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Numerical Modelling of Waterlogging Problem in New Urbanized Communities in Al-Qairawan area, Kuwait

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ABSTRACT
Expanding the urbanization of new communities within the limited low flat desert surfaces of Al-Qairawan area, Kuwait has started to face the continuous growth of population. The traditional urbanized logged areas affect urbanization of these flat desert surfaces as a result of the difference in the topographic level, inadequate drainage system and the existence of inland Sabkhas beside shallow-depth clay lenses beneath these sites. Moreover, the soil water depths vary from few centimeters below ground surface to 5.5 m and the soil-water moves generally from the southwest to the northeast towards the Arabian Gulf. The present paper threw light on a trial to mitigate the waterlogging problem due to the bad use of water resources in Gardening-irrigation activities in the relatively high-land areas of the present traditional urbanized communities in Al-Qairawan area applying mathematical modeling. The groundwater flow model, Visual MODFLOW v.3, was used to test the reliability of the proposed solution for mitigation and its limitation. Three proposed scenarios for mitigation of waterlogging problem were checked. Decreasing the soil water level using wall sheet system was proposed as a first scenario. The second scenario proposed suitable dewatering system while the third one assumed the construction of transverse open drainage system in the southern boundary of the study area. The results showed that the third scenario was the best solution since it reflected both the lowest soil water level (2.72m) and least cost economically (146250 Kuwait-Dinar). Accordingly, the solution concerning soil water rise control in the study area through applying the construction of transverse open drain in the southern boundary of the study water logged area is highly recommended.

Keywords: Hydrogeology, Water logging problem, Visual MODFLOW, Cost benefit ratio, Kuwait

I. 1-INTRODUCTION

Waterlogging problem is age-old nemesis of both urbanized areas and irrigated agriculture, and it continues to plague urbanization development and irrigated regions around the world. In fact, about 25% of the world's irrigated land is affected by waterlogging and salinity due to saline high water tables (Tanji 1990, Ghassemi et al. 1995). It has been estimated that 2.5 to 5 million acres of mostly prime agricultural land are becoming severely damaged through irrigation-induced salinization each year (Umali 1993, Kovda 1983). Ghassemi et al. (1995) estimated that worldwide productivity loss is valued at about $10 billion per year. Also, concern is strong regarding possible long-term damage to the environment from downward percolating waters, return flows to rivers, and disposal of saline drainage water.

In addition, the special adherence to the water logging situation in the metropolitan cites on the world , there are so many examples and case studies has been done like in Bangladesh , the Teknaf urban area are affected by internal rain fed flood, this project also provide some recommendation to get rid of this stations (Anisha et al., 2014). Another case study has been made in Dhaka, the capital of Bangladesh have also faced the problem of water logging due to poor urban drainage problem which impact on the population by environmentally (water pollution, Water borne diseases etc) and socially (disruption of traffic , disruption of normal life, etc) (Alom et al., 2014). In India a case study has been drawn over four metropolitan cities like Kolkata, Chennai, Delhi and Mumbai, about the urban flooding from the period of 1988 to 2007 (Roy and Dhali, 2016). They have identified the reasons and showed how the people are impacted in this situation and provide some recommendation (Singh et al., 2013).In Egypt, the results of mathematical modeling studies concluded that the dewatering system is the most prefer method for water logging problem (Attia, 1989, Gad, 2000, Sakr, et. Al., 2002, El-Rayes and Geriesh, 2002, Gad, 2004, El-Hefnawy, et al., 2006, Saafan, et al. 2009, El Sheikh et. Al., 2013, and Kaiser et al., 2013).

In Saudi Arabia, El-Nimr 1991, 1994 & 1995 studied the impact of groundwater rise on the infrastructures in Al-Riyadh applying mathematical modeling. In Kuwait, Al-Rashed, et al. (1998)

mentioned that the groundwater level rises by about 3 m in urban areas which threatening the integrity of several buildings and roads. So, the best solution of water logging problem in Al-Qairawan Urbanizes Logged Area (AQULA), Kuwait can be formulated in different ways but the basic approach in this work is to use simulation models to identify strategies that come close to maximizing economic net benefits over AQULA (Gates and Grismer 1989, Gates, Wets, and Grismer 1989, Grismer and Gates 1991, Garcia, Manguerra and Gates 1995).

1.1-Site Description and Climate

AQULA is located west of Kuwait city by about 30 Km and south of Arabian Gulf by about one Km (Fig.1). It is limited between latitudes 3240290 and 3253453 due North and longitudes 758015 and 779143 due East with an area of about 278 Km2. A strip of about 3 Km wide separates AQULA from Arabian Gulf. From west, Al-Jahra table land area bounds AQULA while from the north, Arabian Gulf forms the northern boundary of AQULA. The climate of Kuwait can be divided into two main seasons, hot with temperature ranges between 46 ^{o}C and 50 ^{o}C and from 20 ^{o}C to Zero ^{o}C during winter months (November through March). The mean annual precipitation was about 115 mm, and the monthly average 9.6 mm while the mean daily Pan-A evaporation rate recorded varied from 4.7 mm in January to 31 mm in July, with an average mean daily rate of 16.6 mm (Safar 1985).

1.2 Geomorphological Setting

AQULA is classified into four geomorphological units, Coastal hills, Sand dune fields, Flat desert surfaces and Wadis (Al-Sarawi 1982, El-Baz & Al-Sarawi 1996 & 2000, Al-Sulaimi and Al-Ruwaih 2004) (Fig.2). The coastal hills occupy the northern and southern parts of Kuwait, which are a hard, flat desert with shallow depressions and small conical hills with an average height of about 40m. The sand dune fields and dust accumulation pattern occupy an area covering 350-500 km^{2}. The highest rates of sand transport occur across this region. Flat desert surfaces cover most of the lowland of southern Kuwait, and are controlled by wind action. The surface topography reflects a long period of deflation. Wadi Al-Batin is a large valley that forms a natural boundary between the State of Kuwait and the Republic of Iraq and varies in width from 7 to 10 km with relief up to 57 m. The wadi extends over a distance of 180 km in Kuwait.

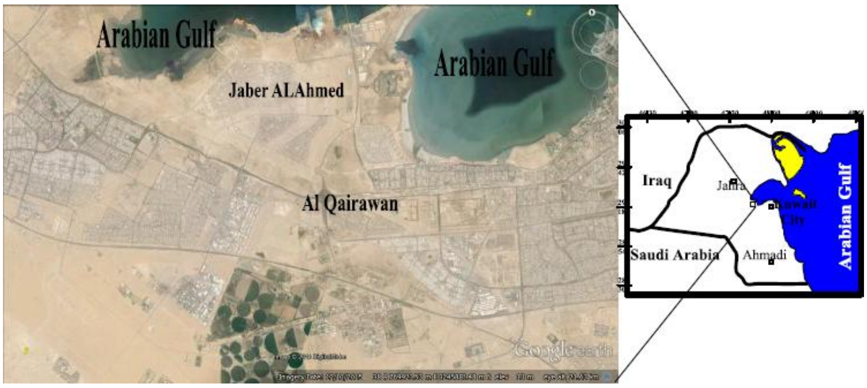


Fig. 1: Location map of the study area

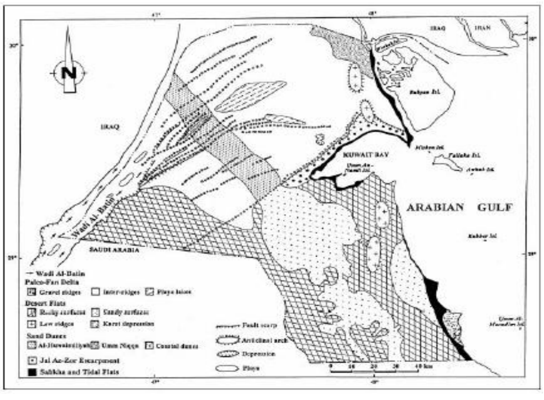


Fig. 2: Geomorphic provinces of Kuwait (after El-Baz & Al-Sarawi 2000)

1.3 Geological Setting

The details of the geology of rock units of AQULA have been presented by Owen and Nasr (1958), Milton (1967), Fuchs et al. (1968), Burdon and Al-Sharhan (1968), Omar et al. (1981), Clarke (1988), Al-Sulaimi (1988), Amer et al. (1989), Al-Sulaimi and Pitty (1995), Mukhopadhyay et al. (1996), Al-Sulaimi and Mukhopadhyay (2000), Al-Sulaimi and Al-Ruwaih (2004) as well as the geologic maps and landsat images (El-Baz & Al-Sarawi 2000) in addition to field investigation (Fig.3). Based on these studies, the main lithostratigraphic units forming the bedrock of Kuwait are unconsolidated to semi-consolidated clastic sediments of the Kuwait Group (post-Eocene Age), which unconformably overlies the dolomitic Dammam Formation of the Eocene Age. The surface of Kuwait is predominantly covered by Quaternary sediments which include Pleistocene gravel and sand of the upper member of the Dibdibba Formation and Holocene sediments including marine sand, coastal deposits, beach rocks, sabkha deposits, desert floor deposits, alluvium and aeolian sands.

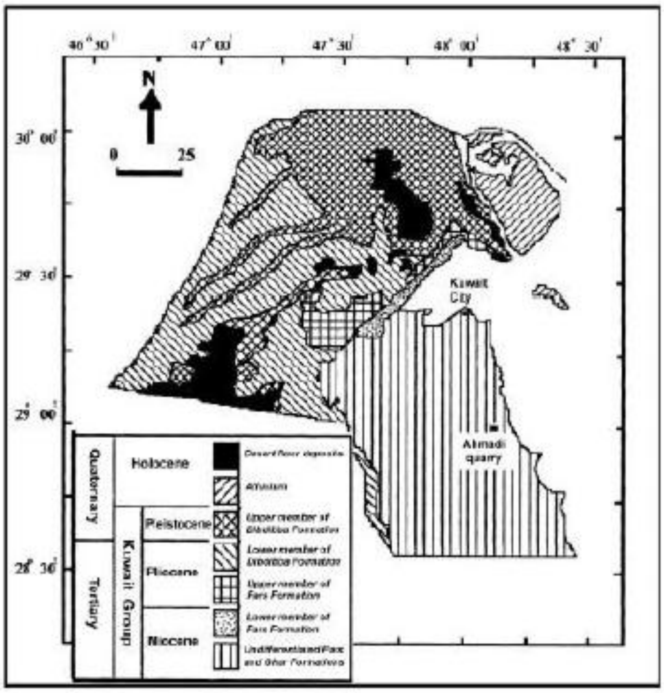


Fig. 3: Simplified surface geological map of Kuwait (after HGG 1981)

Structurally, Kuwait lies on the Arabian Shield, an area noted for its stability since the Cambrian period. The Shield tilts slightly to the northeast, giving rise to sedimentation of the Arabian Shelf, and consists of a sequence of laterally extensive, but thin limestones, marls, shales, sandstones and evaporites. Tertiary geological events in Kuwait influenced the present lithology, depth, thickness, and geometry of the major rock units in Kuwait (Fig.4).

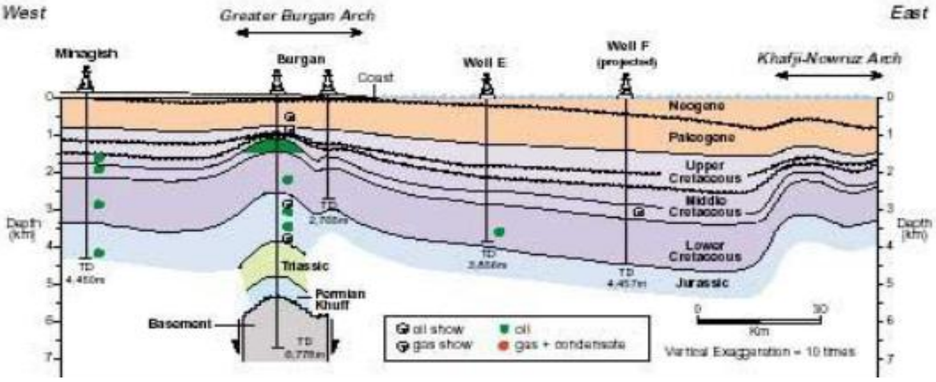


Fig.4: Geological cross section of Kuwait off shore and coastal area.

Pre-Neogene (pre-Miocene) movement shaped the configuration of the Paleocene - Eocene (Paleogene) rocks of the Hasa Group and determined the geometry of the pre- Neogene unconformity surface, on which the Kuwait Group was deposited.

1.4 Hydrogeological setting

The aquifers in Kuwait discussed in this study occur in the Dammam Formation and the Kuwait Group. Their lithological characteristics and depth are functions of geological sedimentation, deformation and erosion. Thus, the previous studies of the lithology, stratigraphy, structure, and regional geology of the area are essential to understanding the hydrogeology of AQULA. Moreover, salinity distribution, water types, water genesis and the condition of saturation with respect to most common minerals of the aquifers was studied. On the other hand, the hydrological conditions include the occurrence of a thick net of Gardening-irrigation system and presence of huge surface water bodies; e.g. Al-Qairawan lake. Besides that the Quaternary aquifer is poor in hydraulic properties where the porosity ranges from 5% to 20% (GII, 2010) while the transmissivity, hydraulic conductivity and storativity values were estimated by reanalyzing the available raw data of pumping test recorded by (GII, 2010) applying Jacob's straight line method (Cooper and Jacob, 1946) (Fig. 5 and Table 1). It ranged from 17 to 71 m/day. The highest estimated transmissivity value reaches 1998 m2/d while the storativity reaches 0.00018. The groundwater rise reaches 0.8 m/year. Moreover, the soil water depths vary from few centimeters below ground surface to 5.5 m and the groundwater moves generally from the southwest to the northeast towards the Arabian Gulf.

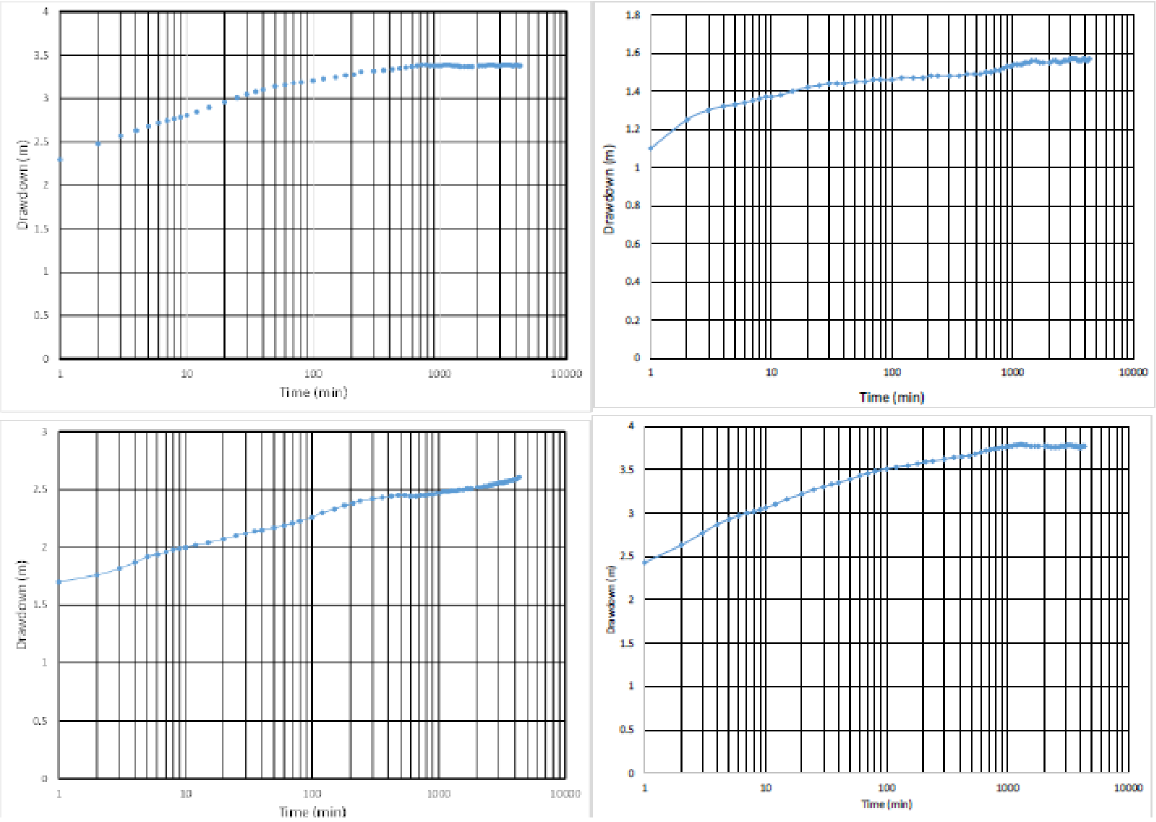


Fig. (5): Field data curves for observation wells JB-A JB-B JB-C, and JB-D.

Table 1. Hydraulic parameters of Kuwait Group aquifer at AQULA

Location	X (UTM)	Y (UTM)	Q (m^3/d)	T (m^2/d)	K(m/d)	Ss
JB-A	769,617	3,247,120	916.47	987.56	35.27	1.8 x 10^{-4}
JB-B	768,828	3,247,669	916.47	466.18	16.64	1.8 x 10^{-4}
JB-C	770,069	3,248,464	654.62	1997.9	71.35	1.8 x 10^{-4}
JB-D	770,016	3,248,400	916.47	645.48	23.05	1.8 x 10^{-4}
JB-E	767695	3250053	589.16	263	17	1.8 x 10^{-4}

II. MATERIAL AND METHODS

The materials used in this paper were collected through carrying out four field trips in AQULA during the period 2015-16. A network of five well distributed observation wells penetrating the Quaternary aquifer in AQULA was chosen for periodic recording of soil water level during the year 2015. Installation of three Micro Divers inside three observation wells required for soil water pressure periodic monitoring beside one Baro Diver for recording the Barometric pressure were done during these field trips. The periodic monitoring of the soil water level was carried out automatically every 5 minutes. In the end of the time record interval the records were downloaded by Diver-Office 2012.1 software program (Fig. 6).

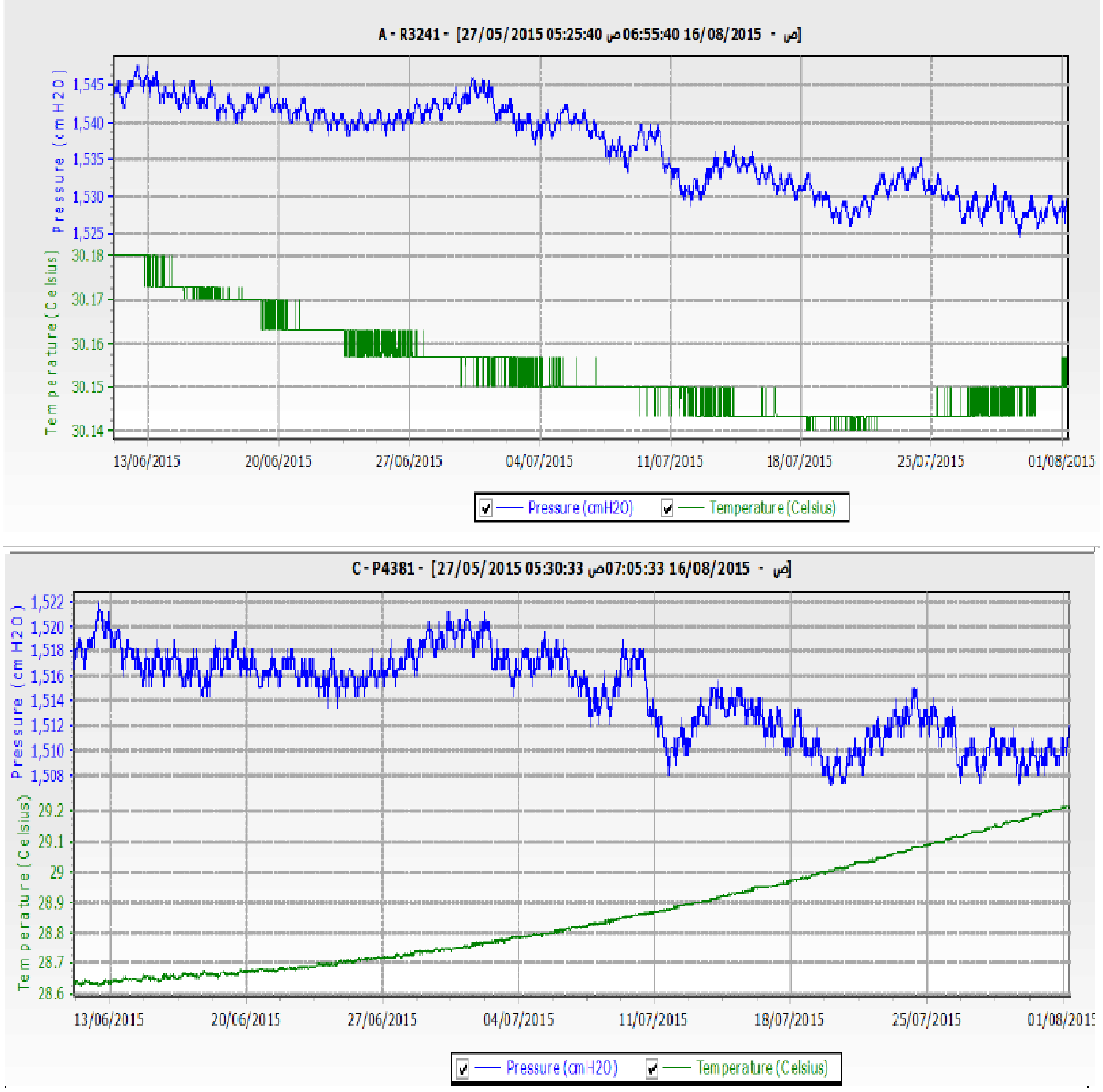


Fig. 6: The recorded groundwater fluctuation in piezometer A (upper) and piezometer C (lower) in AQULA

To calculate the water level in relation to a vertical reference datum using the Diver and Baro-Diver's measurements, Figure (7) represents a typical example of a monitoring well in which a Diver has been installed. In this case, the height of the water level (WL) in relation to the vertical reference datum is measured. If the water level is situated above the reference datum it has a positive value and a negative value if it is situated below the reference datum.

The top of casing (TOC) is measured in relation to the vertical reference datum and is denoted in the diagram below as TOC cm. The Diver is suspended with a cable with a length equal to CL cm. The Baro-Diver measures the atmospheric pressure (Pbaro) and the Diver measures the pressure exerted by the water column (WC) and the atmospheric pressure (PDiver). The water level (WL) in relation to the vertical reference datum can be calculated as follows:

$$WL = TOC - CL + 9806.65\frac{p_{Diver} - p_{baro}}{\rho \cdot g} \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

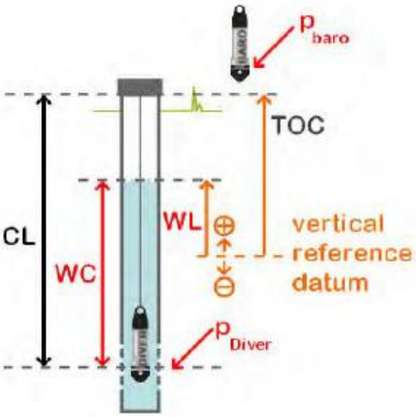


Fig. 7: Schematic diagram for water level calculation from Diver data

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)-W=S_S\frac{\partial h}{\partial t} \quad \ldots\ldots\ldots\ldots\ldots(2)$$

In addition, the methodological approach used in this paper is based on the mathematical modeling techniques. Characteristics of the water logging problem in AQULA and its spatial and temporal variation, as well as its future behavior, were thoroughly investigated by means of numerical code (Visual MODFLOW, McDonald and Harbaugh1988). Visual MODFLOW (v.3) was applied to calibrate the physical parameters for the flow mechanism, and the initial conditions for flow were evaluated accordingly. The model describes groundwater flow under non-equilibrium conditions in a heterogeneous and anisotropic medium according to the following equation (Bear, 1979 and Bear & Verruijt 1987):

Where Kxx, Kyy, Kzz are values of hydraulic conductivity along the x, y and z coordinate axes (LT^{-1}); h is the piezometric head (L); W is a volumetric flux per unit volume and represents source and/or sinks of water (T-1); Ss is the specific storage of the porous material (L^{-1}) and t is time (T).

Construction of the groundwater flow model

The conceptual model of AQULA was based on the geology of the AQULA which was comprised Quaternary Kuwait Group sediments. The hydrogeologic system was concerned one aquifer with one complex layer that is composed mainly of very fine to coarse sand with 18 m thickness (Dibdibba Formation). Thin siltyclay layer of 3 m and sometimes sandy clay covers the water bearing Formation all over the AQULA while the bottom layer of this aquifer consists of clay and shale with 3m thickness. This Quaternary groundwater aquifer occurs under the confining and semi-confining conditions and is characterized by lateral and vertical facies changes. The groundwater flows generally from the south and southwest to the north and northeast. The main recharging source is the seepage from the surface water of irrigated gardens while the main discharging source is the draining to the Arabian Gulf.

The simulation procedure was started by dividing the AQULA domain into a suitable grid pattern of 6300 cells (60 rows and 105 columns). The top and the bottom of the aquifer layer and the boundary conditions were assigned to this grid (Fig.8). The model domain with flow boundary conditions was chosen to cover an area of 278 km^2. The modeled AQULA is surrounded by General-flow boundary (pre-scribed head) from south and southeast in which the general groundwater head of 55 masl is present (Fig.8). This area is considered as groundwater recharge area. In the other side, the constant head boundary is obvious in the northern boundary of the AQULA due to the fact that the previous mentioned Arabian Gulf in the northern part of the studied area is very large and water head in it is relatively constant all over the year (Fig.8). Moreover, model geometry includes top and bottom of the aquifer layer. The top aquifer layer is extracted from DEM file (90x90m) of the AQULA while the bottom layer is generated by subtracting the aquifer thickness (18m) from the top aquifer layer data. The groundwater system is built by assigning the horizontal hydraulic conductivity (m/day) and the Transmissivity values (m^2/day) (Table 1) beside the initial hydraulic heads (m) (Fig.9) to the model grid by the previously mentioned method.

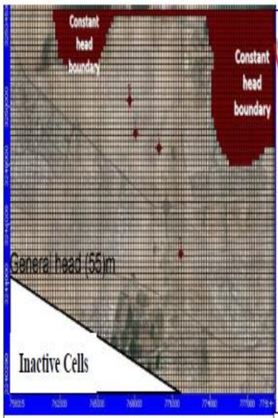


Fig. 8: Model grid and boundary conditions

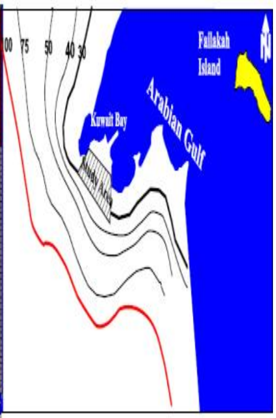


Fig 9: Initial groundwater level at 2010

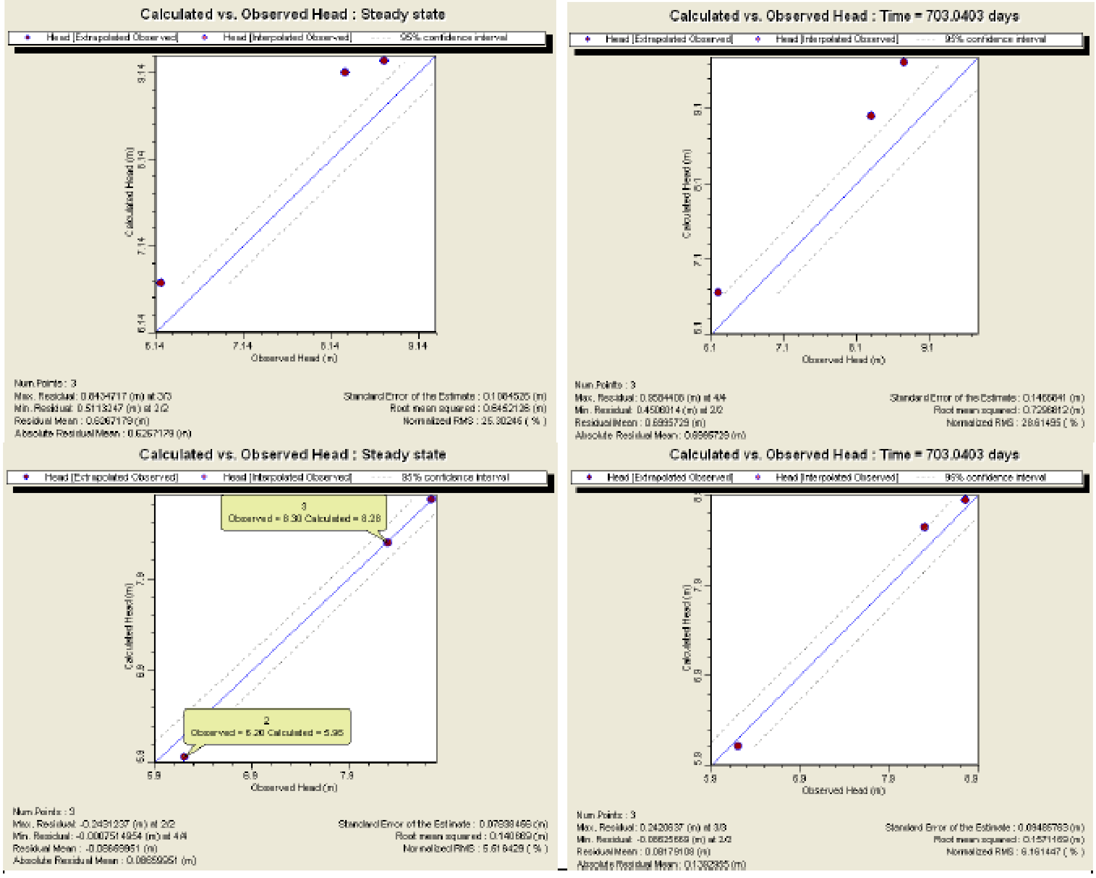
After the complete entering of the data required for building the model, it is allowed to run. If there is a convergence, an input data error is present which should be repaired time after time until the running process goes successfully.

Model calibration

Calibration is an essential step that makes simulated heads, match the actual measurement values with an acceptable range of error. Trial-and-error method is used in calibrating the Quaternary aquifer model of AQULA due to the great variations in K-values and T-values. Three piezometers' data are used to check the relation between the calculated and observed heads. After many times of changing the k values, the variance between the observed and calculated heads in case of steady state calibration was minimized and the normalized root mean squares (RMS) was decreased from 25.5% to 5.51% while it was decreased from 28.61% to 6.16% in case of unsteady state calibration by changing the Ss values (Fig. 10). The model was calibrated in steady state based on the soil water level in year 2010 (Fig.9) and in transient state according to the groundwater levels recorded by the Divers at 2015. Subsequently, good agreement between observed and calculated water levels had been reached.

Testing scenarios

After completing the stage of calibration, the output of the first round was used to replace the initial condition with the condition of studying the best scenario of water logging control. Among the methods of water logging control, three testing scenarios were chosen (Wall sheet scenario with three proposed cases, Dewatering scenario with two cases and Open Drain scenario with two cases). The first proposed case in Wall sheet scenario lies in the north of the logged area with depth of 9 m and length of 5 km while the second proposed case surrounds a lake in the south of the logged area and the third one lies in the south of the logged area. Otherwise, the first proposed case of dewatering scenario lies in the north of the logged area and supposes 20 dewatering wells with discharge rate of 2400 m^3/day/well while the second one lies in the middle of the logged area with discharge of 1500 m$^{3/}$day/well. In addition, the first location of the proposed Drain based on the third scenario incorporates the southern part of AQULA while the second proposed location of Open Drain is due NE.



Num Points : 3
Max. Residual: 0.8434717 (m) at 3/3
Min. Residual: 0.5113247 (m) at 2/2
Residual Mean : 0.6267179 (m)
Absolute Residual Mean : 0.6267179 (m)
Standard Error of the Estimate : 0.1064526 (m)
Root mean squared : 0.6452126 (m)
Normalized RMS : 25.30246 (%)

Num Points : 3
Max. Residual: 0.8584406 (m) at 4/4
Min. Residual: 0.4508014 (m) at 2/2
Residual Mean : 0.6995729 (m)
Absolute Residual Mean : 0.6995729 (m)
Standard Error of the Estimate : 0.1466841 (m)
Root mean squared : 0.7296812 (m)
Normalized RMS : 28.61495 (%)

Num Points : 3
Max. Residual: -0.2431237 (m) at 2/2
Min. Residual: -0.000751 4954 (m) at 4/4
Residual Mean : -0.08669851 (m)
Absolute Residual Mean : 0.08659051 (m)
Standard Error of the Estimate : 0.07838466 (m)
Root mean squared : 0.140889 (m)
Normalized RMS : 5.618428 (%)

Num Points : 3
Max. Residual: 0.2420837 (m) at 3/3
Min. Residual: -0.08625669 (m) at 2/2
Residual Mean : 0.08179108 (m)
Absolute Residual Mean : 0.1362865 (m)
Standard Error of the Estimate : 0.09466763 (m)
Root mean squared : 0.1571169 (m)
Normalized RMS : 6.161447 (%)

Fig. 10: Steady (left) and unsteady (right) state calibration results of the modeled area

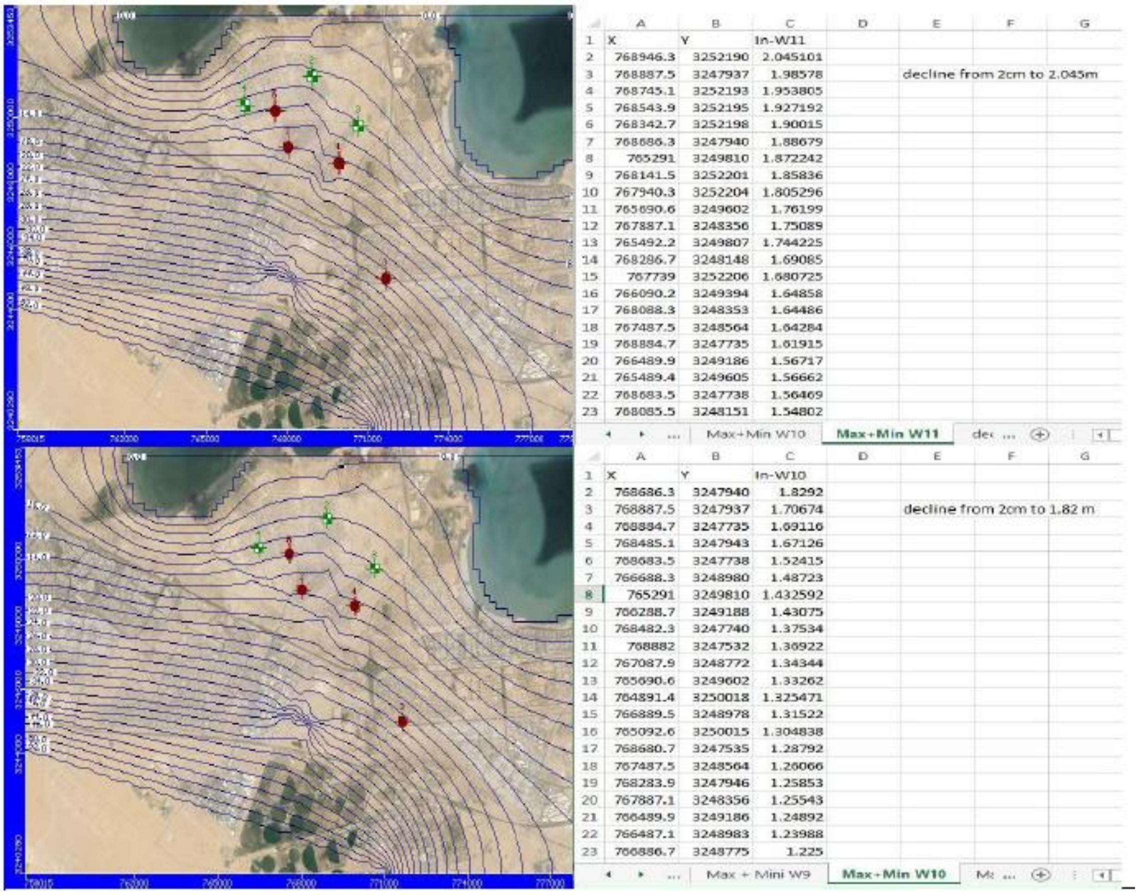
III. RESULTS AND DISCUSSION

According to the groundwater level measurements (Table 2) the groundwater levels raised from 5.3 masl in Pizometer No. JB-B to 6 masl and from 5.8 masl in Pizometer No. JB-A to 6.2 masl with an increase of 0.7 m/year and 0.4 m/year respectively. Moreover, the water table map at 2010 (Fig. 9) shows the curvature of contour lines relative to the directions of the irrigation network which indicates that the irrigated-Gardening network acts as influent streams (recharge areas) in both southern and eastern boundaries, while it operates as effluent streams (discharging areas) in the northern part. Moreover, there is a remarkable rise in groundwater levels in the middle and western parts of the flat areas indicated by the concentric contour lines. This local rise may result either from the downward seepage from the irrigation water or the upward leakage from underlying aquifers (fractured limestone).

Table 2: Records of groundwater levels in AQULA during the interval 2015-2016

Water Level above sea level in meter at AQULA (2015-2016)			
Pizometer No.	May 2015	**August 2015**	**April 2016**
JB-A	5.8	6	6.2
JB-B	5.3	5.8	6
JB-C	5.5	6	6.3

In addition, the results of simulation model show based on the first scenario which proposed wall sheet barrier with thickness 15cm and depth 11m below ground surface to change groundwater direction far from waterlogged area caused water table decline of 2.2m (Fig. 11).



	A	B	C	D	E	F	G
1	X	Y	In-W11				
2	768946.3	3252190	2.045101				
3	768887.5	3247937	1.98578		decline from 2cm to 2.045m		
4	768745.1	3252193	1.953805				
5	768543.9	3252195	1.927192				
6	768342.7	3252198	1.90015				
7	768686.3	3247940	1.88679				
8	765291	3249810	1.872242				
9	768141.5	3252201	1.85836				
10	767940.3	3252204	1.805296				
11	765690.6	3249602	1.76199				
12	767887.1	3248356	1.75089				
13	765492.2	3249807	1.744225				
14	768286.7	3248148	1.69085				
15	767739	3252206	1.680725				
16	766090.2	3249394	1.64858				
17	768088.3	3248353	1.64486				
18	767487.5	3248564	1.64284				
19	768884.7	3247735	1.61915				
20	766489.9	3249186	1.56717				
21	765489.4	3249605	1.56662				
22	768683.5	3247738	1.56469				
23	768085.5	3248151	1.54802				

	A	B	C	D	E	F	G
1	X	Y	In-W10				
2	768686.3	3247940	1.8292				
3	768887.5	3247937	1.70674		decline from 2cm to 1.82 m		
4	768884.7	3247735	1.69116				
5	768485.1	3247943	1.67126				
6	768683.5	3247738	1.52415				
7	766688.3	3248980	1.48723				
8	765291	3249810	1.432592				
9	766288.7	3249188	1.43075				
10	768482.3	3247740	1.37534				
11	768882	3247532	1.36922				
12	767087.9	3248772	1.34344				
13	765690.6	3249602	1.33262				
14	764891.4	3250018	1.325471				
15	766889.5	3248978	1.31522				
16	765092.6	3250015	1.304838				
17	768680.7	3247535	1.28792				
18	767487.5	3248564	1.26066				
19	768283.9	3247946	1.25853				
20	767887.1	3248356	1.25543				
21	766489.9	3249186	1.24892				
22	766487.1	3248983	1.23988				
23	766886.7	3248775	1.225				

Fig 11: Predicted ground water contour maps applying wall sheet scenario with 11m depth (upper) and 10m depth (lower) of AQULA

The results of the second scenario for simulation of water logging mitigation was proposing 20 pumping wells with discharge capacity of 100m3/hr distributed around waterlogged area. The working period for pumping well system was one year. The maximum drawdown resulted from this scenario was 2.35m and the minimum drawdown was 1.68m (Fig. 12). Otherwise, the results from the third scenario (surface drain perpendicular to groundwater direction to lower groundwater level) exhibits maximum drawdown of 2.72m and minimum drawdown of 1.62m (Fig. 13).

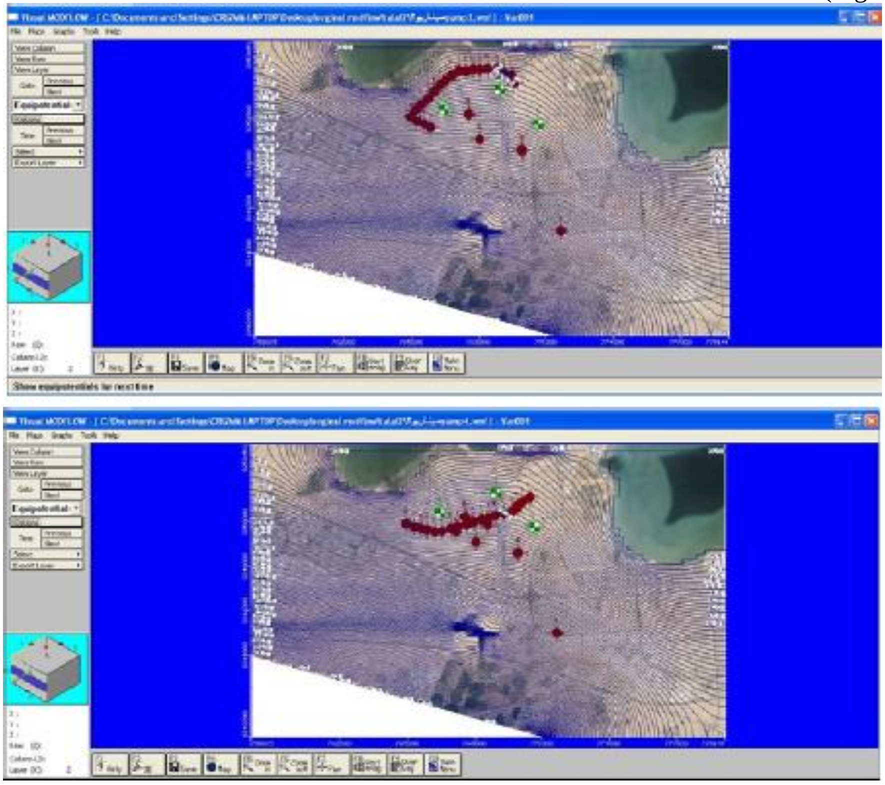


Fig 11: Groundwater level contour maps in case of dewatering system scenario in the upper side (upper map) and in the lower side (lower map) of AQULA.

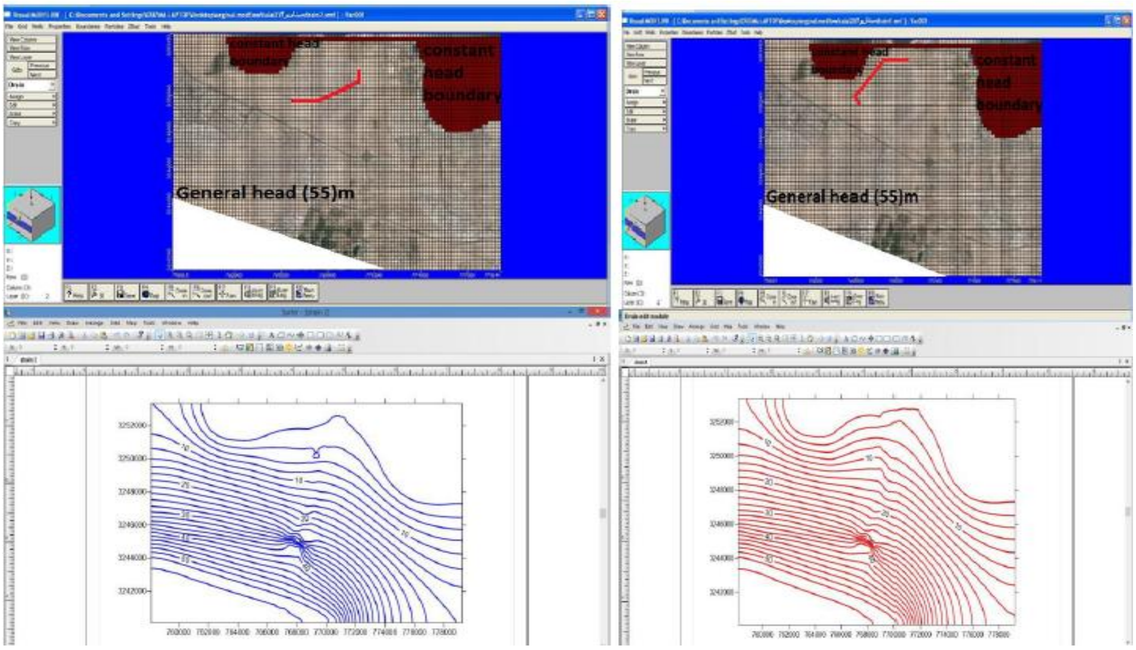
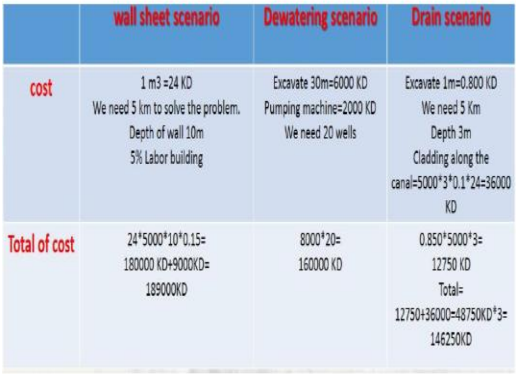


Fig 13: Ground water level contour maps applying open drain scenario in the southern part (left) and in the northern part (right) of AQULA

In the other side, to study the economics of the different proposed solutions of water logging problem required for urbanization development of AQULA, cost benefit ratio of every scenario was estimated. The results of these estimations were tabulated in (Table 3) which reflects that the best solution of the waterlogging problem in AQULA was the Open drain scenario since its cost was the smallest one (146250 KD).

Table 3: The estimated costs of the different proposed scenarios of AQULA



	wall sheet scenario	Dewatering scenario	Drain scenario
cost	1 m3 =24 KD We need 5 km to solve the problem. Depth of wall 10m 5% Labor building	Excavate 30m=6000 KD Pumping machine=2000 KD We need 20 wells	Excavate 1m=0.800 KD We need 5 Km Depth 3m Cladding along the canal=5000*3*0.1*24=36000 KD
Total of cost	24*5000*10*0.15= 180000 KD+9000KD= 189000KD	8000*20= 160000 KD	0.850*5000*3= 12750 KD Total= 12750+36000=48750KD*3= 146250KD

IV. CONCLUSION AND RECOMMENDATIONS

From this study it is concluded that the water logging problem is critical problem and threatens the urbanization development in the study area. Also, the flood irrigation of the cultivated lands and gardens is the essential reason for water logging problem. The obtained results from numerical simulation of the water logging problem reflect the bad needy of applying the most effective scenario, i.e., Open drain system.

According to the results of this study, there are many considerations to be take in the future as guide for similar studies, these consideration are:

1. Study the optimum management of soil water resources by studying the optimum abstraction from the aquifers.
2. Study the effect of salty lakes at the quality of groundwater in AQULA.
3. Changing the irrigation system from flood irrigation to modern irrigation system like drip irrigation.
4. The establishing of open drain system is essential for mitigate water logging problem in AQULA.

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