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Study Evaluation Of Groundwater Resources In Wadi Yalamlam and Wadi Adam Basins, Makkah Al-Mukarramah, Al-Mukarramah Area

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Abstract

The government of Saudi Arabia has given great attention and effort to supply the holy city of Makkah Al-Mukarramah with sufficient amount of high quality water. The search for and the development of new water resources in the Makkah Al-Mukarramah area is considered among the top priorities as the consumption of water is rising with time. This research aims at assessing the groundwater potentials of the both Wadi Yalamlam and Wadi Adam as an additional strategic future water supply for Makkah Al-Mukarramah area.

Wadi Yalamlam is located 70 km south of Makkah city. It drains a large catchment area of 1610 km^2. The catchment area starts from escarpment of Ashafa mountains which are characterized by a high amount of annual rainfalls of more than 200 mm. Wadi Yalamlam has surface running water most of the year. Recharge rate was estimated as 20 million m^3/year, water discharge to the Red Sea is about 4 million m^3/year.

Wadi Adam is located 50 km south of Makkah city. It drains a catchment area of about 400 km^2, this catchment area is characterized by high amount of rainfall of about 180mm/year. Recharge rate was estimated as 3 million m^3/year, water discharge to the Red Sea is about 0.9 million m^3/year.

The hydrochemical study indicated that the average total dissolved solids in Wadi Yalamlam is 1900mg/l, and in Wadi Adam is 1500mg/l. This means that groundwater is suitable for irrigation purposes only. Concentrations of trace elements are generally within the normal limits.

Introduction

Saudi Arabia, except the Scarp Mountains of Hijaz, is located in an extremely arid zone of the world. It is characterized by very little, unpredictable, and irregular occurrence of precipitation, but very extensive during the local storms. In addition, there are no perennial streams in the proper sense. These conditions make it necessary to conserve and develop every single drop of water in this area.

The Saudi Arabian government has given a great attention and effort to supply Makkah Al-Mukarramah area with sufficient amount of high quality water. The search for development of new water resources in this area is considered among the top priorities as the consumption of water is rising with time, especially in Hajj and Omrah seasons. Makkah Al-Mukarramah area is a part of this arid region; it receives good amount of precipitation from the Hijaz Mountains in the east (Ashafa and Al-Hada areas) in different seasons. Major wadis in Makkah Al-Mukarramah area, such as Fatimah, Naman, and Khulays, have been developed and used for groundwater supply. The groundwater in these wadis is highly decreasing with time due to the extensive use for irrigation, and domestic use. In the mean time most of water supply for Makkah Al-Mukarramah area (more than 90%) is obtained from desalination plants on the Red Sea (Sogreah, 1968; Şen, 1983, Fourth and Fifth Development Plan, 1985, 1990).

Wadi Yalamlam and Wadi Adam comprise major undeveloped groundwater aquifers near Makkah Al-Mukarramah area. These wadis are bounded by Latitudes 20^{o} 30$^{'}$ and 21^{o} 30$^{'}$ N and Longitudes 39^{o} 45$^{'}$ and 40^{o} 30$^{'}$ E. They are located 70 km and 50 km south of Makkah Al-Mukarramah, respectively (Figure 1). These Wadis are part of the Scarp-Hijaz Mountains of the Arabian Shield, which extends from north to south parallel to the Red Sea. This escarpment is one of the outstanding landscape features of Saudi Arabia. Three physiographic units, namely, the Red Sea coastal plain, the hills, and the Scarp-Hijaz Mountains, characterize the area. Yalamlam basin drains a wide catchment area of about 1600 km^2, while Wadi Adam drains a small catchment of about 400 km^2. Both catchment areas start from the Hijaz Escarpment (Ashafa and Al-Hada areas), and characterized by high amount of annual rainfall of more than 200 mm. Towards the drainage opening on the plain, both Wadis lose their defined course and becomes wide spans of sheet wash, while further downstream it is integrated as part of the Red Sea coastal plain.

The only paved road to reach the mouth of this Wadi is the Makkah-Jeddah-Jizan road along the Red Sea coastline, as shown in Fig.1. Several tracks connect the lower parts of the Wadi to the upper reaches in the east, near Ashafa foothills. The activities of the local population are controlled by different geographical, economical, and social factors. However, the majority of the population is concentrated in the middle and down stream areas.

Due to low income from the small agricultural business and the lack of civil services, there is an increase migration from the Wadi to neighboring cities such as Makkah, Jeddah and Al-Lith. From the agricultural development point of view, the upper reaches of the Wadi have limited agricultural potential, while the middle and lower sites offer better potentialities due to better flood distribution (El-Khatib, 1980; Noory 1983; Subyani and Bayumi, 2001; Subyani et al. 2004).

In this paper, investigation of hydrogeological and hydrochemical features of unconfined alluvial aquifer of Wadi Adam and Wadi Yalamlam has been made. These features including groundwater occurrence and movement, aquifer hydraulic characteristics, and quantitative analysis of groundwater recharge and discharge volumes, quality and usability.

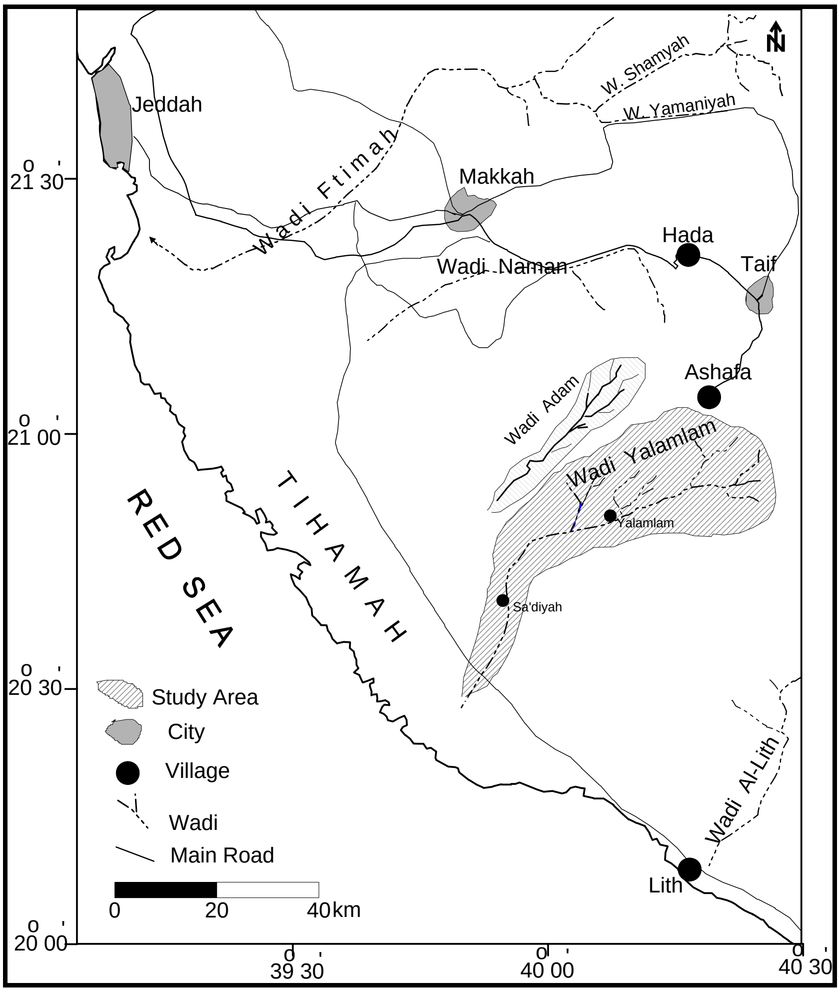

Figure 1. Location map of the study area.

Geological Setting

Wadi Yalamlam and Wadi Adam drain part of the Arabian Shield to the Red Sea coastal plain (Tihamah). The Arabian Shield is vast occurrence of Precambrian crystalline, meta-volcanic and meta-sedimentary with their associated plutonic equivalents, together with local Tertiary and Quaternary basalt flows and alluvial sediments cover part of the Precambian rocks. The following is a summary compilation of the geology of the study area based on the work of Brown et al. (1963); Palister (1986); Moore and Al-Rehaili (1989); Alshanti (1993). *Precambrian Rocks*

The late Precambrian rocks are classified into layered and intrusive rocks. The layered rocks consist of volcanic, volcanoclastic, and metamorphic rocks, which are intruded by igneous bodies (Figure 2).

In the southwest of the study area the oldest layered rocks, Sa'diyah Formation, consist of quartizite, schist, marble and amphibolite. This formation is mainly metasedimentary in nature and is located in the southern part of the study area (Fig. 2.). These rocks are locally interlayered with Baish group, and probably rank among the oldest units in the area. This formation was metamorphosed and suffered multiphase deformation during geological time.

In the eastern part of the study area, post tectonic intrusive rocks, is called Naaman Complex. This complex is a northeast-trending, elongated granite- gneiss batholith. Most of the Ashafa and Al-Hada Mountains belong to Naaman complex. This batholith intrudes rocks of the oldest rock units.

Abbasah Formation, in western side of Wadi Adam, consist of metamorphic lavas and associated volcaniclastic rocks that range in composition between basaltic and rhyolitic which are metamorphosed to paragneisses and schists (Smith, 1980). These rocks are isoclinally folded and correlated with Sa'diyah formation in the south of the study area.

Tertiary Rocks

The two main rock units of the Tertiary rocks in the study area are Adam dike complex and Harrat Adam. Adam dike complex include such as an alkali basalt, Hawaiite, trachyte, dacite, and rhyolite dikes. Most of the dikes are parallel and are mainly trend in the north-south direction. These dikes are also predominant in downstream of the main channel of Wadi Adam, and they may affect the subsurface water flow (Kotb et al., 1990). Harrat Adam is an alkali basalt flow, which crops out in the northwest of Wadi Adam. It consists of olivine, olivine-plagioclase, and porphyritic basalt rocks fragments. The lava flows are nonvesicular to moderately vesicular. Harrat Adam unconformably overlies Precambrian rocks (Fig. 2).

Quaternary Deposits

Quaternary deposits in the study area are bounded by and overlie the Precambrian rocks in the eastern parts of the study area. They are of continental origin, while in the alluvial plain these deposits start to overlap and mix with marine sediments and soils in the coastal zone. There is a general agreement among several authors that the coastal plain including both alluvial and marine deposits belongs to the Quaternary period (Brown et al., 1963; Al Sayari and Zölt, 1978).

Alluvial deposits consist of unconsolidated sand, silt, and gravel deposited in the wadi channels and outwashed plains. They also occur as terrace deposits along Wadi Adam and as fan deposits close to the Red Sea shore as well as at the foot of the coastal hills. This soil unit is grayish yellow to brown in color, but has dark bluish color tone on satellite images due to the tarnished granodioritic gravels on the surface. The average thickness of these deposits increases from 2m in the upstream of the wadi to 20 meters in the downstream near the main coastal road (Figure 2).

Geological Structure

The resent geological studies have showed that the Arabian Shield has been deformed by a series of orogenic episodes and by younger major fault system. Uplifts and faulting have resulted in steep escarpment facies along the Red Sea coast through which numerous wadis cut down their valleys with torrents such in deep valleys that are directed to move slowly across the coastal plain, and frequently reach the Red Sea. During the Tertiary time, Adam fault was activated along the north-western margin in the study area with north-west trend. These dikes mainly trend in the north-west direction. In addition, the eruption of basaltic flows in the area (Harrat) has occurred mostly along fissures with the dikes previously mentioned constituting their feeders.

Another faulting event occurred during then Oligocene and Miocene which gave rise to the formation of the Red Sea Graben. The northwest-trending Quaternary faults are in the form of concealed fault system parallel to Red Sea, which is related to Shua'iba fault. This fault has resulted in the formation of the sabkhas and extensive alluvial gravels in the lower course of wadi system (Matsah et al., 2004).

Hydrological Setting

Yalamlam and Adam basins are affected by the high pressure of the subtropical zone in addition to the local topography. Both regional and local circulations have dominant influence on the climate of the region. According to the world climate classification as established by Glenn, 1954, Yalamlam and Adam basin can be divided into three main climate types:

1) Hot desert climate prevails in the Red Sea coast (Tihamah), (2) Low latitude semi-arid climate prevails in the Plateau, and (3) Warm temperate rainy climate with dry winters prevails in the Scarp Mountains (Şen, 1983).

On the Red Sea coast, there are two basic climates; cool to warm and stable air originating from the Mediterranean during the winter period, and warm and moist air due to monsoons coming from the Indian Ocean during summer.

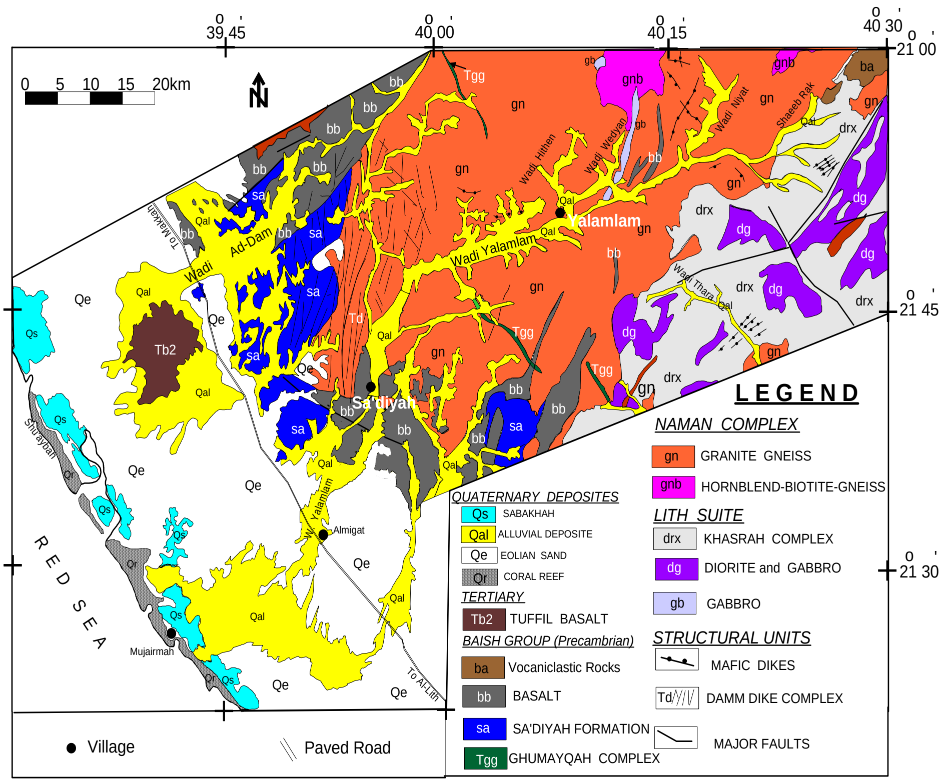

Figure 2. Geologic Map of Study Area (Adopted from Pallister, 1986 and Johnson, 1989).

From the temperature records in the Red Sea coast stations, the mean monthly maximum temperature is 38^o C and the mean monthly minimum temperature is 20^{o}C. The highest recorded temperature in July is 49^{o}C and the lowest in January is 12^{o}C. The relative humidity varies from 80% in summer to 50% in winter.

The climate of the Plateau is generally characterized as mild with some rains in winter and spring, and hot and dry in summer and fall. The mean monthly maximum temperature is 30^o C and the mean monthly minimum temperature is 15^{o}C. The highest temperature recorded in July is 38^o C and the lowest in January is 8^{o}C. The relative humidity ranges from below 20% in summer to 45% in winter.

The Scarp Mountains area, which are characterized by high altitude, tend to have a lower annual range of temperature than the surrounding low areas. The mean minimum temperature is as low as 0^o C in scattered locations, especially in high peaks in winter. The mean monthly maximum temperature is 25° C in summer. The relative humidity ranges from 35% in summer to 65% in winter (El-Khatib, 1980; Aljerash, 1989).

Rainfall distribution and variability over study area

Rainfall distribution in the study area is quite variable both in space and in time. The climatological data used in this project were collected from the Hydrology Division of the Ministry of Water and Electricity in Riyadh. The meteorological measurements in the study area comprise monthly rainfall data only. Unfortunately, some of the important stations near the studied basins have very short rainfall records, such as Sa'diyah (1year) and Mujairmah (4 years), while other stations are lumped in the mountains, such as Ashafa, Taif, Hada, and Jarmooz. The overall available rainfall database consists of 15 to 25 years of mean monthly records. From scientific point of view and for unbiased spatial distribution of climatological stations, some of stations with long rainfall records were chosen as shown in Table 1.

The mean annual rainfall distribution map is presented in Figure 3, which shows the spatial variation of precipitation. This figure also reflects the topographic impact; hence annual rainfall generally increases with elevation. In addition to the orographic effect, seasonality is very important factor which affects the rainfall amount and distribution in the study area. The isohyetal lines passing through Malakan and Adam basins range between 130 and 210 mm/year, which indicate that these basins area receiving reasonable amount of rainfall compared to other basins (Subyani, 1999).

Hydrogeological Features

Intensive hydrogeological fieldwork was carried out during the present study. The field activities covered Yalamlam and Adam basins and included a well-point inventory, pumping tests and a collection of aquifer material samples for laboratory tests. A total of 31 and16 wells are scattered along the mid-stream of Wadi Yalamlam and Adam main channels, respectively. These wells are grouped into two categories; large-diameter (hand-dug) and small diameter wells. Electrical conductivity, pH and temperature of groundwater were measured in situ.

Water Table

An adequate number of data points were found along the midstream parts of the wadi so contours could be drawn with a certain degree of accuracy. The data points comprise water levels measured in the wells. It is obvious from the measured water table contour map of both wadis (Fig's. 4 and 5) that the groundwater flow follows the surface drainage of the main channel. It is clear that the hydraulic properties of the alluvial aquifer are more or less homogenous. The average hydraulic gradient along wadi Yalamlam is in the order of 0.002 and 0.008 in wadi Adam and it decreases slightly in the downstream areas. The volume of groundwater flowing through any cross-section of the main channel can be calculated once the transmissivity of the aquifer material is estimated.

Table 1. Mean annual rainfall around the study area.

St. Name	Longitude	Latitude	Mean Annual Rainfall (mm)
Adham	40.91	20.48	327
Firrain	40.12	21.37	192
Wadi Muhrem	40.33	21.27	185
Ashafa	40.36	21.07	260
Jermuz	40.42	21.07	180
Lith	40.28	20.15	90
Ghomaiga	40.45	20.33	75
Makkah	39.83	21.427	100
Bahrah	39.7	21.43	60
Jeddah	39.18	21.568	60
Dahya	40.28	21.27	165
Shadad	40.22	21.35	130
Kur	40.253	21.344	131

Pumping Tests

Pumping tests were carried out in the study area and there are several methods available for pumping test data analyses. The choice of a certain method for a certain test based mainly on how far the field conditions and aquifer type are closed to such a method, though almost all field conditions are far from ideal in the sense used by Theis (1935). Based on the above mentioned boundary conditions the following analytical methods were found most suitable:

-Slope-matching method (Şen, 1986), large-diameter wells (Papadopulos and Cooper's, 1967), unconfined aquifers (Boulton's method, 1963), and Theis recovery method (1935).

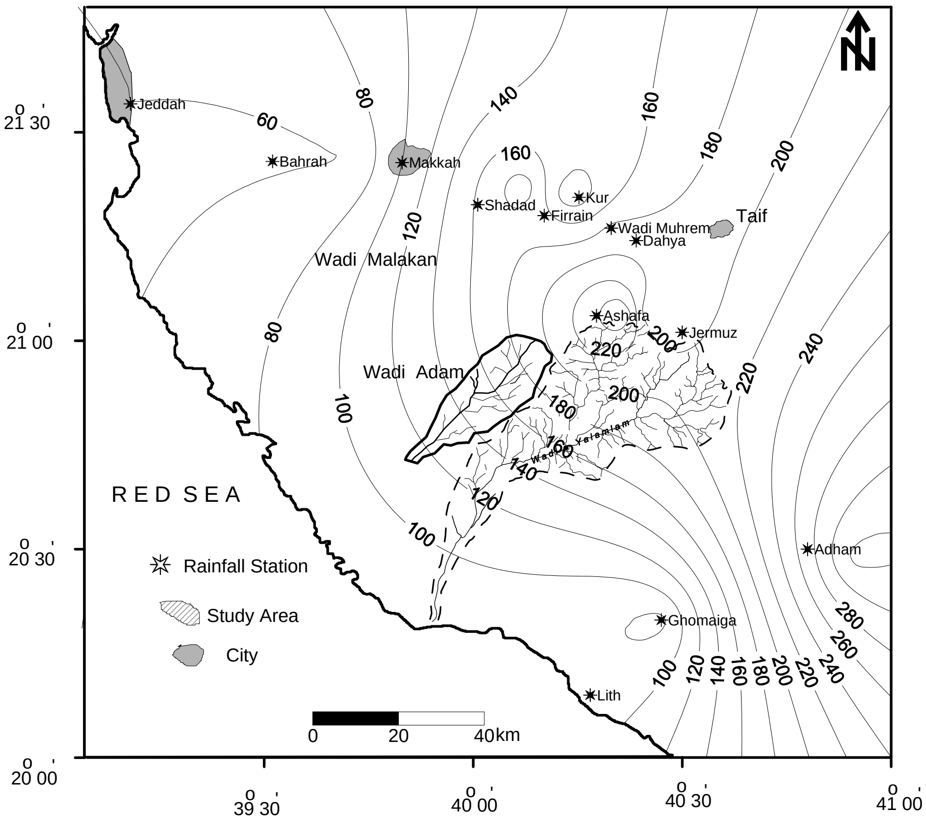

Figure 3. Annual rainfall distribution over study area.

The basis of each method, analysis of data and its ability to predict aquifer behavior can be obtained from the original papers as mentioned in references. In Wadi Yalamlam, 4 Two tested wells were carried out for pumping and recovery tests. The average transmissivity is about 500m^2 day^{-1} . Using the criteria given by Ghearghe (1979), it follows that the aquifer in this area is of high potential. On the other hand, lower values are estimated for Almigat area range between 0.007 and 0.05, which possibly indicate prevalence of leaky aquifer conditions. In Wadi Adam, 2 test wells were carried out for pumping test. The average transmissivity is about 133m^2 day^{-1} and storativity is about 0.1, which is typical for unconfined aquifer.

Groundwater Recharge and Discharge

In arid regions, groundwater recharge is exclusively based on the rainfall, recharge determination is usually very difficult, because great changes in the spatial and temporal distribution of the hydrologic inputs and outputs lead to large uncertainties in determining the recharge either locally or regionally.

However, there is a relatively straightforward way of estimating groundwater recharge by considering the chloride ion as a tracer, which is concentrated by evaporation, and it is defined as a chloride mass-balance method (Wood and Imas, 1995; Wood and Sanford., 1995; Flint et al., 2002). It has become a useful operational tool in determining the amount of recharge. This technique involves the using of chloride-ion concentration ratio in rainfall to chloride-ion concentration in groundwater.

In the chloride mass–balance method, recharge is computed from the following relationship:

$$q = R_{eff}\ Cl_{p} / Cl_{gw}$$

where q is the recharge (mm/year), R_{eff} is the effective rainfall (mm/year), Cl_p is the average chloride concentration of rainfall (mg/l), and Cl_{gw} is the average chloride concentration of groundwater.

Many studies of recharge calculation in arid regions using chloride mass-balance method suggested that the recharge rate is about 10% of annual rainfall (Ting et al. 1998; Bazuhair et al., 2002; Edmonds, 2002; Subyani, 2004).

In the study area, the annual recharge volume can be calculated as:

Recharge Volume = Mean annual rainfall *Effective area*Recharge rate

The effective area of the basin is taken as the moderate to high altitude areas in which most of the year rainfalls (about 66% and 45% of Yalamlam and Adam basins, respectively

Hence, the annual recharge can be calculated as:

Recharge in Yalamlam = 200mm*(1600*0.66) km2*0.1≈ $21*10^6$ m^3 $year^{-1}$.

Recharge in Adam = 180mm*(400*0.45) km2*0.1≈ $3.2*10^6$ m^3 $year^{-1}$.

Naturally, the groundwater in both wadis is discharged into the Red Sea. The amount of this discharge volume has been estimated by Darcy's law to the portion of the aquifer at cross section. In Wadi Yalamlam, the cross-section extends for 3 km. Using the average values of both the aquifer transmissivity (500m^2 day^{-1}) and the hydraulic gradient near the cross section (0.0074) yields an estimated flow rate of about 4 million m^3 annually. Artificial abstraction in the Yalamlam basin is about 300,000 m^3/year, which is low compared to the natural discharge into the Red Sea. In Wadi Adam, the cross-section extends for 3 km. Using the average values of both the aquifer transmissivity (133m^2 day^{-1}) and the hydraulic gradient near the cross section (0.006) yields an estimated flow rate of about 0.9 million m^3 annually. Artificial abstraction in the Adam basin is about 198,000 m^3/year, which is low compared to the natural discharge into the Red Sea.

Hydrochemical Features

Hydrochemistry is the subject that relates groundwater and its dissolved materials with the environment surrounding them, and therefore, it is considered to be an integral and essential part of any hydrogeological study. The dissolved constituents in the groundwater can be very useful in indicating the geological evolution; the mode of the groundwater origin within the hydrological cycles; soil or rock mass influences and its influence on the borehole materials such as screen and casing.

During the field work of the study, 13 and 15 groundwater samples were collected from Yalamlam and Adam basins, respectively. These samples were analyzed for major cations and anions. Durov diagram was used to determine the water type as shown in Figure 4. This diagram divided the water type into two groups; upstream (recharge area) and downstream (discharge area). In the upstream area, calcium (Ca^{+2}) and sulfate (SO_4^{-2}) are the dominant ions, indicating that the groundwater character is calcium sulfate water. In the lower parts sodium (Na^+) and chloride (Cl^-) are the dominant ions, indicating that the groundwater character is sodium chloride water. This simple dissolution or water type changing from calcium sulfate to sodium chloride water distinctly matches the general flow of groundwater.

In Wadi Adam, the Durov diagram was used as shown in Figure 5. Accordingly, groundwater is occupied by a Ca^{+2}-SO_4^{-2} water type in its middle parts and a Na^+-Cl^- water type in its lower parts. This ion exchange can be explained by the occurrence of clay media in the relatively deeper aquifer. This simple dissolution or water type change from calcium sulfate to sodium chloride water type distinctly matches the general flow of groundwater. (Lloyd and Heathcote, 1985, Wanielista, 1997).

Conclusion

Wadi Yalamlam and Wadi Adam comprise major undeveloped groundwater aquifers near Makkah Al-Mukarramah area. They are located 50 km and 70 km south of Makkah Al-Mukarramah city, respectively. These basins receives more than 200 mm of annual rainfall, and they constitute potential strategic water resource. The main objective of this study is to evaluate the groundwater resources in this basin using hydrological, hydrogeological studies.

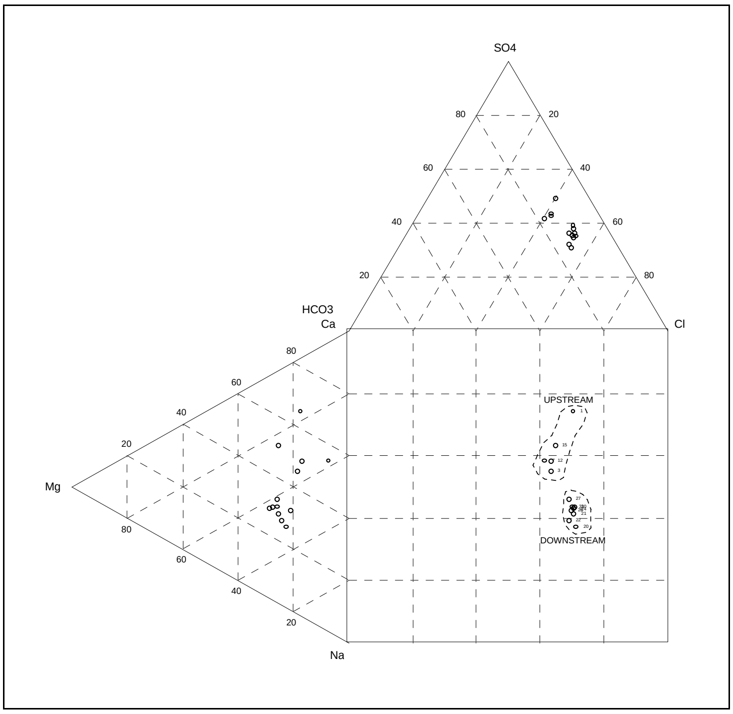

Figure 4. Water types grouped using Durov diagram for Wadi Yalamlam.

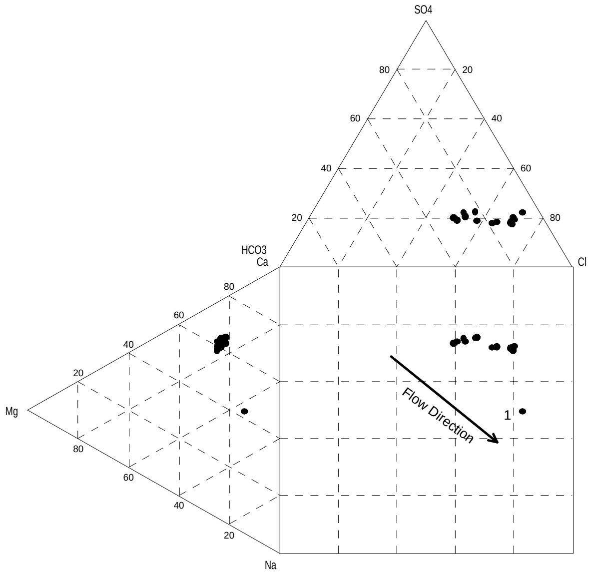

Figure 5. Water types grouped using Durov diagram for Wadi Adam.

Wadi Yalamlam drains a wide catchment area of about 1600 km^2, while Wadi Adam drains a smaller catchment of about 400 km^2. Both catchment areas start from the Hijaz Escarpment (Ashafa and Al-Hada areas) in the east to the Red Sea in the west.

From pumping test analysis using different methods, the average transmissivity and storativity in Wadi Yalamlam and Wadi Adam are $500m^2$ day^{-1} and $133m^2$ day^{-1}, and .03 and 0.01, respectively. Both wadis are moderate to high potential unconfined aquifers.

Hydrochemical investigations of groundwater samples for both wadis shows that water type Ca^{+2}-SO_4^{-2} in the middle parts and a Na^+-Cl^- water type in the lower parts of wadi. This means that groundwater is suitable for irrigation purposes only. Concentrations of trace elements are generally within the normal limits.

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دراسة وتقييم مصادر المياه الجوفية في حوضي وادي يلملم ووادي أدام, منطقه مكة المكرمة

علي بن محمد الصبياني
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الملخص تحتاج منطقة مكة المكرمة والمشاعر المقدسة بكثافتها السكانية وما يفد اليها من حجاج ومعتمرين إلى مصادر للمياه بصفة مستمرة ومتزايدة، إن تأمين الماء للشرب أو للإستعمالات الأخرى يعتبر من الأولويات التي توليها حكومة المملكة العربية السعودية جل إهتمامها . وهناك عدة مصادر تؤمن الماء حالياً وبشكل جيد لمنطقة مكه المكرمه و المشاعر من خلال مياه التحليه والمياه الجوفية من الوديان المجاورة. وهذا البحث يهدف إلى دراسة مصادر جديده للمياه في الأوديه الغير مدروسه بمنطقة مكه المكرمه وهي حوضي وادي يلملم ووادي أدام، ويجب أن نذكر أن مصادر المياه في هذين الحوضين لم تدرس حتى الآن وكذلك فإن الكثافة السكانية قليلة والنشاط الزراعي قليل أيضاً.

يقع وادي يلملم على بعد 70 كلم جنوب مكة المكرمة، ويصرف حوضاً كبيراً تبلغ مساحته 1600 كلم ^{2} يحده شرقاً حد توزيع المياه بمنطقه الشفا. أوضحت الدراسات الهيدرلوجيه والهيدروجيولوجيه والجيوفيزيائيه أن معدل الأمطار السنوي يبلغ 200 ملم وهي من ضمن القيم الأعلى في المملكة حيث يتواجد في الوادي مياه جاريه طوال أيام السنة في أجزاء كبيره من فروع الوادي وأن التغذيه المطريه لهذا الحوض تبلغ حوالي 20 مليون متر مكعب في السنه، وبه مخزون مائي جيد يمكن إستغلاله كمصدر استراتيجي متجدد لمنطقة مكه المكرمه.

أما وادي أدام فإنه يقع حوالي 50 كلم جنوب مكة المكرمة ويصرف حوضاً مساحته حوالي 380 كلم ^{2}، وهذا الحوض يحده من الشرق خط توزيع المياه على منطقة الهدا وكذلك فإن معدل الأمطار السنوي يبلغ حوالي 180 ملم. ومن الدراسات الهيدرلوجيه والهيدروجيولوجيه والجيوفيزيائيه تم حساب كميه التغذيه حيث بلغت حوالي 3 مليون متر مكعب سنوياً وكمية المياه الخارجه من نهاية الوادي حوالي 9,. مليون متر مكعب سنوياً باتجاه البحر الأحمر، حيث يمكن إستغلال مخرج الوادي كمصدر استراتيجي متجدد لمنطقة مكه المكرمه.

أظهرت نتائج التحليل الكيميائي للمياه أن متوسط مجموع الأملاح الذائبه في وادي يلملم تبلغ 1900 ملغ/لتر وفي وادي أدام تبلغ 1502 ملغ/لتر وكلاهما صالح للإسخدام الزراعي والبشري عدا الشرب، أما العناصر الضاره فهي تحت المعدل المسموح به.