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Groundwater Management in Egypt

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Abstract: *Egypt is arid country in Africa, but has a large hydro geologic potential with many aquifers widely distributed throughout the country. Egypt is facing increasing water needs, demanded by a rapidly growing population, by increased urbanization, by higher standards of living and by an agricultural policy which emphasizes expanded production in order to feed the growing population. The effect of intrusion of seawater in coastal aquifer in western north coastal aquifer of Egypt is studied. The shape of the fresh-salt water interface and the water table profile is drawn by using Glover equation. The objectives of strategy of aquifer management are studied. The effect of increasing water table and salinity on the crop revenue is studied in Bahr Mashtoul canal command area as a case study by using OPDM model. The effect of the change in groundwater quantity and salinity from on the total gross revenue of total command area and on the gross revenue of each crop is calculated.*
Keywords: *Groundwater; Management Practices; Costal aquifer; intrusion of seawater; OPDM; Egypt.*

I. Introduction

Groundwater plays an essential and increasing role in global drinking water supply and food security. Groundwater reserves provide a first rate buffer against climate variability and any associated decline in other water sources, and will play an increasing role where aridity is on the increase.

There are a lot of researches about this topic such as Betcher R., Grove G. and Pupp C. (1995) [1] produced jointly by Environment Canada (the State of the Environment Reporting and the National Hydrology Research Institute) and the Manitoba Department of Natural Resources. Many provincial and federal officials provided support and assistance in the form of information and reviews. Bredenhann L. and Braune E. (2000) [2] wrote a report to represent a strategy which was practical, affordable and easily implemented. Mook W. (2000) [3] provided a comprehensive review of basic theoretical concepts and principles of isotope hydrology methodologies and their practical applications with some illustrative examples. FAO (2003) [4] made a report to establish links between the social and technical aspects of groundwater management against a contemporary background of rapid groundwater depletion and aquifer degradation and search for guiding principles and criteria for establishing more sustainable paths to groundwater management through practical actions. Liu, Mink and Dai (2005) [5] modified the robust analytical model, or RAM by including transport processes of salt advection and dispersion. The usefulness of the modified RAM was demonstrated by applying it to an evaluation of the sustainable yield of the Pearl Harbor aquifer. Parikh et al (2007) [6] wrote a report which had suggested an approach to sustainable management of groundwater. It included an input into policy formulation for the plan which helped in sustainable development of groundwater in India. Wagdy A. (2008) [7] described how Egypt would safeguard its water resources in the future, both with respect to quantity and quality, and how it would use these resources in the best way from a socio-economic and environmental point of view. Brian D. Smerdon, Todd E. Redding, and Jos Beckers (2009) [8] provided an introduction to the role of groundwater in watersheds, presented an overview of groundwater resources in British Columbia, and reviewed the potential effects of forest management activities. Gondwe B. (2010) [9] developed conceptual hydro geological models for the study area (Sian Ka'an Yucatan, Mexico), based on the collected data and developed numerical hydrological models of the groundwater catchment. El Osta M., El Sheikh, A. and Barseem M. (2010) [10] studied twenty one soundings using the Schlumberger configuration are carried out at selected sites especially in missing parts from wells to delineate the groundwater setting in such sites. Eight of them were conducted in the close vicinity of water wells, where pumping test data of these wells are available to relate hydrologic measurements. El-Samanoudi M. et al (2011) [11] presented an approach to evaluate the groundwater conditions in El- Gora and its vicinities, El Sheikh Zowyed and Rafah areas. The investigated area occupies a part of the northeastern portion of Sinai Peninsula of about 830 km. Gad M., El Sheikh A. and El Osta M. (2011) [12] introduced an application of mathematical and genetic algorithm (GA) techniques. The proposed model of optimization was based on the combination of the MODFLOW simulation with GA. The performance of the proposed model was tested on groundwater management problem. Working Group (2011) [13] wrote a report which outlined the broad contours of the process of developing a National groundwater management program, beginning with an aquifer mapping approach in India. Ackermann R. (2012) [14] took a purely pragmatic approach to identify practical and demand-driven ways to resolve some of the deep-seated problems in the water sector. El-Arabi N. (2012) [15] presented the preliminary hydro geological investigation and tested scenarios for the aquifer storage which used to evaluate the technical environmental, consideration in Abu Rawash farm as a case study. Foster S. and Ait-Kadi M. (2012) [16] studied Integrated Water Resources Management (IWRM). IWRM was the process of managing water resources holistically and of promoting coordinated consideration of water, land and related natural resources during developmental activity. King A. et al (2012) [17] explored methods and costs of remediation of groundwater nitrate contamination in the Tulare Lake Basin and Salinas Valley. Youssef, Gad and Ali (2012) [18] optimized and conserved the use of groundwater In the new reclaimed areas of Wadi El-Farigh in Western Desert, some strategies were considered, such as managing the supply and the demand, improving the efficiency of groundwater use, reducing the waste water and ensuring sustainability. Mabrouk et al (2013) [19] presented, categorized analyzed and synthesized the most relevant research regarding climate change and development challenges in relation to groundwater resources in the Nile Delta. They showed that there was a gap in studies that focused on sustainable groundwater resources development and environmentally sound protection. Barthel R. (2014) [20] focused on the regional scale (areas of approx. 10^3 to 10^6 km^2), which was identified as the scale where integration is most greatly needed, but ironically the least amount of fully integrated research seemed to be undertaken.

This present paper aims to 1) estimate a strategy to manage the groundwater in Egypt; 2)study the effect of intrusion of seawater in coastal aquifer in western north coastal aquifer of Egypt as a case study by using Glover equation; 3) use the OPDM program to study the effect of change in groundwater quantity and salinity in the crops revenue in Bahr Mashtoul canal command area as a case study.

II. Water Resources In Egypt

The Nile River supplies about 97% of the annual renewable water resources in Egypt. Out of the Nile's average natural flow of 84.0km^3/yr reaching Aswan, a share of 55.5Billion m^3/yr is allocated for Egypt according to the Nile Water Agreement (1959). This account for an average per capita share of about 800m^3/cap/yr as of year 2004, while projections forecast a share of about 600m^3/cap/yr by the year 2025. The water sources in Egypt are shown in Fig.1 [13]. Fossil groundwater is hosted in deep aquifers as non-renewable water resources. Also, non-conventional resources include agricultural drainage water reuse, sea water desalination, municipal wastewater reuse, rain harvesting, and brackish water desalination. Fossil water exploitation is estimated at a rate of 1.65 Billion m^3/yr mainly concentrated at the oases of the Western Desert. The municipal wastewater reuse capacity is currently of the order of 2.9Biilion m^3/yr, while the agricultural drainage reuse is projected around 9.7 Billion m^3/yr in the Nile Valley and delta.

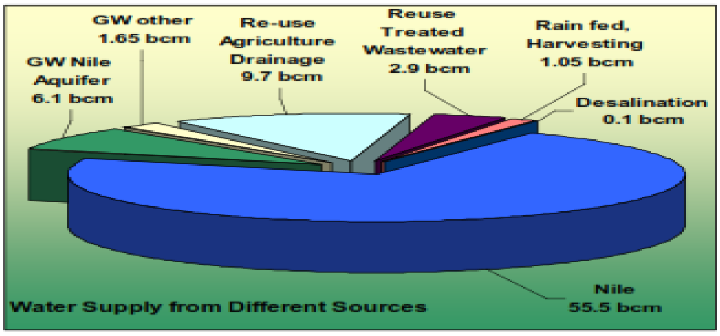

Fig.1: Sources for Water Supply

2.1 Groundwater in Egypt

Groundwater in the Nile aquifer system and desert fringes is not a resource in itself as it is replenished from the river Nile by seepage from canals and deep percolation from irrigation application. The annual groundwater abstraction in the Nile aquifer system and fringes is about 4.6billion m^3. Another 0.5 billion m^3 is abstracted from the desert aquifers and the coastal areas. Groundwater abstraction is expected to increase considerably to 11.4 billion m^3. The main aquifers in Egypt are as shown in Fig.2:

1) The Nile aquifer system, assigned to the Quaternary and Late Tertiary, occupies the Nile flood plain and desert fringes;

2) The Nubian Sandstone aquifer system, assigned to the Paleozoic-Mesozoic, occupies a large area in the Western Desert, and parts of the Eastern Desert and Sinai;

3) The Moghra aquifer system, assigned to the Lower Miocene, occupies mainly the western edge of the Delta;

4) The Coastal aquifer systems, assigned to the Quaternary and Late Tertiary, occupy the north western and eastern coasts;

5) The certified carbonate aquifer system, assigned to the Eocene and to the Upper Cretaceous, predominates essentially in the north and middle parts of the Western Desert;
6) The fissured and weathered hard rock aquifer system, assigned to the Pre-Cambrian, predominates in the Eastern Desert and Sinai renewable and underlies the Nile Delta and is characterized by its high productivity and shallow depth of the groundwater table allowing the abstraction of large quantities of water (100-300 m/hr) at low pumping cost.

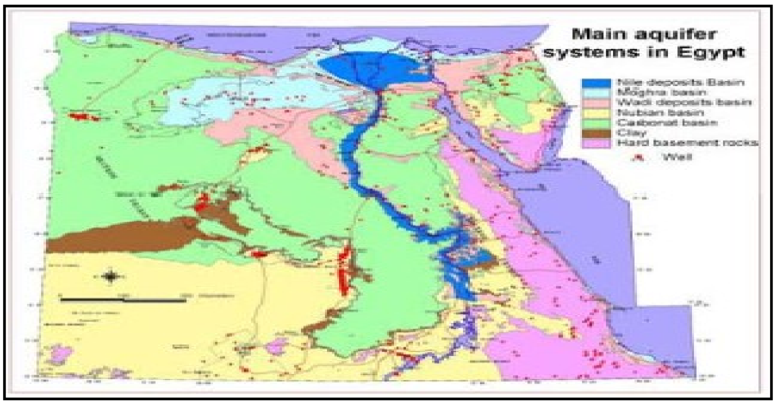

Fig.2: Main Aquifer Systems in Egypt

III. Groundwater Management In Egypt

Groundwater is the most preferred source of water in various user sectors in Egypt on account of its near universal availability, dependability and low capital cost. The increasing dependence on groundwater as a reliable source of water has resulted in indiscriminate extraction in various parts of the country without due regard to the recharging capacities of aquifers and other environmental factors. On the other hand, there are areas in the country, where groundwater development is sub-optimal in spite of the availability of sufficient resources, and canal command areas suffering from problems of water-logging and soil salinity due to the gradual rise in groundwater levels. The development of groundwater in the country is highly uneven and shows considerable variations from place to place. Management of groundwater resources in Egypt is an extremely complex proposition. The highly uneven distribution and its utilization make it impossible to have single management strategy for the country as a whole. Any strategy for scientific management of groundwater resources should involve a combination of supply side and demand side measures depending on the regional setting.

The annual groundwater draft is used in estimating stage of groundwater development as follows:
Stage of groundwater development = Annual gross groundwater draft / Net annual groundwater availability. Management of groundwater resources in Egypt is an extremely complex proposition as it deals with the interactions between the human society and the physical environment. The highly uneven distribution of groundwater availability and its utilization indicates that no single management strategy can be adopted for the country as a whole. On the other hand, each situation demands a solution which takes into account the geomorphic set-up, climatic, hydrologic settings, groundwater availability, water utilization pattern for various sectors and the socio-economic set-up of the region.

3.1 Demand Side Measures

Apart from scientific development of available resources, proper groundwater resources management requires to focus attention on the judicious utilization of the resources for ensuring their long-term sustainability. Ownership of groundwater, need-based allocation and pricing of resources, involvement of stake holders in various aspects of planning, execution and monitoring of projects and effective implementation of regulatory measures wherever necessary are the important considerations with regard to demand side groundwater management.

3.2 Supply Side Measures

As already mentioned, these measures are aimed at increasing the groundwater availability, taking the environmental, social and economic factors into consideration. These are also known as 'structural measures', which involves scientific development and augmentation of groundwater resource. For an effective supply-side management, it is imperative to have full knowledge of the hydrologic and hydro-geologic controls that govern the yields of aquifers and behavior of groundwater levels under abstraction stress. Interaction of surface and groundwater and changes in flow and recharge rates are also important considerations in this regard.

IV. Coastal Areas

As the multi-aquifer systems in coastal areas are likely to have all possible dispositions of fresh and saline water, it is necessary to take-up detailed studies to establish the saline–fresh water interface and establish the replenish able discharge of groundwater to sea. This will ensure the implementation of groundwater development plans. Costal Aquifers in Egypt are:

1- Western north coastal aquifer of Egypt
2- Al-Exandria costal aquifer;
3- Eastern north coastal aquifer (El-Abd well in Romana region)
4- El-Aresh-Rafah aquifer
5- Western north coastal aquifer of El-Akaba gulf (Noweba, Dahab and Sharm El-Shekh)
6- Red sea costal (El-Zafrana and Halayeb)

4.1 Case Study

Western north coastal aquifer of Egypt is studied as a case study, the rate of flow from this aquifer to the sea is 1.5m^3/day/m and the hydraulic conductivity is 12.8m/day. Glover equation [21] is used to calculate the shape of the fresh-salt water interface and the shape of groundwater surface from the shoreline to 1 km towards the ground surface. Glover equation is as following:

$$Z = \sqrt{\frac{2*q*x*G}{K} + \left(\frac{G*q}{K}\right)^2} \quad \text{..........(1)}$$

Where;
Z: the depth of fresh salt water interface below sea level (m)
q: the rate of flow from the aquifer to the sea(m^3/day/m);
x: the distance from shoreline (m);
G: factor depends on the water density;
K: the hydraulic conductivity (m/day);

$$G = \frac{\rho_f}{\rho_s - \rho_f} \quad \text{..........(2)}$$

Where;

ρ_f: Fresh water density = 1(gm/cm^3); ρ_s : Sea water density= 1.25(gm/cm^3);

To calculate water table profile according to Glover, this equation is used:

$$h_f = \sqrt{\frac{2*q*x}{G*K}} \quad \text{..........(3)}$$

Where;
h_f: the depth of water table above the sea surface;
The shape of the fresh-salt water interface and the water table profile are shown in Fig.3.

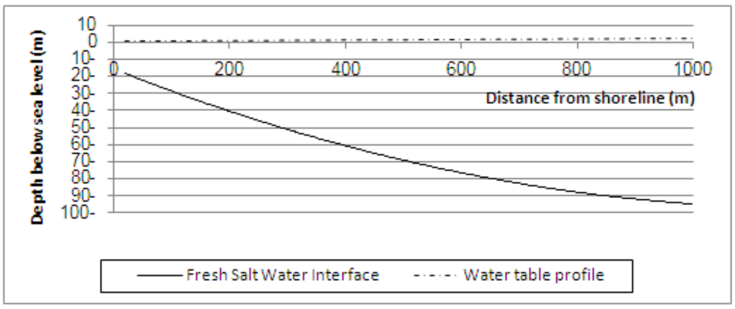

Fig.3: The Shape of the Fresh-Salt Water Interface and the Water Table Profile of Western North Coastal Aquifer of Egypt

V. Management Of Aquifers

Aquifer management strategies will be required for aquifers to achieve the following objectives:
• Identify and initiate protection of groundwater quality from degradation;
• Facilitate collection and management of groundwater quality data;
• Identify areas of poor quality groundwater;
• Identify and facilitate implementation of remedial action;

The physical properties of an aquifer such as thickness, rock or sediment type and location, play a large part in determining whether contaminants from the land surface will reach the groundwater. The risk of contamination is greater for unconfined aquifers than for confined aquifers because they usually are nearer to land surface and lack an overlying confining layer to impede the movement of contaminants. Aquifer management will similarly follow an approach which requires consideration of the whole aquifer system. The management unit best suited to a systems approach is an aquifer. In order to rationalize and integrate surface and groundwater resource management, catchment and aquifer management must be integrated. The institutional structures which are put in place for catchment management will therefore also be used for aquifer management. There are two distinct conditions as regards to induced recharge from the river/stream to groundwater aquifer. The first condition involves setting up a hydraulic connection between the aquifer and the river as recharge boundary due to heavy exploitation of groundwater and expansion of cone of depression. This condition is common in case of perennial rivers and leads to changes in river flow conditions in the downstream. The hydraulic connection between the river and the aquifer ceases as soon as pumping is stopped. The second condition is more common in case of rivers having intermittent flows; the loose sediments in the flood plains are more or less saturated resulting into shallower groundwater level. The heavy withdrawal of such flood plain aquifers during the non-monsoon creates ample space in the groundwater reservoir which gets recharged by the river during the flood season. In absence of such created space the river water would overflow.

6.1 Groundwater Aquifer Systems in Egypt

There are different groundwater aquifers with different importance for exploitation in the Nil Delta region in Egypt. These aquifers are the semi-confined aquifer. Recharge of groundwater in Nile Delta area takes place by different processes as infiltration of rainfall water; infiltration and downward leakage of excess irrigation water and leakage from canals; and inter-aquifer flow of groundwater. Recharge by rainfall is negligible and takes place only during the winter months. The main recharge occurs through seepage from surface water, especially from irrigation canals and by downward percolation of subsurface drainage water in traditionally cultivated lowlands. Inter-aquifer flow is minor component of recharge, which occurs from the Nile Delta towards the aquifers in the Western Nile Delta region. In the Eastern Nile Delta fringes, where no drainage system exists, all the subsurface drainage water percolates to the aquifer. Discharge of groundwater takes place by different components including direct extraction, groundwater return flow to canals and drains, evapo-transpiration and inter-aquifer flow of groundwater.

6.2 New Policy for Managed Aquifer Recharge

The main purpose for managed aquifer recharge is to efficiently store water for later use, but it can also have positive effects on the overall water quality. Some projects may add water to saline aquifers. Adding fresh water to saline aquifers can lower salinity levels. Compared with building above ground storages, storing water below the ground is a relative low cost option. It may also retain water more effectively than above ground storages as there are not the same high rates of evaporation.

VI. Effect Of The Groundwater Management On Crop Revenue In Egypt

The effect of increasing water table and salinity on the crop revenue is studied in Bahr Mashtoul canal command area as a case study by using OPDM model.

7.1 Description of (OPDM) Model

OPDM stands of the operation and planning distribution model, was developed by the Department of Biological and Irrigation Engineering, Utah State University (USU), with the United States Agency for International Development (USAID). This model is used to find salinity and gross revenue by editing the layout of the area which contains water supply, weather, crops, aquifer data and groundwater data. OPDM is the best program to manage agricultural areas, optimize crops, calculate highest gross revenue and lowest soil salinity.
The objective function is the maximization of gross revenue which can be expressed as:

$$MaxGR = \sum_{i=1}^{ni} \sum_{j=1}^{nj} R_j X_{ij} \quad \text{.......(4)}$$

Where;

GR: Max gross revenue; Rj: Gross revenue;

Xij: the area cultivated with crop (j) in command area (i);

ni: Number of command area; nj: Number of crops.

7.2 Case Study (Bahr Mashtoul)

7.2.1 Area and Location

Bahr Mashtoul Canal Command Area is located on the western edge of Sharkia Governorate. Bahr Mashtoul Canal is 24.51 kilometers long and is fed from the Bahr Mouis Canal at KM 36 close to Hanout Canal; the area served of Mashtoul Command Area is 50,434 feddans.

7.2.2 Soil

The soil texture in this area varies from moderately light to very heavy. The clay cap in the western part of the area is about 1.0 m. while it is up to 5.5 m in the central and western parts of Mashtoul Command Area.

7.2.3 Scenarios

Change in groundwater quantity which used for irrigation from -50% to 50% and show the effect of this change on the total gross revenue of total command area and on the gross revenue of each crop. Change in groundwater salinity from -50% to 50% with a 10% increment and show the effect of this change on the total gross revenue of total command area and on the gross revenue of each crop.

7.3 Results and Analysis

The result of effect of change of groundwater quantity and salinity on the total gross revenue of total command area is shown in Fig.4. By increasing the groundwater quantity from 0% to 50%, the total gross revenue increases from71.657 million L.E. to 73.8 million L.E., by decreasing the groundwater quantity from 0% to -50%, the total gross revenue decreases from71.657 million L.E. to 69.8 million L.E. By increasing the salinity from 0% to 50%, the total gross revenue decreases from71.657 million L.E. to 66 million L.E., by decreasing the salinity from 0% to -50%, the total gross revenue increases from71.657 million L.E. to 75 million L.E.

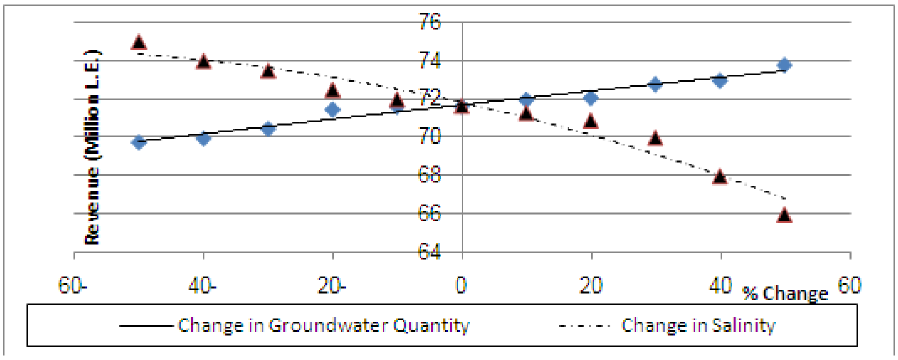

Fig.4: The Effect of Change of Groundwater Quantity and Salinity on the Total Gross Revenue

The effect of change of groundwater quantity and salinity on the total gross revenue of each crop is shown in Fig.5 to Fig11.

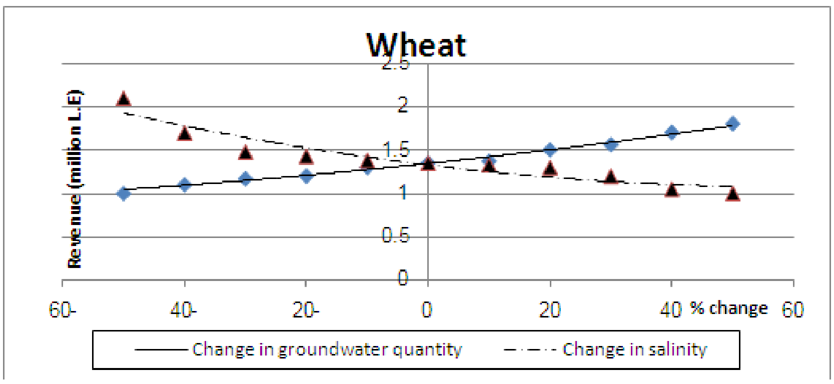

Fig.5: The Effect of Change of Groundwater Quantity and Salinity on the Total Gross Revenue for Wheat

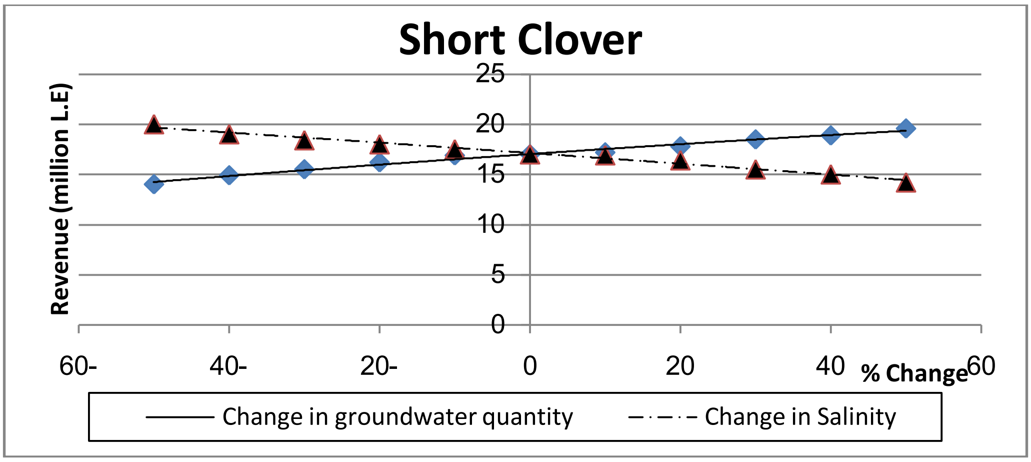

Fig.6: The Effect of Change of Groundwater Quantity and Salinity on the Total Gross Revenue for Short Clover

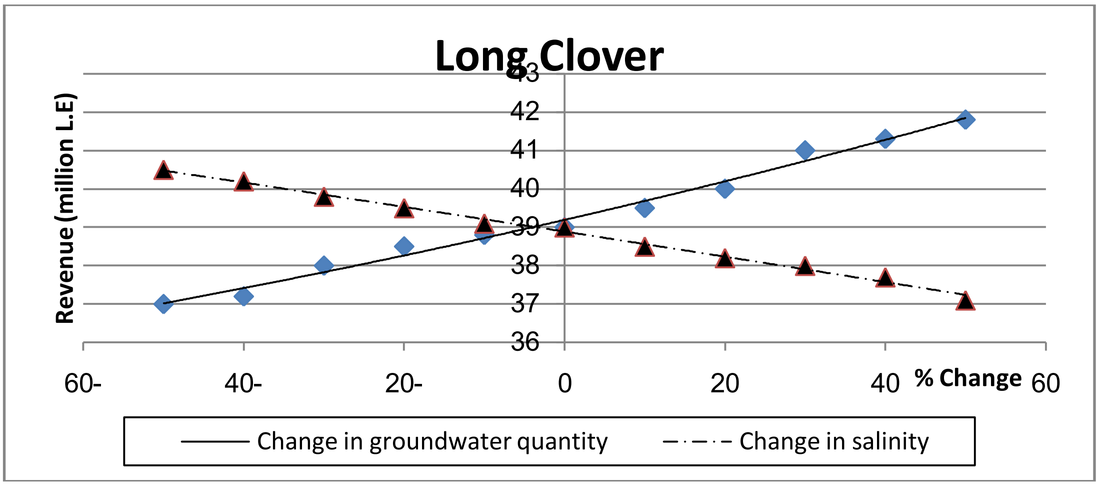

Fig.7: The Effect of Change of Groundwater Quantity and Salinity on the Total Gross Revenue for Long Clover

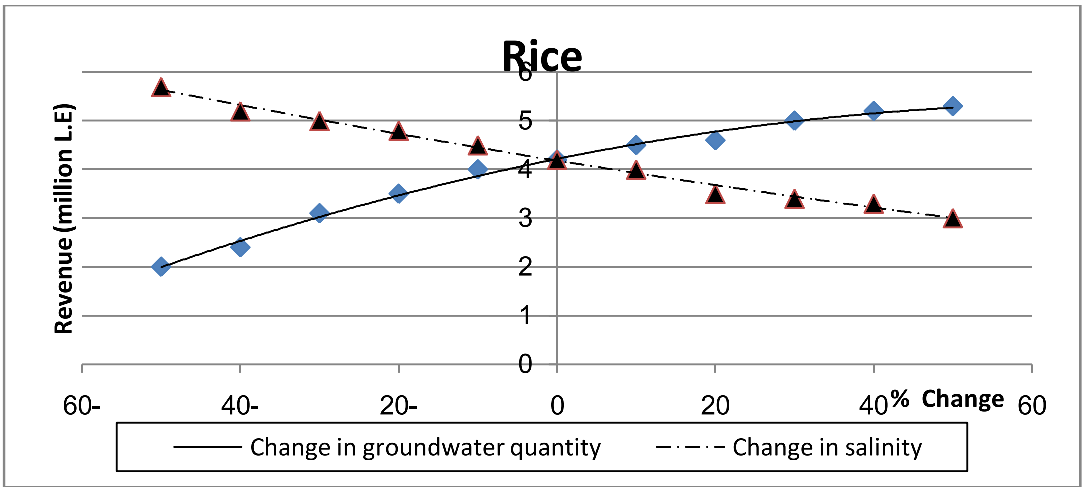

Fig.8: The Effect of Change of Groundwater Quantity and Salinity on the Total Gross Revenue for Rice

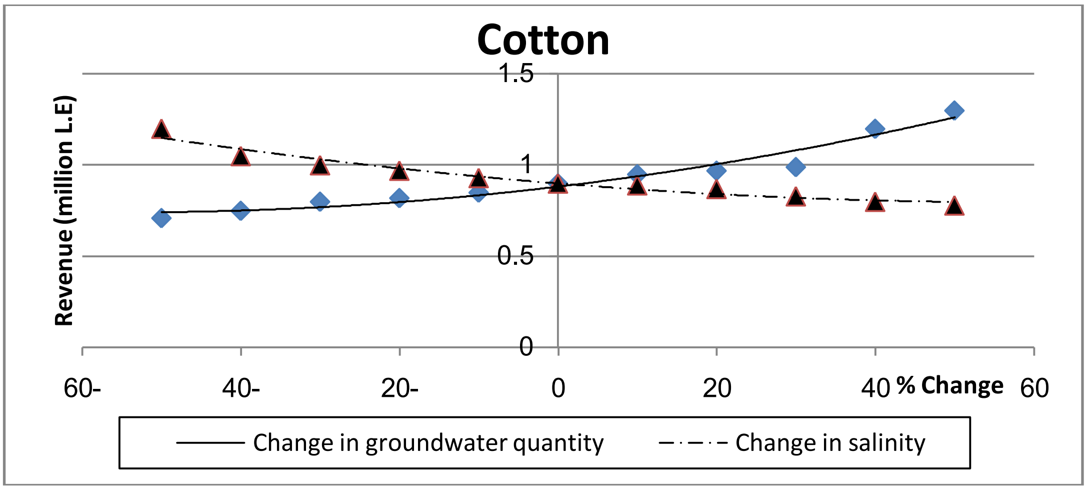

Fig.9: The Effect of Change of Groundwater Quantity and Salinity on the Total Gross Revenue for Cotton

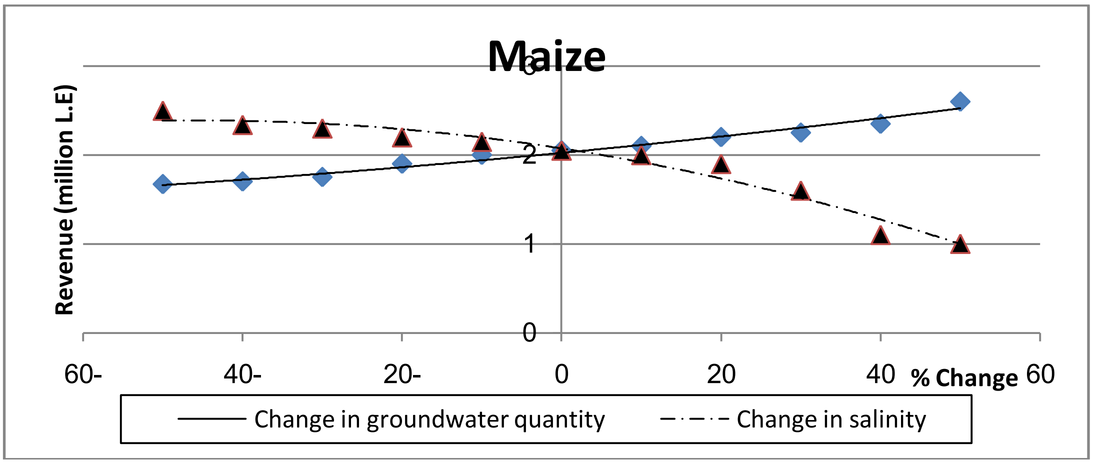

Fig.10: **The Effect of Change of Groundwater Quantity and Salinity on the Total Gross Revenue for Maize**

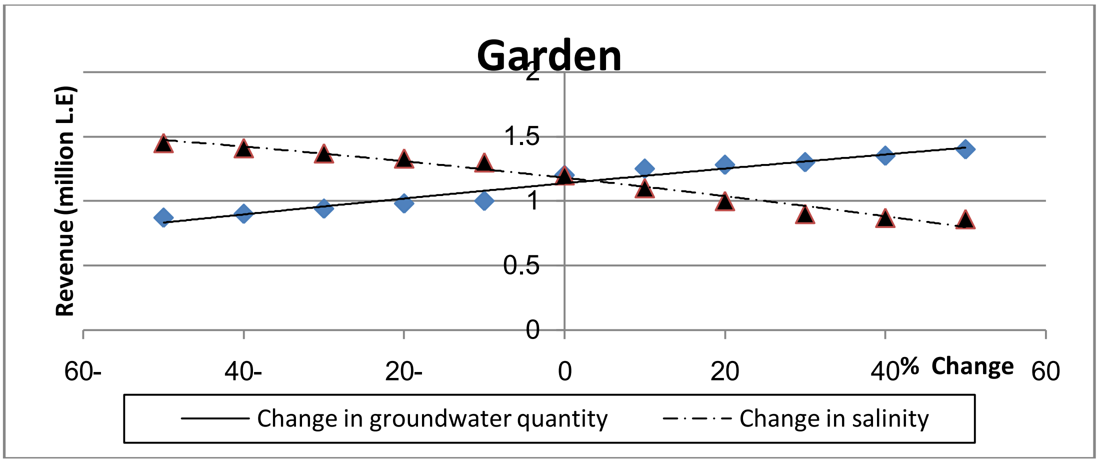

Fig.11: The Effect of Change of Groundwater Quantity and Salinity on the Total Gross Revenue for Garden

VII. Water Treatment

The most common water quality problem in rural water supplies is bacterial contamination. The main causes are the high permeability of its litho-logy as well as its localization in the vicinity of an irrigated area with intensive use of fertilizers. There is no similarity between vulnerability classes and water susceptibility classes. Thus, this proves the impact of the irrigation water quality on the aquifer groundwater quality. The current national plan for wastewater treatment, though highly expensive and ambitious, yet, fails in encountering the pressing environmental burdens. This is particularly true in the cities of complex industries, e.g., 10th of Ramadan, northern Cairo. Primary treatment is always insufficient to accomplish the objective for clean environment (Cairncross, 1989). Thus, it is important to adapt inexpensive and simple technology systems regardless to their large area requirement, particularly for sewage treatment (i.e., artificial wetlands and gravel bed hydroponics). The water treatment plants have got to face the following problems that largely affect the quality of water produced:

a- The relatively high levels of alum dose and the relevant problems in terms of aluminum residues in water and the duly high expenses of water produced.

b- The relatively high levels of added chlorine to raw water to reduce total counts of bacteria and fungi and similarly the added chlorine to the filtered water. The high level of bacteria is ascribed to the drained sewage, which leads also to growth of fungi and to increased amounts of nitrogenous and phosphorous salts. As the dose of chlorine increases, it leads to increased concentration of organo-chlorinated compounds that are known as carcinogenic and mutagenic.

c- The currently implemented processes of water treatment are inefficient in removing residues of pesticides and organo-chlorinated pollutants. Furthermore, they are also insufficient in removing parasites, viruses, and other non-parasitic microorganisms. As a result, these residues of chemical and biological pollutants may persistently remain in drinking water.

d- The growing levels of biological and chemical pollutants in raw water impose heavy burden on the efficiency of sand filters leading to blockages and development of microbial colonies, such as Nematode larvae which may eventually be present in drinking water.

Other difficulties are related to the drinking water distribution system, such as the ageing of some networks, leakage to groundwater and sewer systems, deterioration of municipal and buildings' water reservoirs, and the chlorinated compounds.

VIII. Conclusions

Egypt is facing increasing water needs, demanded by a rapidly growing population, by increased urbanization, by higher standards of living and by an agricultural policy which emphasizes expanded production in order to feed the growing population. Effective management of available groundwater resources requires an integrated approach, combining both supply side and demand side measures. Similarly, urgent action is required to augment the groundwater in the water stressed areas. However, focus on development activities must now be balanced by management mechanisms to achieve a sustainable utilization of groundwater resources. The effect of intrusion of seawater in coastal aquifer in western north coastal aquifer of Egypt is studied. The shape of the fresh-salt water interface and the water table profile is drawn by using Glover equation. The objectives of strategy of aquifer management are studied. The effect of increasing water table and salinity on the crop revenue is studied in Bahr Mashtoul canal command area as a case study by using OPDM model. The effect of the change in groundwater quantity from -50% to 50%on the total gross revenue of total command area and on the gross revenue of each crop is calculated. The effect of the change in salinity from -50% to 50%on the total gross revenue of total command area and on the gross revenue of each crop is calculated also. The result of effect of change of groundwater quantity and salinity on the total gross revenue of total command area is shown in Chart-3. By increasing the groundwater quantity from 0% to 50%, the total gross revenue increases from71.657 million L.E. to 73.8 million L.E., by decreasing the groundwater quantity from 0% to -50%, the total gross revenue decreases from71.657 million L.E. to 69.8 million L.E. By increasing the salinity from 0% to 50%, the total gross revenue decreases from71.657 million L.E. to 66 million L.E., by decreasing the salinity from 0% to -50%, the total gross revenue increases from71.657 million L.E. to 75 million L.E.

References

[1]. Betcher R., Grove G. and Pupp C. "Groundwater in Manitoba: Hydrogeology, Quality Concerns, Management" Environmental Sciences Division, National Hydrology Research Institute, Environment Canada, Saskatoon, Saskatchewan, March 1995.

[2]. Bredenhann L. and Braune E. "Policy and Strategy for Groundwater Quality Management in South Africa" Department of Water Affairs and Forestry Private, Bag X313, Republic of South Africa, First Edition 2000.

[3]. Mook W. "Environmental isotopes in the hydrological cycle" Technical Documents in Hydrology 1, No. 39, Vol. IV, UNESCO, Paris, 2000.

[4]. FAO "Groundwater Management, the Search for Practical Approaches" Food and Agriculture Organization of the United Nations, Rome, 2003.

[5]. Liu, Mink and Dai "Simple analytical groundwater modeling for sustainable yield estimation" In Proceedings of AWRA Summer Specialty Conference, June 2005.

[6]. Parikh, Shah, Chadha, Dubash, Mohanty, Jagawat and Reddy "Ground Water Management and Ownership" Report of the Expert Group Government of India, Planning Commission, New Delhi, September 2007.

[7]. Wagdy A. " Progress in Water Resources Management: Egypt" Proceedings of the 1st Technical Meeting of Muslim Water Researchers Cooperation (MUWAREC), Malaysia, December 2008.

[8]. Brian D. Smerdon, Todd E. Redding, and Jos Beckers "An overview of the effects of forest management on groundwater hydrology", BC Journal of Ecosystems and Management (JEM), 10(1):22–44, 2009.
[9]. Gondwe B. "Exploration, Modeling and Management of Groundwater-Dependent Ecosystems in Karst" PhD Thesis, DTU Environment Department of Environmental Engineering Technical University of Denmark, March 2010.
[10]. El Osta, M. El Sheikh A., and Barseem M. "Comparative Hydrological Study on the Quaternary Aquifer in the Deltas of Wadi Badaa and Ghweiba, El Ain El Sukhna Area, Northwest Suez Gulf, Egypt" Hindawi Publishing Corporation International Journal of Geophysics, Article ID 585243, 15 pages, 2010.
[11]. El Samanoudi M., Ebid G., Rofail N., Ismail Y. and Hawash S. "Assessment of Groundwater Resources in Northeastern Sinai Peninsula Constrained by Mathematical Modeling Techniques" Fifteenth International Water Technology Conference, IWTC-15, Alexandria, Egypt, 2011.
[12]. Gad M., El Sheikh A. and El Osta M. "Optimal management for groundwater of Nubian aquifer in El Dakhla depression, Western Desert, Egypt" International Journal of Water Resources and Environmental Engineering, 3(14): 393-409, 2011.
[13]. Working Group "Sustainable Groundwater Management" Report submitted to planning Commission Government of India, New Delhi, 2011.
[14]. Ackermann R. "New Directions for Water Management in Indian Agriculture" Global Journal of Emerging Market Economies, 4(2): 227–288, 2012.
[15]. El-Arabi N. "Environmental Management of Groundwater in Egypt via Artificial Recharge Extending the Practice to Soil Aquifer Treatment (SAT)", International Journal of Environment and Sustainability, 1(3):66-82, 2012.
[16]. Stephen Foster & Mohamed Ait-Kadi " Integrated Water Resources Management (IWRM): How does groundwater fit in?" Hydrogeology Journal, 20:415–418, 2012.
[17]. King A., Boyle D., Jensen V., Fogg G. and Harter T. "Groundwater Remediation and Management for Nitrate" Technical Report 5 California Nitrate Project, Center for Watershed Sciences, University of California, July 2012.
[18]. Youssef, Gad and Ali "Assessment of Groundwater Resources Management in Wadi EFarigh Area Using MODFLOW" IOSR Journal of Engineering (IOSRJEN), 2(10): 69-78, 2012.
[19]. Mabrouk, Jonoski, Solomatine, and Uhlenbrook "A review of seawater intrusion in the Nile Delta groundwater system – the basis for assessing impacts due to climate changes and water resources development" Hydrology Earth System Sciences Discuss., 10:10873–10911, 2013.
[20]. Barthel R. "Integration of groundwater and surface water research: an interdisciplinary problem?" Hydrology and Earth System Sciences, 11:2011–2044, 2014.
[21]. Hunt B. "Unsteady Stream Depletion from Groundwater Pumping" GROUNDWATER, 37(1), February 1999.