

Evaluating Water Table Rising Under Eastern Cairo (Metro Line)

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Abstract
The booming increase in population in last decades led to poor environmental condition in some areas in the capital city of Egypt. The main two tackled environmental impacts from the increased population, in this research, are the heavy traffic densities jam and groundwater rise in many areas in the city. The massive population causes traffic congestion in the capital due to the increased poor planned urban expansion. The groundwater rise is resulted from leakage from over loeaded and poorly maintained drinking and sanitary water networks. More than 40% of the capacity of these networks leaked to ground, moving, with the topographic gradient sub-surfable to the lower areas; transporting all pollutants and dissolved salts from soil to the aquifer. This, also, threatens the buildings stability and prevent the usability of these buildings. The government is currently exerting massive efforts and increasing the investments tremendously on solving the traffic congestions and implementing new roads. Zooming into the study area, replacing the non-working old metro track into a road to link between Mansheyet El-Bakry and El-Demrdash is faced with the high groundwater table occurring in the area. The main objective of the current research is, to evaluate the proposed alternatives for solving the traffic problem through implementing new road, taking into consideration conducting a suitable solution for the high groundwater table. Moreover, investigating the main causes of the groundwater rise and assess environmentally the impact on the study area. Several proposed alternatives were evaluated for solving the concerned issues through extensive field and hydrogeological investigations, pumping tests, and numerical model (GMS- modflow) to simulate the hydrogeological conditions of the study area and test the proposed solutions. The alternatives were, also, assessed through a designed weighted impact assessment to analyze the best solution. the weighting assessment factors include efficiency, initial and operational costs, extracted water volume, lower groundwater rise, building stability, construction feasibility. The comprehensive investigation and assessment indicated that the most effective solution. Nevertheless, prevention at source is also urgently needed through rehabilitation of drinking and sanitary water networks in the capital to minimize the seepage and losses percentage of the transported water.
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1. Introduction

Moving outside the residential area around river Nile was very difficult due to absence of basic life requirements leading to tremendous increase in population in the Nile Delta and valley. Greater Cairo now comprises more than 17% of the total population (Abd Elrahman & El-khateeb, 2016). Recently Cairo city has experienced rapid population growth, where the population increased from 2.5 million in 1950 to 21 million in 2022. Several factors affected the increasing population attraction in Cairo, such as; it is the capital city, and the availability of all essential life requirements: health, education, job opportunities, etc.(Salem et al., 2019). Moreover, migration of low-income groups to the capital seeking for improving their economic situation. As a result, informal housing increased to occupy low and middle class. Groups Slums also, have increased significantly especially after the uprising of 25th of January revolution(Abd Elrahman & El-khateeb, 2016). More than 12 million of Egyptian population (about 40%) lives in slums with high density, low standard of housing, deteriorated infrastructure and lack of services (Abouelmagd, 2014).

In the past, Egypt had a notable history of planning shortcomings since the middle of the 20th century (Nicolopoulou et al., 2021). The observed increase in population drove the government to permit an increase in number of floors to solve the hosing problems. Most of the buildings changed from 2 or 3 floors to about 12 floors with decreasing the apartments areas to fit the rapid population increase. However, the infrastructure of the city was not designed to accommodate the prementioned increase in building capacities and urban areas.

The population increase and informal housing without adequate infrastructures resulted in deteriorating the infrastructure in the capital (Salem et al., 2019). sewage network was designed to function as open channels flow (flows by gravity). But with the increased amounts of sewage water, the network changed to pipe flow with water heads network.

Leakage from the networks takes place worldwide. It ranges in some countries from 7% to 50 % of total water input (Adedeji et al., 2017). In Egypt, most of previous research stated that the losses from networks ranged from 30 to 40 % of total water input in many parts especially, the old districts (Ghodeif et al., 2018;

Mahmoud et al., 2018). Also, with the deteriorated conditions of the domestic water supply network which carries water more than its capacity, the leakage and losses exceeded 40% of the input water to networks (Abdel Rahman Attia, 1999). All those factors have contributed in deteriorating the groundwater in Cairo city.

During the last four decades, water table rise in Greater Cairo has become a source of danger that threatens the safety and durability of existing ancient and recent building (Masuch-Oesterreich, 2017). The problem has become more sever in the old districts of Cairo City in the east of the Nile. Basements of old buildings, mosques and churches are suffering from groundwater seepage. The aggressive effect becomes more severe when groundwater is contaminated with sewerage water(Abdelhafiz et al., 2021).

The most threatened locations due to groundwater rising are the areas with low topographic levels especially, at the eastern part of greater Cairo. The digital elevation models (DEM) indicate that the ground levels inclination from south east to north west till the limits of the Delta flood plain then, the inclination disappeared (figure 1). The border of the Delta peripheries is the limiting line for the most deteriorated zone by the groundwater rise. And therefore, the metro line track in the El-Qoba district, is one of the most deteriorated projects due to its location at the Delta peripheries, and at the low elevation levels (figure 2).

One of the current strategic goals for the government is to solve the heavy traffic densities in the capital. According to the traffic suggested solution, replacing the old metro track with new road that links Mansheyet El - Bakry with El Demrdash can effectively contribute in solving the traffic congestions in this area. The metro track was designed as an open tunnel below the ground level about 5 meters. It was designed as a tunnel to avoid the junction of roads in the crossing of El- khalifa El-maamoun and El- Fangari street. There were three levels of roads in that crossing; the metro track in the tunnel: underground, the surface road: at ground level and Kobri El-koba bridge: 6 meters above ground level. There were two alternatives for switching the metro track to be used as a road. The first, was to use the track as a road at the same low existing levels. The second, was to elevate the track level to the normal ground level using the backfilling materials. The advantages of the first alternative are solving the problem without any modification in surface road or bridges elevations. Also, protecting the adjacent buildings from the groundwater level rise, as the track is acting as an open drain that lower the groundwater level. The disadvantages are the necessity to setup dewatering system to control the water level along the track. moreover, using the track at its existing level will decrease the road width because of the inclination of tunnel sides. The advantages of the second alternative, is a convenient road width without facing the groundwater problem. The disadvantages are the need to modifying all roads and bridges levels at the intersection area.

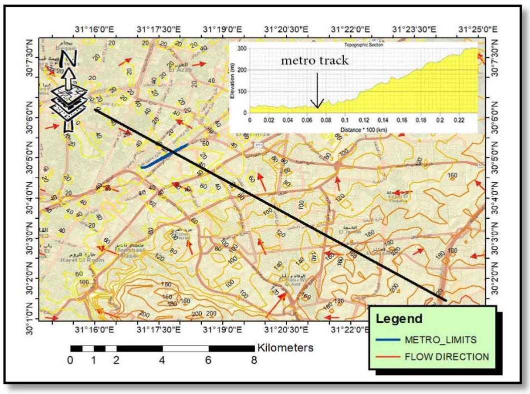

Figure 1: Inclination in topographic levels from East to West

Figure 2: Groundwater rise in metro line station

The main objective of this research is to assess the water table rise problem in the study area and select the most optimized solution to control the groundwater levels in the deteriorated areas. Also, to compare between the proposed alternatives for solving the traffic congestions from the technical and financial perspectives. The objective was achieved through investigating the hydrogeological system in the study area, using historical data and extensive field data. Measuring Extraction rates, chemical analysis for water samples and two precise pumping tests were conducted. Consequently, development and application of finite element model for the aquifer system at the deteriorated area. And based on the numerical model, the different proposed solutions are presented, discussed and assessed according to the impact assessment investigation.

2. Materials and methods

In order to achieve the research objectives, it was important to conduct a hydrogeological study for the area. The study included field investigation and measurements. Then, the field data was analyzed and used to build up a numerical model to simulate the hydrogeological system in the study area. The developed model is then been used to test the proposed solution and find the most optimized alternative to deal with the problem.

2.1 General approach

The main objective of this research is achieved through the following inter-related activities.

- Field investigations including ground surveying and groundwater levels measurements;
- Chemical analysis for collected water samples;
- Determine the water discharge from the study area to the sewage network;
- Conducting pumping test to identify the aquifer hydraulic properties;
- Simulating the hydrogeological system of the study area using numerical finite element model

2.2 Physical and hydrogeological settings

Cairo is located on banks of the River Nile. It lies between latitudes 29º 40' 00" and 30º 12' norths and between longitudes 31º 00' 00" and 31º 40' 00" easts (figure 3). The city extends about 50 km along the Nile with a width varying between 5 km in Helwan and 35 km in Qualyubia (Shahin, 1990). At Cairo, the Nile floodplain has a width of 12 km and a relative elevation of 17 to 21 m (AMSL). Along the eastern portion of the alluvial plain, El Mokattam plateau rises steeply to about 150 m (AMSL). A similar plateau to west, entitled Pyramid's plateau, rises to an elevation of 100 m (AMSL). The Cairo City is subject to arid climate conditions with low rainfall and moderate humidity. Average daily temperature is between 40 c in summer and 8 °C in winter. Relative humidity ranges between 50 – 70% and increases in the north. The mean annual rainfall is about 21 mm, and the mean annual evaporation is about 4000 mm (El-Sayed, 2018).

Cairo is one the most populated cities in Africa. The present permanent population of Greater Cairo is about 21 million(Kamel and el BILALI Hamid, 2022) . The land use in Greater Cairo can be distinguished as, the urban portion covering about 72 % of the total area, the agriculture portion, totally disappeared, and the desert land portion covering about 28%(Atlas of Urban Expansion - Cairo, 2022). The industries and industrial activities are scattered all over the city (Urban and Agricultural Change in Cairo, 2022). The urban area is generally served with a sewer system while the scattered rural areas and some unplanned settlements are either unserved or served with local networks or septic tanks. The changes anticipated in land use involve essentially in increasing the urban portion by cutting both agricultural and desert land portions. Therefore, renovation and rehabilitation of the networks are necessary in order to cope with the rapidly increasing population and urbanization.

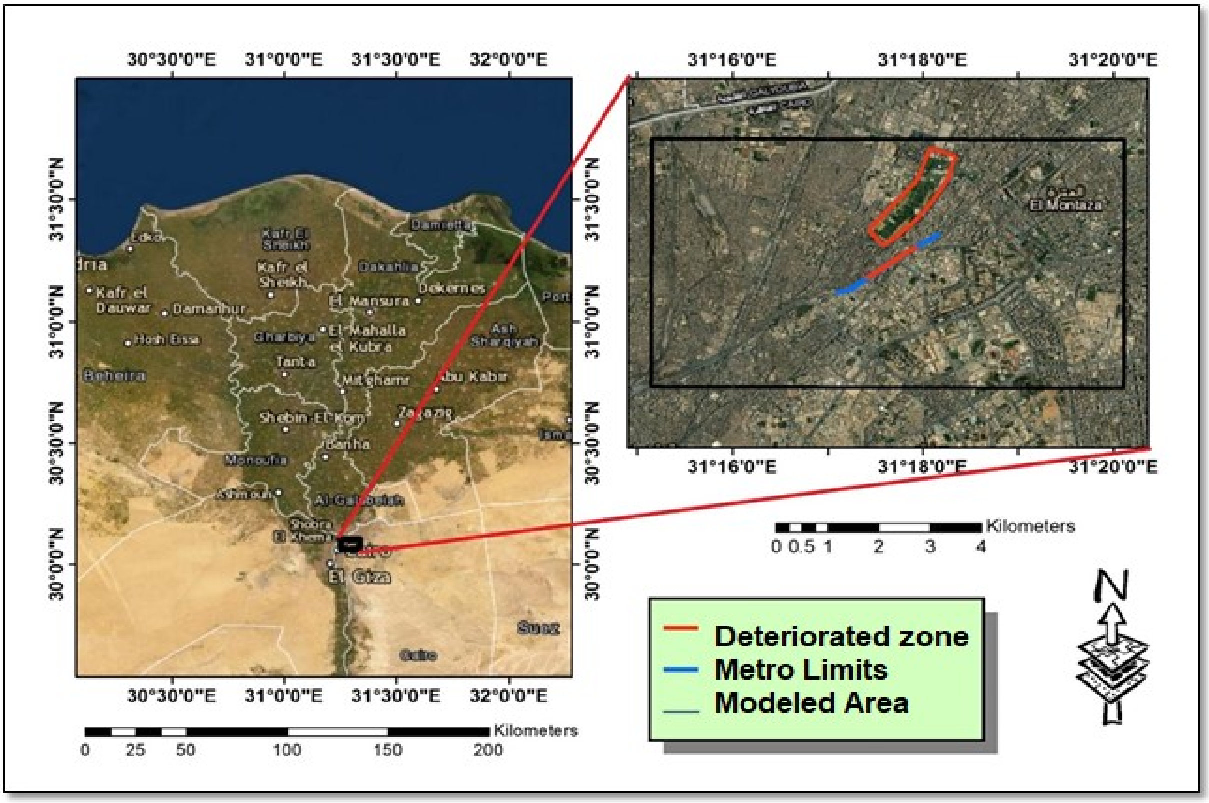

Figure 3: Study area and deteriorated zone

The main aquifer system is the quaternary, it consists of coarse massive sand and gravel intercalated by clay lenses, and belonging to the late Pleistocene. The aquifer underlain the floodplain is covered with a silty-clay. This top layer acts as semi pervious aquitard. This layer has a nonuniform thickness varying from 5 m to 20 m and vanishing near the eastern and western fringes (Sadek and Abd El-Samie, 2001). The aquifer thickness ranges from 20 to 140 m.

The areal extent of the aquifer is limited from the east and west by the limestone escarpments (Eocene and cretaceous). The bottom of the aquifer system rests either directly on the Eocene sediments or on the Pliocene clay or becomes faulted against the Eocene Limestone which is assumed as an aquiclude. In the semi -confined part of the aquifer system, there are mutually and hydraulic interaction between piezometric head and water table. This interaction depends, in magnitude and direction, on the hydraulic characteristics of the top layer and the hydraulic head difference between the two water bodies. The horizontal hydraulic conductivity of the main aquifer ranges from 20 to 70 m/ day and the storage coefficient ranges from 0.0005 to 0.01(El-Shahat et al., 2016).

2.3 Historical groundwater status

The monitoring groundwater heads for the period 1970 to 2018 are compiled and analyzed to construct the piezometric contour head maps; in order to estimate the groundwater fluxes and the changes in groundwater levels, as shown in (figure 4) in study area. The chart indicates significant fluctuation in groundwater level and an observed trend for water level increase with time

The aquifer is replenished through seepage from the river and irrigation canals, deep percolation from excess irrigation water and seepage from drinking water supply network. Also, in unsewered region the aquifer is infiltrated from the sewage trenches and pits. On other hand, discharge occurs as, groundwater return flow to river, interception of the sewage system, and groundwater withdrawals.

Groundwater quality monitoring for the quaternary aquifer in Cairo region indicates high salinity and sulphate content in the groundwater. In the areas east of the Nile, the salinity (TDS) is more than 1200 ppm and reaches 8000 ppm moving to the east (El-Shahat et al., 2016). The sulphate content is higher than 400 ppm, which is classified as aggressive water type. This water quality reacts with the building materials causing decay of foundation elements of these buildings. The groundwater quality in this part of the city indicates the presence of different type of recharge water.

Groundwater rise in Greater Cairo is one of the important environmental problems facing the area. Many places, especially along the eastern bank of the Nile river, are suffering from this problem. In such locations, ground surface depressions reveal the problem bluntly. At present, many antiquities, mosques and old buildings are suffering from such problem. The rise in groundwater levels, which has taken place everywhere east of the Nile (especially old Cairo areas) over the past four decades, is due to the continuous extensive recharge from the massive losses of sewage and drinking networks. Also, at the newly urban settlements (located along the high eastern fringes) which was built with no coverage of sewage system; the water from septic tanks infiltrates to groundwater.

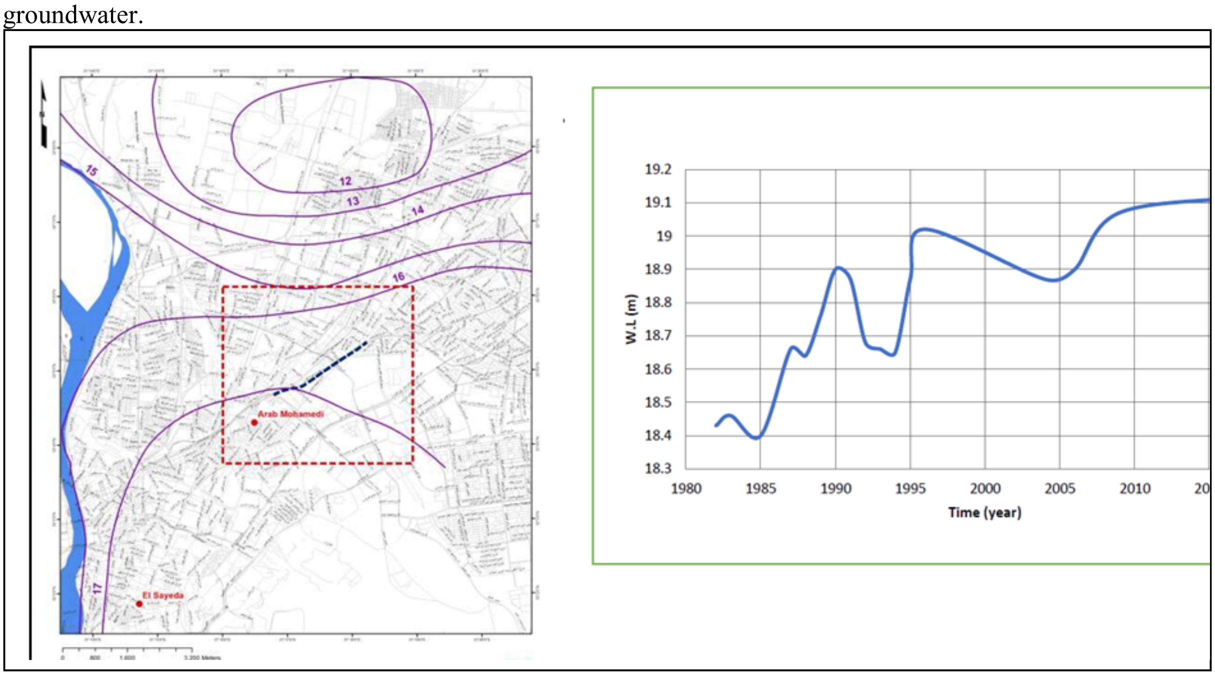

Figure 4: Observed piezometric heads and levels fluctuation from 1980 to 2018 in Arab El-Mohamady monitoring point

2.4 Field investigation

Implementation of the current research required special data set that was not found in the literature. So, an extensive filed investigation has been conducted; starting with surveying and determining the deteriorated locations then, evaluating the current drainage system. The topography and groundwater levels were surveyed. Water samples were collected and analyzed chemically to predict the water sources. Moreover, two pumping tests with 24 surrounding piezometers were conducted to calculate the aquifer hydraulic parameters for the aquifer.

Field visits

Field visits for the study area was essential to determine and allocate the deteriorated location. The most deteriorated spot was the metro track that was fully submerged under groundwater levels. Investigation revealed a strong dewatering system consists of 6 pumps inside the track and 8 pumps in the surrounding area with extraction rate about 50,000 cubic meter / day. Most of the adjacent buildings to the metro track were critical prone building for having underground basements; which are threatened by being submerged with water immediately with any pumping disfunction.

survey works

In order to calculate the flow direction and ground surface inclination, a detailed survey work was conducted. The topographic & groundwater levels were measured. The field data were then, used to produce contouring maps to clarify the ground surface levels, groundwater heads and depth to water (figure 5). The general topographic slope is from east south to west north ranging between 25 to 21 meters AMSL. The groundwater gradient is the same as ground levels with levels range between 22 to 18 meters AMSL. Finally, the depth to groundwater was calculated ranging from 1 to 4 meters.

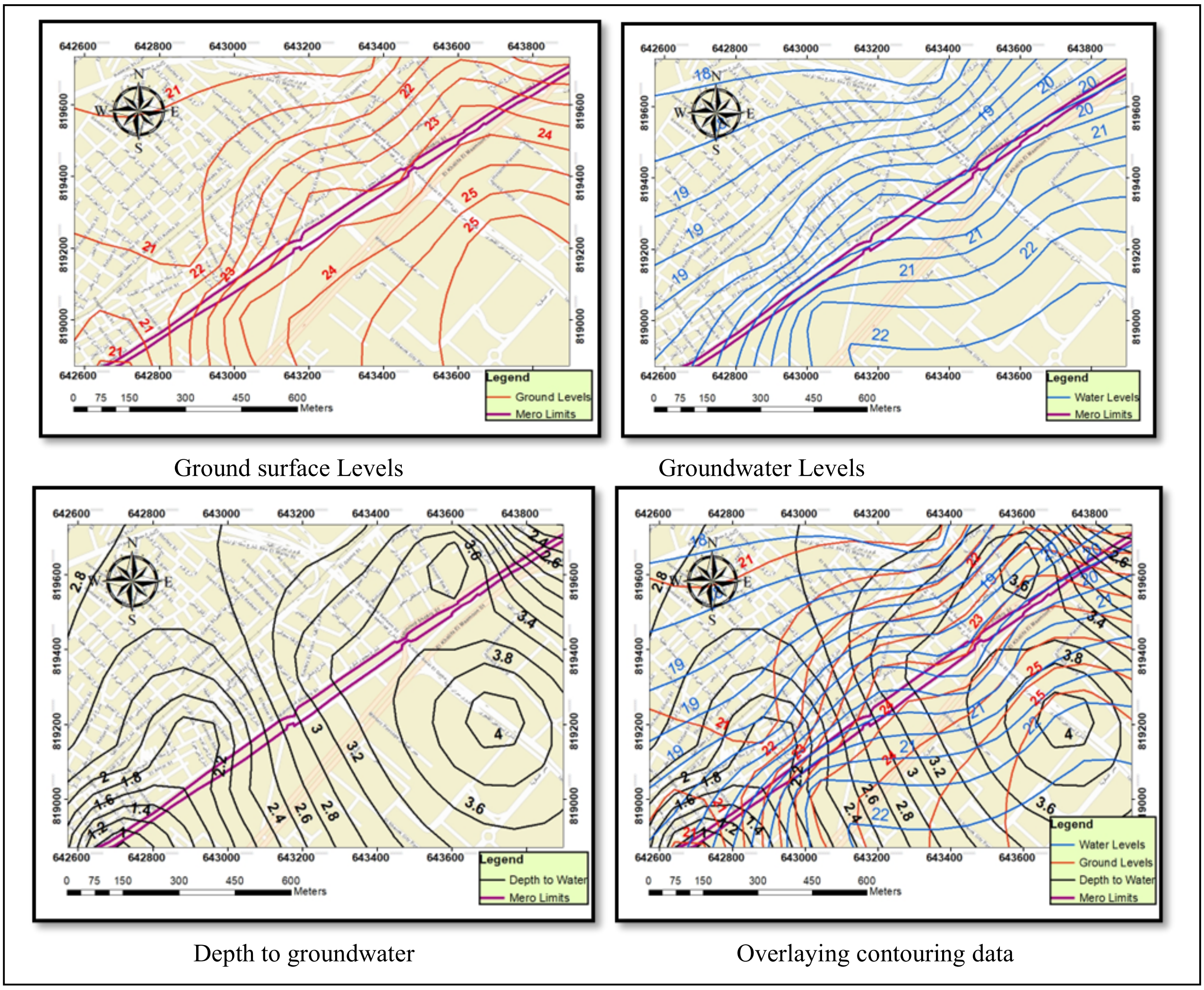

Figure 5: Survey work for ground surface, groundwater and water depth

Chemical analysis for water samples

Chemical analysis for the groundwater samples was essential to predict the water sources and direction. Five samples were collected from specified locations as shown in Figure 6. Four samples were considered shallow groundwater as, they were collected from the metro track and the shallow dewatering systems (M1, M2, M3 and M4). The fifth sample was collected from the drilled pumping well, with depth of 25 m. In addition, historical chemical analysis for the area was collected from two monitoring points from (RIGW) database. The elements of pH, TDS, Ec and Do were measured in the field and the results are listed in Table 1. Four samples were tested in the lab. Table 2 presents the results of four samples chemical laboratory analysis. The results indicate that the water is from the same source with high level of salinity ranging between 8,000 to 10,000 ppm, while for the well sample; it reaches 12700 ppm. The predominant salt is sodium chloride, in addition, the organic pollution is low at all monitoring points. As per the chemical historical data (D001C & D002C), the first is located in the north west of study area at distance of 1.5 km, and the second one is located in the south east at distance of 2 km. For the first point, the TDS value was measured once through 1988 with value of 500 ppm, that matched the quaternary aquifer water quality. However, the TDS value for the second point increased from 3300 to 5000 ppm over the last from 1987 to 1991.

Figure 6: Distribution and locations of collected water samples

Table 1: Field chemical analysis results

Element	unit	Sample			
		M 1	M2	M3	M4
pH	--	7.17	7	6.96	7.01
EC	mS/cm	10.27	10.18	12.9	16.9
TDS	mg/l	6570	6520	8256	10816
DO	mg/l	5.28	4.44	6.6	3.6

Table 2: Laboratory chemical analysis results

Element	unit	Sample			
		M2	M3	M4	P. Well 1
SAR	--	26.8	25.8	26.2	20.03
TSS	mg/l	796	500	912	-
Turbidity	NTU	8	4.13	16.4	-
Cations	Milliequivalent / liter				
Ca		9.3	9.5	9.6	33.01
Mg		10.5	11.1	12.5	20.33
K		0.79	0.74	0.81	2.17
Na		84.4	82.5	86.3	134.3
Anions					
Cl		84.1	81	80.1	158.5
SO_4		9.4	9.2	10.1	35.64
HCO_3		9	10	9	6.031
CO_3		0	0	0	0
BOD	mg/l	4	3	4	10
$N-NH_4$	mg/l	0.56	0.55	0.54	-
$N-NO_3$	mg/l	0.51	0.54	0.5	0.7
NH_4	mg/l	0.74	0.69	0.72	-
NO_3	mg/l	2.2	2.16	2.21	0.7
PO_4	mg/l	0	0	0	<0.2

Current dewatering system discharge

Most of investigated deteriorated buildings are adjacent to the metro line. The basements of these buildings are suffering from submergence under groundwater. These buildings are locally protected by separate dewatering systems to control the groundwater levels at desirable levels. The total counted number of pumps in the study area were 14 pumps. Six pumps were inside the metro line, and eight pumps were distributed in some strategic buildings. The electromagnetic flowmeter had been used to evaluate and measure the discharge from these systems. The total measured discharge from these pumps was about 50,000 m3/day. Which is discharged totally to the overloaded and exhausted sewage network.

Aquifer hydraulic parameters (pumping test)

One of the main objectives of the current research is to select the most effective dewatering system to control the groundwater levels at a desirable level. The efficiency of the suggested dewatering systems and the operating schemes were tested through numerical model; which simulates the aquifer behavior in the study area. hence, it was essential to determine accurately the aquifer properties and hydraulic parameters. The available data from previous studies and literature were collected. however, it was not sufficient to create the required model. Therefore, it was important to calculate the required data precisely through conducting two pumping tests in the study area. Each of these pumping tests was conducted by drilling an extraction well with 24 m depth and a number of 12 piezometers surrounding each pumping well. The depth of piezometers was about 10-meter and distributed x& y direction with variable average distance 6, 12 and 50-meter from the center of pumping well (figure 8). The resulted drawdown, due to continuous pumping with average extraction rate 125 m3/ hour after 24, 48 and 72 hours, was described in figure 7. The pumping test data was analyzed using the aquifer test software to calculate the aquifer hydraulic parameters. The calculated transmissivity was ranging from 1120 to 2430 m^2/ day, whereas the hydraulic conductivity was about 85m/ day and the aquifer is isotopic. Finally, the specific yield ranged between 0.003 and 0.28. The radius of influence of well was about 100 meters from the center of pumping wells according to pumping rates.

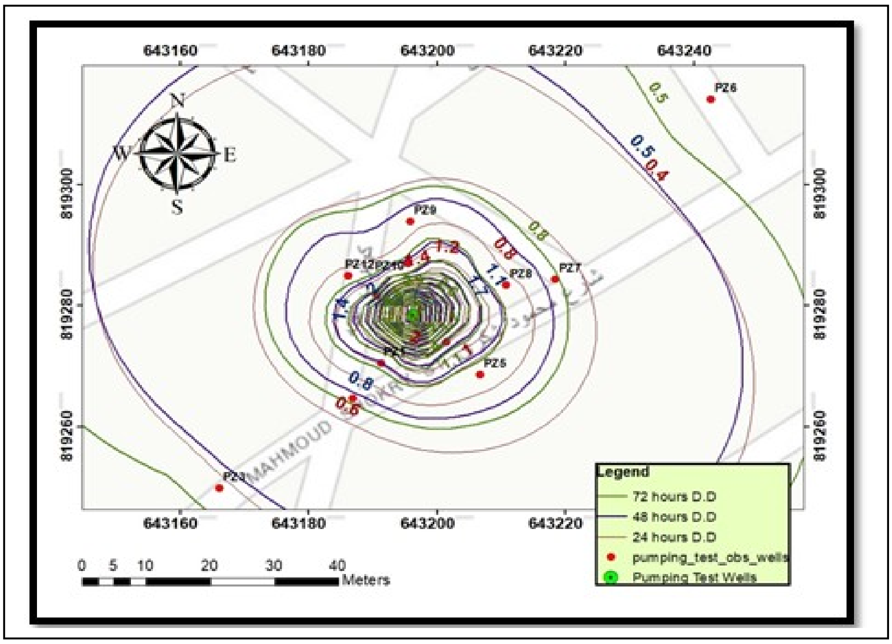

Figure 7: Location of pumping well and surrounding piezometers. And drawdown contouring map according to continuous pumping for 3 days

2.5 Groundwater numerical modeling

Numerical models play an essential role in simulating the aquifer system. As, it can easily predicts the efficiency of any proposed solution for different problems. GMS is an three dimensional advanced groundwater numerical modeling software that operates through USGS mudflow code. The modeled area was about 8000 * 4500 * 100 meter in x, y & z direction respectively. The model mesh was 160, 90 and 2 in x, y and z direction. The topographic levels were measured through ground surveying. The soil layers and stratification were obtained from the drilling data and hydrogeological maps. The first layer is a clay cap with 7m thickness and intercalated by sand lenses. The second layer is the quaternary aquifer layer which consists of sand and gravel. All actual extraction rates were applied to the model. The model boundary condition in north west was considered constant heads depending on the radius of influence results of simple analytical models. The model was calibrated in a steady state condition taking in consideration, the existing dewatering system in the modeled area. the simulated model was calibrated against the measured field groundwater levels, recorded from the piezometers. Figure 8 indicates strong matching between calculated and measured groundwater heads.

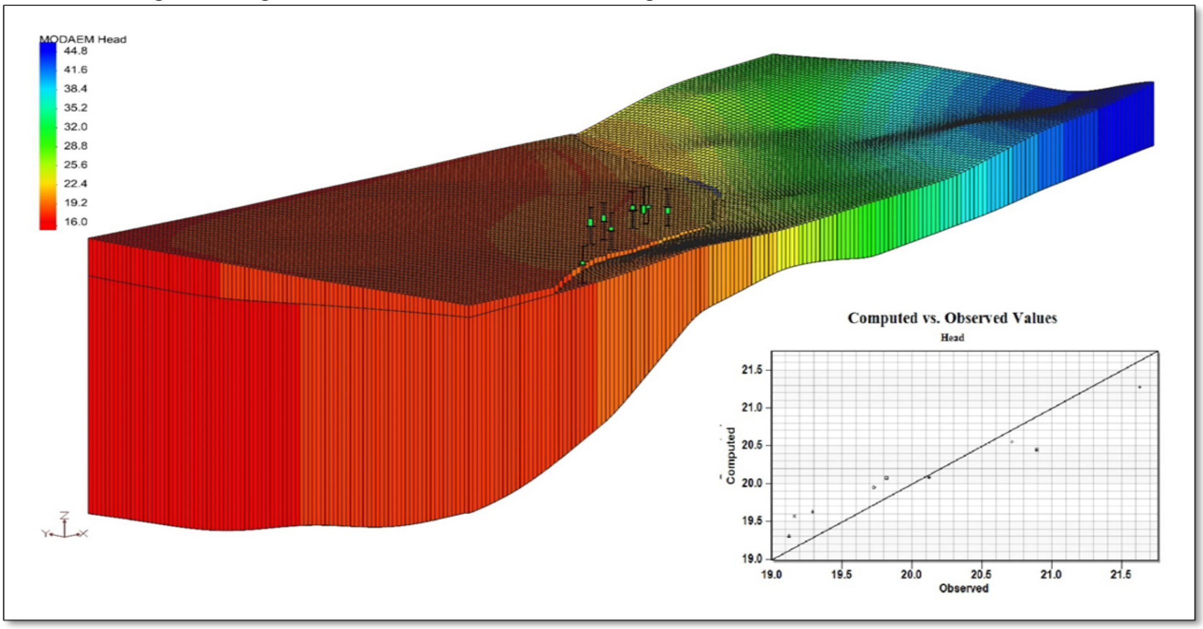

Figure 8: 3D modeled area using GMS code and calibration chart indicates the relation between calculated and measured groundwater heads.

3. Results and discussion

The government is exerting efforts to solve the traffic congestion inside the capital. Turning Misr Elgadida metro line to a road is one of the most effective alternatives for solving traffic congestion in the area through one of the two alternatives for turning process; the first is to construct the new road at the same level for the old metro line, or the second is to fill the metro line to construct the road at the ground level. The old metro line level is lower than the ground level by five meters and acts as an open drain, collecting groundwater from the area. six pumps are settled inside the track discharging about 30,000 cubic meters / day. And whenever those pumps stop for any reason, most of adjacent buildings get submerged by water. Evaluating the two proposed solution from efficiency, environmental effect and cost perspectives is needed, to determine the pro and cons for each alternative. From the efficiency perspective, the two proposed alternatives will solve the traffic congestion. However, the second alternative allows an increase in the road width more than the first one, as the inclined sides of the tunnel in first alternative decreases the width of the new road. Hence, according the alternatives efficiency the filling solution will be more effective than the first one. From the environmental and cost perspective; it was important to investigate the hydraulic features of study area, to determine the required components for controlling the water table levels needed for the proposed solutions. Also, to calculate the initial and running cost for the solutions. From the detailed hydrogeological investigation, it shows that the nearest monitoring point indicates 0.7-meter rise in groundwater levels over the last 40 years, and indicates a fluctuation range of 0.50 m through five years step. The increase in groundwater levels are resulted from change in recharge. From assessing the hydrogeological setting of the main aquifer (the quaternary aquifer), it is recharged from two sources; 1) leakage from excess irrigation in agriculture areas, canals and drains that covers most of the aquifer, 2) leakage from water networks losses and gardens irrigation in residential area. The effect of the first source is seasonal as it depends on crops types and water distribution plan in canals that covers the area. However, the effect of the second is continuous in residential areas. The fluctuation is mainly because of the first source, but the increase in level is because of the two recharge sources.

The topographic levels in the area shows significant inclination in ground levels from the south east to north west direction, almost in the perpendicular direction for the metro track. And for that reason, the track acts as an open drain cutting the leakage water flow lines. The geological setting shows that, the study area is limited from south east direction by limestone escarpments (Eocene and cretaceous). The water flows in similar types of soil in the vertical direction by gravity till reaching the impermeable layer then it flows with soil layer inclination. In the current study, the water table levels and flow direction take the same topographic gradient. Moreover, the leakage from the drinking and sanitary networks, and landscape areas from Al-mokatam and Naser city districts, east of the study area, flows subsurfacely in an inclined pathway to the study area. The groundwater levels and the flow direction prove the only source of recharge to the aquifer is from the network's leakage in the study area. From RIGW database, an observation point, located at 1.50 km from the study area, recorded a measured TDS value of 743 ppm, in 1980; showing a matching TDS with quaternary groundwater quality. However, a second point recorded TDS values from 3300 to 5000 ppm through 80th to 90th of last century, near the study area. Currently, the measured TDS in the study area is ranging between 8000 to 10000 ppm for shallow groundwater; and reaches 12700 ppm from the deep groundwater. The sample analysis indicates that no bacterial pollutants in the collected samples, and that the predominant salt is sodium chloride. Hence, the cause of the salinity increase in groundwater is the upward leakage from the deep layers in the aquifer, and from leakage of water networks in the higher surrounding areas in the south east; which dissolves the natural salts from soil and transport it to the lower deteriorated zones. The second assumption is more accurate, as there is no deep aquifer in this area. Most likely, the bacterial pollutants faded in the high salt content in the water and with transport time.

One of the essential components of this research, is to assess the groundwater recovery in case of total pumps failure. The results indicated that instantaneous water table rise all over the area in case of pumping failure; reaching to 1.7 m increase in water table level in 24 hours inside metro track. The groundwater levels and the water table show direct hydraulic connection between them. Moreover, the short recovery time indicates high permeability of soil layers; which matches the pumping test results.

The groundwater model was used to test the possible proposed alternatives to control the water table levels and solve the traffic congestions. The two alternatives were: applying dewatering system or filling the metro line.

A. Dewatering system

The suggested dewatering systems to control the water table are dewatering wells or side ditches. And here as the two systems are discussed and assessed.

Pumping wells

The first alternative is using pumping wells. The model was used to test the system to achieve a drawdown of 1 m below the new road. The model revealed that a number of 120 pumping wells with average depth 20 meter are required to achieve the required drawdown. The system is designed as follows: 60 wells at each side at distance of 20 m apart and average extraction rate for each well is 40 m^3/ hr. The components of the proposed system (wells pipe, water rising pipe line and pumps etc.) must endure high salinity that reaches 12000 ppm. pumping well dewatering system is one of the most effective techniques that controls the groundwater level. However, it has negative effects on building stability in the surrounding area. Moreover, implementation of this system and drilling the wells may be difficult due to high urbanization density and heavy traffic. In addition, also, the system requires permanent source for power supply. Finally, the tremendous amount of collected cannot be discharged to the overloaded sewage network and cannot be used due to its high salinity except in limited usages.

Side ditches

The second dewatering system is suggested through cutting the flow line by sheet piles from the two sides and constructing two side ditches at the sides of the metro line track. The simulated sheet piles depth is designed 5 m depth to cut the flow line and decrease the leakage water volume to the metro line; with two concrete side ditches at the two sides with 1300 m length and 0.2 % slope to collect the leakage water from metro line to underground tanks. Five concrete underground concrete tanks, with dimensions:10 m length *2 m width *4 m depth, at distance not more than 220 meters are needed to collect the leakage water. This system can solve the problem for the metro line, moreover, it can be easily constructed without disturbing the traffic in the area. Nevertheless, there would be no risk on the building stability in the dewatering area. The disadvantages of the current system are: difficulty of constructing the sheet piles in old coating reinforced concrete present in metro line, and it will only solve the problem at the metro line track but not the entire study area.

B. Backfilling the metro line

The last tested solution is to fill the unused metro line track and replace it with a road at the same ground levels as the surrounding roads and streets; without conducting any dewatering processes inside the area. And all the surrounding deteriorated buildings located in the area can construct separate / standalone dewatering systems. This solution is very simple and easy in construction, also, it allows increase in road width, with no running cost for operation and maintenance. However, it will not contribute in solving the groundwater rise problem and it requires modification of bridges and roads, in terms of ground levels, in the study area.

Initial and operational costs are estimated for each proposed solution. Table 1 presents the estimated costs.

Table 3: Comparison between proposed solution cost

No	Proposed Solution	Initial Cost	Operational Cost / year
1_a	Dewatering wells	30,000,000	2,500,000
1_b	Side ditches	45,000,000	1,000,000
2	Filling solution	15,000,000	0

The table shows that from cost aspect the filling solution is the cheapest in terms of initial and operational costs. However, the side ditches are the most expensive solution in term of initial cost. The dewatering wells initial cost is lower than the side ditches but the operational and maintenance costs is high. Finally, in terms of operational solution, the most expensive solution is the pumping well then, the side ditches and the cheapest one is the filling solution.

According to the previous analysis, and in order to decide the best proposed solution; impact assessment weighing is conducted. All problem factors are weighted according to its contribution degree in solving the problem. Then, each proposed solution is graded from 0 to 10 according to its efficiency in the item. The results of the weighted assessment are listed in table 3. And as per the weighted impact assessment conducted, the most effective solution is the filling solution.

Table 4: The results of weighted impact assessment for the proposed alternatives.

Factor	Weight	Dewatering Wells		Side Ditches		Filling Solution	
		Grade	Efficiency	Grade	Efficiency	Grade	Efficiency
Efficiency	40%	9	3.6	9	3.6	10	4
Initial Cost	5%	5	0.25	2	0.1	10	0.5
Running Cost	15%	1	0.15	5	0.75	10	1.5
Extracted Water volume	10%	2	0.2	4	0.4	10	1
Building Stability	15%	2	0.3	6	0.9	10	1.5
Lowering GW In Area	10%	10	1	3	0.3	0	0
Construction Feasibility	5%	2	0.1	5	0.25	10	0.5
Total	**100%**		**5.6**		**6.3**		**9**

4. Conclusion

Egypt's growing population has driven the government to develop effective solution to accommodate the heavy traffic densities and solve the increased traffic congestion in the capital. Turning Misr Elgadida metro track to a road that links Manshet Elbakry and Emtidad Ramsis areas is among the proposed effective solutions for the problem. The metro line track ia an open channel tunnel at the intersection with Elfangary street. The tunnel acts as an open drain collecting the shallow groundwater in the study area. And the water were being pumped by 6 pumps from the tunnel and discharged to the sewage network in the area. This research investigated the optimum solution for the groundwater rising and the need to establish a new road. The comparison between the two proposed solution was conducted. The first is to fill the tunnel and construct the road at the same ground level, and the second was to keep the tunnel and construct suitable dewatering system to control the groundwater level at desired levels, either by pumping well system or side ditches. Weighted impact assessment for different proposed alternatives is assessed. Appropriate weighting is given to each factor included in the assessment; which are efficiency, initial and operational costs, extracted water volume, evaluating environmental effect on groundwater and building stability and finally construction feasibility. each grade is then multiplied by the appropriate weighting, giving a weighted grade. Field investigations and numerical model were conducted to identify the suitable solution. The results indicate that the source of water is the leakage from drinking and sewage networks in the elevated ground levels residential areas to east then, which during its flow in the soil dissolves salts and transport it to study area increasing the salinity of the aquifer to 12000 ppm. According to the conducted pumping tests, the aquifer shows high productivity in the study area and very rapid recovery time. As per the tested alternatives, both dewatering systems, pumping wells or side ditches, are expensive and unfeasible in the current case. However, the filling solution can be more effective from the perspective of accessible road width. Moreover, it has the lowest cost which are estimated with 15 million, initial cost without operational costs. In addition, there would be no hassle in dispose huge amount of water; as it will be drained naturally to the aquifer. Also, there is no concern about building stability and very easy to be constructed. The only disadvantage is the negative impact on the groundwater level rise in adjacent buildings, which can be managed by constructing separate dewatering system for each threatened building.

Finally, it is highly recommended to rehabilitate and replace the drinking and sanitary water networks in the capital to minimize the seepage and losses percentage of the transported water. Moreover, legislation and strict supervision on prevention of flood irrigation systems in landscape area and parks in the capital, especially which are located in high elevated lands.

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