic pressure on the underlying aquifer system.

Kometan Fissured aquifer:

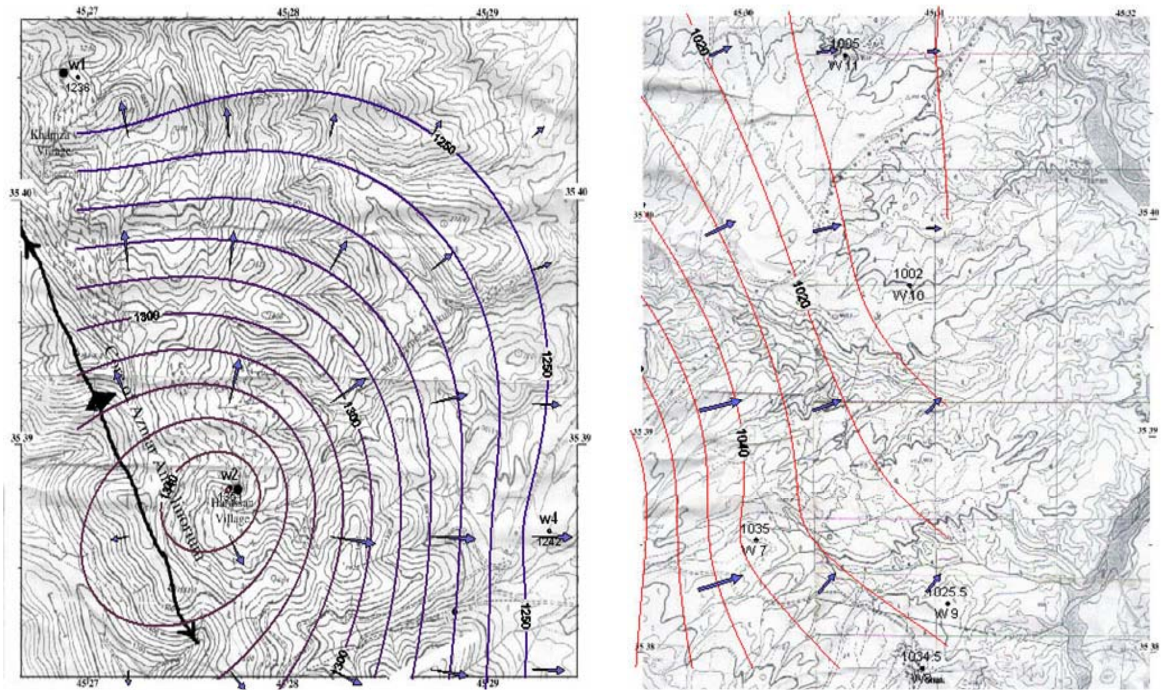
Most of the supply drinking water for inhabitants in Sulaimani city comes from Sarchinar spring, where groundwater is issuing from karstic and fissured conduits of the Kometan Formation. According to [16] during the recession periods of the extremely dried 1999-2000, the minimal discharge of this spring was around 600 l/sec, and the maximum was 7454 l/sec in march, 2003. Thus Kometan is considered as an important aquifer around the area. But, in the study area this aquifer is dry; no drilled wells within this aquifer reached the water table. Absence of the groundwater may be the result of:

Carbonate rocks of the Kometan are weathered, fractured and karstified due to intense tectonic and exogentic effects, which have enhanced permeability and provide pathway for

percolation of groundwater downward toward the plunge of the Piramagroon mountain where the Kometan Formation is exposed and drained the accumulated water in Sarchinar spring, thus the discharge of Kometan may be controlled by draining of Sarchinar spring.
According to the [17], there is an important reverse angle fault
(named North Sarchinar fault) striking NNW-SSE, by this fault the southeastern end of the plunge (locally called Girdy Sarchinar) is suddenly subsided. The role of the fault was even more significant during past before enhancement of the flow direction by karstification.

Flow net directions of the area

Groundwater levels with reference to mean sea level (reduced level) have been used to prepare a static water level map with contour interval of 10m (Figure 4A, B). This map is based on water table from 3 wells for the Balambo aquifer system and 6 wells which penetrating Tanjero aquitard. Generally, in both flow net contour maps, groundwater direction is from the core of Azmar anticlinorium towards the east and north east direction of the area. The hydraulic gradient within the Balambo is more than 0.105, while decreases to less than (0.07) within the Tanjero aquitard, especially towards the Sitak village.



A **1000m** **B** **1000m**

Legend

●W7 **1035** Elevation of static water level in meter (a.s.l). 1040 isopotential lines

Groundwater flow directions

Figure 4: Static water level contour map of the water bearing beds in the study area in meter (a.s.l). A (Balambo aquifer system), and B (Tanjero aquitard)

Due to occurrence of highly fractured and karstified rocks in Kometan and Balambo aquifers, hydraulically they may be inter-connected; in some cases it may form a joint aquifer system; however this statement is not proved due to insufficient data and lack of recent techniques.

Parameters of major water bearing units

The hydraulic parameters of water bearing beds were obtained by pumping test. Those parameters comprise the transmissivity (T) and storage coefficient (S), by applying the computer software {AQTESOLVE 4.02 and INFINITE EXTENT}. Most of the tested wells were applied the AQTESOLVE 4.02, because it is capable of computing transmissivity (T) and storage coefficient (S) even for the single well and partially penetrating case. All methods were applied for the un-steady state flow condition for both drawdown and recovery tests, especially for the Balambo aquifer system and for the most tested wells of the Shiransh and Tanjero aquitard. In certain cases particularly within the Shiransh, steady state was reached very fast after pumping started. This is because the well discharge rate was very low (108 m^3/day) and the T was high (75 m^2/day), typical cases are recorded in (W 5), where the aquifer is semi-confined. The computation of T from the resultant curve was carried out only in the initial drawdown measurements when the unsteady state conditions were prevailing, therefore T values obtained by the methods applying drawdown test measurements are lower compared to those applying recovery test measurements especially for the Balambo aquifer, while the computation of T for the Tanjero aquitard both by drawdown test and recovery test were close.

The average T value is around (75 m^2/day) for the Balambo aquifer system, while it ranges from 2 m^2/day in most wells that penetrate the Tanjero aquitard to more than 100 m^2/day just in (W7), which may penetrated lower part of the Tanjero aquifer due to increasing the coarse clastic with good sorting deposits and low matrix porosity. It also noticed that, there is a wide variation in aquifer parameters especially for the Tanjero aquitard, these variations are due to one or more of the following factors:

a) Lateral and vertical variation in the lithology of the water bearing beds.
b) Undulation of the water bearing beds as a result of the tectonic activity.
c) Variation of the physical characteristics of the aquifer such as grain size, compaction and cement material.
d) Unsuccessful well design.

The storage values (S) of the Balambo aquifer were found to be around (0.001-0.01). While for the Tanjero aquitard were assigned to be around (0.01-0.6). In the well (W3) which penetrates the Shiransh aquiclude it was (0.0002). Finally, it can be concluded that, wells which were drilled in the Tanjero aquitard have higher storage coefficient which indicate unconfined condition, while wells that penetrate the Balambo aquifer may reveal semi-confined to unconfined condition.

A well discharge is another factor affecting aquifer parameters. In the study area, well yielding vary considerably from 43m^3/day in (W1) to 583m^3/day (W8). Many factors appear to have affected the well yields in the study area, such as:

- ❖ Lithological properties of the aquifers.
- ❖ Variation in the well depth.
- ❖ Type of pumping equipments and the capacity of the pump.

The hydraulic parameters differ, due to variation in lithology, aquifer thickness, and duration of pumping tests, as well as total discharge of the tested wells. To show aquifer characteristics, some relationship can be analyzed:

- ❖ Some wells have low discharge or low rate of flow (less than 70m^3/day) but they have high drawdown (more than 4m), such as (W10, W11) around the Bazageer village. These wells are considered to be low yielding wells and need to be developed.
- ❖ Other wells (W1 and W2) have discharges of 43m^3/day and 130m^3/day respectively, but their drawdown is less than 1m, they are penetrating Balambo aquifer system. Such wells have good yielding capacity and appear to be highly developed, thus it is possible to change pumps and increase the discharge rate because these wells have high potential.
- ❖ Some wells which have relatively low T (around10 m^2/d) but their discharge is relatively high (200-600 m^3/d). The drawdown in these wells attains (40m), therefore the high rate of the discharge for these wells will affect badly the productivity of the wells which can cause failure or even lead to the dryness in the future, examples of these wells are (W3, W9, and W11).

C- Conclusions and Recommendations

Cretaceous carbonate and clastic water bearing rocks were evaluated hydrogeologically in combination with aquifer parameters derived from single well test methods. Although this information was collected at a specific field site, some of the observation can be generalized:

1. The main water bearing units in the area are as follows:

- ❖ The Balambo Formation is considered as an **aquifer system** due to presence of multi-layered aquifer. The condition of this aquifer mostly classify within semi-confined aquifer for the lower part and unconfined aquifer in the upper part, but it becomes confined aquifer when it descends below the Shiransh Formation passing under the Kometan Formation.

- Hydrogeologically, the Tanjero Formation can be classified into two main water bearing units:

- **Upper unit**; which has thickness of about 400m, it has a characteristic of aquitard and lies mostly under unconfined aquifer with delay yield condition.

- **Lower unit**; Thickness is about 50m and can be classified as an aquifer since it has high transmissivity (around 100 m^2/d) due to thick succession of conglomerate and coarse sandstone with relatively low matrix porosity, it lies under un-confined aquifer condition in area where its outcrop is exposed. This unit appears in restricted area in buried valley, it disappears in most locations around the area; therefore the term aquitard is mostly applied with mentioning the Tanjero Formation.

- The Lower part of the Shiransh Formation can be classified as an aquitard. Thickness varies considerably due to the degree of subsidence, while the Upper part has characteristics of aquiclude and it separates the two major water bearing beds in the area (Tanjero aquitard from the underlying Balambo aquifer system).
- Kometan Fissured aquifer; locally can be considered as a dry aquifer, since no wells in the area reached the water table. The exposed outcrop of Kometan in the plunge of Piramagroon Mt. where Sarchinar karstic spring is drained, may control the accumulated water of Kometan fissured aquifer.

2. The Balambo aquifer reflects the best hydraulic properties (more than 75 m^2/day T) and (around 0.001-0.01 S), same parameters were estimated for the Tanjero aquitard as $2m^2$/day and (0.01-0.6) respectively.
3. Based on groundwater contour map, the hydraulic gradient is stepper within the Balambo aquifer (more than 0.105), while it is gentler within the Tanjero aquitard (around 0.07).
4. Two different types of water bearing beds have been recognized (Balambo aquifer system and Tanjero aquitard which separated by Shiransh aquiclude), in both groundwater flows from the limb of Azmar towards the east and north east direction.
5. Drawdown of about 60m will be expected by the discharge of $432m^3$/day in the first 4 hours of pumping after which the Tanjero aquitard may approach the steady state and the drawdown may be minor.
6. The groundwater storage in the Balambo aquifer indicates considerable volume that sustained water for long period in the region. Hence, drilling of more wells and establishment of more projects (close to the outcrop of Balambo) relying on groundwater is recommended.
7. Increasing drilling wells that associated with increasing tourist activity and irrigation projects in the recent years, may affect most of the area within the Tanjero aquitard, while this effect is limited within the Balambo aquifer system.

The Transmissivity values obtained by recovery test methods reveal as high as double values calculated by constant pumping test methods particularly for the Balambo aquifer, thus constant pumping test results were considered and recommended for any future study in the area. While results for the Tanjero aquitard are close and similar

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APPENDIX – Well Informations

Well	Location	Latitude	Longitude	Depth	W.T	W.T (A.S.L)	P.W.L	s	D	Q (m3/d)	Al(A.S.L)	For.	Aquifer types	Condition
w1	Khamza	35 40 32	45 26 53	53	24.6	1235.45	25.07	0.52	90+30	43.2	1260	Balambo	Aquifer system	Semi conf.
w2	Harassan village	35 38 49.7	45 27 41	48	4.9	1351.1	6.06	1.16	120+30	129.6	1356	Balambo	Aquifer system	Semi conf.
w3	Badir army	35 37 45	45 29 23	126	17	1226	63	46	480+60	224.6	1243	Shiransh	Aquitard	Semi conf.
w4	Kani azmer	35 38 38.04	45 29 03	480		1242					1242	Kometan	Dry aquifer	Unconfined
w5	Sitak-azwar sec.5	35 38 47	45 29 11.4	123	48.2	1097.8	49.35	1.15	50+25	108	1146	Shiransh	Aquitard	Semi conf.
w6	weir dam site	35 38 58.56	45 29 29.04	150	127	983.5					1110	Shiransh	Aquiclude	Semi conf.
w7	Sitak-super mark	35 38 30.6	45 30 3.6	58	27.8	1035.2	28.4	0.6	170+90	95.04	1063	Tanjero	Aquifer	Unconfined
w8	Sitak-orchard pro	35 37 56	45 30 50.4	61	15.6	1034.4	25.7	10.1	180+5	583.2	1050	Tanjero	Aquitard	Unconfined
w9	Sitak village	35 38 12.48	45 30 59.4	140	10.4	1025.6	71.2	60.8	360+120	432	1036	Tanjero	Aquitard	Unconfined
w10	Orchard area-sita	35 39 43.8	45 30 46.2	110	28.2	1001.85	32.15	4	120+60	45.84	1030	Tanjero	Aquitard	Unconfined
w11	Bazageer school	35 40 48.7	45 30 30.4	60	1.2	1004.8	10.6	9.4	115+90	69.12	1006	Tanjero	Aquitard	Unconfined
w12	Tagaran	35 40 14.5	45 29 43.44								930	Red bed		
W13	Siramerge	35 41 13	45 29 13	125	60	1027	83.6	23.6	50+45	155.52	1087	Shiransh	Aquiclude	Semi conf.

W.T depth to water table

W.T (a.s.l) Elevation of water table above sea level

P.W.L Pumping water level

s Drawdown

Alt (a.s.l) Altitude above sea level

For. Formation

Dri. Well Drilling date

Depth depth of wells in meter

D (90+30) Duration of pumping test in minutes (first value is constant pumping test, the second value is recovery test period).

Appendix (2)

Values of Transmissivity (T) in m^2/day and Storage coefficient (S), calculated from constant pumping and recovery test data using different methods in different hydrogeologic conditions by (AQTESOLVE 4.0 -2006)

Well No.		W 1	W 2	W 3	W 5	W 7	W 8	W 9	W 10	W 11
Constant	**T**	**70**	**106**	**2.1**	**75**	**141**	**35.5**	**2.63**	**3.6**	**2.2**
Pumping test	**S**	**0.0134**	**0.008**	**0.02**	**0.12**	**0.22**	**0.01**	**0.65**	**0.203**	**0.18**
Recovery	**T**	**130**	**260**	**0.54**	**36**	**108**	**14.5**	**2.84**	**3.48**	**2.38**
Pumping test	**S**	**0.003**	**0.0027**	**---**	**---**	**0.66**	**0.24**	**---**	**0.18**	**0.2**