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Research article

Effects of Climate Change on Groundwater Resources (Gaza Strip Case Study)

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Abstract

Gaza Strip water sector management is essential for sustaining life. The knowledge of the occurrence, replenishment and recovery of groundwater assumes special significance in quantity-deteriorated regions, as Gaza Strip because of scarce presence of surface water. Thus, a research is essential to confirm the relationship between groundwater in Gaza Strip region and the sustainability of such climate conditions. Given the role of natural resources within the current conflict dynamics, climate change has a significant role to play in groundwater management within the region in next years. Studying the relation between climate change and groundwater resources was carried by estimating the recharge quantities that infiltrate to the aquifer using WetSpass software, then studying its effects on groundwater depth using Modflow software. Finally forecasting the possible scenarios may occur in the future and its effects on groundwater resources were studied.

The research showed a minor decrease in temperature and decreasing trend of the rainfall after 1995 which implied the climate change, and consequently influenced the recharge values. The temporal relation between the most sensitivity parameter (rainfall) and the recharge was studied in three presented locations in Gaza Strip: Beit lahia, Gaza City and Rafah rainfall stations with high correlation between the rainfall and recharge trends ranges between 0.99 to 0.96. It's noticed that after year 1995 rainfall decreased by 63.8 % in Beit lahia station that caused deficit in recharge values with 87.64 %, and lastly decrease in groundwater storage. Then, recharge values were input to calibrated transient groundwater model (Modflow software) for the northern part of Gaza Strip. Model output showed a large decreasing in the water table from -3 m at year 2010 to -6, -7.5, -8 and -8.5 m at the middle and from 2 m to -3.31, -6, -7 and -7.5 m at the boundary for years 2015, 2020, 2025 and 2030 respectively with clear expansion in the deficit region over time. Therefore, it is recommended that all water resources management plans in Gaza Strip should consider the impact of climate change.

Keywords: Gaza Strip, Climate Change, Groundwater, Management,

Introduction

Groundwater is a critical source of fresh drinking water for almost half of the world's population and it also supplies irrigated agriculture (Holger et al. 2012). It is now the most significant source in quantity-deteriorated regions, as Gaza Strip because of scarce presence of surface water, It's important for sustaining streams, lakes, wetlands, and ecosystems in many countries, supplying nearly half of all drinking water in the world (The United Nations World Water Development Report 3, 2009) and around 43 % of all water effectively consumed in irrigation (Siebert et al. 2011).

The knowledge of the occurrence, replenishment and recovery of groundwater assumes special significance. Water problem is expected to grow and the deficit in terms of quantity will reach to about 100 Mm^3/y by year 2020, while the water quality will be deteriorated dramatically according to Palestinian Water Authority (PWA) (Yaqoubi, 2007). While groundwater is a major source of Gaza's water, relatively little researches has been undertaken to determine the sensitivity of groundwater systems to changes in critical input parameters, such as temperature, precipitation and runoff. Changes in climate are expected to affect the hydrological cycle, altering surface - water levels and groundwater recharge to aquifers with various other associated impacts on natural ecosystems and human activities.

Furthermore, an understanding of the climate processes is essential to make sensible predictions of the possible impact of climate change on groundwater resources. The main objective of this research is quantifying the present risks of climate change on the groundwater resources in terms of quantity of Gaza Strip under possibly future conditions using a physically distributed water balance model (WetSpass) and groundwater modeling program (Modflow). The scientific understanding of an aquifer's response to climate change has been studied in several locations within the past decade:

These studies link atmospheric models to unsaturated soil models, which, in some cases, where further linked into a groundwater model. The groundwater models used were calibrated to current groundwater conditions and stressed under different predicted climate change scenarios. Allen et al. 2004 used a simplified approach to quantifying impacts of climate change on groundwater. Mean annual recharge to the Grand Forks aquifer in the semi-arid region of south central British Colombia (BC), Canada was modeled using HELP for current and future climate change. Extreme conditions for temperature and precipitation, based on projections from global climate models (GCMs) were used to adjust climate parameters (Allen et al. 2004).

Paulina Pokojska 2004 applies and verifies a model of water balance of spatially distributed parameters in a meso-scale river catchment. The model was applied in the Basin of Rega River, with the use of meteorological and hydrological measurement data from the years 1956–1995. The output from modelling was constituted by the raster maps of area evaporation, surface runoff and supply of the underground water resources (Pokojska, 2004). S. T. Woldeamlak. O. Batelaan. F. De Smedt (2007) modelled the effects of climate change on the groundwater resources in the Grote-Nete catchment, Belgium, using wet, cold and dry climate scenarios. Low, central and high estimates of temperature changes are adopted for wet scenarios. Seasonal and annual water balance components including groundwater recharge are simulated using the WetSpass model, while mean annual groundwater elevations and discharge are simulated with modular groundwater flow model (MODFLOW) (Woldeamlak et al. 2007). This study might be considered as one of the unusual contributions in quantitatively modeling of the relation between groundwater resources and climate change in Gaza.

Gaza Strip Data

Gaza Strip is a strip of land on the eastern coast of the Mediterranean Sea, located in the Middle East (at latitudes 31°16" and 31°45"N and longitudes 34°20" and 34°25"E) (Aish et al. 2004) bordered by the Mediterranean Sea in the West and the Negev Desert and Egyptian Sinai Peninsula in the South with a total area of 365 Km^2. Land surface elevations range from mean sea level (msl) to about 110 msl

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in the eastern parts. Gaza's water resources are essentially limited to that part of the coastal aquifer that underlies its area (Al-Talmas et al. 2012) (Fig. 1).

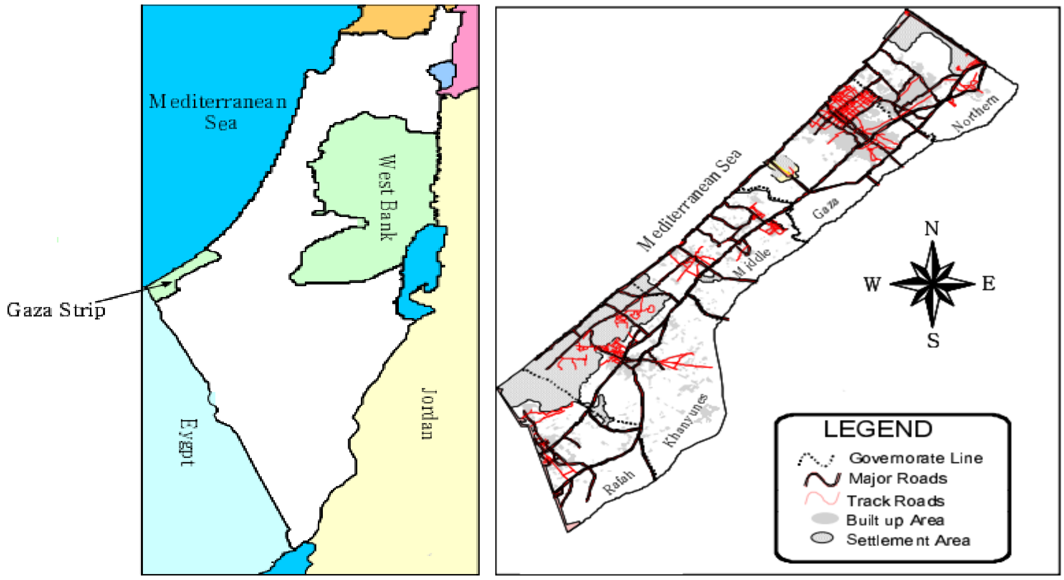

Figure 1: Location map of Gaza Strip, Palestine

The coastal aquifer is the only aquifer in the Gaza Strip and is composed of Pleistocene marine sand and sandstone, intercalated with clayey layers. The maximum thickness of the different bearing horizons occurs in the northwest along the coast (150 m) and decreasing gradually toward the east and southeast along the eastern border of Gaza Strip to less than 10 m. The base of coastal aquifer system is formed of impervious clay shade rocks of Neogene age (Saqiyah formation) (PWA, 2003).

Depth to water level of the coastal aquifer varies between few meters in the low land area along the shoreline and about 80 m along the southern eastern border (PWA, 2003). The coastal aquifer holds approximately 5000 Mm^3 of groundwater of different quality. However, only 1400 Mm^3 of this is "freshwater", with chloride content of less than 500 mg/l. This fresh groundwater typically occurs in the form of lenses that float on the top of the brackish and/or saline ground water. That means that approximately 70 % of the aquifer is brackish or saline water and only 30 % is fresh water (Yaqoubi, 2007). The major source of renewable groundwater to the aquifer is rainfall. Rainfall is sporadic across Gaza and generally varies from 425 mm/y in the North to about 140 mm/y in the south.

Research Methodology

Groundwater modeling

Differential equations that govern the groundwater flow can essentially represent the groundwater flow system derived from the basic principles of groundwater flow hydraulics. The main flow equation for saturated groundwater flow is derived by combining a water balance equation with Darcy's law, which leads to a general form of the 3-D groundwater flow governing equation:

$$\partial \frac{d}{dx}(K_x \frac{\partial h}{\partial x}) + \frac{d}{dy}(K_y \frac{\partial h}{\partial y} + \frac{d}{dz}(K_z \frac{\partial h}{\partial z} + R(x,y,z) = S_s \frac{\partial h}{\partial t} \qquad (1)$$

Where K_x ,K_y and K_z, are the hydraulic conductivity components in the x, y and z direction (LT^{-1}), h is the hydraulic head (L), R is the local source or sink of water per unit volume (T^{-1}), Ss is the specific storage coefficient (L^{-1}) and t is the time (T).

Darcy's law

In differential form, Darcy's law is expressed as:

$$q = -K.\ \mathrm{grad}\ (h) \tag{2}$$

where q is the groundwater flux (LT^{-1}), K is the conductivity tensor (LT^{-1}) and grad (h) is the gradient operator. This equation clearly shows that the cause of groundwater movement is the difference in the hydraulic potential. The potential is a function of all three space coordinates, that is h = h(x, y, z), the rate of change of head with position giving the gradient, which multiplied by the conductivity yields the groundwater flux (Wang et. al., 1982). The hydraulic conductivity is represented by a second order tensor that takes into account anisotropic conditions. Usually, anisotropy is only considered in the vertical and horizontal direction, hence

$$q_x = -K_x \frac{\partial h}{\partial x} \tag{3.1}$$

$$q_y = -K_y \frac{\partial h}{\partial y} \tag{3.2}$$

$$q_z = -K_z \frac{\partial h}{\partial z} \tag{3.3}$$

Where q_x, q_y, q_z are the three components of the flux, and Kx, Ky, Kz the hydraulic conductivity values in the horizontal (x,y) and vertical (z) direction. In case of isotropic conditions, $K_x = K_y = K_z$ each component of q is the same scalar multiple K of the corresponding component of -grad (h), such that the vectors q and -grad (h) both point in the same direction (Harbaugh et al. 2000).

WetSpass model

Batelaan and De Smedt (2001) developed a steady state spatially distributed water balance model "WetSpass" upon the foundation of the time dependent spatial distributed water balance model "WetSpa" (Batelaan et al. 1996). It uses long-term average climatic data together with an elevation, land use and soil map of an area to simulate average spatial patterns of surface runoff, actual evapotranspiration and groundwater recharge in the area. This model is fully integrated or embedded in the GIS ArcView (version 3.x) as raster model, coded in Avenue. Parameters, such as land-use and related soil type, are connected to the model as attribute tables of the land-use and soil raster maps. This allows for easy definition of new land-use or soil types, as well as changes to the parameter values.

WetSpass stands for Water and Energy Transfer between Soil, Plants and Atmosphere under quasi-Steady State (Batelaan et al. 2001). It is a physically based model for the estimation of long-term average spatial patterns of groundwater recharge, surface runoff and evapotranspiration employing physical and empirical relationships.

WetSpass was completely integrated in GIS ArcView as a raster model, coded in Avenue. Inputs for this model include grids of landuse, groundwater depth, precipitation, potential evapotranspiration, wind-speed, temperature, soil, and slope where by parameters such as land-use and soil types are connected to the model as attribute tables of their respective grids.

Water Balance Calculation

The water balance components of vegetated, bare-soil, open-water, and impervious surfaces are used to calculate the total water balance of a raster cell as briefly mentioned earlier,

$$ET_{raster} = a_vET_v + a_sE_s + a_oE_o + a_iE_i \quad (4)$$

$$S_{raster} = a_vS_v + a_sS_s + a_oS_o + a_iS \quad (5)$$

$$R_{raster} = a_vR_v + a_sR_s + a_oR_o + a_iR_i \quad (6)$$

Where ET_{raster}, S_{raster}, R_{raster} are the total evapotranspiration, surface runoff, and groundwater recharge of a raster cell respectively, each having a vegetated, bare-soil, open-water and impervious area component denoted by a_v, a_s, a_o, and a_i, respectively. The computation of each component's water balance is discussed below:

Vegetated Area

The water balance for a vegetated area depends on the average seasonal precipitation (P), interception fraction (I), surface runoff (S_v), actual transpiration (T_v), and groundwater recharge (R_v) all with the unit of [LT^{-1}], with the relation given below

$$P = I + S_v + T_v + R_v \quad (7)$$

Interception

Depending on the type of vegetation, the interception fraction represents a constant percentage of the annual precipitation value. Thus, the fraction decreases with an increase in an annual total rainfall amount (since the vegetation cover is assumed to be constant throughout the simulation period).

Surface runoff

Surface runoff is calculated in relation to precipitation amount, precipitation intensity, interception and soil infiltration capacity. Initially the potential surface runoff ($S_{v\text{-}pot}$) is calculated as

$$S_{v-pot} = C_{sv}(P - 1) \quad (8)$$

Where, C_{sv} is a surface runoff coefficient for vegetated infiltration areas, and is a function of vegetation, soil type and slope. Saturated surface runoff occurs in groundwater discharge areas giving rise to a very high surface runoff coefficient. This is due to the reduced dependency on soil, vegetation type and the vicinity of the area to the river, the coefficient is here usually assumed to be constant.

In the second step, actual surface runoff is calculated from the Sv-pot by considering the differences in precipitation intensities in relation to soil infiltration capacities.

$$S_v = C_{Hor} S_{v-pot} \quad (9)$$

Where C_{Hor} is a coefficient for parameterizing that part of a seasonal precipitation contributing to the Hortonian overland flow. C_{Hor} for groundwater discharge areas is equal to 1.0 since all intensities of precipitation contribute to surface runoff. Only high intensity storms can generate surface runoff in infiltration area (Batelaan et al. 2001).

Evapotranspiration

For the calculation of seasonal evapotranspiration, a reference value of transpiration is obtained from open-water evaporation and a vegetation coefficient:

$$T_{rv} = c\, E_o \tag{10}$$

Trv = the reference transpiration of a vegetated surface [LT^{-1}];

Eo = potential evaporation of open water [LT^{-1}] and

c = vegetation coefficient [–], can be calculated from Penman-Monteith equation.

Recharge

The last component, the groundwater recharge, is then calculated as a residual term of the water balance, i.e,

$$R_v = P - S_v - ET_v - I \tag{11}$$

ET_v is the actual evapotranspiration [LT^{-1}] given as the sum of transpiration T_v and E_s (the evaporation from bare soil found in between the vegetation).

Bare-soil, Open-water, and Impervious surfaces

A similar procedure as that for the vegetated surfaces is followed for the calculation of the water balance for bare-soil, open-water, and impervious surfaces. The only difference is that there is no vegetation in these cases and thus there is no interception and transpiration term. The ET_v in this case becomes E_s (Batelaan et al. 2001).

Discussion of the Results

WetSpass Model

WetSpass model output grids include 3 sets of results with each set having seven grids. The First set is the winter output while the second and third sets are for the summer and yearly cases. The output grids are Runoff, Evapotranspiration, Interception, Transpiration, Soil evaporation, Recharge and Error.

Figure 2 showed that the maximum rainfall in year 1990 was 572.9 mm while Figure 3 showed the maximum rainfall 404.9 mm in year 2005. The Recharge was calculated using the WetSpass model for 1990, 1995, 2000, 2005 and 2010 years; the recharge maps for 1990 and 2005 years are presented in Figure 2 & 3 respectively. It was noticed that the recharge values for Gaza city and Rafah stations are less than Beit Lahia station values. This implies to the soil classification and runoff coefficient of the station which considered as a main input criteria in the point of view of the model. Beit Lahia station is sandy soil region while Gaza and Rafah are clayey soils.

It can be seen from Figures 2 and 3, the maximum recharge values decrease from 275 mm in 1990 to 144.45 mm in year 2005 due the decrease of the rainfall in the same period. This reflects the change of the climate which led to the change of the rainfall and consequently change in the recharge quantity.

The temporal frequency of the relation between the rainfall and the recharge where studied in three locations in Gaza Strip: Beit lahia, Gaza City and Rafah stations. The period from 1990 to 2010 using 5 years interval was considered.

Figures 4, 5 and 6 show the temporal relation between Rainfall data records and Recharge values obtained from WetSpass model for Beit Lahia, Gaza City and Deir Balah Stations respectively. The figures show high correlation between the rainfall and recharge trends range between 0.99 to 0.96. The figures also show unsteady trend of the rainfall which implies the climate change between year 1990 to year 2010. That climate change is illustrated in the three areas: where in year 1995 there is increase in the rainfall while after this year and up to year 2010 the rainfall decrease with 63.8 % in Beit lahia stations. The same unsteady trend is found in recharge values where according to the WetSpass model results there is a decrease in the recharge quantities in Beit lahia station with 87.64 %. This will adversely influence the groundwater storage and mainly the groundwater level will decrease due to the decrease in the recharge values. The trends of the rainfall and recharges in other locations (Gaza and Rafah stations) are the same as Beit lahia with different decrease percentages.

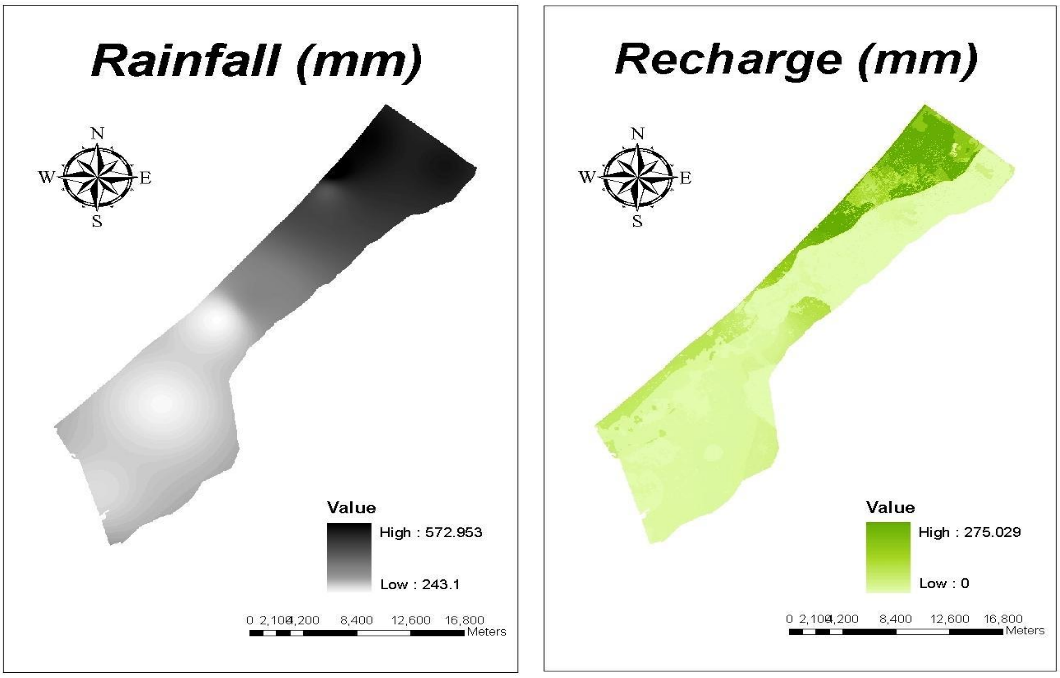

Figure 2: Annual groundwater recharge, calculated by the WetSpass model for year 1990

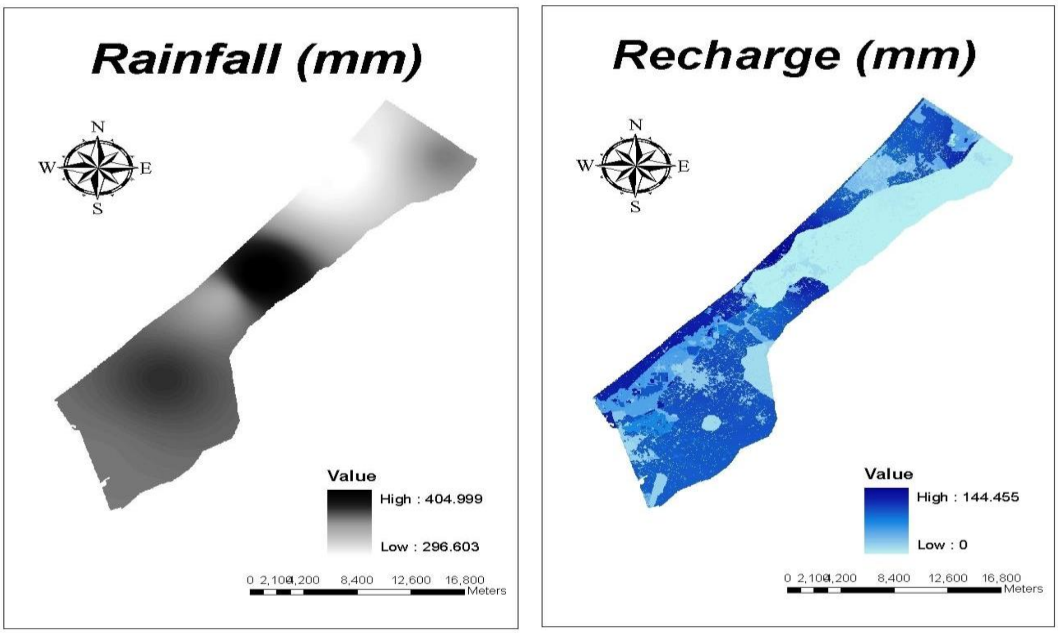

Figure 3: Annual groundwater recharge, calculated by the WetSpass model for year 2005

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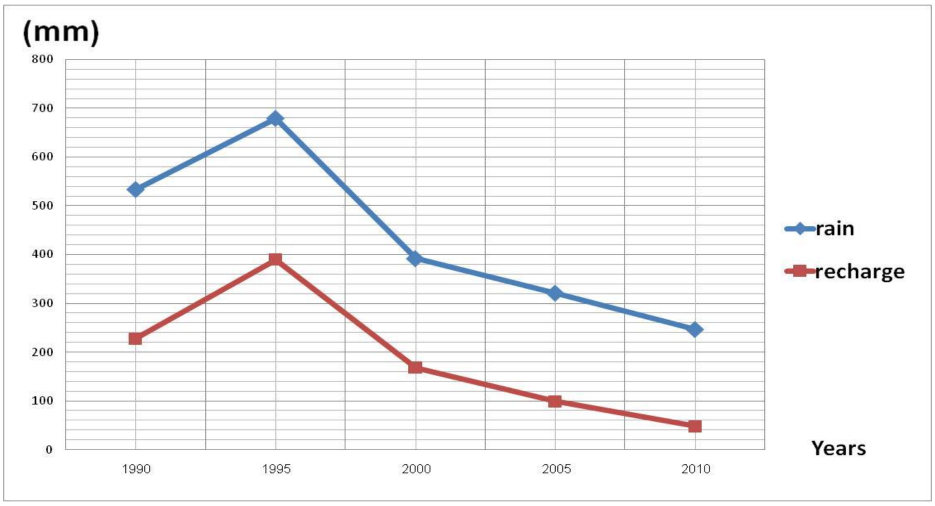

Figure 4: Relation between Rainfall and Recharge for Beit Lahia Station

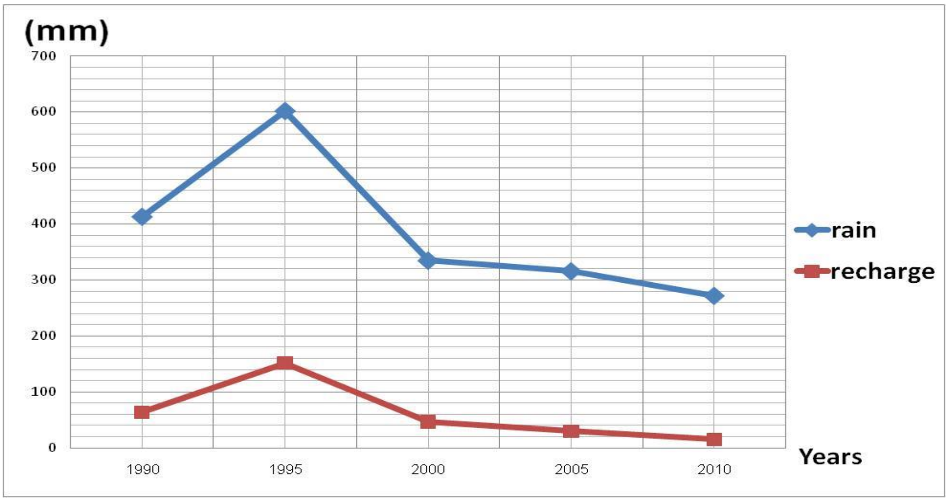

Figure 5: Relation between Rainfall and Recharge for Gaza City Station

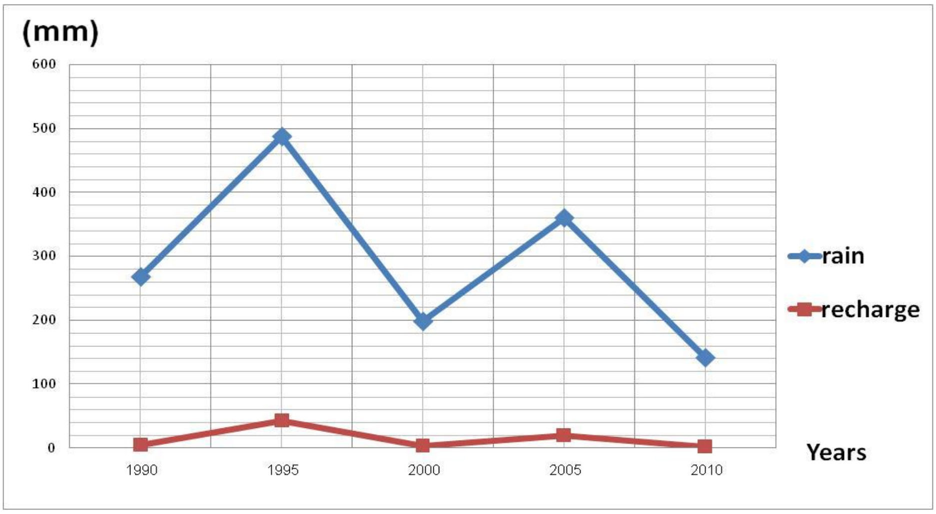

Figure 6: Relation between Rainfall and Recharge for Rafah Station

Groundwater Flow Modeling

After computing the values of recharge using WetSpass Model, these values were used as input to the groundwater model, VISUAL Modflow 4.2, software was used. The output of the groundwater model will give a good indicator of how will the climate change parameters affect the aquifer. The groundwater flow model used the northern part as a case study. The groundwater model domain encloses an area of 17 x15 km in the north part of Gaza Strip. The model domain is a uniform square grid comprising with a grid spacing of 200 x 200 m. A constant head boundary was assigned in west, the north, south, and east boundary was assigned as no flow boundary. In the study area there were 73 municipal wells in year and about 1213 registered agricultural well, the municipal wells were inserted to the model by their abstraction schedule, but the agricultural wells were inserted to the model by estimating their abstraction. 34 observation wells were used to calibrating the model.

Modflow model was calibrated from 1 October 2004, start date, and run to show results for years 2005, 2010, 2015, 2020, 2025 and 2030. The recharge of year 2000 was used. Head values at start date ranges from -3 m at the middle area to 2 m at the boundaries. The model run to 1 January 2005, then the calculated Head map. Values range from -3.86 m at the middle of the northern area to 2.04 m at the eastern boundary. That's because of the middle area wells abstract larger than the boundaries wells.

To distinguish the model results accuracy, observed head wells data were used in order to get comparison between calculated values and observed values, with 95 % confidence interval. The obtained Correlation Coefficient was 0.94 which was considered as a good results. After that the recharge value for year 2005 was used as initial value and the model was run for 5 years (up to year 2010) in order to get aquifer state at year 2010. Figure 5.18 shows that the head values drop from -3.86 m at the middle to -5 m with an obvious expansion at this area, and from 2.04 m at the boundaries to - 3.31 m (Fig. 8).

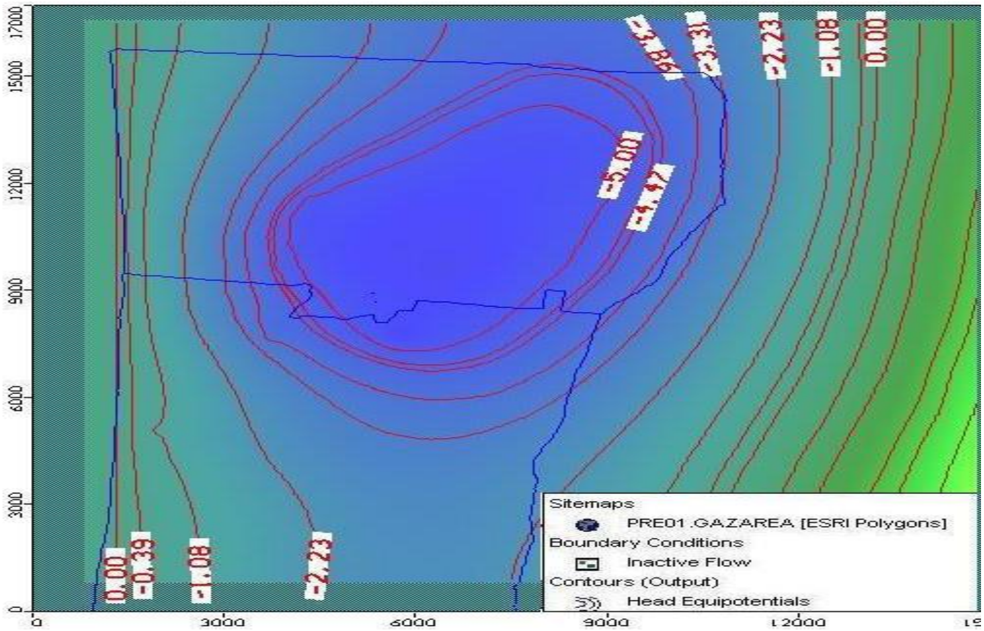

Figure 8: Head calculated by the MODFLOW model for year 2010

The Correlation Coefficient was 0.917 between the observed and calculated water level which also enhance model results accuracy.

Prediction of Climate Change Impacts

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After calibration the model, as it appeared from calibration graphs, the model is used in the stage of future prediction of what will be the aquifer state in the next years? Two scenarios were considered.

First Scenario: the recharge of year 2010 still remains.

The 2010 year recharge values were used as initial value for the calibrated model, and the model was for 20 years. Then the results were explored for each 5 years interval, for 2015, 2020, 2025 and 2030.

Results show the expected calculated head in the north Gaza area in years 2020 and 2030 respectively. It is noticed that the head values decreases from -5m at the middle at 2010 year to -6, -7.5, -8, -8.5 m at years 2015, 2020, 2025 and 2030 respectively. Even though the same value of -3.31 m last for year 2015, decrease index last for the boundary regions, that's clearly appeared from value of -3.31 m at year 2010 to the values -6, -7 and -7.5 m for years 2020, 2025 and 2030 respectively. Figures 9 and 10 show the states of the years 2020 and 2030 respectively.

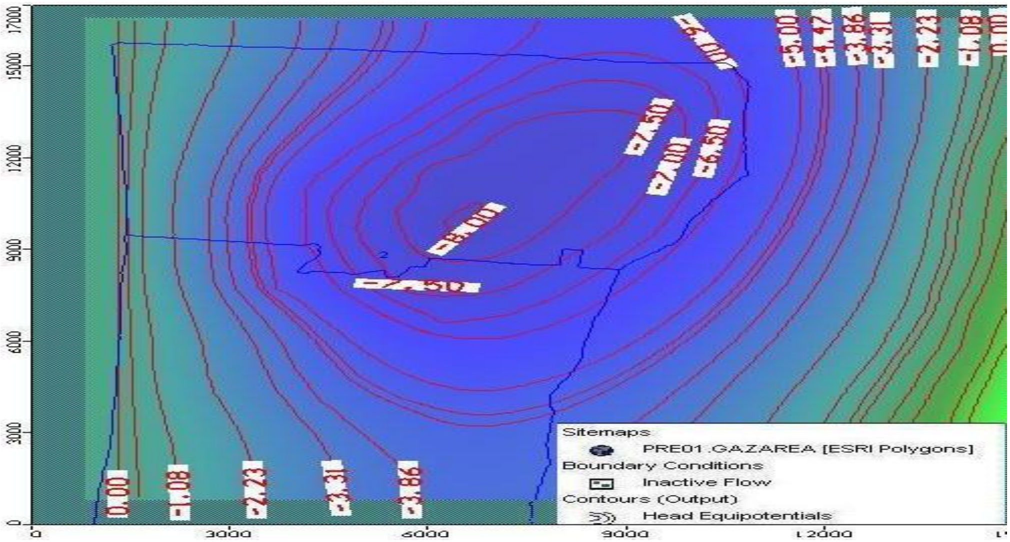

Figure 9: Head calculated by the Modflow model for year 2020

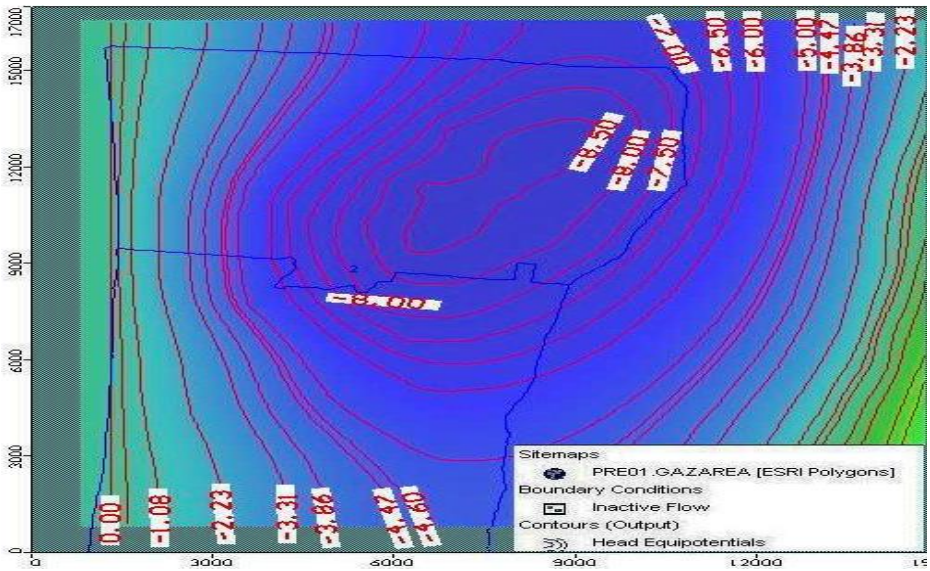

Figure 10: Head calculated by the Modflow model for year 2030

Second Scenario: recharge rate decreases.

The trend line of recharge values for Beit Lahia station that lies in the north area was developed. Recharge value redefined to Modflow program input as recharge rate with a start date of 1 January 2015 and the calculated head of 2015 considered as initial head value. Results of 1825 days will present the aquifer state for year 2020, as well as 3650 and 5475 days will present years 2025 and 2030 respectively.

Figures 11, 12 and 13 show the calculated head values obtained from Modflow program for years 2020, 2025 and 2030 respectively. As it appeared the expected head in the middle area will decreases to the value -8.5 m with increasing expansion of this region over time. In the eastern boundary head value will reach -7.5 m in year 2030. This breadth in the deficit area clearly shows the magnitude of the aquifer problem in the next years as effect of the climate change.

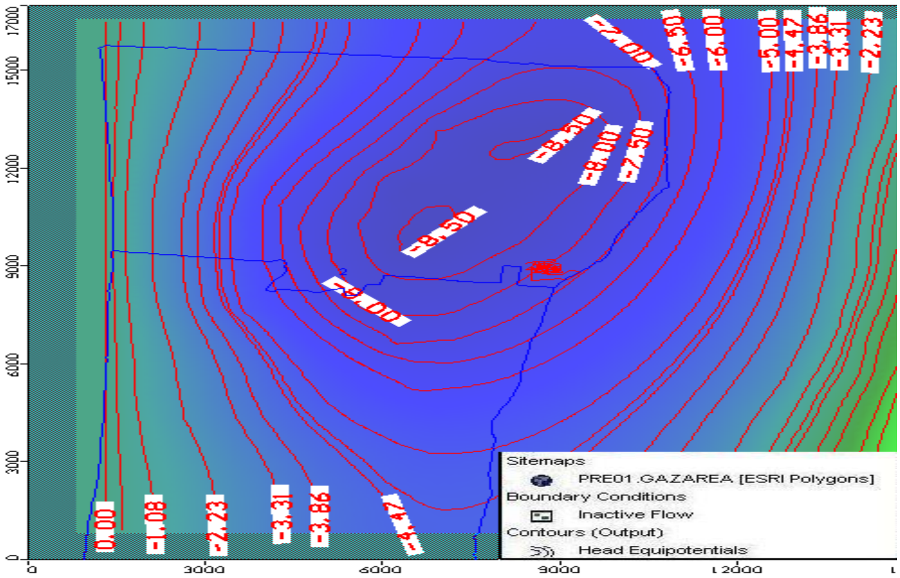

Figure 11: Head calculated by the Modflow model for year 2020

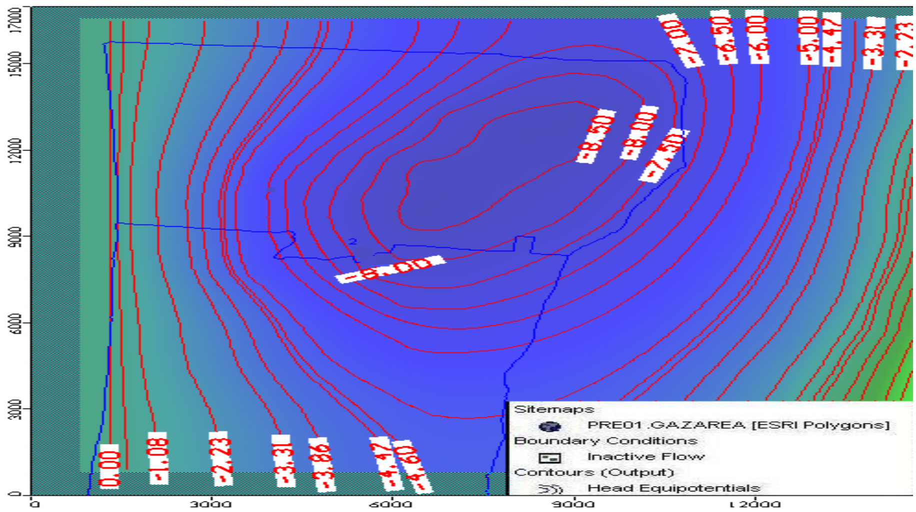

Figure 12: Head calculated by the Modflow model for year 2025

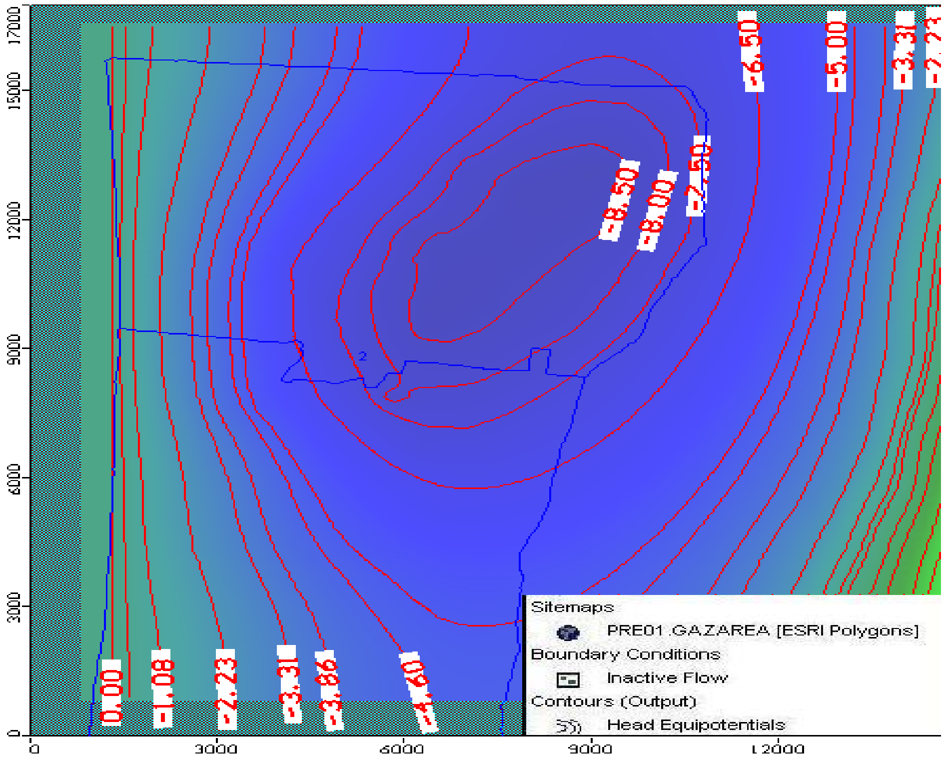

Figure 13: Head calculated by the Modflow model for year 2030

Also, it is noticed that the head values decreases in the second scenario more than as it in the first scenario. This is because that the second scenario used the recharge value of year 2015 which is lower than recharge value of 2010 that used in the first scenario.

In term of quality, it expected that groundwater will be deteriorated rapidly as a sequence of the deficit in groundwater table due to climate change effects, therefore this will lead to sea water intrusion and that calls every effort to help and save the unique source of water in that area.

Conclusions

- Studying the effects of climate changes on groundwater resources is considered as a main point in groundwater management system. Recently understanding the influence of climate change can contribute in an integration of water resources management.

- Effects of climate change in Gaza strip may include minor decrease of temperatures.

- This research presented that there is a considered effect of climate changes on rainfall values which has an impact on recharge values. The research illustrated that in the last 20 years there is decreasing trends in rainfall values. This decreasing occurs after year 1995 that caused deficit in recharge values and lastly caused a decrease in groundwater storage.

- Estimating groundwater recharge is critical for developing an effective management strategy that will ensure the protection of the fresh water resources of Gaza Strip. The physically based hydrologic model WetSpass was integrated with ArcView GIS to estimate spatially distributed groundwater recharge rates for the Northern part of Gaza Strip over a period of 25 years, from October 2004 to December 2030. The use of the GIS was essential and helpful due to the large volume of data required for numerical modeling of area processes at the regional scale.

- The case study of the Northern area illustrate that the middle and southern areas would be worsen, it's have not as much rainfall quantity as Northern part have, and no clear differentiation abstraction between those areas, hence recharge quantities infiltrate aquifer will reduce and the deficit will be larger.

- If groundwater is not managed properly in Gaza Strip, there is a high probability that it would be depleted in the next years, depending on the anticipated climate change scenario.

- Constructing hydrologic models, through which we can realize the behavior of the Gaza Strip coastal aquifer, is reached and provides a complete insight of the groundwater flow in the coastal aquifer. Groundwater program (Modflow) and hydrologic model (WetSpass) as well as all automated data (such as rainfall, landuse, temperature, wind, evapotranspiration, depth and level of water table and slope of the topography, etc,) will be very valuable for the responsible for further researches and development.

Recommendations

- This study can be used as a guide to the concerned authorities and in charge of the follow-up to the quality and quantity of groundwater behavior. It showed clearly the effects of many predicted scenarios on climate change and water level in the Northern part of Gaza strip.

- The continuous careless abstraction of Gaza Strip aquifer should be stopped. Management integration can help to stop the deterioration of the aquifer. It is the first step in management the groundwater quantity. The second step is to search for other sources of water from the aquifer. Alternative sources can be reducing the massive deficit in the future.

- The study will be more efficient if it take in account the extend aquifers beyond the area.

- Considering the results of this study, the concerned authorities should closely monitor groundwater levels, especially at the end of the summer, both in groundwater recharge and discharge zones.

- The monitoring program for groundwater quality should be designed with a selection of parameters and frequency that allows the effect of the climate change on the groundwater resources to be observed.

- The best way to solve the deterioration problem in the groundwater resources due to climate change effects is the combination of many options:

    - Reduction the extreme rates of abstraction from the aquifer by using alternate resources, in order not to exceed the sustainable yield.

    - Rearrangement of abstraction works based on a deep study in the deficit and deteriorated areas.

    - Implementation artificial recharge system in order to compensate the present deficit. Increasing groundwater recharge could counteract the projected effects of climate changes on the groundwater system.

    - Construction new management system helps in monitoring the groundwater system in terms of quantity and quality.

- As a general recommendation, PWA, MoA, CMWU, and other related authorities has to construct an integrated database for hydrological data of Gaza Strip.

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