



An Assessment of the Hydrogeology and Hydrochemistry of the main Aquifers in Darnah Region, NE. Libya

Fathi M. Salloum*

ABSTRACT

The aim of this paper is to evaluate the Hydrogeology and hydrochemistry in the main aquifer in Darnah region, the Eocene Apollonia and Darnah formations, which are exposed only in the northwest center, and consists mainly of fossiliferous limestone; perched aquifers from the Tertiary Oligocene (Al Baydah and Al Abraq Formations) and the Miocene Al Faidiyah Formation) in which the limestone are contributing to the water resources in the eastern side, Martubah area. Most of the southern part of the study area is covered by the Neogene rocks of Al Faidiyah Formation. A number of chemical analyses from previous consultant studies in the Darnah region were reviewed and analyzed. In addition, more samples from different localities were collected during June 2006. Some of these samples are from pumped wells and others from natural flowing springs. The newly performed analyses show a reasonable agreement with the previous data whenever cross-checking was possible. The salinity of the main aquifer in the western part of the study area shows a quite regular increasing trend west to east and north to south (Fig. 4 and Fig. 8), the water quality trend is matching closely to the groundwater flow direction. Many trials have been performed to estimate the recharge of aquifers in the area. The

*University of Benghazi, P.O.Box 9108, Benghazi, Libya. Fathi_Salloum@Ittnet.net



climate of the study area has been discussed in order to understand the relation and link with estimation of aquifer characteristics in terms of recharge and water balance, these parameters are important for long term water management for Darnah region. Climatic data were identify the environment and further more classify the area in the range of weather humid up to Desertic class. Water resources have been also discussed, discharge measurements of springs were evaluated through the last decades with respect with water wellfields in the upper stream.

Introduction

The context of this paper was a part of the work performed on June 2006 by a group of Scientist from universities of Tripoli and Benghazi within the Environmental assessments base line survey on Block 42-44 Darnah region, led by Professor Mustafa J.Salem.

Darnah is located in the north eastern part of Cyrenaica, Al Jabal Al Akhdar, east Libya. The study area extends from the Mediterranean coast in the north to about 100km in the south. It extends from Wadi AnNagah in the west, to Wadi Al Khalij east of Darnah. The actual size of the area is about 3750km² (Fig.1). Darnah city is considered one of the most important and largest centers between the cities of the Eastern region.

Al Jabal al Akhdar is a crescent-shaped ridge attaining a height of more than 850 meters a.m.s.l, in its central part west of Darnah. The northern flank consists of step plateaus which has been formed as a result of a series of faults and beach terraces. These plateaus are more or less parallel to the Mediterranean Sea, the flank of Al Jabal al Akhdar dips gently toward the south direction forming the Cyrenaica Plateau.



Due to the high relief, the wadis in the north are short and deeply cut, reaching the sea after only few kilometers, e.g. Wadi Darnah. While toward the south, wadis get wider and shallower. The landscape in this area gradually becomes lower and forms large, undulated platform, lying at an altitude of 100-200 m. with discontinuous scarps. The general gentle dip of this area was found to be toward the east and to southeast. Two escarpments (upper and lower) is intersected the study area

The groundwater reservoir is made of thick calcareous series of Tertiary main aquifer (Eocene, Darnah Formation). In correspondence with extensive development of marly layers in the Oligocene (Al Baydah, Abraha and Al Faidiyah Formations), perched aquifers occur locally. The groundwater is generally fresh, its quality deteriorates progressively southward and eastward, due to leaching of evaporites in Tertiary rocks. In coastal areas, increasing salinity by sea water intrusion was due to the over pumping of the huge number of the drilled wells in the area. Chemical analyses of previous collected data were checked and reviewed with the most recent which were inventoried, and collected over 23 water points, these are analyzed in the framework of the present study. Recharge mechanism is complex, because deep percolation of rainfall is controlled by several factors.

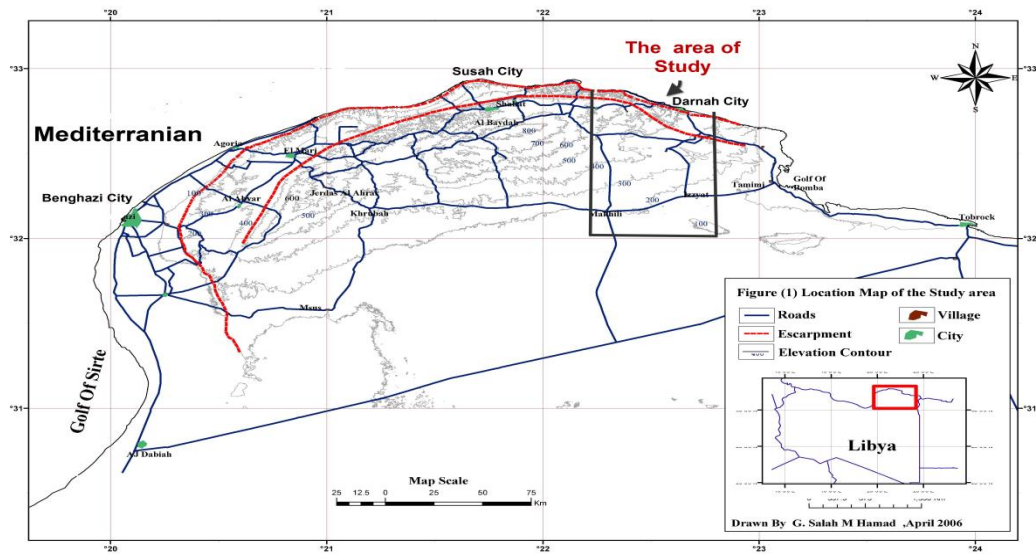


Fig. 1: Topographic map shows the study area (Salloum et al., 2006)

Isotope tools were also used for recharge analysis through water age dating, recharge sampling campaign of groundwater and rainfall had been performed.

Climate

The records of climatic parameters data were taken from the Meteorological Data Center in Tripoli, Darnah Metrological Station and Al Fatayeh Agriculture Project. Other information were collected from Darnah for the years 2004-2006. These later information will be dealt separately. It is important to emphasize here that the reliable data during this survey were only for the areas in the northern parts, namely Darnah and Al Fatayeh. It is expected therefore that some variations between these mentioned sites and the central and southern parts of the area where a semi-desert environment prevail with less rainfall and humidity. The Darnah area has moderate climatic conditions dominant year-around. As the area is located on the Mediterranean Sea from north and northeast



on one side and high topography on the other, while it is open to the semi-desert topography from its southern direction.

The mean monthly temperature ranges in the region between 14.9 °C in winter (January) and 27.3 °C in summer (August). However, High relative humidity prevail, it ranges between 70% in the winter and 78% in the summer, and the maximum value of the relative humidity was recorded in October.

The rainfall is irregular in Darnah area, the monthly rainfall ranges was found between 0.1 mm. in July and 58.9mm in January. While In Al Fatayeh Agriculture Project east of Darnah, it was 0.1 mm. in July and August, to 88 mm in December. The maximum total monthly rainfall in December 1991 was 323.4 mm. When considering the number of rainy days in the Darnah Area it was recorded at 0.0 in the months of July and August, and 10.4 days in January, as an exception in Darnah area in 1991 the number of rainy days was 24 in December of the said year. The highest annual rainfall in the neighboring areas to Darnah is at the town of Al Gaigab west of Darnah, where the rainfall reaches 350 mm. On the other hand to the south of Darnah in Al Mekhili (west of Al Ezziat village), the annual rainfall is only 40 mm. However, at Martubah (southwest of Al Fatayeh) is only 130 mm/year. It can be conclude that annual rainfall increases west of Darnah. While it decreases southwards from Darnah, where the topography gets lower, away from the coastline, therefore the semi-desert environment prevails.

Data from the year 2004 are partially missing, while complete data from the year 2005 gave a reliable relationship, where the highest Evaporation was recorded in July. According to the temperature, wind,



sunshine, and humidity data, Evapotranspiration was found to be 73% as calculated by previous consultants (GEFLI, 1974).

General Geology

Most of Al Jabal Al Akhdar lithostratigraphic units are Tertiary in age, with the exception of small areas of late Cretaceous age. The Eocene (Apollonia and Darnah Formations), Oligocene (Al Baydah and Al Abraq Formations) and Oligo-Miocene (Al Faidiyah Formation), have been recorded. Most of the area of study is covered by Al Faidiyah Formation and Darnah Formation (Fig. 2). The following is a brief summary of the exposed formations in the study area:

Apollonia Formation (Early to Middle Eocene):-

Only the upper part of this formation is exposed, along the northwest part of the area. It is composed of intercalated of limestone and chalky marl with some chert in places. The maximum thickness reaches 300m in subsurface well (Zert, 1974). This formation is overlain by Darnah Formation with a transitional conformable surface. However, laterally interfingered with Darnah Formation as well.

Darnah Formation (Middle to Late Eocene):-

The Darnah Formation is overlying and sometimes interfingering with Apollonia Formation, it is composed of limestone to dolomitic limestone with large chert nodules at some level. The base of this section is characterized by the massive, hard with common *Nummulites*. The reported thickness at the type section reach 100m (Zert, 1974).



Al Baydah Formation (Early Oligocene):-

It consists of two members, the lower Shahhat Marl Member and the upper Algal Limestone Member. The Shahhat Member consists of yellowish marl and chalky limestone of 20m thick, The Algal Limestone Member consists of skeletal limestone which is very rich in coralline red algae, in the study area around Darnah only the Algal Limestone Member is present, this formation thins out towards the south east. Al Baydah Formations unconformably overlain by Al Abraaq Formation.

Al Abraaq Formation (Middle Oligocene):-

It consists of calcarenitic to calcilutitic limestone locally becomes dolomitic limestone, dolomites or marls. In the area of study, the uppermost part is characterized by massive, yellowish marly limestone, with common echinoids and bioturbation.

Al Faidiyah Formation (Oligo-Miocene):-

This formation covers most of the area of study. It consists of two units: A basal clay unit usually dark green and glauconitic, which is overlain by the younger fossiliferous limestone unit. This formation rests on the older rocks with an erosional unconformity surface.

Structurally, the entire area of Northeast Libya and Al Jabal al Akhdar in particular including Darnah are tectonically unstable. It is generally considered as a faulted oriented WSW-ENE with slightly curved axis Anticlinorium, including Darnah area, It is thought that the area experienced uplifting since Late Cretaceous time. The uppermost Cretaceous and Paleocene strata may be missing in some areas as a result



of the said uplift. While thick Eocene, Oligocene and Neogene sequences were deposited.

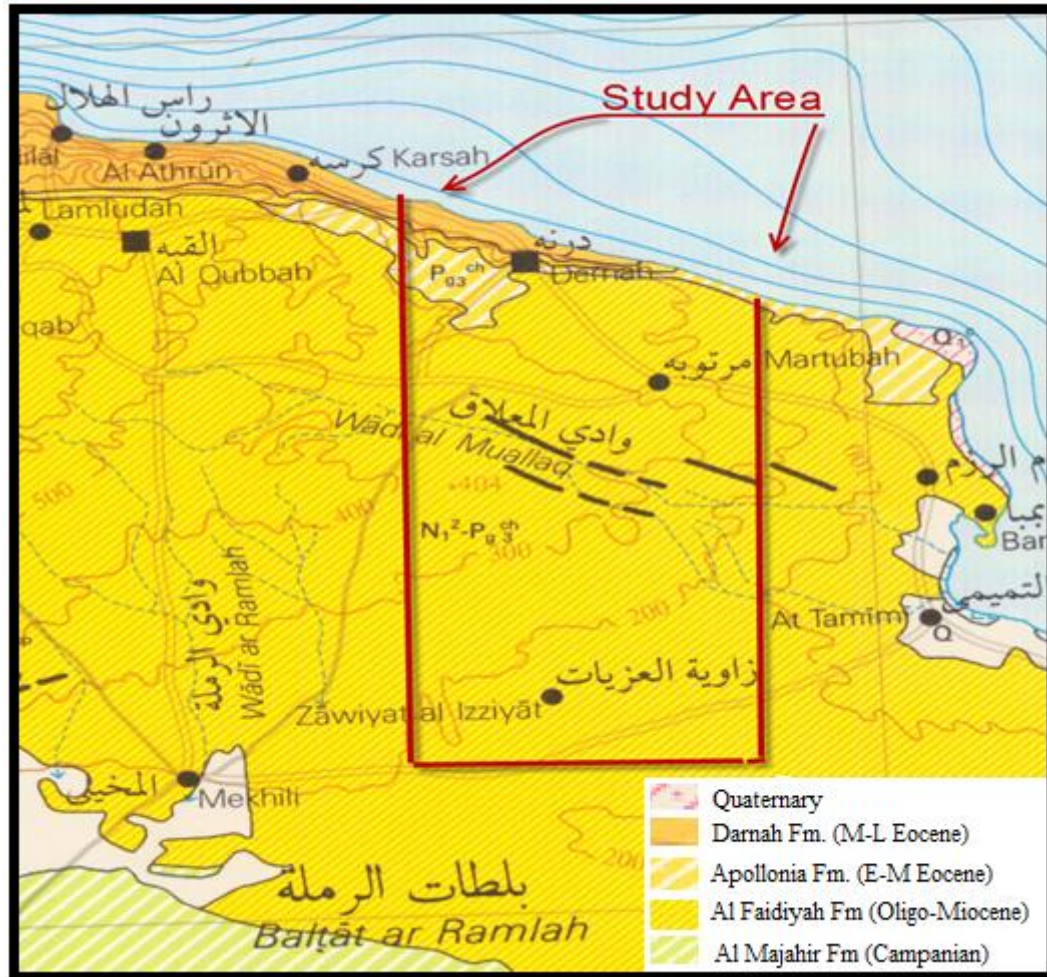


Fig. 2: Geological map of NE Libya Scale 1,000,000, showing the study area, after (IRC, 1985)

In the western part of the study area there are three major fault zones, the coastal belt between Darnah and Ras-Attin, the escarpment line between Martubah and Umm Ar-Razzim and the important lineament of Wadi Al Muallag, most wadis in the study area are controlled by structure framework, The marine erosion which produced the coastal escarpments also followed the main trends of tectonic features. In the south-western and southern parts of the study area extensive jointing indicates that

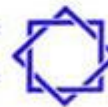
tectonics exists also in these areas as is the case in the north, where several minor fault systems such as NW-SE and NE-SW, (Fig. 3). In the north toward N-NE, in the east toward NE-E, in the middle W-E to SE, in the south wadis are N-S to SE. (Salem and Salloum, 2006).

Geomorphology

Apart from the deepest incisions formed by the main wadis especially in the northern and eastern parts of the area, and the escarpments which flank the coastal strip of the northwestern and eastern part of the region, the rest of the study area is generally flat or gently rolling. Due to this generally flat landform small and linear morphological undulations give good indications and may be important for interpreting regional and local structures. (Salem, and Salloum, 2006).

Two escarpments are prominent in this area. The first one runs along the southern margin of Damah city, while the second one lies further southeast cutting the village of Martubah. Other smaller terraces at different levels were also recorded as being old shoreline (Fig. 3).

The escarpment which runs parallel to the shoreline is the highest in the most westerly part of the area where it exceeds 300m.a.s.l. This escarpment diminishes toward the northeast corner of the area where it reaches the sea-level. The maximum high topography which prevails on the northwestern edge of the study area slopes gradually into the southern area also where it descends to lower than 150 m.a.s.l. in the central and southern parts of the area. These topographic highs and lows are very much coincident with and controlled by structure influence of anticlinal swells and faulting (Salem, and Salloum 2006).



Drainage:-

Northwest part of the Area: The drainage pattern in the northwestern part of the area is characterized by deep and relatively short wadis that run more or less from south-southwest toward north-northeast. Wadi Darnah in particular starts to flow toward the southeast then turns northeast to flow into the sea at Darnah city. In the eastern part of the area, wadis flow from west-southwest toward east northeast into the sea just outside the study area. (Fig. 3).

Two principal wadis runs nearby Martubah area, Wadi Al Khalij and Wadi Al Hemaysah, the total catchment area reaches 550km^2 . Wadi Al Khalij Catchment area is 361 km^2 and flows eastward, then deviate north-northeast across the Al Fatayeh plateau for a distance of about 23 km, from the axis of Darnah-Tobruk highway (Fig.3).

Central Parts of the Area: Wadis in the Central Zone, flowing from west to east long stretches of these wadis run E-W and NNW-SSE, being clearly controlled by faulting and fracture systems which strike the same way as can be seen in Wadi Al-Muallag, its catchment area is 778km^2 , and it flows over a distance of about 100km from the southern flank of Al Jabal Al Akhdar to eastwards ends at Al Tamimi in the east. Wadi Al Shaggah drains an area of about 500km^2 south of Wadi Al Muallag; it terminates at the western side of the Gulf of Bombah at Al Tamimi town.

Southern Parts of the Area: The area shows a poor climatic pattern. The area is devoid of limestone are supported on top by a hard calcareous crust forming a cap made of caliche deposit. Natural caves as well as dug cisterns are found to collapse in many instances once the supporting thin caliche layer deteriorates from below and becomes weak. Such collapse



dolines are common in the area of study. (Salem and Salloum, 2006). Wadi El Ezziat, Catchment area is 2059km², this Wadi contains a number of running parallel long and wide wadis rarely flowing, they drain most of their water just south of Wadi Al Muallag, and they finally disappear further south of Al Ezziat end at very flat areas known as Baltah. Wadi Al Ramlah, catchment area is 931km², this Wadi is the biggest in the southern area in terms of discharge, and however it is flowing outside of the study area (Fig. 3).

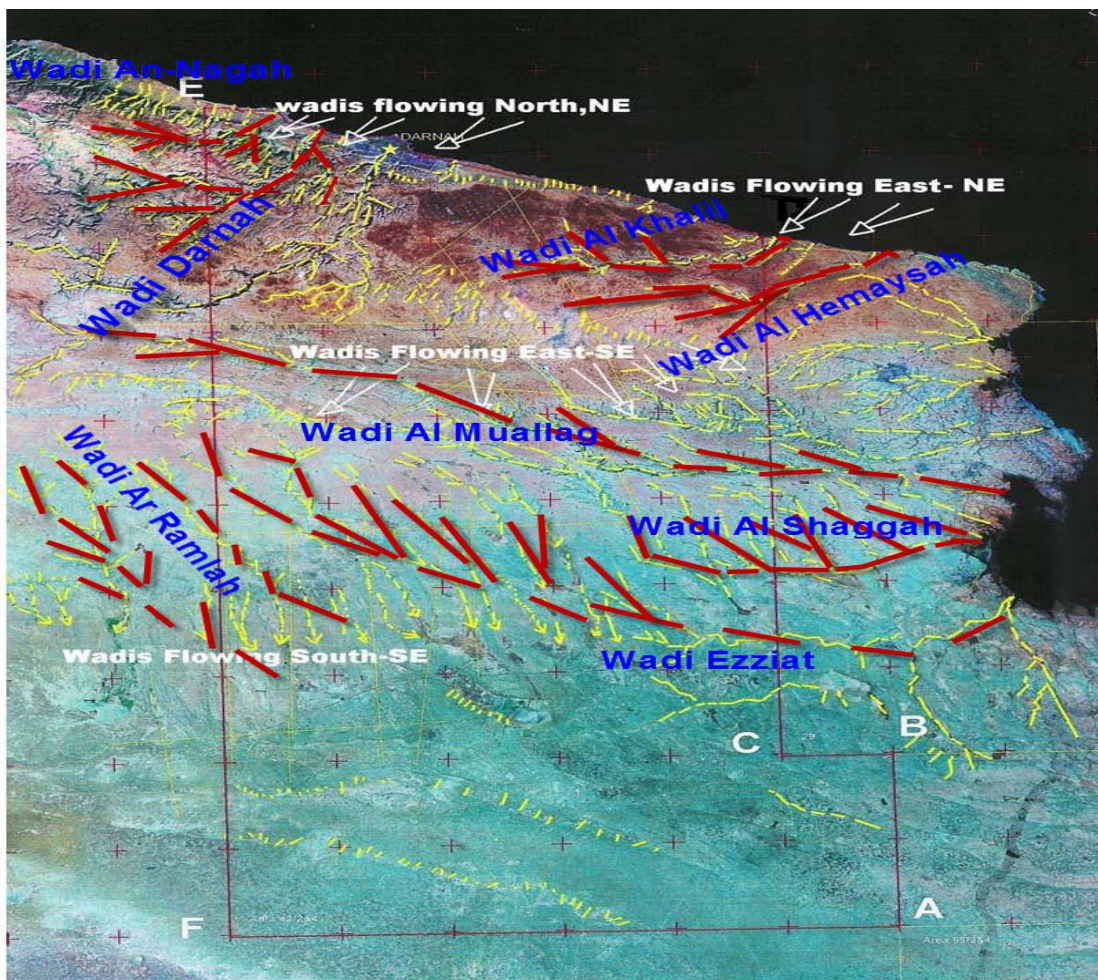


Fig. 3: Satellite image of Darnah region shows major drainage pattern. (Note: The wadis flow are coinciding With structural pattern (after Salem and Salloum, 2006))



Cavernous Phenomena:-

Many types of Karstic features are of erosion action, by solution of near surface rocks, forming caves, potholes, grooves, other Karstic features are sink holes and surface caves on mainly softer rock of Al Faidiyah and Al Abraq formations, the biggest cave in Darnah Region in Wadi Ehtas SE Wadi Darnah tributary is Al Shagaia Cave with multi-levels, connected holes, full of Stalagmites and Stalactites of various sizes.

Hydrogeology

Until recent years, the intense hydrogeological research have been initiated, several studies have been conducted, the most important ones were done by Marchetti (1958), GEFLI (1972), and the Institute for Geological and Geophysical Research (IGGR, 1971). According to the geology, hydrogeological conditions as well as the water resources allocations, the study area fall in the second hydrogeological unit which include Al Gubbah-Darnah and Al Bumbah (Pallas,1979).

Available studies and the results of the deep and shallow drilling suggest that the natural groundwater outlets are confined to the limestone formations of the Eocene, Miocene and Oligocene. Potential Aquifers are located in Darnah and Apollonia formations, from which spring water discharge through the wadi Darnah and Wadi Al Athroun (Ayn Dabbusiah) as well as the wells that have been implemented. Groundwater is also found in Al Baydah and Al Abraq formations, many wells have been drilled in the region and some springs in Wadi Al Nagah and along the mountain slope adjacent to the sea and the mountain slope (GWA, 2005)



The main aquifer, Darnah Formation is composed of Nummulitic limestone, characterized by high permeability and good transmissivity resulting from the nature of the rocks with common cracks and cavities. The free water level in these formations present at different levels and in accordance to the morphological and geological conditions (structural properties and lithology of water bearing rocks). However, water levels deviates steadily toward the east, feeding younger formations, (Fig. 4) where the water level gradient inclination to the east is less than slope of the formations. The thickness of the main aquifer is about 150 meters above the shale and mud intercalated with limestone, this led to the formation of many springs, with variable productivities. (GWA, 2005).

The middle Oligocene aquifer has a limited thickness, Al Baydah Formation is composed of weathered, permeable algal calcarenitic limestone with medium transmissivity, and draws its water from direct recharge of the Quaternary sediments, and where strong hydraulic connection is locally related to the main reservoir in the region by direct contact through the cracks within the impermeable beds. This formation is underlain by the impermeable Shahat Marl Member.

Al Faydiah Formation, where its bottom is lined with clay layers to form water bearing formation, this aquifer draw its water from direct infiltration, there have been locally direct hydraulic contact with the main reservoir in the region (Hydroprojekat, 1971) but the water in this aquifer is considered the primary source to feed aquifers regional level, which are geographically extended on the plateau which is the most rainy areas. The shallow reservoir is the main source of water resources in the region



and the ancient underground through many small springs and wells (Fig. 4).

Groundwater Flow:

From the examination of the piezometry map (Fig. 4) the groundwater flow regime in the respective aquifers can be appraised, as well as the possible interrelationship between the different ground water bodies described above. groundwater flow the main aquifer which ensures in the north-western part of the study area is essentially a consequence of the groundwater flow generated in the central parts of Al Jabal Al Akhdar, lying to the west of the study area where water level elevations are the highest. On the other hand, in the southern and eastern parts of the study area groundwater flow is quite difficult since these areas are characterized by very uniform water levels near to sea level elevation, which result from the generally very scattered control points. In fact, in these areas, due to the extremely low or even absent hydraulic gradients, effect groundwater flow in the Main Aquifer: most prominent piezometry feature which dominates the groundwater flow is the west-east oriented mound with water table elevations ranging from about 120 to 200m.a.s.l (Fig. 4). This groundwater mound is maintained by under flowing groundwater, from the parts of the Jabal Al Akhdar lying to the west of the study area. A sharp permeability increase of the aquifer in the south is also testified. The very steep hydraulic gradients, immediately south of the sea coast to the east of Darnah town, indicating a low permeability in the northern direction. This- low permeability zone, however, cannot be viewed as an impervious boundary as it was supposed on some previously prepared piezometric



maps (Hydroprojekat, 1971 and GEFLI, 1974), since there are no geologic evidences for such an assumption. Along the lower reaches of Wadi Darnah the steep gradient noted above are attenuated due to the drain effect of the Wadi itself starting at about 10 km inland from the sea coast.

By considering a local increase in permeability over the respective area as evidenced in the GEFLI report, by considering a percolation from the overlying perched Oligocene (Al Abraq) aquifer back into the main aquifer, particularly along the northern part of the piezometric plateau, where the perched aquifer has been identified. The variability, according to different directions of the hydraulic gradients, which generally can be observed since the gradients in the north-south directions considerably steeper than those of northwest-southeast. It is considered that such circumstance indicate the presence of directional transmissibility which is quite common in fractured aquifers.

With regard to the extension of the Oligo-Miocene Al Faidiyah Perched aquifer, water level control points are relatively scarce. The groundwater flow apparently originates on the second plateau in the surroundings of Martubah where water levels are in excess of 300m.a.m.s.l., and from here it is directed towards east, south and west consist of low to very low yield springs frequently reduced just to a trickle.

Groundwater flow in the Perched Oligocene (Al Abraq) aquifer can be appraised only in the most north-western part of the Al Fatayeh Plateau. The zone where groundwater flow originates in this aquifer is not identified due to lack of data, however, it can be supposed



as already mentioned that it is diverted from the piezometric mound of the main aquifer where water level elevations exceed 170 m.a.s.l. The high elevation piezometry is maintained along a south-north axis due to the flat structure.

Hydraulic Characteristics (Main Aquifer)

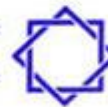
Information on the hydraulic characteristics of the main aquifers are numerous, in particular in the northwestern part of the study area. only in this area the hydraulic characteristics can be appraised in major details, while in the southern and eastern parts, very scattered data on aquifer Transmissibility and specific capacity , they are not sufficient to evaluate in more reliable terms the regional aquifer parameters. Data have been obtained from the pumping tests performed in the numerous completed wells. Where they are only available on the main aquifer. Such as Specific capacity data, reflecting the Transmissibility in the vicinity of the bore hole, together with aquifer and well constants. Transmissibility data determined during long duration pumping tests; Short term storage coefficient data from tests having an observation wells .The specific capacity data, which are numerous (86 values in the northwestern part of the study area). (GEFLI, 1972) reported that, the results of the step drawdown tests showed, the maximum value of specific capacity obtained, was considered for each test, in order to minimize the effect of well loss (CQ2). The maximum value, as normal, has generally been obtained at lowest discharge rates. The low Transmissibility resulting from step-drawdown tests is confirmed also by the analysis of this parameter directly determined in the Martubah wells as reported by GEFLI (1972) from the pumping test



data obtained in these wells, both in drawdown and recovery phases, a Transmissibility variation with time is generally an evident indicating partial penetration effect. The storage coefficient is very uncertain since only one pumping test (in Martubah well and related piezometry) furnish relevant data. The storage coefficient from this pumping test is 1.76×10^{-4} which would be characteristic for a confined aquifer. This is in contrast with the assumption that in the area the aquifer is in water table conditions (unconfined). However, it must be pointed out that in thick non homogeneous anisotropic reservoirs, which is the case of the main aquifer.

On the basis of the studies and investigations performed by Franlab (1974), in the southern part and confining areas to the west, a very high Transmissibility (in the order of 10^{-1} to 10^{-2} m²/sec characterizes this part of the study area, which seems matching with the flat piezometric surface.

The Groundwater levels ranges from 25 to 600 meters in the area of Ras Al-Hilal-Darnah and Martubah-, water is flowing toward the southeast in the direction of the Gulf Al-Bombah (Fig. 4). While Groundwater level was found to be 0 meters towards the east near Ayn Al-Gazela area which are on the sea shore, the ground water flows towards the north in the direction of the Gulf of Bombah. Franlab (1974) have studied the area of Mechili, Ezziat and Kharuba. The groundwater level ranges from 10 to 30m.a.m.s.l. in Mechili area, water flowing towards south-south-east, the water quality is fair (medium quality) ranging from 1700-2500 Micro-mhos/cm represented well fields of Al Ezziat and Buhindi and Al Thuban (Fig. 5). The rest of Southern Jabal



Akhdar area, groundwater level ranges from 10 to 400 meters of water flowing towards the south and south-east, the quality ranging from 1000 to 7000 Micro-mhos / cm.

Springs

Most of the important springs flow out from the area at Wadi Darnah and Al Gubbah (west of Darnah). A number at 19 springs were identified, and measured. Some springs are permanent and produce water with high discharge and good quality. Others are less significant. The springs in the region are mainly flowing from the Karstified beds of the Eocene rocks of Darnah Formation and the underlying Apollonia Formation, the inventoried springs in Darnah region which produce appreciable amounts of water are as follows:- Bu Mansour springs, Ayn Al Blad, Ayn Al Khalij, Ayn At Tanji, Al Mugger, and Ayn Martubah

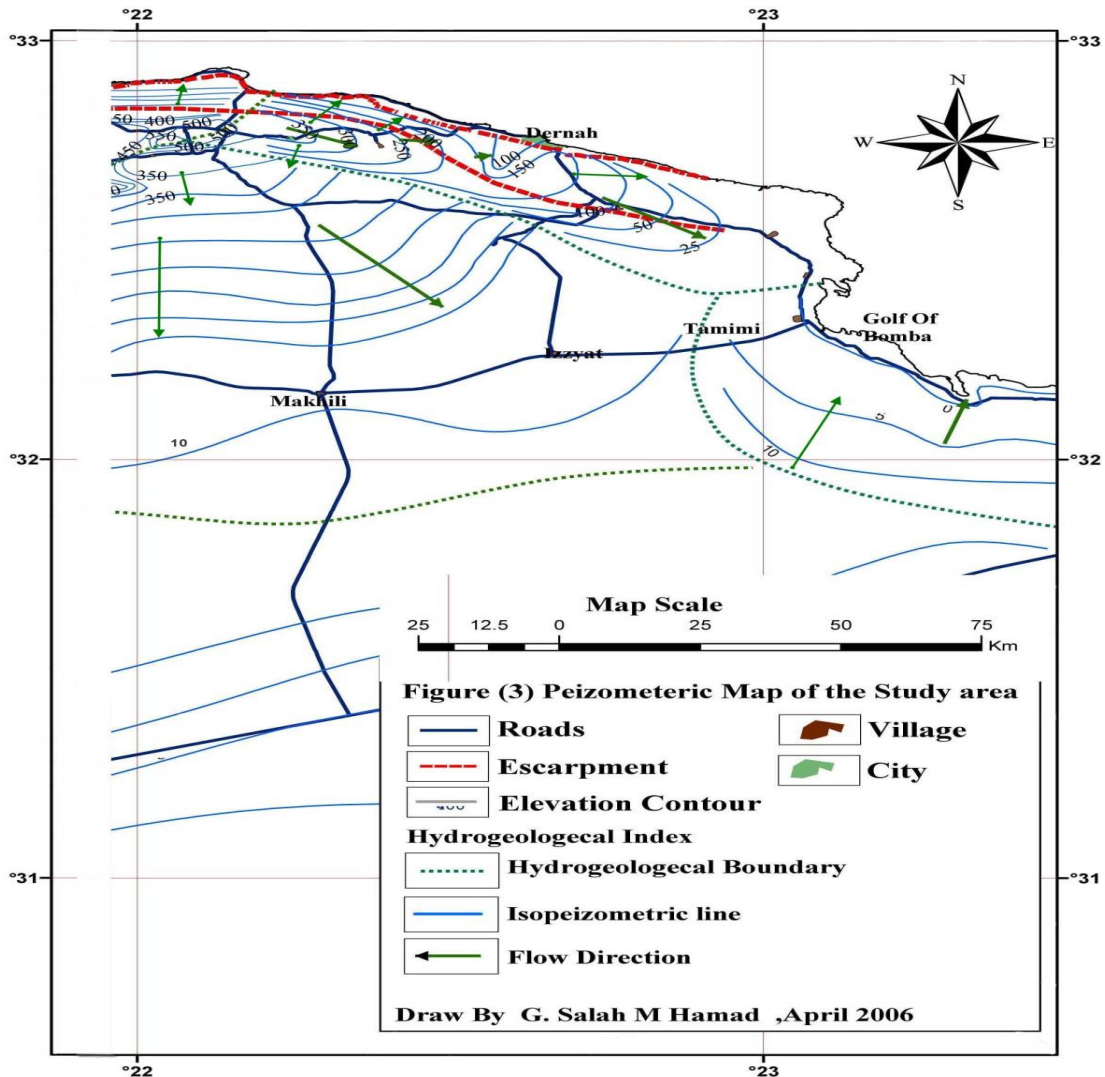
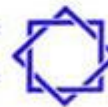


Fig. 4: Piezometric map of the study area (Salloum et al, 2006)

out at the above springs and many others, only Ayn Bu Mansour and Ayn Al Blad are the most producing and dependable permanent sources of water in Darnah, these springs were the subject at many studies by numerous researchers and consultants, the latest was performed under the supervision of the author in 1997 for the purpose of water management in wadi Darnah.



Ayn Al Blad

The spring is located in the western edge of Wadi Darnah about 4.2 km away from Darnah city, its catchment area is about 25 km. Ayn Al Blad is a very important source of water supplying the city of Darnah with potable water .

The Pleistocene Wadi terraces about 15-30m thick play an important role in the process of feeding the spring these sediments are highly permeable with an infiltration rate of 1.2 to 3.4×10^{-4} m/s., the spring was measured by several workers. It was found that its discharge was about 65 to 145 l/s in 1977 (Hydroprojekat, 1971), and 67 l/s (Italconsult, 1977), 60 l/s measured by General Water Authority in 1977, and LTCC, 1997. We have measured the spring in June 2006 and found that the discharge is seasonally variable, our value was 30 to 45 liters /second. the reason for lowered of discharge level is similar to that of Ayn Bu Mansour, namely the drilling of water wells upstream had seriously effect on the spring discharge. Water samples from Ayn Al Blad spring was analyzed chemically (Table 2) the salinity is still within the international standards, as its total dissolved solids 565 mg / l.

Bu Mansour Spring

Ayn Bu Mansour is in fact a group of openings on both sides of Wadi Darnah , and most of them flowing out the west side of the wadi , since these openings are at the end been collected in one channel, they may be called with one name. The spring was studied by Gefli 1972, and Italconsult 1978, (Salloum et al 2006).

Ayn Bu Mansour is located about 6 km from the main Dam in Wadi Darnah, this spring is flowing out of highly Karstified thick limestone



rocks through the Darnah - Apollonia contact, thick sequence of Travertine sediments were deposited downstream of these springs, this may be due to the presence of barriers and high flow rates in addition to the high Wadi floods during the Pleistocene or Plio-Pleistocene.

The discharge of this spring was measured several times, and was found to be ranging between 195 to 230 liters / second (Gefli, 1972), and about 120l/s. In 1997 the discharge was measured by the author using Price current meter, it was reduced to about 80 l/s. Continuing lowering of spring discharges were noticed, probably due to mainly increased number of drilled water wells in the same aquifer upstream. Some of the newly drilled wells we sampled in June 2006 during the field survey. The measured salinity was 582mg/l, this salinity increases in the direction to the east of Wadi Darnah. Gefli (1974) indicated that the source of water to this spring may be from the west of Darnah (Ayn Marah), they made their hypothesis on pumping operation of the wells in Ayn Mara , which when they are in operation ,the production of the spring was directly affected. Bu Mansour Tunnel is located at an elevation 119-135 m.a.s.l, it is a Man-Made excavated Tunnel for the collection of springs water, it was inventoried by our team only up to 300m long due safety reasons, The discharge of the spring was adopted by (GAW 2005) to 100l/s (8640 m³/day).Table 1 presents the water resources from wellfields and the main springs in the area around Darnah City which are mainly used for municipal supply , these were used for future planning, there still more efforts should be implemented to evaluate the water resources with respect to the rapid growth of population and the capability of the resources.



Table 1. Available water resources for Municipal and Agriculture uses (estimates of the year 1998), (GWA, 2002)

Source	Capacity m ³ /day	Capacity Mm ³ /yr.
Shaihah Well field	7,776.00	2,838,240.00
Desalination Plant- Mengar Rabeh	7,776.00	2,838,240.00
Water Desalination – Bu-Msafer	2,592.00	946,080.00
Ayn Al Bald (Spring)	2,592.00	946,080.00
Bu Mansur Tunnel and springs	8,640.00	3,153,600.00
Sewage Plant resources water resources	9,504.00	3,468,960.00
Al Hishah Well field instead of Al Maggar wells	10,368.00	3,784,320.00
Al Dahar Al Hamar well field	8,640.00	3,153,600.00
Total	57,888.00	21,129,120.00

Water Quality of the study Area

A number of chemical analyses data of the groundwater in the Eocene aquifers (Darnah and Apollonia), and the Oligo-Miocene Aquifers (Al Faidiyah and Al Abra) are available from previous studies, for Darnah region including the southern part, these data (Table 2) were checked and reviewed in comparison with our recent data. Over 35 water points were inventoried, complete analyses to a number of 23 water samples (Table 2) were conducted in the framework of the present study (Fig. 5). During the Field survey, water quality was tested in the field from water wells, springs and cisterns, the type of collected data were, site location (geographic with coordinates), well depth, well number (if any), and any other available information. The field measurement data was mainly Electrical Conductivity (EC), pH, and Temperature, (Table 2).

The water samples were analyzed in Benghazi (The Scientific Center for Research and Development-Chemical and Bacteriologic analyses), reliability of data was checked by the Laboratory of

Man-Made River Authority in Benghazi. The analysis includes calcium, magnesium, sodium, potassium, bicarbonate, carbonate, sulphate, total dissolved solids (TDS), total alkalinity and total hardness (Table 2)

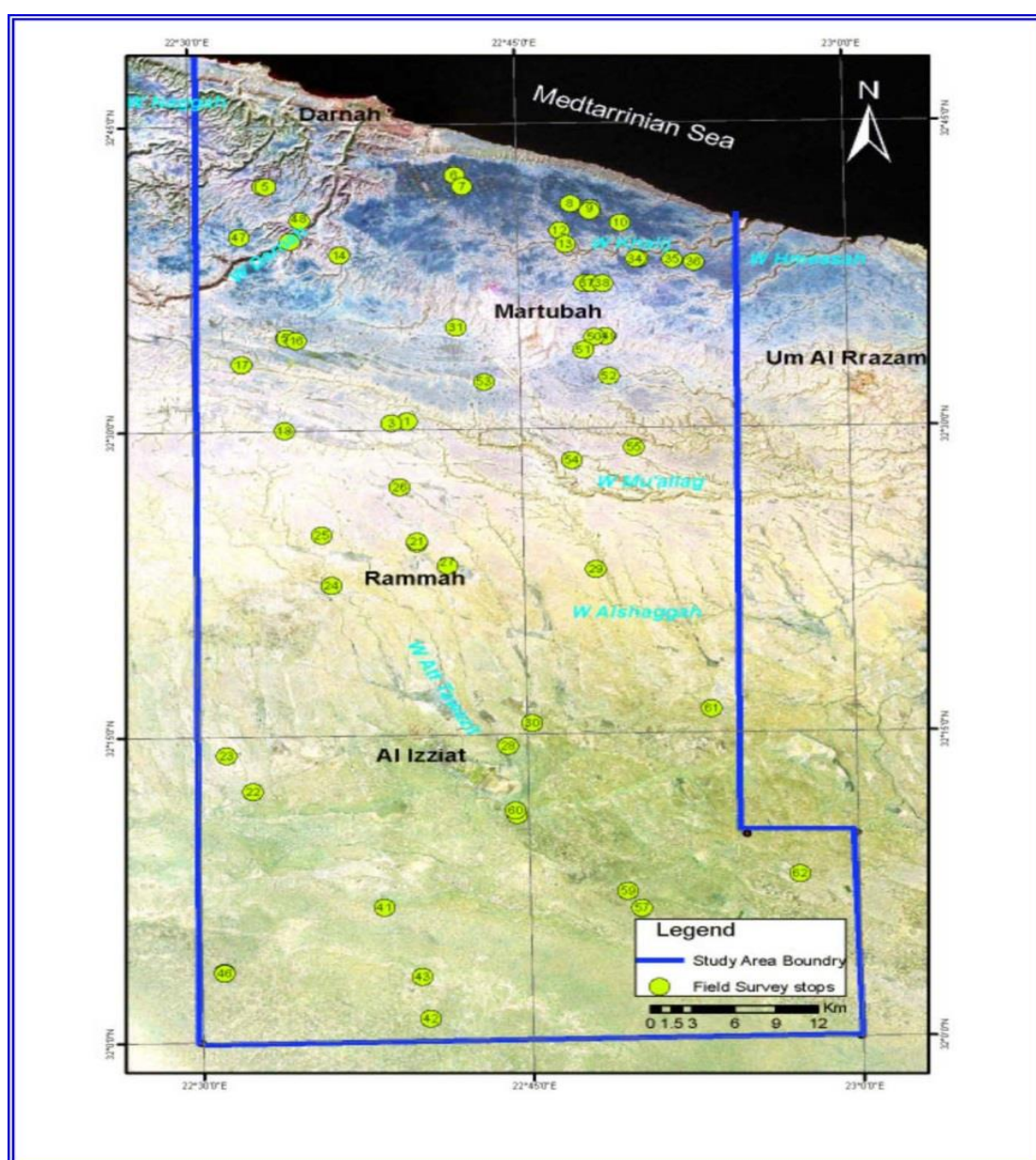
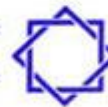


Fig. 5: Satellite image shows water sampling locations in Darnah Region.



Field Measurement and Physical Parameters

Water Temperature Measurement:

The overall water temperature of the study is ranging from a minimum of 21 °C to a maximum of 27.1 °C, depending on the different exposure of the water, from contact springs, they have lower temperature than water from drilled wells, water traveled through deeper fractures in the Karsts shows higher temperature. The pH values for study area ranges from 6.4 to 8.4 with an overall average of 7.82. The pH value shows a difference between the mean (7.82 mg/l) and median (7.9 mg/l), which is very small (0.08) statistically indicating approximately normal distribution.

Electrical Conductivity (EC) and Total Dissolved Solid (TDS):

The electrical conductivity values of water in the study area ranges from 5696 to 730 micro-Siemens per cm (μS). The conductivity measurement is an excellent indication of total dissolved solids in water (Hem, 1985). The total material in solution may be quantified by conductivity (EC) and total dissolved solids (TDS), the actual relation between them is dependent upon the individual ionic composition / organic content and silica content for each water. Most natural waters have a ratio of between 0.55 and 0.7 (TDS/EC). The concentration of total solid in the study area ranges from 405.9 to 3132.8 (mg/l). Both TDS and EC is considered high in the study area, the reason for that is the week recharge to aquifers, and the dissolution of the Karstic limestone.



Total Alkalinity:

The total alkalinity show a difference between the mean values (225.82 mg/l) and median (228 mg/l), which is very small. Statistically indicating approximately normal distribution concentrations. The hardness of water in the study area ranges from 236 mg/l as CaCO_3 to a maximum of 1200 mg/l as CaCO_3 with an overall average of 236 mg/l as CaCO_3 . It is classified as a very hard water.

Presentation of results chemical analyses

The software package, Groundwater for windows, Rock Works and GWW (UN 1995) has been used to plot the water chemistry of the study area (Table 2) the data can be expressed in milligrams per liter (mg/l) for many proposes, the data may also displayed in graphical form. Two graphs have been used from the package named Piper diagram (Fig. 6) and Stiff pattern (Fig. 7) the results of these graphs showed useful information regarding determination of the classification and type of water.

Piper or Trilinear diagram

The major ionic species in most natural waters are (Na^+ , K^+ , Ca^{2+} , Mg^{2+} , Cl^- , CO_3 , HCO_3 , and SO_4) Trilinear diagram can show the percentage composite ion of their ions by grouping Na and K together the major Cations can be displayed on one Trilinear diagram likewise if CO_3 and HCO_3 – are grouped there also there of the major anions (Piper 1944).



Table 2, Chemical analyses of water samples from the Darnah region (Salem and Salloum, 2006)

ID	Location Name	N	E	ELEV m	Temp	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	HCO ₃ mg/l	CO ₃ mg/l	SO ₄ mg/l	Cl mg/l	TDS mg/l	Total hardness, as CaCO ₃ mg/l	Total Alkalinity CaCO ₃	EC mic-sim/ cm	pH	TDS Calculated	Calculated EC
1	W-5	32 39.119	22 41.498	251	25.6	78.3	71	260	7	200	0.1	109	487	1139	488	205	2160	7.6	1212	2299
10	Fatyeh-1	32 41.966	22 42.506	242	27.1	65.4	58.4	229	7	216	0.1	121	378	1001	408	221	1820	7.9	1076	1956
11	VI-431/2	32 41.052	22 47.499	217	25	57.1	51.8	275	13.9	172	0.1	99	445	1066	356	177	1960	7.9	1114	2048
12	W7/206	32 36.691	22 25.603	441	21.3	37.9	34.4	122	7	196	0.1	61	152	542	236	201	852	8.4	610	960
13	W_8/206	32 39.701	22 37.981	292	26.2	58.4	53	229	41.9	229	0.1	84	370	975	464	234	1620	8.24	1065	1770
15	KT-J3	32 39.474	22 54.998	3	24.6	102	92	230	21	260	0.1	230	514	1430	638	265	2600	7.8	1449	2635
16	H.48	32 45.056	22 36.757	267	25.1	76.2	68.2	189	11	260	0.1	67	480	799.7	475	265	1454	7.5	1153	2095
19	W.1_Ardam	32 34.575	22 34.314	359	21.8	66.2	60.1	81	6	223	0.1	54	177	405.9	413	228	738	6.4	667	1213
2	Martuba Spring	32 24.202	22 48.493	258	21.5	50	45	221	13.9	176	0.15	94	390	942	312	181	1720	8	990	1808
21	VI-2-2106	32 44.378	22 35.683	265	24	76	68.2	80	4	260	0.1	38	163	437	475	265	795	7.8	690	1256
25	S-1	32 23.540	22 41.835	239	25.5	112	1001	230	10	223	0.1	480	355	1183.1	700	223	2151	7.1	2411	4384
26	AYN-BLAD	32 42.702	22 37.176	62	22.5	49	45.1	78	50	236	0.1	29	184	465	310	241	847	7.43	671	1223
28	W.4	32 42.334	22 40.513	250	27.1	70.4	63.8	147	70	236	0.1	38	369	588	438	241	1069	7.4	994	1808
3	Ayn Bu Mansure	32 41.952	22 36.626	108	21.2	48.8	44.3	92	13.9	200	0.1	34	214	582	304	205	969	8	647	1077
30	S-5432	32 40.854	22 48.382	217	25.5	72.2	65.5	230	13	223	0.1	135	461	828	450	228	1507	7.7	1200	2184
31	W-3	32 40.539	22 35.072		21.6	47.3	42.9	78	40	223	0.1	35	199	437	295	228	796	7.8	665	1212
0	Aldram Well					44.3	40.2	107	20.9	216	0.1	45	172	560	276	221	970	8.3	646	1118
5	Martuba/2 A.30	32 34.578	22 45.607	279	23	54.5	49.5	191	13.9	172	0.1	82	351	865	340	177	1660	8.1	914	1754
6	WS.206	32 45.822	22 33.619	267	22.5	50.7	46	92	13.9	251	0.1	59	158.2	572	316	256	989	8.1	671	1160
7	Tunnel_S-1	32 40.111	22 36.668	103	22.4	46.2	41.9	115	7	241	0.1	53	156	577	288	246	941	8	660	1077
8	Ayn Al Muggar	32 37.377	22 31.232	274	21	57.7	52.4	244	13.9	113	0.1	89	476	1024.2	360	118	1840	8.2	1046	1879
29	Meteorology	32 24.080	22 34.847	26	26	192.5	174.7	920	44	347	0.1163	240	1986	3132.8	1200	352	5696	8.28	3765	
9	Az.c.w	32 13.635	22 35.334	190	26.7	93.7	85	260	7	200	0.1	304	413	1288	584	205	2260	8.3	1363	2391
	Max					192.50	1001.0	920.0	70.0	347.0	0.15	480.0	1986.0	3132.8	1200	352.0	5696.0	8.40	3765.00	4383.63
	Min					37.9	34.4	78	4	113	0.1	29	152	405.9	236	118	738	6.4	610.4	959.52
	Mean					69.86	102.50	204.35	19.57	220.57	0.10	112.17	393.49	906.07	440.26	225.35	1626.70	7.84	1116.55	1786.66
	Median					58.40	53.00	191.00	13.90	223	0.10	82.00	369	828.00	408	228.00	1507.00	7.90	994.30	1788.93
	SD					32.80	197.94	171.12	17.33	44.08	0.01	107.56	370.44	569.95	204.00	44.08	1047.64	0.46	702.29	763.53
	% CV					46.95	193.12	83.74	88.51	19.99	10.51	95.89	94.14	62.90	46.34	19.56	64.40	5.85	62.90	42.73
	n					23	23	23	23	23	23	23	23	23	23	23	23	23	23	22.00

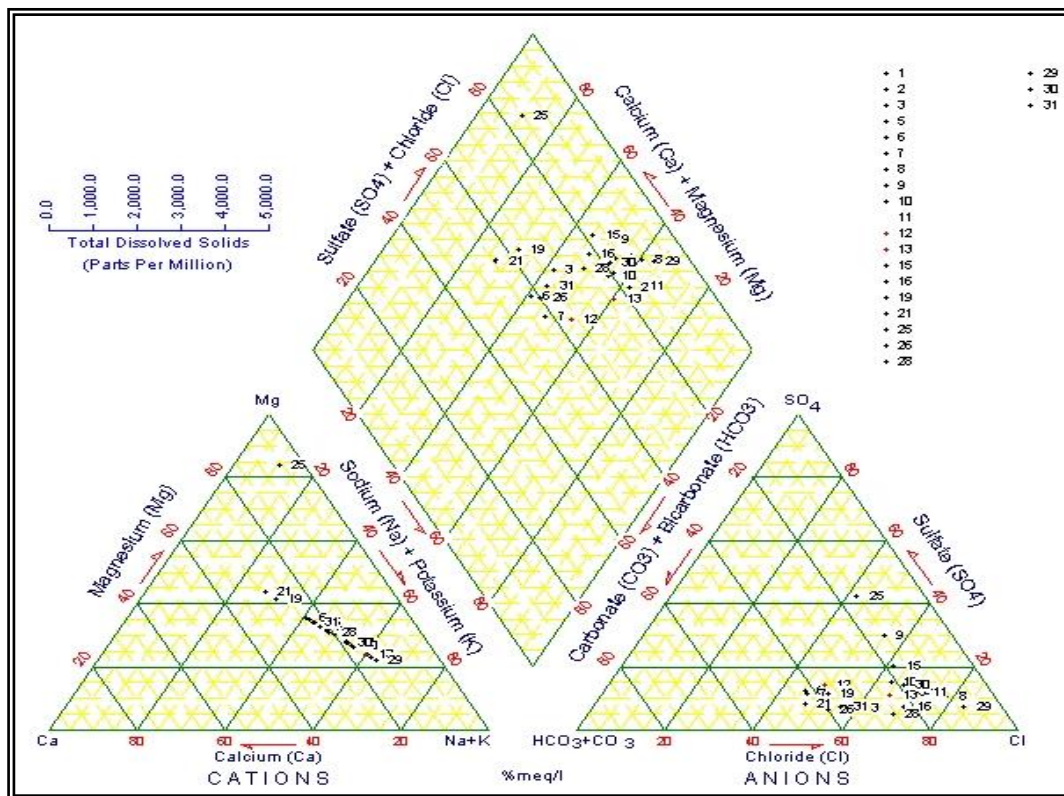
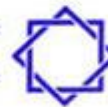


Fig. 6: Piper (Trilinear) Diagram presents the analysed water samples in the study area

Stiff diagram:

A second type of graphical presentation of chemical analyses is the Stiff pattern by (stiff, 1951) Data from the study area have been plotted in (Fig. 7) a polygonal shape is created from four parallel horizontal axes extending on either side of a vertical zero axes. Stiff Pattern is useful in making a rapid visual comparison between water from different sources. The larger the area of the polygonal shape, the greater the concentrations of various ions. The diagram has shown one type water which is NaCl



except for three locations, two of them are (W.1-Ardam and W-2-2106) showed MgCl and one location showed $\text{SO}_4\text{-Cl}$. The reason for that is the ion exchange between Na and Mg as result of the dissolution of dolomite, the 3rd is SO_4 that is due to the dissolution of the gypsum.

The following is the type of water resulted from Stiff Pattern, reference (location Map Fig3. and Table 2)

- Water samples of Sodium Chloride type are :-

W5, S5432, Khlij-3, W8206, H48, W432/2, Izz.cw, Fatayeh, Ayn Mugger, Martubah 2/A30, Martubah Spring, Ayn Bu Mansour, and W4.

- Water Samples of Sodium Bicarbonate type are :-

W3, ws206, Tunnel S1, W7206, W1 Ardam, W2-2106, and Ayn Blad

- Water Samples of Magnesium Sulfate :-

Only one sample is S1, in the area of Rammah north of Al Ezziat. Since all data of water samples in (Table 2) were represented and interpreted through three Stiff Diagrams. The result is showing in (Fig. 7).

Dissolution – precipitation:

The computer program called MINTEQA2 was used to calculate the thermodynamic properties of the ionic components of the water samples. The program calculate the saturation indices (SI) of all possible minerals by listing the percentage distribution of components among dissolved and absorbed species.



The recorded data in Table 2 show the saturation indices of water as calculated by MINTEQA2 program (Brown and Allison, 1987), for the selected minerals (Anhydrite, Aragonite, Calcite, dolomite and Gypsum). Further the concentration of carbonate was very low, and ranged from 0.1 to 0.15 mg/l. The concentration of bicarbonate was high, it ranges from 113 to 347 mg/l. It is clear that the main process in water quality is the mixing of water with in the aquifer and dissolution of carbonate minerals as the water moves in Karstified limestone.

Geochemical aspects

The groundwater chemistry as shown in Table 2, has been examined from both the total salinity and the ionic composition of dissolved solids Point of view. Naturally, the attention was focused on the main Eocene aquifer. The total salinity in the main aquifer in the western part of the study area shows a quite regular increasing trend from west to east and from north to south as shown in water quality map (Fig. 8) and (Table 2), in terms of electric conductivity. This increasing trend is particularly evident in the northwestern zone, where the control points are dense. Salinity ranges here from about 500 mg/l to 2000 mg/l. The salinity values along the sea coast, in view of the extreme variability due to local conditions, should be disregarded when examining the regional picture, extreme result which has been discarded was such our sample from the Meteorological Station near the coast at the eastern side of Darnah city, where the ground water exploited mainly from the shallow quaternary aquifer, and the well was drilled to 80m, and water was discharged from 20m below sea level, water in this level is already considered saline.

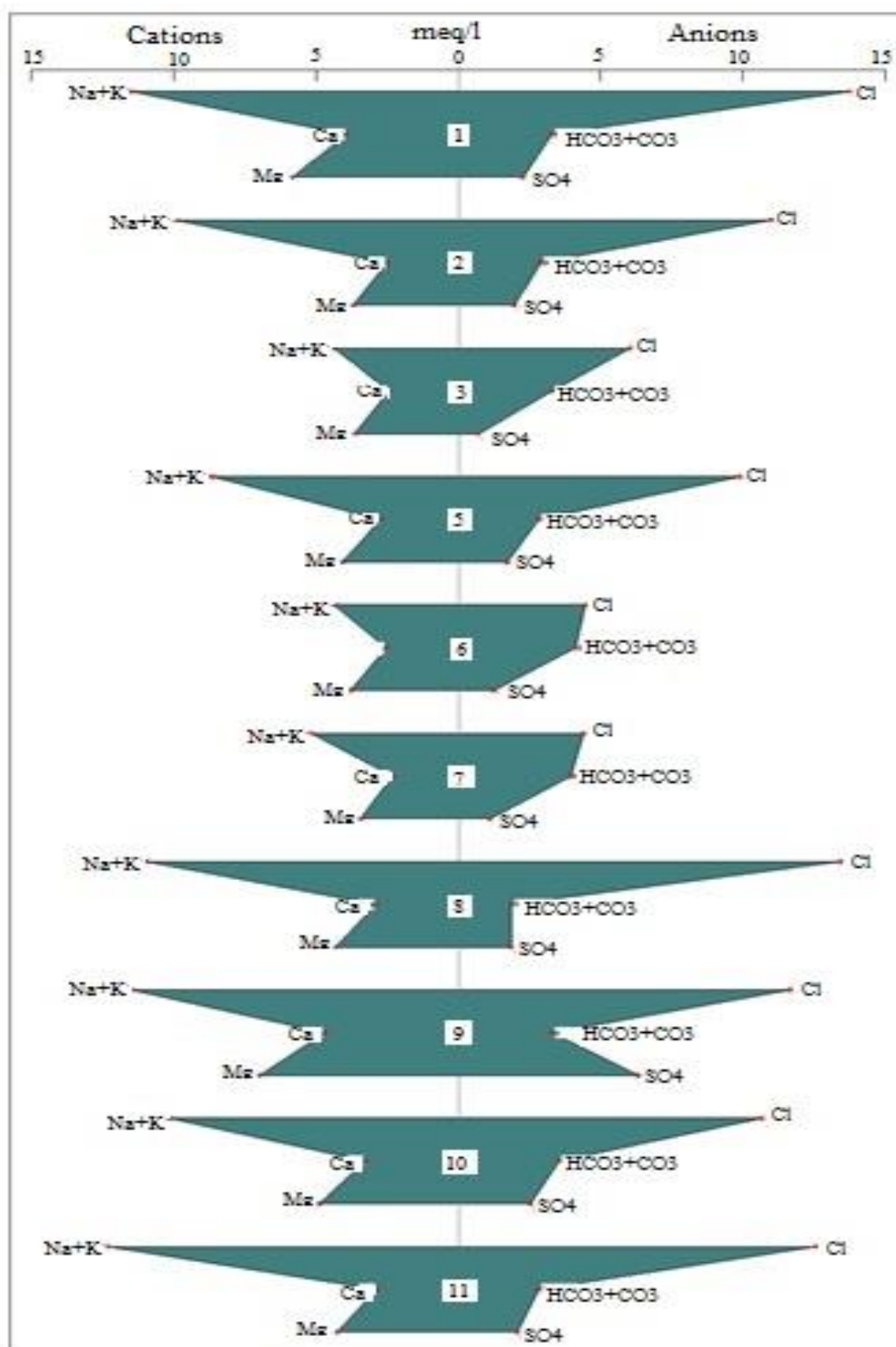


Fig. 7: Stiff diagram (For samples no. see Table 2)

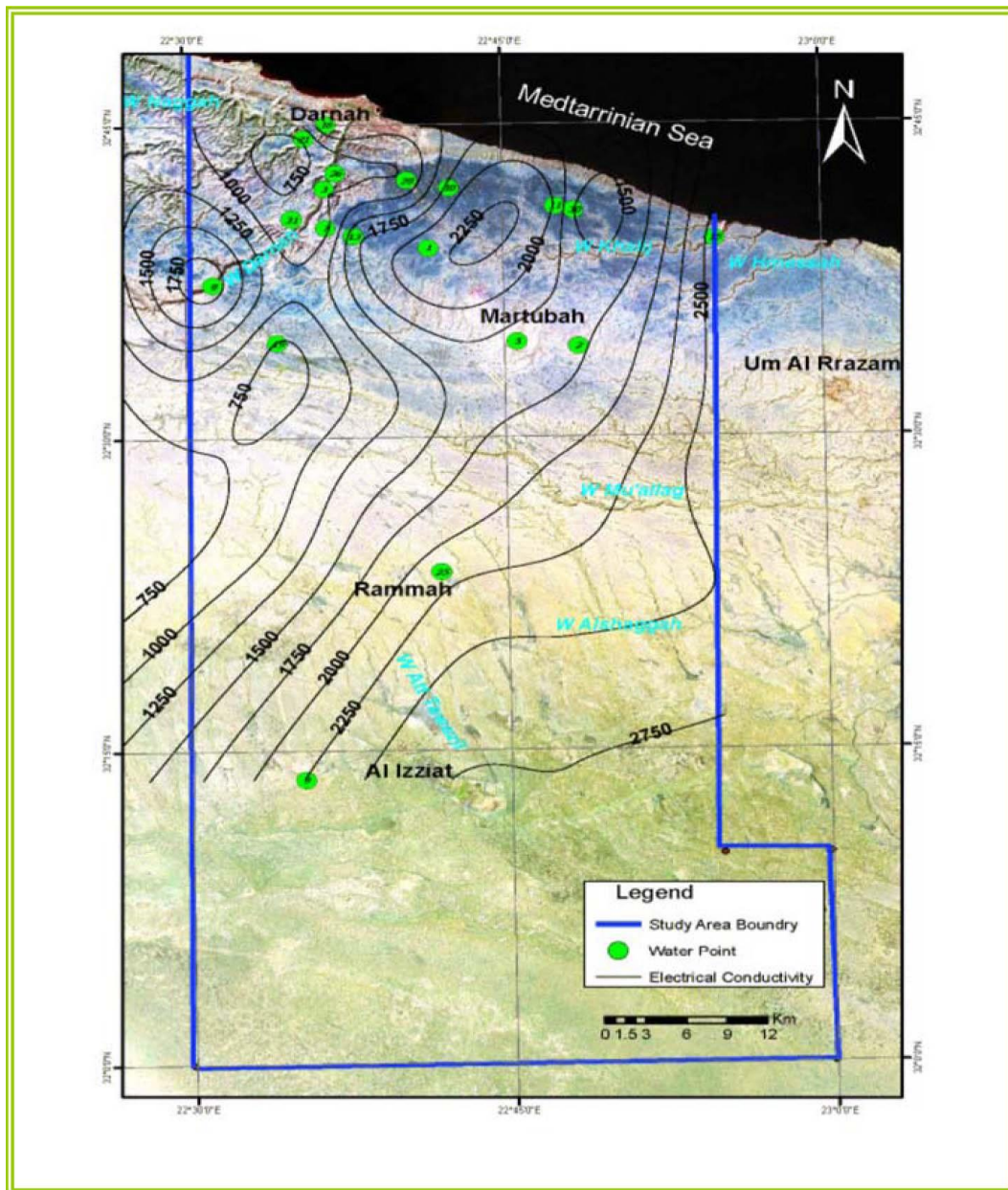
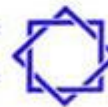


Fig. 8: Variation in Electrical Conductivity map, Darnah Region (Salem and Salloum, 2006)

To the south of the study area, as it can be deduced from the very few information available, groundwater salinity for a considerable distance is averaging around 1500 mg/l. Only further south, near Al Ezziat Village, there is a rapid increase in total salinity in the directions of both, south and eastward of the study area (Fig. 8). Due to lack of water points available in the area, only one sample was collected from the Camp well



of Al Ezziat, It is however, believed that this single value is not sufficient, and may be considered not representative to the huge area (south of the study area). From our results, In the eastern and southern parts of the study area, salinity in the main aquifer is generally high, and no regular trend of salinity variations can be recognized, however previous data, Franlab (1974) and Italconsult (1978), gave indications of very high salinity values, over 4000mg/l of ground water salinity was observed in wells from Al Kharuba to Al Tamimi in the east. with the exception of the spring water samples in the Wadi Darnah area, and Al Hishah (South west of Darnah), have the lowest salinity, water sample were mostly taken from drilled wells which penetrate for a considerable thickness of the Eocene aquifer. With the present information available, the matter of salinity variation with depth, the relationship is generally straight in the area east and south of the study area. Salinity increase is essentially due to the increase of chloride content, as shown in (Table 2), while sulphate salinity is only occasionally of relevant amount, the values from the samples of Al Rammah and Al Ezziat are examples.

low salinity values is encountered along the Escarpment, in the area west of Darnah ,while values from Al Fatayeh - Martubah line, of low salinities cannot be regarded as representative, since they refer to thin fresh water bodies floating on the underlying saline water in the Eocene Aquifer. The accumulation of fresh water can be considered due to local recharge from floods and/or rain water, through the locally Karstified, Al Faidiyah and Al Abraq Formations. The composition of the dissolved solids is quite variable. In view of the very variable total salinity, the matter of ionic composition has been examined with the aid of



milliequivalents percentages of the seven main ions (Ca, Mg, Na, K, HCO_3 , SO_4 , and Cl)

Utilization Aspect

The results of water analyses were examined also from the utilization point of view. As far as potable use is concerned, the waters below the total salinity of 1500 mg/l, which is considered by W.H.O (1984). The maximum permissible salinity, are suitable for this purpose. The groundwater in the south even with this total salinity value occasionally show a sulphate content in excess, of the maximum permissible limit of 400 mg/l. This may cause problems, in particular if the relatively high Mg content is also considered. NO_3 is usually present in groundwater. However, the amount rarely exceeds the 45 mg/l limit, considered by W.H.O. as a concentration potentially hazardous for infants. The high salinity waters encountered in the eastern part of the study area are interpreted as waters having a very long residence time in subsurface formations. This supposed long residence time is in accordance with the fairly flat piezometry and the probably poor recharge, due to relatively low rainfall surplus.

Considerations on Recharge

Several methods have been used to calculate the recharge in order to evaluate water balance, accordingly; evapotranspiration was calculated using Oliver, Blaney-Kriddle, Turc, Penman, Hassan and Thornthwaite in comparison with piche method. Since all these methods have advantages and disadvantages. However, Penmann (1948) found that his method is the most accurate and suitable for water balance calculations, which takes in consideration all climatic variability affecting rainfall. (Bukcheim,



1986). Had used penman's method, and found that the losses increase between March and November, this stimulate the soil to replenish and compensate moisture. Accordingly, the groundwater will be recharged by the rainfall during December which was found to be about 2% of the total annual rainfall in winter season, its maximum value reach in January about 8.9%.

Considering and comparing other locations of Libya with similar rainfall conditions, such as, Benghazi Plain, Al Jifarah Plain. Rainfall surplus values have been estimated for 18 stations for a number of years and these values were plotted against the respective values of annual rainfall (Fig.9), the scattered points on the graph indicate that the relationship between the two factors is quite irregular but there appears to be a general trend of rainfall surplus increasing with increase in the amount total rainfall. An annual rainfall of less than 175mm is likely to produce nil or very little surplus (Raju, 1980). So similar condition might exist in the Darnah region. However, trials been performed using another tool as the Isotope techniques for recharge analysis through water age dating. (Italconsult, 1978), had performed a sampling campaign of groundwater during 1977 for Tritium (^3H), Deuterium (^2H) and Oxygen (^{18}O). Eleven most representative groundwater samples were collected from Perched and the main aquifer at Darnah area. It can be concluded that Tritium was found in samples in Wadi Darnah, indicating recent water in the main aquifer, flood occurrence of Wadi Darnah was quite frequent, more recent water tend to accumulate in the upper part of the aquifer. The areas east of Wadi Darnah and Wadi Al Muallag show no Tritium content, indicating no contribution from rain water or local flood to the aquifer. The Tritium content from flood water can be expected only

in quite narrow strip along Wadi Darnah. The results show that the Tritium concentrations varied from 0.2 to 6 TU. From the higher ^3H values, it has been estimated that the proportion of modern water since 1963 could represent about 5 to 10% of the sampled water, the basis of this assumption has been the tritium concentration of 100 TU for the cumulative rainwater sample for the period 1963 to 1977. ^3H content below 1 TU in groundwater was considered as an indication of negligible content of modern water content. As the annual rainfall in the region varied from 79 to 277 mm, 5 to 10% recharge yields 4 to 27.7 mm to be the average value of groundwater recharge in Wadi Darnah.

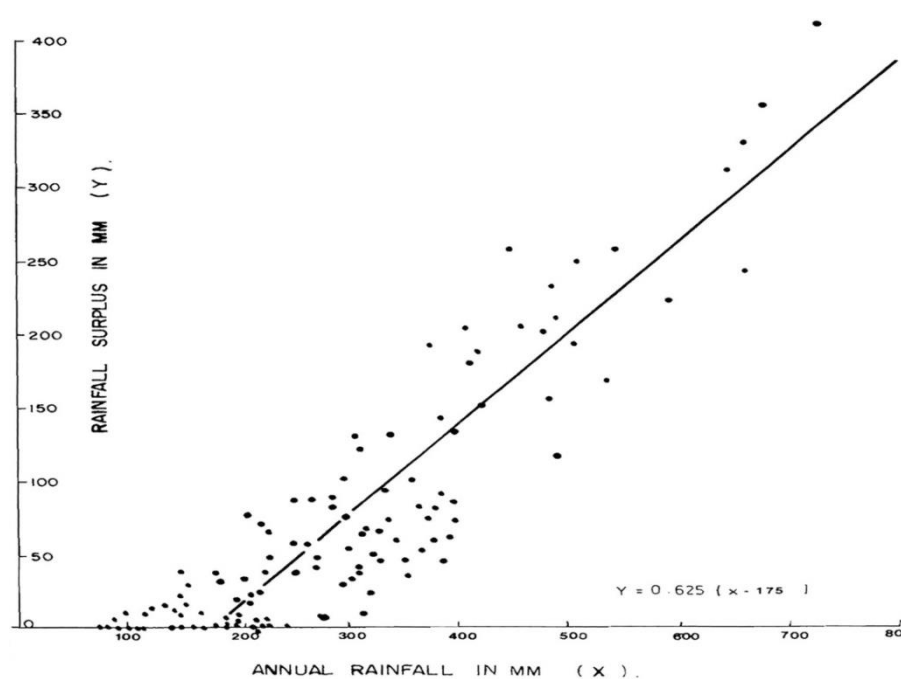


Fig. 9: Relationship of annual rainfall and rainfall surplus (Raju, 1980)



Bahadur et al., (1980) have summarized recharge evaluations which were recorded in NE Libya as a reference (Table 3). The results indicated that changes in hydrogeological situations, variability in precipitation and scanty knowledge about soil moisture in the unsaturated zone make it difficult to evaluate recharge to the groundwater. However, there have been some empirical approaches to estimate the recharge from climatic parameters in the region tabulated below.

Table 3: Average annual groundwater recharge in north Cyrenaica (Bahadur et al., 1980)

Source	Studied area	Recharge (mm/year)
GEFLI(1972)	Eastern region	19.9 – 49
Jaroslav Cerni (1973-74)	Goat Al Sultan	40 - 122
Franlab (1976)	Southern Al Jabal Al Akhdar	3.7 - 10.6
Italconsult (1977)	Bombah- Tobruk	4.0 – 27.7
Pallas (1978)	Eastern region	1 – 93
NCB (1979)	Benghazi region	38.6
Hydrogeo 1985	Al Baydah – Bayiadah	Un-measurable

However, the Hydrogeo (1992) have found that age value indicates the occurrence of modern water in the upper part of the main Eocene aquifer and that the whole groundwater system is active and recharged under the present climatic condition. An evaluation of the recharge is however, not possible with the isotopic data available, and above all because of the complex nature and the hydrogeological characteristics of the aquifer.



Conclusion:

Darnah region is characterized by moderate climatic conditions dominant year-around. Where the weather conditions are quite stable from year to year as the changes from one year to other is quite small. The region's climate has been classified as Semi-arid. As the area is located on the Mediterranean Sea from north and northeast on one side and high topography on the other, while it is open to the semi-desert topography from its southern direction.

Groundwater is confined to the limestone formations of the Eocene, Oligocene and Miocene ages, and aquifers are located underground Darnah main formation and Apollonia, including the flow of water through the springs of the Valley and the wadi Darnah and Al Athrun (Ayn Dabbusiah).

The groundwater level is shallow in Mechili area, water flowing towards south - south-east, the water quality is fair (medium quality), ranging from 1700 to 2500 Micro- mhos / cm .near the wellfields of Ezziat,

Buhindi and Al Thuban.

The rest of Southern Jabal Akhdar area, groundwater level ranges in depth water flowing towards the south and south-east, the quality ranging from 1000 to 7000 Micro-mhos / cm the shallow reservoirs represent Quaternary formations which is composed of beach rocks and sediments of streams and wadis deltas .Wadi Darnah is considered to be the most important shallow reservoirs, which were until recently the main source of permanent water in the region.



Groundwater flow is quite difficult since these areas are characterized by very uniform water levels near to sea level elevation, which result from the generally very scattered control points

The difference concentration of ions of water can be explained by mixing effect and mainly by the dissolution of the karst limestone as the groundwater moves within the aquifer. Water is classified as very hard

The main hydro-chemical processes in the study area is dissolution of Karst limestone, which involves ion exchange and dissolution of carbonate minerals especially gypsum and dolomite. Water quality (calcium bicarbonate to mixed bicarbonate chlorine) high rang exist from north-western region, to the north and in the east Martubah to Al Bombah, it get more saline towards the south. The water samples collected for hydro chemical analysis were sufficient for a detailed evaluation, and was reasonable, and geographically distributed within the study area. The newly performed analyses show a reasonable agreement with the previous data whenever cross-checking was possible, the water quality trend is matching closely to the groundwater flow direction.

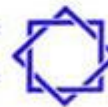
Several methods have been used to calculate the recharge, almost all methods have advantages and disadvantages, however, from experience, Penman method is the most accurate and suitable for water balance calculations, which takes in consideration all climatic variability affecting rainfall, there still more efforts should be implemented to evaluate the water resources in the area with respect to the rapid growth of population and the capability of the resources. No long monitoring records in any groundwater and hydrological studies been performed, this leads to



question reliability of data use in some aspects which deals with water resources management and Planning.

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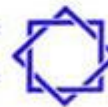


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تقييم الهيدروجيولوجيا والهيدروكيميا في طبقات المياه الجوفية لعصر الايوسين في منطقة درنة

فتحي محمد سلوم*

الملخص

الهدف من هذه الورقة هو تقييم الهيدروجيولوجيا والهيدروكيميا في خزان المياه الجوفية الرئيسي في منطقة درنة ، بتكوينات الايوسين (ابولونيا ودرنة) وهذه التكوينات تتكشف اساسا في وسط الشمال الغربي ، وتتكون من الحجر الجيري و الحجر الجيري الاحفورية . الوحدات الصخرية للخزان المعلق المعروف بخزان البيضاء و الابرق (تكوينات الاوليوسين و المايوسين) ، التي تطفوا فوق خزانات المياه الجوفية الرئيسية تساهم جزئيا في توفير الموارد المائية بشرق المنطقة بمرتوبة ويغطي طبقات النيوجين (تكوين الفايديّة) غالبية الجزء الجنوبي من منطقة الدراسة .

هناك عدد كبير من التحاليل الكيميائية من الدراسات الاستشارية السابق في منطقة درنة تم استعراضها و تحليلها .

بالإضافة فقد تم جمع مزيد من العينات من مناطق مختلفة خلال فترة الدراسة الحقية بشهر يونيو 2006 ، بعض هذه العينات تم تجميعها من الابار التي يتم ضخها او من بعض العيون التي تتدفق طبيعيا و خاصة بوسط وادي درنة ، تم دراسة هذه التحاليل الكيميائية ومضاهاتها ، حيث تبين اتفاق نتائج هذه العينات مع نتائج بيانات سابقة . درجة ملوحة المياه الجوفية بالخزان الرئيسي في الجزء الغربي من منطقة الدراسة اظهرت زيادة طبيعية في الاتجاه من الغرب الى الشرق ومن الشمال الى الجنوب ، كما تم مضاهاة نوعية المياه مع اتجاهات سريان المياه الجوفية . وقد اجرى العديد من التجارب لتقدير تغذية طبقات المياه الجوفية في المنطقة . تم البحث احصائيا بمناخ منطقة الدراسة من اجل فهم التعرف على المناخ و البيئة وكذلك تصنيف نطاق الطقس العلاقة الارتباط مع تقدير خصائص طبقات المياه الجوفية هناك محاولات و استعمال طرق مختلفة لتقدير مدى استجابة الخزانات للتغذية و اعادة الشحن و التوازن المائي ، هذه المعايير مهمة لإدارة موارد المياه على المدى الطويل لمنطقة درنة ، تمت مناقشة الموارد المائية ، وتقييم تصريف مياه العيون او الينابيع خلال العقود الماضية في المجرى العلوي لوادي درنة .

* جامعة بنغازي – قسم علوم الارض