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INTEGRATED MANAGEMENT OF THE PLEISTOCENE AQUIFER IN BORG EL ARAB, WEST ALEXANDRIA, EGYPT

BY

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ABSTRACT

The Borg El Arab area is suffering from a remarkable rise in groundwater levels (water logging) that has caused a significant deterioration of agricultural lands. The main objective of the present work is to understand and solve this phenomenon of water logging through the calculation water budget to determine the external hydrological stresses that lead to this problem and to avoid it in the future. Canal seepage was estimated according to the Moritz formula and the equation of FAO/UNESCO. In addition to the application of the of Chatterjee and Ray's equation to calculate the recharge of aquifer from the rainfall. The evaporation rate was calculated by using the Penman formula. The obtained results the main aquifer in Borg El Arab area consists of consolidated detrital oolitic limestone (Pleistocene) in the coastal areas and Pleistocene clastic sediments in the Abu Mina basin area. The water budget indicates that the total amount of inflow components equals about 54.37 million m3/year, while the total amount of outflow components equals about 22.13 million m3/year. The amount of storage in groundwater equals about 32.24 million m3/year, which means that there is a rise in groundwater levels in the Pleistocene aquifer in the study area. The use of a water budget is an important mean of knowing the external hydrological conditions affecting the aquifer. The results show that the amount of recharged water exceeds the discharged once by 32.24 million m3/year, consequently the increasing of the water level leads the phenomenon of the water logging in the Borg El Arab.

Key Words: Water budget, Water logging, Recharge, Borg El Arab, and West Alexandria

INTRODUCTION

Salinization of the coastal aquifer in the Nile Delta's northwestern zone is caused by a combination of processes including both seawater intrusion and water-rock interaction, as well as over pumping from the groundwater aquifer, which can harm water quality by speeding up seawater intrusion. To prevent further groundwater deterioration, a balance is required between using surface water from Nile-derived channels and local groundwater (Sharaky et al., 2019).

The hydrogeological framework of Egypt includes the following hydrogeological units: the Nile aquifer, the coastal aquifer, the Moghra aquifer, Aquiclude, the Nubian aquifer, and the Basement (fissured basement complex aquifer) (Sharaky et al., 2021) (Fig. 1).

The continuous rise in water level in the aquifer at various rates is extremely noticeable, implying that lateral water movement from south to north is more rapid than vertical water movement from direct percolated water (Morad and Abdel Latif, 2017).

The source and amount of recharge, type of sediment, and groundwater flow are mainly affecting the geochemical characteristics of the Quaternary aquifer in Burg El Arab area. The Quaternary groundwater is mainly fairly fresh to saline in character, with TDS ranging from 1562 to 8813 mg/l (Embaby and Shanab, 2012).

The subsurface is compounding of five geoelectrical layers with a gentle general slope toward the Mediterranean Sea. The third and the fourth layers in the succession were suggested to be the two water bearing formations of which the third layer is saturated with fresh water overlying saline water at the bottom of the fourth one. The fresh water depth varies between 50 and 354 m under the ground surface. The thickness of the fresh water aquifer varies from 9.5 to 66 m; and the saline water depth varies between 116 and 384 m below the ground surface, the thickness of saline water aquifer differs from 34 to 90.5 m (Alhussein et al., 2014).

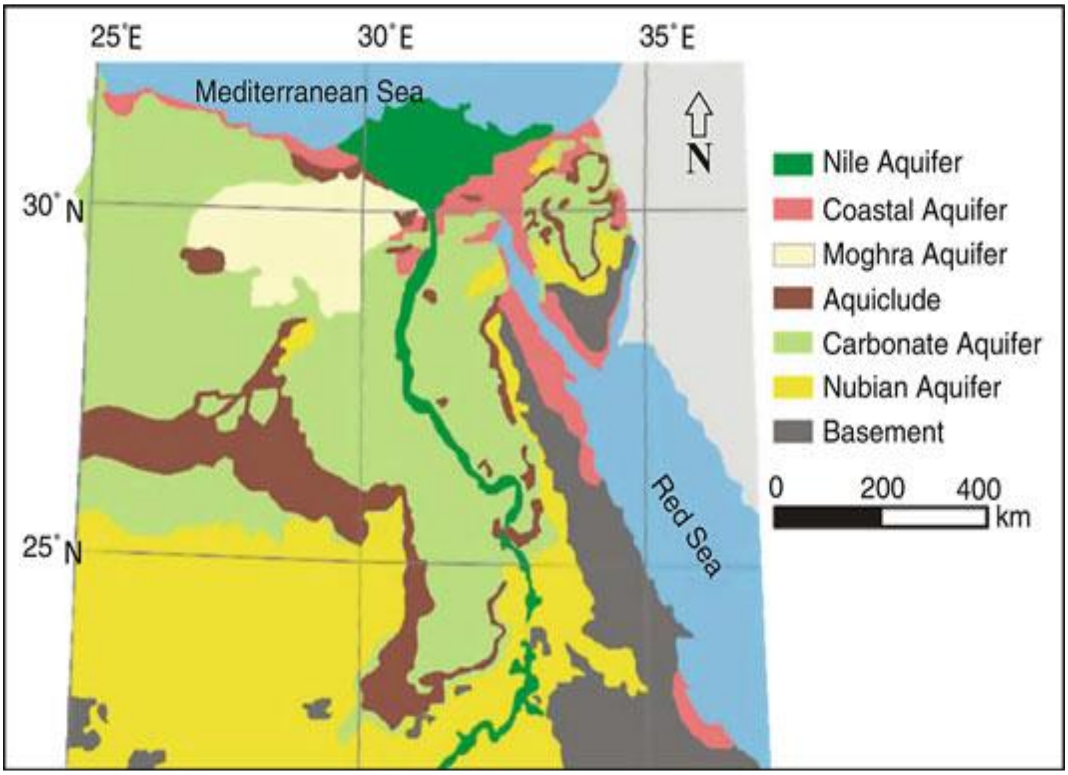


Fig. 1: Distribution map of major groundwater aquifers in Egypt (RIGW, 1998).

A rise in groundwater levels has been detected in Borg El Arab area (water logging), causing widespread soil flooding. As a result, salt lands, ponds, and soil degradation are evident phenomena in the studied area (Fig. 2). The main purpose of this paper is to determine the external hydrological stresses impacting the Pleistocene aquifer using the water budget.

The studied area is located along northwestern coastal zone of Egypt (Fig. 3). It is bounded by longitudes of 29° 18' and 29° 40' E, and latitudes of 30° 43' and 30° 57' N. It covers an area of about 610 km2. The average annual rainfall ranges from 146 to 152 mm, and the average annual evaporation rate ranges from 2050 to 2250 mm.

Sedimentary rocks from the Holocene, Pleistocene, and Late Neogene periods cover the majority of the studied region. On the other hand, the depression areas may be predominantly occupied by alluvial deposits and sand dune accumlations. The sediments of the Pleistocene can be divided into two units. The first is oolitic limestone, which has a wide exposure along the Mediterranean Sea's coastal strip. The second unit (40 m thick) is made up of fluviomarine facies of sands, clays, and gypsiferous clays and is mostly found in the Abu-Mina basin (Mohamed et al., 1979). The Pliocene sediments are not visible on the surface. They underlies the oolitic calcareous bars of the Pleistocene sediments in the coastal zone and is overlain by clastic sediments of the Pleistocene age in the Abu

Fig. (2): Salty lands and ponds as an environmental degradation that is common phenomenon in Borg El Arab area.

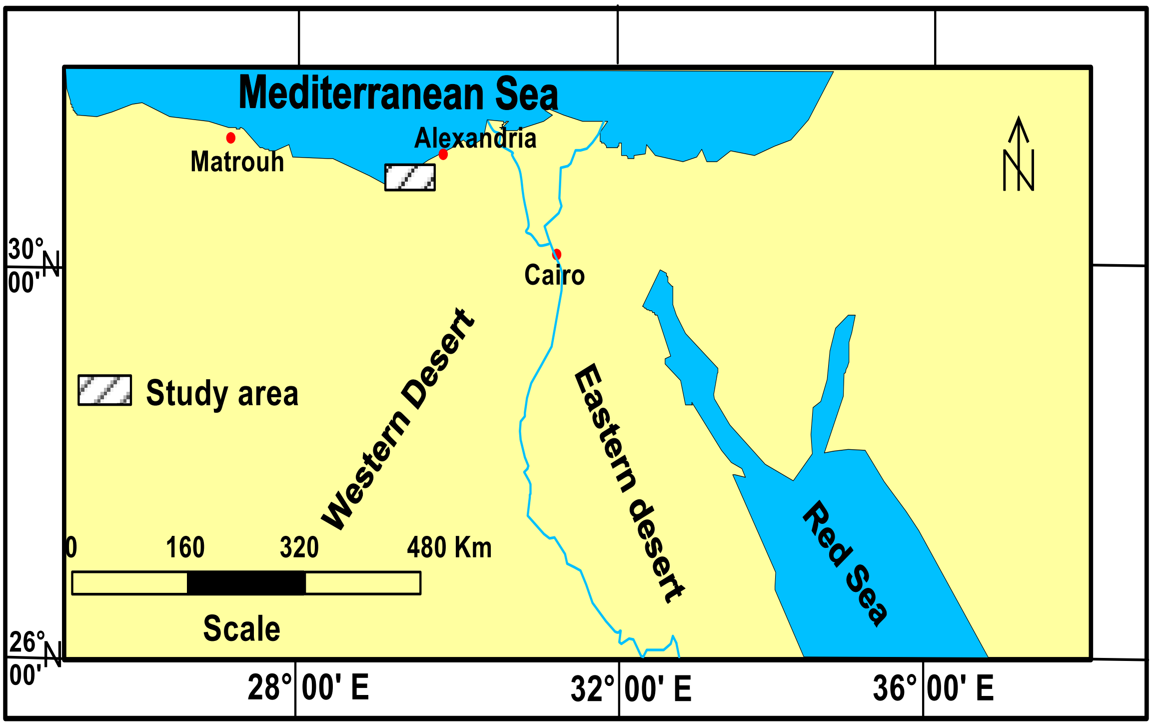


Fig. (3): Location map of Borg El Arab area, West Alexandria, Egypt.

Mina basin. The main aquifer units in the coastal zone areas are consolidated detrital oolitic limestone (Pleistocene) and Pleistocene clastic deposits in the Abu Mina basin area (Atwia et al., 2013).

ELEMENTS OF THE WATER BUDGET

Inflow components

1-Canal seepage

Canal seepage is one of the important factors in the management of water resources that represents the major part of water losses from canals, causing a rise in shallow groundwater levels (Omar, 2017).

Figs. 4 and 5 represent the relationship between the surface water and the groundwater in the studied area. Different sections are plotted along the longitude of El Hammam canal (H1, H2, H3, and H4) and El Nasr canal (N1, N2, and N3). These sections represent seepage into the groundwater aquifer from the El Hammam and El Nasr canals.

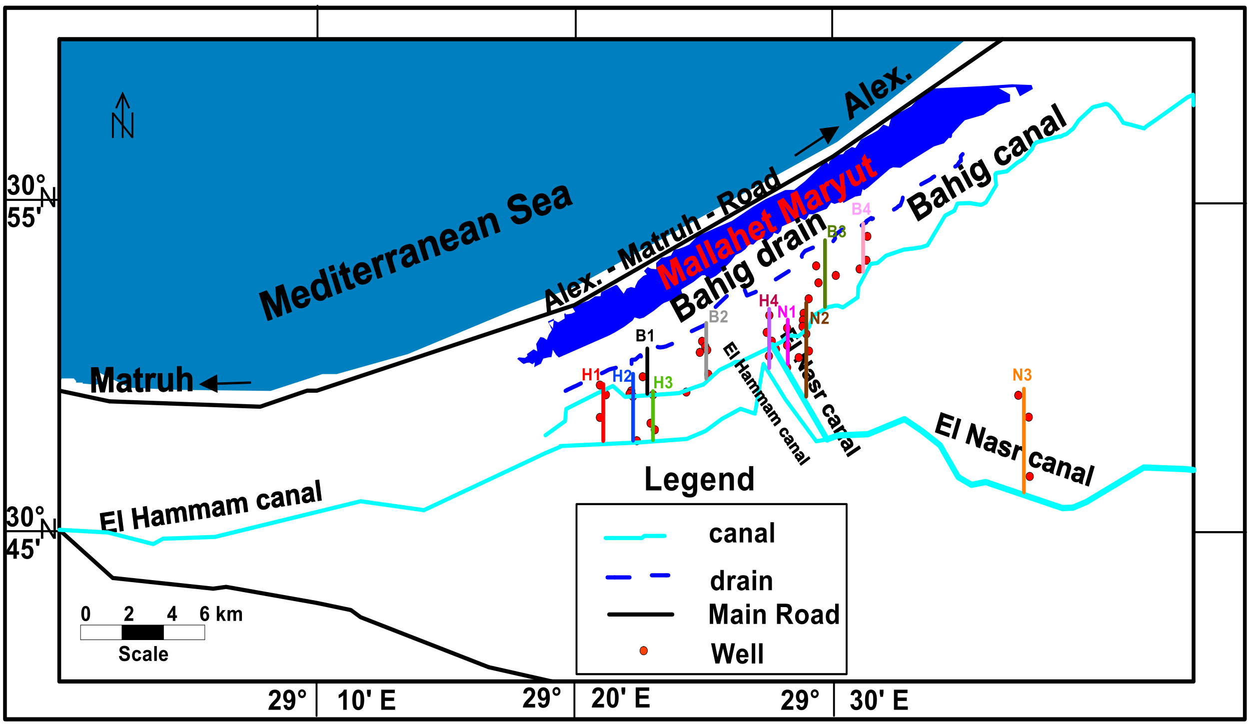
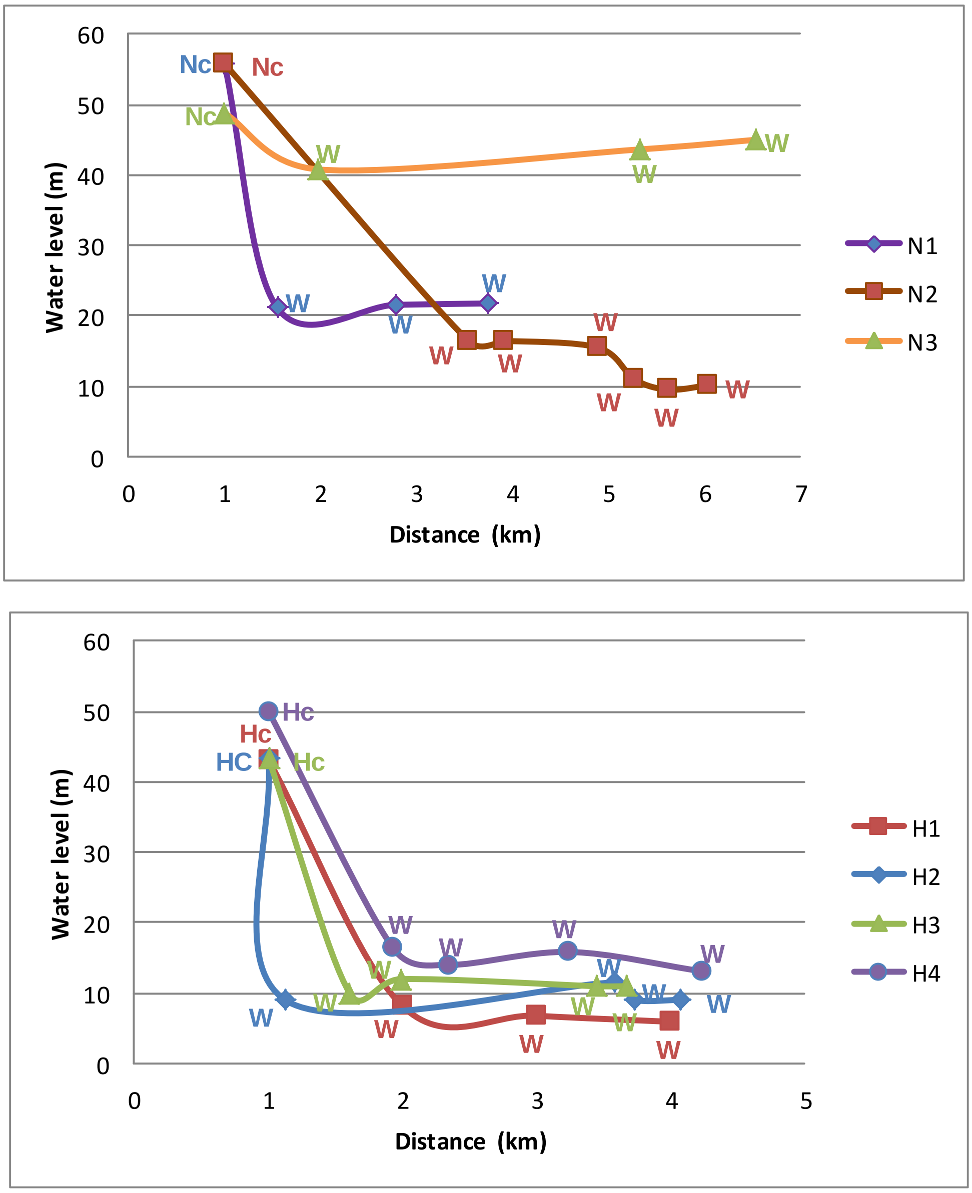


Fig. 4: Longitudinal sections to identify the change in groundwater levels.

Canal seepage is estimated from the following equation, according to the Moritz formula cited by the US Bureau of Reclamation (USBR, 1967):

$$S = 0.2C\sqrt{\frac{Q}{V}} \qquad (1)$$

Where S = Canal seepage in ft3/sec/mile.
Q=Canal discharge (ft3/sec).



Hc : Wter level of El Hammam canal (m)
Nc : Water level of El Nasr canal (m)
W : Water level of groundwater (m)

Fig. (5): Water levels in El Hammam and El Nasr canals, as well as groundwater in The Pleistocene aquifer, Borg El Arab area, West Alexandria, Egypt.

V = the mean velocity of the flow (ft/sec).

C is constant. Its value is 0.33 in the case of concrete lining.

The seepage from El Hammam canal is about 10.51 x 106 m3/year on two sides, which means that on one side it is about 5.26 x 106m3/year.

FAO/UNESCO (1967) proposed the following equation for estimating the canal seepage:

$$\mathbf{S} = \frac{\mathbf{A} \times \mathbf{L}}{\mathbf{100} \times \boldsymbol{Q}^{\boldsymbol{m}-\mathbf{1}}} \qquad (2)$$

Where,

S: Total seepage (m3/sec).
Q: Discharge (m3/sec) of the delivered water in the canal.
L: Canal length (km).
A & m: Emprical constants depending on soil permeability.

El Nasr canal seepage is calculated by applying the above equation in the lined sector, which reaches about 115.3x106m3/year on both sides, it is equalto57.65 x 106m3/year, for each side.

The seepage from lined canals is 0.11 m/day, while the seepage from unlined canals is 0.37 m/day (Rushton, 1986). According to the WRRC (1980), seepage from lined canals in good condition is 0.003 m/day, while seepage from unlined canals is 0.25 m/day. According to Rushton's and WRRC's theories, seepage from El Nasr and El Hammam canals is 8.94 x106, and 0.81 x106m3/year, respectively, in the studied area, which indicates the necessity of lining the canals.

2- Return Flow after Irrigation:

Return flow after irrigation is defined as the part of irrigated water that is neither consumed by the crops nor evaporation, but infiltrated to the water table. The estimation of the return flow after irrigation essentially depends on the percentage of irrigation efficiency in cropped areas. According to different methods of irrigation applied in the studied area, irrigation efficiency is variable, ranging from 50% for crop irrigation using the old surface irrigation system from the Bahig canal to 85% (FAO, 1980) for crop irrigation using the modern system (drip and sprinkler) from El Hammam canal. The total amount of water applied for irrigation of the Bahig canal isabout 38.97 M m3/year.

Then 50% of the water applied to the field could be considered as return flow after irrigation, and it estimates about 19.49 M m3/year from the Bahig canal. If modern irrigation methods are applied, the amount of return flow after irrigation to the Pleistocene aquifer would be (5.85 M m3/year), which indicates the necessity of using modern irrigation methods. While the total amount of irrigation water applied on both sides of El Hammam canal is about 183.51x106m3/year. For one side in the studied area, it could be as high as 91.76 x 106m3/year. Then 15% of the water applied to the field could be considered as retrun flow after irrigation, and it estimates about 14.22 M m3/year from El Hammam canal.

3- Recharge from rainfall

Rainfall is a critical factor in determining the hydrological regime. There are many approaches to the distribution gauges' measurements of the precipitation. The isohyetal method is used to determine the distribution precipitation in the studied area. From the isohyetal map (Fig. 6), the studied area is embarced between the isohyets of 146 and 152 mm, which means that the mean annual rainfall depth in the studied area is 149 mm.

Chatterjee and Ray (2014) applied the following equation to calculate the recharge from the rainfall:

$$\textbf{Recharge (m3) = Area (m2) x Infiltration factor (\%) x rainfall intensity (m)} \qquad \textbf{(3)}$$

According to Chatterjee and Ray (2014), the estimated infiltration factor percentage for the Quaternary aquifer equals 12% for a precipitation rate of more than 100 mm/year. Aquifer recharges from rainfall in the studied area reaches about 10.91M m3/year.

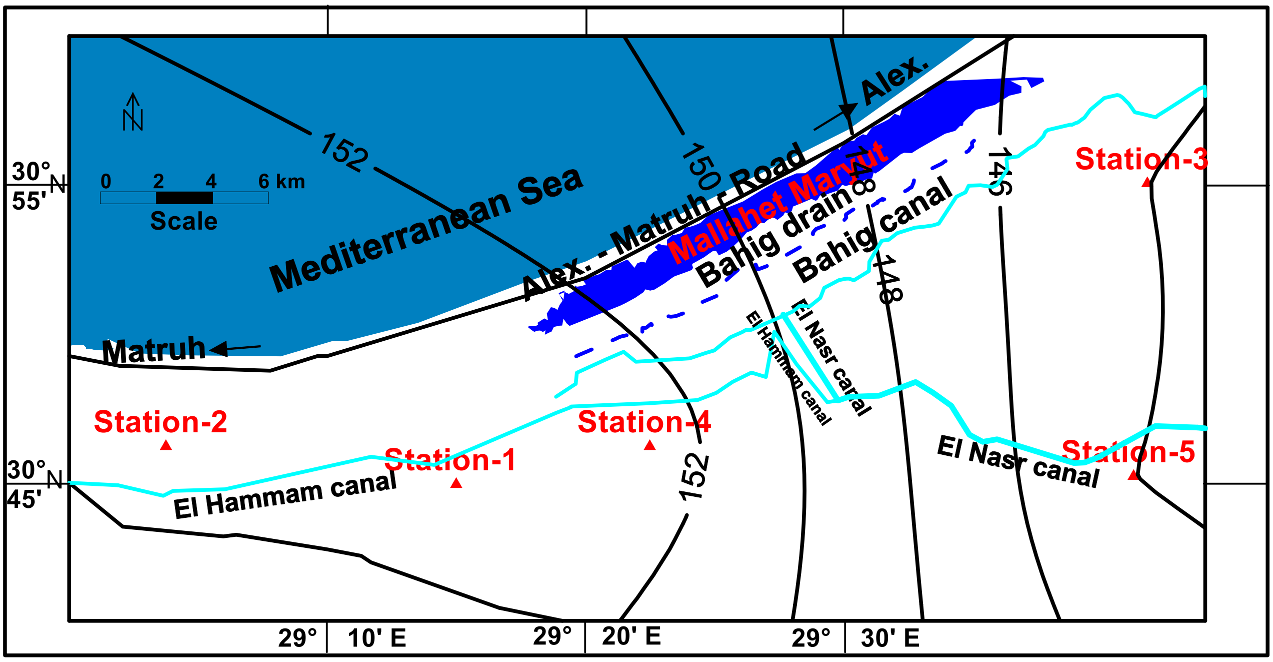


Fig. 6: Isohyetal map, Borg El Arab area, Egypt (mm/year), for the annual rainfall intensity (Power data access (2015-2019)).

Out flow components

1-Evapotraspiration from the water logging area

Evaporation (E0) and evapotranspiration (E) represent some of the important components of the hydrological cycle and water budget equation. The evaporation rate was calculated by using the Penman formula (Linacre, 1977):

$$E0 = (700Tm/(100-A)+15(T-Td)) / (80-T)(\text{mm /day}) \qquad (4)$$

Where,

E0: Evaporation rate (mm /day)

Tm = T + 0.006h,

h : is the elevation (m),

T : is the mean temperature,

A :is the latitude (in degrees) and

Td :is the mean dew point.

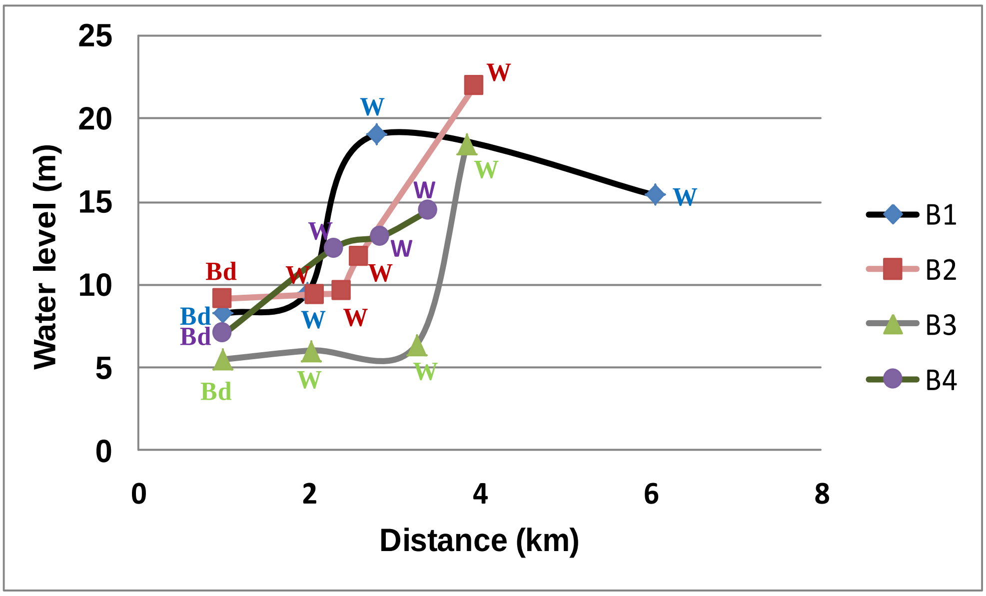
From Fig. 7, the piche evaporation rate map indicates that the annual evaporation rate increases from 2050 to 2250 mm at the eastern direction of the studied area. The evapotranspiration from water logging is calculated from the equation (Omar, 2011):

E= water logging area (m2) x annual mean evaporation rate (m/year). (5)

The total of water logging areas is 9.72 M m2 (Fig. 8), and the annual mean evaporation rate is 2.15 m/year in the studied area. The evapotranspiration from water logging equals about 20.89 M m3/year.

2-Seepage from the aquifer to Bahig drain

Different sections are applied longitudinally to the Bahig drain (B1, B2, B3, and B4) (Fig. 9). These sections represent seepage from the Pleistonce aquifer to the Bahig drain (the Bahig drain is represented as a canal). Equation (2) is applied to calculate the seepage from the Pleistonce aquifer



Bc : Water level of Bahig drain (m)
W : Water level of groundwater (m)

Fig. 7: Piche Evaporation Rate Map, Borg El Arab area, Egypt (mm/year)

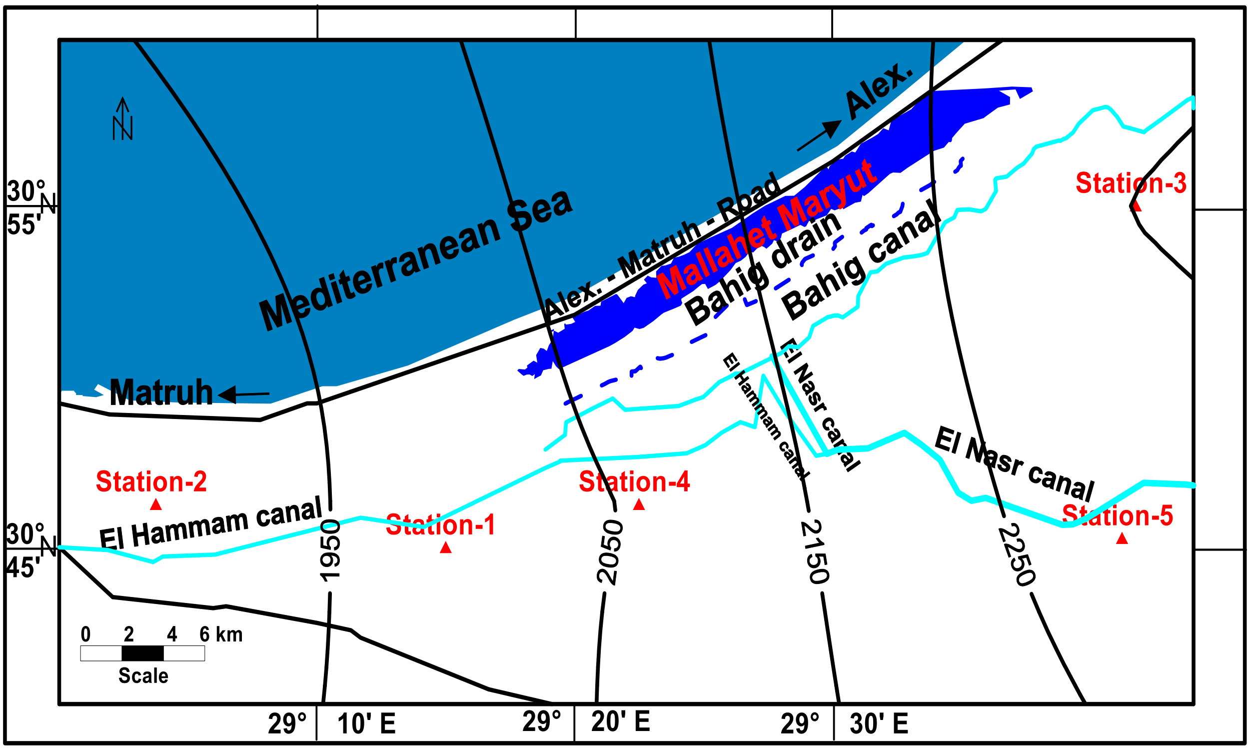


Fig. 8: Water logging areas in Borg El Arab, West Alexandria, Egypt.

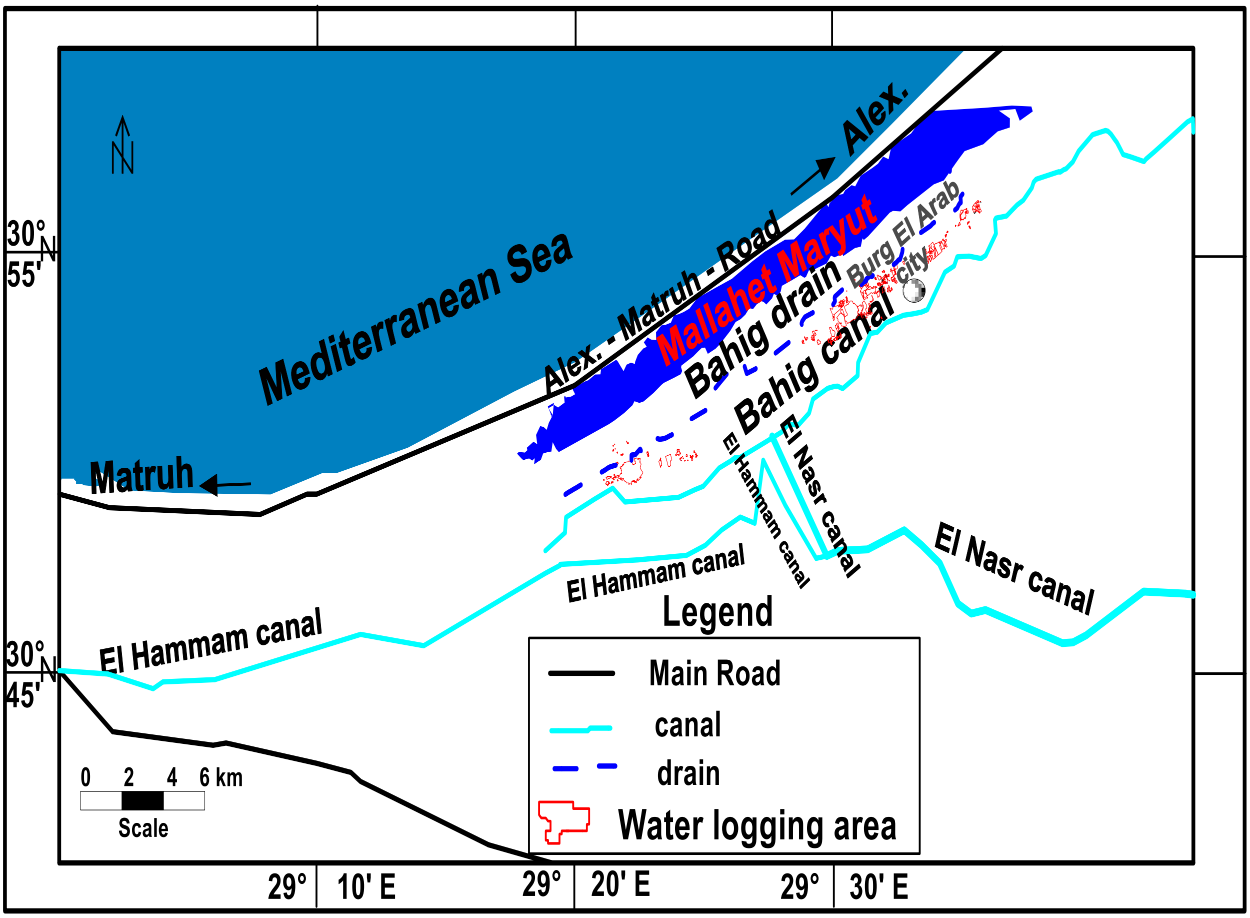


Fig. 9: Water levels of the Bahig drain and groundwater of the Pleistocene aquifer, Borg El Arab area, West Alexandria, Egypt

into the Bahig drain, and discharge from the groundwater aquifer is considered as Q in the aquifer. The total amount of seepage from the Pleistonce aquifer to the Bahig drain is about 54 x 106 m3/year in the studied area.

3-Wells discharge

From the field investigations, the pumping rates of about 255 wells in the winter and in the summer seasons are recorded for each month in the studied area, (Fig. 10). The total amount of groundwater extracted from the Pleistocene aquifer by 255 wells is calculated and expressed in millions of cubic meters. The total amount of groundwater exploitation for the summer and the winter seasons are calculated as 0.424 and 0.276 million cubic meters, respectively. The total amount of wells discharge is equal to 0.70 million cubic meters per year. From the above, there is 0.54x106 m3/year of seepage from the Pleistocene aqufier to the Bahig drain, due to agricultural drainage from irrigated areas by wells.

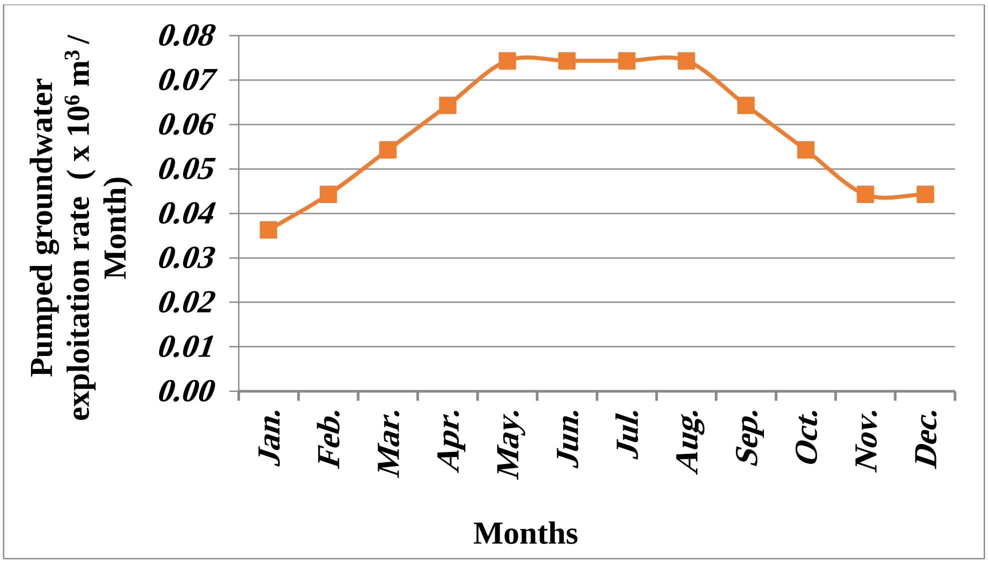


Fig. 10: Monthly rate of groundwater exploitation for the Pleistocene aquifer, Borg El Arab area, West Alexandria, Egypt

EXTERNAL HYDROLOGICAL STRESSES

External hydrological stresses on the Pleistocene aquifer in the investigated area (depicted in schematic diagram Fig. 11) are:

The main resources of the groundwater recharge of the Pleistocene aquifer in the studied area have different sources as follows:

1. The surface water network in the examined area recharges the groundwater of the Pleistocene aquifer. This includes El Hammam and Bahig canals which are emerging from El Nasr canal.
2. Return flow after irrigation,
3. Recharge from rainfall.

Groundwater discharge from the Pleistocene aquifer in the studied area has different components as follows:

1. Evapotranspiration from water logging areas,
2. Wells discharge, and
3. Seepage from the aquifer into the Bahig drain.

WATER BUDGET

The following is an estimation of the Pleistocene aquifer's water budget in the examined area:

Storage change = Inflow components – Outflow component (6)

54.37 x106 m3/year–22.13 x106 m3/year = 32.24 x106 m3/year

A high storage value suggests that groundwater levels in the Pleistocene aquifer in the examined area have been raised.

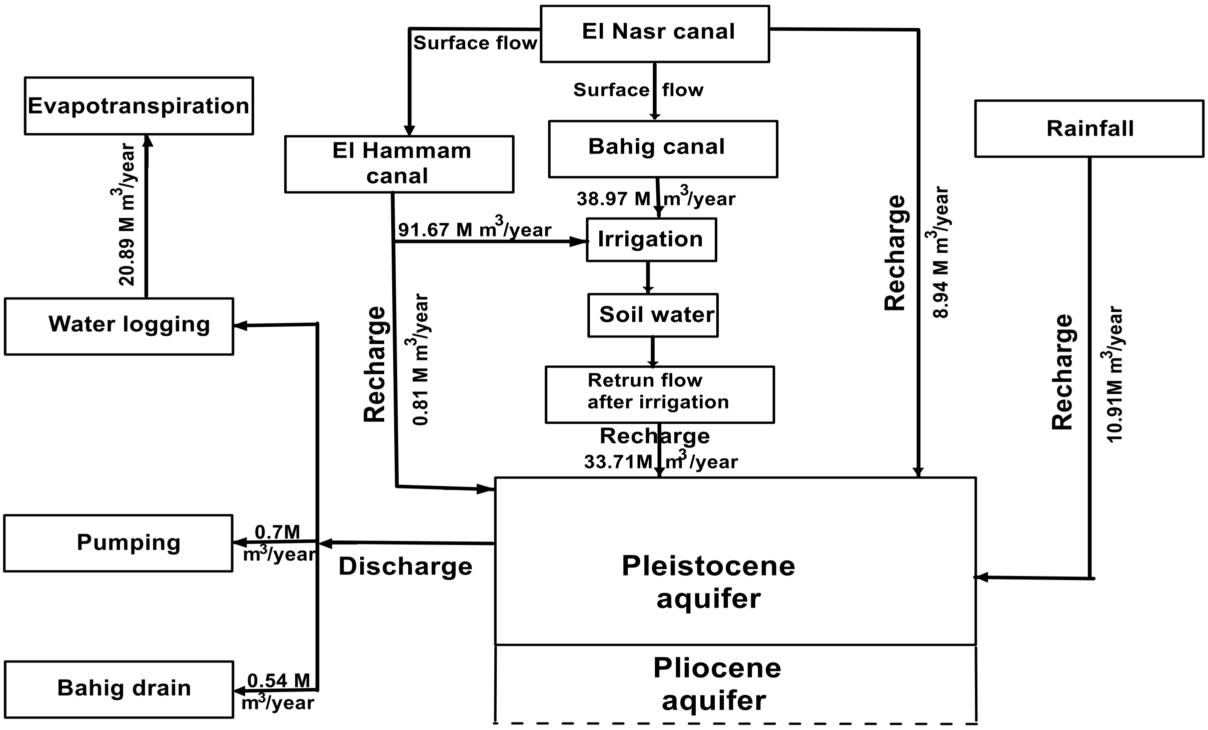


Fig. 11: Schematic diagram representation of the external hydrological stresses of the Pleistocene aquifer, Borg El Arab area, West Alexandria, Egypt.

CONCLUSION

The main aquifer in the Borg El Arab area contains of consolidated detrital oolitic limestone (Pleistocene) in the coastal zone area and Pleistocene clastic sediments in the Abu Mina basin area. The average annual rainfall ranges from 146 to 152 mm/year, and the average annual evaporation rate ranges from 2050 to 2250 mm/year. The inflow components of the water budget are return flow after irrigation, canal seepage, and recharge from rainfall, while the outflow components of the water budget are evapotranspiration from the water logging areas, well discharge, and seepage from the aquifer to the Bahig drain. The total amount of return flow from El Hammam canal irrigation equals about14.22 x 106m3/year, while from Bahig canal irrigation it equals about 19.49 x 106 m3/year. The seepage from El Nasr and El Hammam canals is 8.94x106, and 0.81 x106 m3/year, respectively in the studied area.

The recharge from rainfall in the studied area reaches about 10.91 x 106m3/year. The evapotranspiration from water logging in the studied area equals about 20.89 x 106m3/year. The total amount of groundwater exploitation for the summer and winter seasons are estimated as 0.424 and 0.276 million cubic meters, respectively. The total amount of well discharge equals to 0.70 million cubic meters per year. There is 0.54x106 m3/year of seepage from the Pleistocene aquifer into the Bahig drain, due to agricultural drainage from irrigated areas by wells. The result of the water budget indicates that the total amount of inflow components equal about 54.37 million cubic meters per year, while the total amount of outflow components equal about 22.13 million cubic meters per year. The total amount of storage in groundwater equals about 32.24 million cubic meters per year, which means that there is a rise in the groundwater levels in the Pleistocene aquifer in Borg El Arab area.

RECOMMENDATIONS

To reduce the added amount of water to groundwater storage the following recommendations should be applied

- Modern methods of irrigation should be used instead of traditional (immersion) methods.
- It is necessary to legalize irrigation's reliance on surface water from canals.
- Re-lining and maintenance of existing canals in the area.

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