Simulation of Seawater Intrusion in Libya

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Libya is one of the Southern Mediterranean countries with a shoreline extent of 1900 km where the coastal aquifers are under seawater intrusion risk. The fertile lands of the Gefara plain in the northwest and Jabal Al Akhder in the northeast include more than 80 % of the agricultural activity that entirely depends on rainfall and the groundwater. In recent years, the risk of seawater intrusion is continually threatening coastal part of the Gefara plain that forms one of the most economically significant area in the country.

The potential problem is investigated thoroughly and present position of the seawater intrusion is clearly defined. At present seawater intrusion covers an area of about 250 km2 and is going to extend in the coastal area of the Tripoli region. In order to assess impact of the existing or proposed human activities on the seawater intrusion, this research has been initiated to simulate the problem in the area. A two-dimensional, areal, fully-coupled finite element model is introduced to simulate the flow of freshwater and the diffusion of salt concentration.

Introduction

Due to its semi-desertic climate groundwater is the main source for potable, industrial and irrigation water in Libya. Inevitably, groundwater extraction has been in excess of replenishment due to rapid increase in agricultural and economical activities in the last twenty-five years. This has resulted water level declines and quality deterioration including invasion of seawater along the coastal regions.

It is claimed that seawater contamination in Libya dates back to 1930s after construction of the Salt Canal by Italian occupation. Cedestrom and Bastaiola (1960) were the first researchers who studied water resources in Tripoli area and they stated that saltwater intrusion affected groundwater resources near the Salt Canal constructed by Italian occupation. Later several studies have been performed in order to investigate seawater intrusion in Libya. Kruseman and Floegel (1978) concluded that in the first few kilometers along the coast, the extracted groundwater was partially replaced by intruding seawater. Floegel (1979) conducted a seawater intrusion study along the Gefara coast from Zuarah in the west to Khoms in the east. He collected hydrochemical data along fourteen N-S profiles and defined the intruding wedge and the diffused zone in each profile. Five of the profiles were located in the Tripoli area where the maximum contamination was observed at that time. Meludi and Werynski (1980) studied the seawater intrusion problem in Gargaresh-Swani Well Field, which was considered as a source of water supply to the Tripoli area City since 1976. It was concluded that seawater intrusion into the area progressed and it was accelerated by overpumping of groundwater especially at the well field. Krummenacher (1982) included setting up and operation of a digital simulation model as a part of Gefara Plain Water Management Plan Project undertaken by FAO. The model was based on the Thyson-Weber finite difference method for two-dimensional version of the Laplace's equation. Water quality simulations were incorporated into the model, while the dispersion and molecular diffusion were ignored. The model was used to predict future groundwater levels and water quality distribution in Jefara Plain. Backush (1983) applied a 3-D Trescott model to simulate the aquifer system in Gefara plain for both the steady-state and the transient conditions. He proposed a well field to minimize the saltwater intrusion rate into the upper aquifer. He concluded that maximum drawdown occurs in the middle of the simulated area while the minimum lies towards the shoreline and by this design optimum amount of freshwater may be pumped from the aquifer with minimum saltwater intrusion. Bilal (1987) studied the seawater intrusion in Zanzur area, which is located 10 km west of Tripoli City, and used 23 wells for sampling. As a result of his analysis he concluded that the pumping wells used for industry and domestic uses, were the main causes for seawater intrusion into the area.

Shawi and Philbert (1991) concerned only with the upper aquifer in the Tajura area, located 10 km east of the Tripoli City. He collected 123 water samples and he pointed out that increased water demands for social, agricultural and industrial developments made the seawater intrusion to go farther inland in 1990s than in 1980s.

Upon consideration of these studies a research has been initiated to investigate the seawater intrusion in the Gefara plain, where the seawater contamination is more affective as compared to the other regions in Libya. The study area is located in the north central part of the Gefara Plain and it includes the city of Tripoli (Fig. 1). A finite element model is formulated to simulate the flow and seawater intrusion mechanisms in the area and try to propose optimal management strategies to reduce the rate of seawater intrusion.

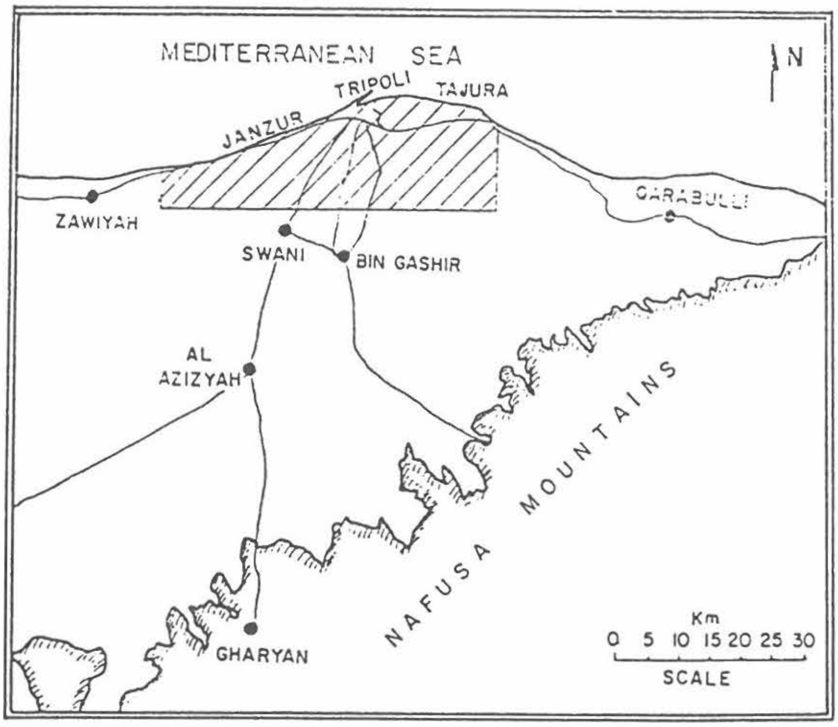


Fig. 1. Location Map of the Study area.

Geological Setting

Gefara Plain forms a flat topography and consists of three parts that are covered by Quaternary deposits. Calcarenites, covered by coastal sandstones and the brown silts of the Gefara Formation form the Coastal strip. Central part of the Gefara Plain stretches from the south end of the coastal strip (10-20 km) to a distance ranging between 60-90 km. Topographic elevation rises gradually toward south and reaches 130 m above mean sea level at the south end. Some of the seasonal streams flow over this region and drain the plateau and they fan out before reaching the sea. Other streams have longer courses and deepen their channels over the plain surface forming Wadis as Wadi Al Majinin, Wadi Ghan and Wadi Zarat. The Central part of the plain is covered mainly by poorly consolidated eolian deposits mixed with brownish silt of the Gefara Formation. The southern border of the Central part interlocks with the Foot Hill strip that is made of fluvial and proluvial coarser sediments. Topography continues to rise in this section and it reaches to elevation of 200 m at the south end of the plain.

Gefara Plain consists of Late Tertiary to Quaternary strata resting on a faulted and tilted Mesozoic basement. Aziziyah fault separates the main Miocene-Quaternary unconfined aquifer from a thin layer of Quaternary aeolian and wadi deposits in the south. The Ouled Chebbi formation (Permian-Triassic) is the oldest unit in the Gefara plain and is encountered in a few deep groundwater wells in the southern part of the plain. It contains cemented, red, sometimes conglomeratic sandstones with a low permeability at the base and a series of red clays with a few sandstone and dolomitic interbeds at the top. The Ras Hamia formation (Triassic) is known as underlying the whole Gefara plain and its thickness varies in the range of 450-600 m. Ras Hamia formation consists mainly of green, red and black sandy clays and shales with intercalations of red and green, often clayey sandstones. In the study area the formation slopes down to depths far in excess of 1000 m. Aziziyah formation (Fig. 2) consists of dolomitic limestone and limestone and it is present throughout the Gefara plain especially in the western and north central parts. In the area north of Aziziyah fault

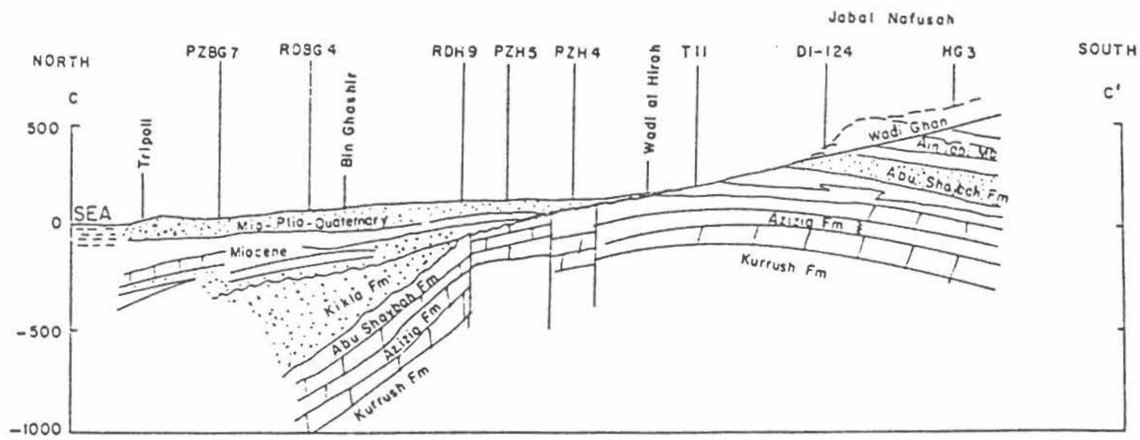


Fig. 2. A Schematic cross section through Gefara plain (Pallas, 1978).

it dips to great depth and reaches to 900 m in the coastal area. Abu Shaybah formation overlies the Aziziyah formation and it is widely distributed over the Gefara plain. It consists of cross bedded sandstone alternating with green and red bands of clays. The Upper Jurassic deposits in the area are represented by the Tokbal, Jawsh and Shakshak formations. They generally consist of sandstones, claystones and dolomites interbedded with black clays and claystones. Kikla and Kabao formations form the Lower Cretaceous units and they consist of light colored, cross bedded, friable quartz sandstone and conglomerates with brown, yellow and red silt and clay intercalations. The Upper Cretaceous formations (Ain Tobi limestone, Yefrin marls and Gharian limestone) form most of the Nafusa escarpment in the south border of the Gefara plain. The Miocene formations are found everywhere in the central and eastern part of the Gefara plain and they cover about two thirds of the northern part. The Quaternary-Miocene series consists of argillaceous sandstone with anhydrite subdivided by clay lens and reaches its greatest thickness in the Tripoli area. Miocene-Pliocene-Quaternary Complex forms the top most series in the northern part of the Gefara plain. This unit consists of fossiliferous detrital limestone and marl formations alternating with yellow clay and sand lenses. The total thickness varies from 40 to 150 m. The Quaternary deposits cover the major part of the Gefara Plain as well as the plateau surface. The Gefara formation consists mainly of fine materials mostly silt and sand occasionally with gravel and caliche bands. In the study area the Gargaresh formation makes steep cliffs along the shore of the Mediterranean Sea. This formation is made up of calcarenite, including shell fragments and minor sand grains, interbedded with silt lenses. The sand dunes and sheets which cover large areas in the region represent the Eolian deposits in the Gefara plain (IRC, 1975; Kruseman, 1977; Krummenacher, 1982).

Hydrogeology

Geology of the area comprises a number of aquifers in the Gefara plain. They are separated by more or less impermeable clay lenses in the north, however they define a single large unconfined aquifer in the inland portion of the plain. The upper aquifer (Quaternary-Miocene-Pliocene) collects water under unconfined conditions and extends throughout the Gefara plain. It is 100-150 m thick and contains good quality water in the central and eastern parts. Along the coastal regions water quality becomes poor where overpumping has led to seawater intrusion. Middle-Miocene aquifer is well developed in the western part of the Gefara plain and it is found 70-120 m below the surface. Thickness of the aquifer varies in the range from 125 to 200 m. Clay layers separate the aquifer from the Quaternary and the Lower Miocene aquifers. The Lower Miocene aquifer consists of sandy limestone and it overlies the sandy facies of the Upper Abu Shaybah formation. Abu Shaybah sandstone aquifer is found in the northern parts, where the Abu Shaybah sandstone is overlain by Miocene units. The aquifer is thought to be hydraulically connected with the Lower Miocene aquifer. The Aziziyah limestone aquifer is found in the north of the Al Aziziyah fault however because of its dip the aquifer formation reaches to a depth of 900 m. in Ayn Zara, southeast of Tripoli. These aquifers show different conduit and storage properties. Table 1 shows the aquifer system parameters as well as the average well yields and the total dissolved solid (TDS) values.

Table 1. Aquifer system parameters (after NCB&MM, 1993).

Group	Formation	Well Yield (m3/hr)	Transmi-ssivity (m2/d)	Storage Coefficient	TDS (mg/l)
Quaternary - Miocene	Gargaresh, Jefara, Qasr Al Haj	15 to 30	20 to 700	4 to 10 %	500 to 2000
Oligocene - Miocene	Al Khums	15 to 70	up to 300	confined	1500 to 3500
Cretaceous / Upper Jurassic	Sidi as Sid Kikla	40 to 90	up to 520	Unconfined Mainly confined	1000 to 1500
Middle Jurassic	Tokbal	< 15	Very variable	-	-
Triassic	Abu Shaybah	about 30	4 to 1555	Confined	-
	Al Aziziyah	30 to 110	up to 450	1 to 5 % confined	1000 to 3000 2000 to 10000
	Kurrush	2 to 10	about 60	Confined	
	Ouled Chebbi	2 to 10	-	Confined	-

The aquifer system in the Gefara Plain is thought to be majorly recharged from precipitation, infiltration from surface runoff, and by inflow from the south (Pallas, 1978; Krummenacher, 1982). In addition to these components NCB and MM (1993) consider the recharge by irrigation returns and by municipal supply losses. The main discharge of the groundwater from the aquifer system in the Gefara plain is by water abstraction by pumping for the irrigation and the domestic purposes.

Seawater Contamination in NW Libya

Cedestrom and Bastaiola (1960) performed a research in the region to quantify the problem of seawater contamination. Their observations for 1957 showed that some of the water wells near the coast started to be contaminated by seawater at that time (Fig. 3). Gefli (1972) obtained a similar distribution for Chloride concentration for 1972, where a slight change can be detected for landward

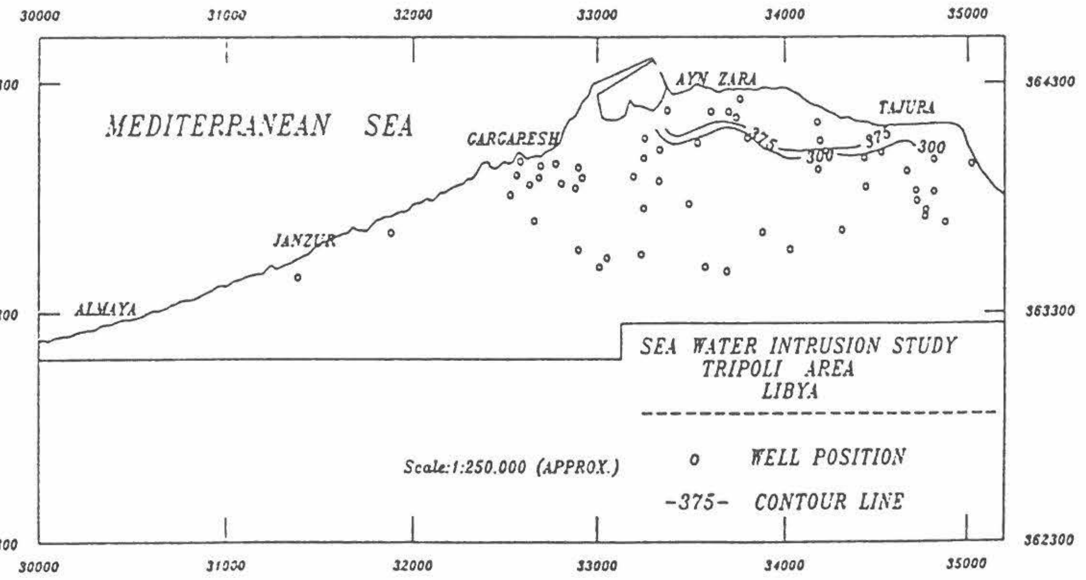


Fig. 3. Chloride concentrations in 1957 (after Cederstrom & Bastaiola, 1960).

movement of the chlorine contours. In recent years, high rate of urbanization and increased agricultural and economical activities have required more water to be pumped from the aquifer. This has continually increased the risk of seawater intrusion and deteriorated the quality of freshwater in the Gefara plain. Observations during this research in 1994 show that 375 mg/l chlorine contour has migrated inland reaching to distances of 10 km from the coast in Gargaresh and Ayn Zara regions (Fig. 4).

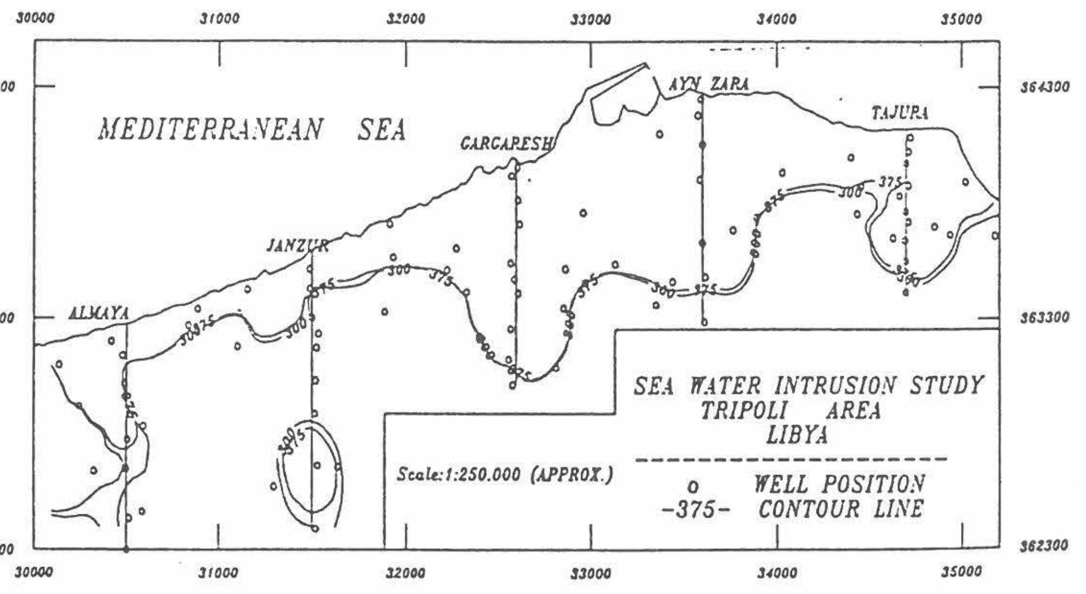
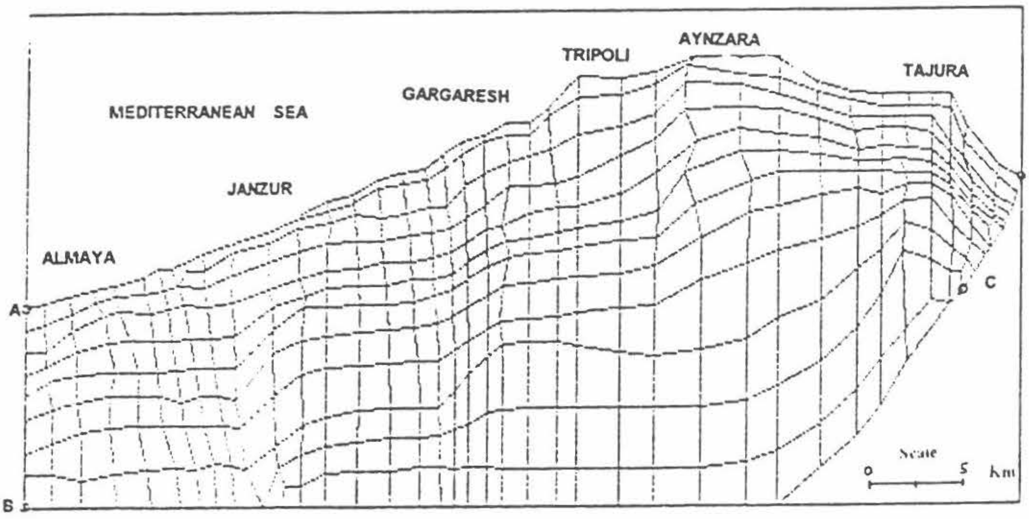


Fig. 4. Chloride concentrations in 1994.

This rapid increase in the seawater intrusion necessitates detailed investigation of the intrusion mechanism for optimum use of the fresh water in the area. For this purpose a finite element model is formed to simulate freshwater flow and salt concentration diffusion in the Quaternary aquifer system. The study area is discretized by means of 4-nodal rectangular elements and a finite element mesh, with 398 elements and 444 nodes, has been constructed (Fig. 5). In the analysis an areal model is



(Boundary A - B and C - D are no flow , Boundary B - C Constant Recharge, Boundary A -D Constant Head)

Fig. 5. Finite element mesh and the Boundary conditions.

formulated in order to study the flow and diffusion mechanisms over an areal surface and SUTRA program has been applied for the computer solutions (Voss, 1984). The model was calibrated for the flow equation under steady-state conditions and the hydraulic conductivity values were determined. Along the boundaries, constant-head (sea boundary), no-flow (western and eastern boundaries) and constant-recharge (for the southern inflow) boundary conditions were applied. During calibration runs computed water table values were compared with 1957 observed heads and the procedure was repeated until a minimum squared deviation was obtained. A sensitivity analysis was carried out to test the model against hydraulic conductivity variation. It has been found that the model is more sensitive to lower values of the hydraulic conductivity than the higher values. Squared deviations between the computed and observed heads increase exponentially upon reduction of the hydraulic conductivity values, whereas they follow a smooth increasing behaviour for the higher conductivities.

Modeling studies continue progressively to perform history matching the water level elevations for 1972 and 1994 observations. This step would be followed by solution of the diffusion equation for the calibration of the diffusion parameters. Then the equation system will be solved in a coupled manner for the water levels and the concentration distributions in order to simulate the intrusion mechanism in the area.

Conclusions

This paper presents a research to investigate the problem of seawater intrusion in Gefara plain, NW Libya. The problem has been clearly defined and a method has been introduced to model the seawater contamination in the region. Following conclusions can be withdrawn from the analysis:

- Groundwater is the main source for domestic, agricultural and industrial use in the Gefara plain, where recharge is limited. Previous investigations reveal that seawater contamination has started in 1950s and its migration rate has increased with time under continual risk of seawater intrusion.

- Groundwater is discharged from the aquifer by means of water wells distributed all over the area. In order to reduce migration rate of the intrusion new management policies should be planned for optimal use of the freshwater in the aquifer.

- Intrusion mechanism can be investigated by means of a numerical method in order to clarify the problem in the Gefara plain. Proposed finite element model and the boundary conditions are found to be appropriate for the study area and the model will be successful in making predictions for future behaviour of the intrusion.

REFERENCES

BACKUSH, I.M.,1983: A quantitative model of Gefara plain central part NW Libya. - M.Sc. Thesis, Ohio University, 125 pp. Ohio.

BILAL, W.M., 1987, Seawater intrusion in Janzur. - B.Sc. Thesis, El Fateh University, 35 pp. Tripoli.

CEDESTROM, D.,& BASTAIOLA, H., 1960, Groundwater in the Tripoli area, Libya. - USGS Open File Report.

FLOEGEL, H., 1979, Seawater intrusion study - SARLD Report, 57 pp. Tripoli.

GEFLI, 1972, Soil and water resources survey for hydro-agricultural development, Western Zone - Unpublished Report, GWA. Tripoli.

IRC, 1975, Geological map of Libya, 1:250 000 Sheet Tarabulus, Explanatary Booklet - Industrial Research Center. Tripoli.

KRUMMENACHER, R., 1982, Report on Groundwater Resources of Gefara Plain. - SARLD Report, 110 pp Tripoli.

KRUSEMAN, G.P., 1977, Evaluation of water resources of the Gefara plain.- SDWR Unpublished Report, 20 pp. Tripoli.

KRUSEMAN, G.P., & FLOEGEL, H., 1978, Hydrogeology of the Gefara plain, NW Libya. - 2nd Symposium Geology of Libya. Tripoli.

MELUDI, H., & WERYNSKI, K., 1980, Seawater intrusion study, Gargaresh Swani Well Field area.- SARLD Report, 7 pp. Tripoli.

NCB & MM, 1993, Water management plan. - Great Man Made River Water Utilization Authority by the National Consulting Bureau of GSPLAJ with Mott MacDonald of the UK, 3 volumes. Tripoli.

PALLAS, P., 1978, Water resources of the SPLAJ, - SDWR, 80 pp. Tripoli.

SHAWI, T., & PHILBERT, M., 1991, A study of seawater intrusion in Tajura groundwater.- B.Sc Project, El Fateh University, 58 pp. Tripoli.

VOSS, C.I.,1984, SUTRA: A finite element simulation model for saturated-unsaturated, fluid density dependent ground-water flow with energy transport or chemically reactive single species solute transport. - U.S. Geological Survey Water-Resources Investigations Report 84-4369, 409 pp. Reston.