

Groundwater Management in the Esna Area, Upper Egypt: An Application of Remote Sensing and Numerical Modeling

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Abstract: The major issues concerning water development and management include water conservation and the efficiency of water use; cost recovery, social and environmental factors. So continuous monitoring was essential to evaluate the reclamation impacts on the groundwater potentiality such as Esna Area, Luxor Governorate, Egypt. The main objective of this work is to determine the new development areas in Esna during the period from 1984 to 2011 using remote sensing technique, the impacts of the present and future development have been evaluated by using the two-dimensional numerical groundwater flow Simulation Package (visual modflow 4.2). The package was used to construct and calibrate a numerical model that can be used to simulate the response of the aquifer in the study area under implementing different management alternatives in the form of changes in piezometric levels and salinity. From land use maps of the study area for year 2011, it was observed a lot of changes in development areas especially on the border of the old land. The change in land reclaimed area was estimated with 44% in the period from year 1984 to 2011. This development accompanied with draw down about 2.5 meters through this period of time. The authors recommended applying different kinds of change detection technique on the study area. Compare between results, continuous monitoring of the development area is highly recommended.

Key words: Remote Sensing • Management of Aquifer Systems • Simulation Modeling • Upper Egypt

INTRODUCTION

Remote Sensing, with its advantages of spatial, spectral and temporal availability of data covering large and inaccessible areas within short time, has become a very effective tool in assessing, monitoring and conserving groundwater resources [1]. Satellite data provides quick and useful baseline information on the parameters controlling the occurrence and movement of groundwater such as geology/lithology, land use/ land cover and hydrological parameters. These parameters have to be integrated to assess groundwater. However, the conventional techniques have the limitation to study these parameters together because of the non-availability of data, integration tools and modelling techniques.

Esna is an important area in Egypt, which has limited water resources although it lies on the upper part of Nile

aquifer as shown in Figure (1). The government established canals network to divert surface water to this area but farmer is still suffering from shortage of surface water, therefore groundwater wells are used to cover demands. Due to extensive abstraction from public and private wells (about.68 BCM), the water level in the well fields declined significantly [2]. To avoid the deterioration of the aquifer system and control side effects of the development in this area, an efficient integrated and sustainable planning and monitoring are needed. Also predict the effects of this development on the groundwater conditions through numerical modeling.

The main objectives of the present study are as follows:

- Producing two land use maps for the study area covering the time interval from 2000 and 2011,

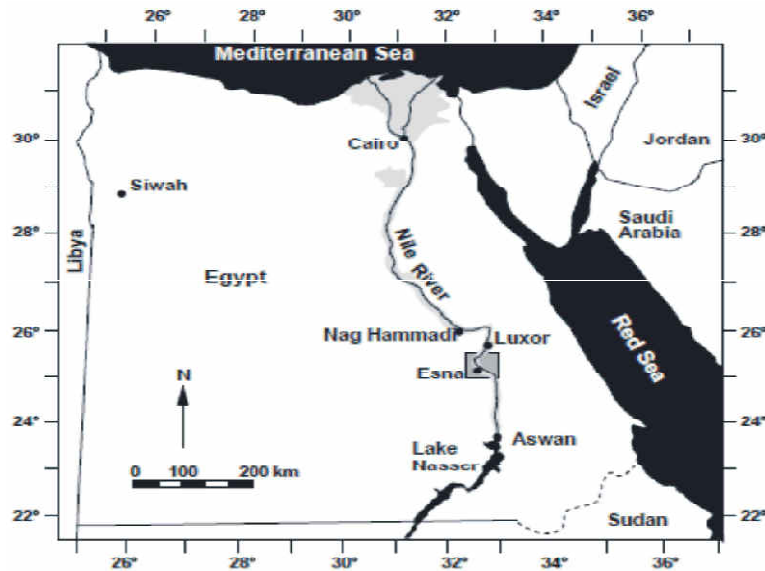


Fig. 1: Location map of the study area

- Producing change detection map that reflects the changes due to land reclamation during the mentioned period, and
- Predicting the implementation impacts of the continuous agricultural developing in Esna on the groundwater potentiality and its quality by employing the Numerical Groundwater Simulation Package (modflow).

MATERIALS AND METHODS

Water resources management is a complex process that requires a multi-disciplinary team in order to take all its facets into consideration. The integrated water resources management approach combines different aspects under one system that balances between water supplies and water demands taking into account the preserve of water quality. To study the impacts of implementing the developing policy on the groundwater potentiality, a groundwater simulation package used to simulate the behavior of groundwater aquifer and its interaction with surface water within the study area. The package is fed with the hydrogeological information about the groundwater aquifer system and the surface water bodies, constructing a numerical model for the Esna aquifer. The model is calibrated against the historical observation records of the groundwater piezometric heads under the steady state condition. Then it is invoked to test many management scenarios of water resources policy and predict the aquifer response in forms of piezometric levels and water quality.

To fulfill the study objectives, the following activities will be carried out:

- ▶ Collection of all available data for the study area including the physical settings (location, topography, meteorological data, land use and irrigation and drainage systems) and hydrogeological settings (geology, aquifer system, aquifer boundary and extent, aquifer hydraulic parameters, groundwater flow pattern and groundwater recharge)
- ▶ Two landsat TM images for the Esna city obtained at 1984 and 2011 are analyzed to produce landuse maps (1984, 2011) then change detection map which illustrates the new the reclaimed areas using Erdase Imagine Software.
- ▶ The final results of the new reclaimed areas that obtained from the change detection map are used to feed the numerical groundwater flow model to simulate the response of the aquifer under the implementation of the present and future water resources policy. The simulation process will be executed by using the Numerical Groundwater Simulation Package Visual Modflow 4.2) was used.

Land-Cover Maps and Change Detection Maps: Esna is an important area in Egypt, which has limited water resources although it lies on the upper part of Nile aquifer and farmers are suffering from shortage of surface water, therefore groundwater wells are used to cover demands. Accordingly, remote sensing technique plays

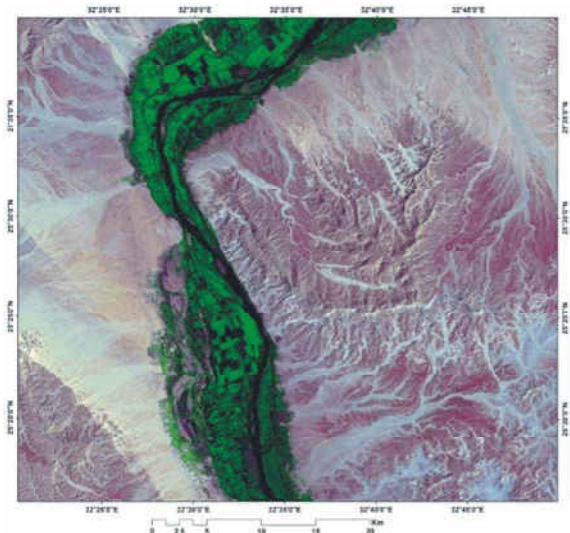


Fig. 2: Landsat TM 1984 (RGB 6,4,2)

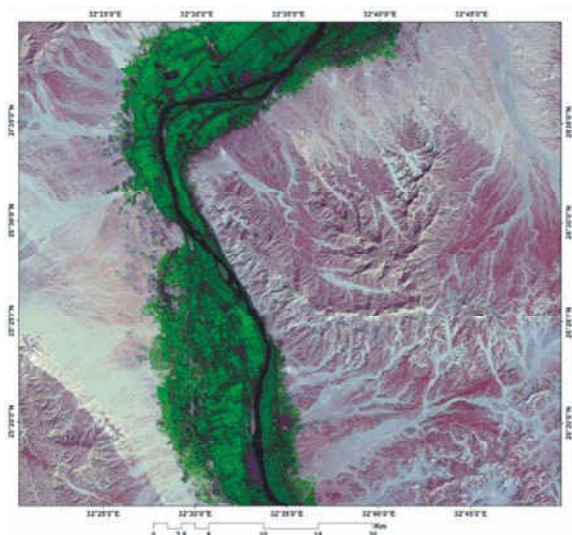


Fig. 3: Landsat TM 2011 (RGB 6,4,2)

an important role in producing land cover map and change map of different stages of development (change detection map)

These changes in reclamation lands were illustrated through two satellite images, at two different dates 1984 and 2011. The image of 1984 represents the beginning stage of development and the image 2011 represents the current stage of development. The procedure used for producing the land cover maps and change detection map will be discussed as follows.

Application of Remote Sensing for Producing Land Cover Maps: Two Landsat TM images cover Esna Region at two different dates (July 1984 & July 2011) were

used (Figures 2 and 3) for producing land cover maps where land cover simply refers to the actual biophysical materials found on that same area [3]. ERDAS Imagine software was used in this study to analyze the Landsat TM images and produce classified images for the study area through the following steps:

Rectification: For the images by the nearest neighbourhood method.

Classification: In order to produce a more accurate classification of the Esna area, the classification of the two images was completed in two stages. First, an unsupervised classification was performed; second supervised classification on both the 1984 and 2011 Landsat TM images. Figures (4 and 5) illustrate the final classified images for study area at the two dates. The result of the process is the creation of 6 separate classes: cultivated area, water, urban, wadis, limestone and wadi gravel. However, the classification technique still incurred a great deal of error. Most of this error occurred due to an inability to differentiate between urban structures and gravel.

Change Detection Application: Change detection application represents one of the important applications of Remote sensing technique. Change detection procedures should involve data acquired by the same (or similar) sensor and should be recorded using the same spatial resolution, viewing geometry, spectral bands, and time of the day. There are different methods which are used in change detection application such as: Image difference, Image ratio and post classification comparison [4].

In this area change detection application using post classification comparison was applied for detecting the changes in cultivated area in Esna during the period from 1984 to 2011. Post classification comparison method was applied through ERDAS Imagine according to the following steps:

- A classified image was prepared for the years of 1984 and 2011 (land use map).
- The Produced land use map at 1984 was subtracted from the produced land use map at 2011 as shown in (Figure 6).
- The resulting change detection map illustrates different changes in the vegetation class during this period of time.

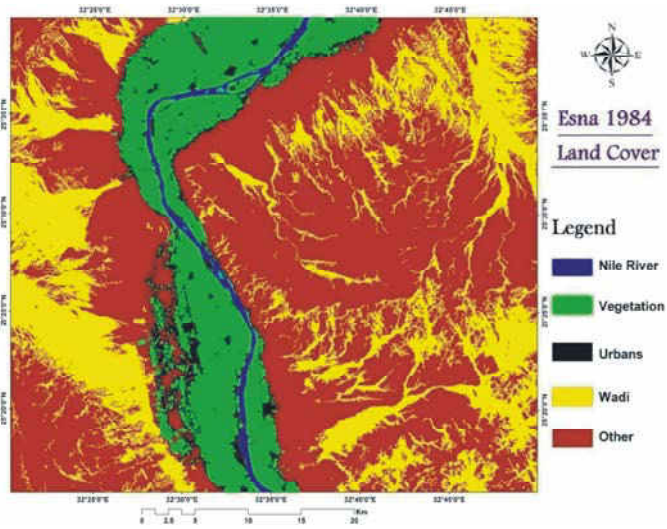


Fig. 4: Landuse map obtained from Landsat 1984

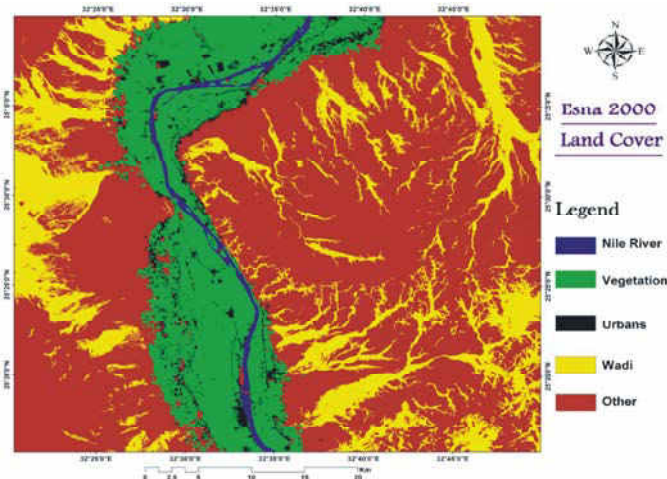


Fig. 5: Landuse map obtained from Landsat 2011

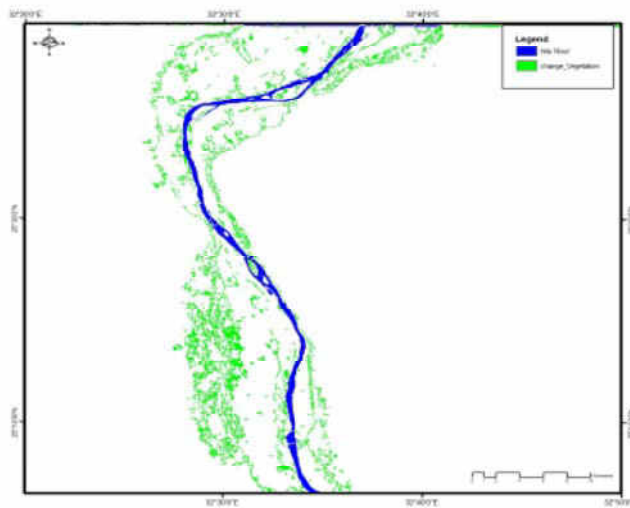


Fig. 6: Change Detection map

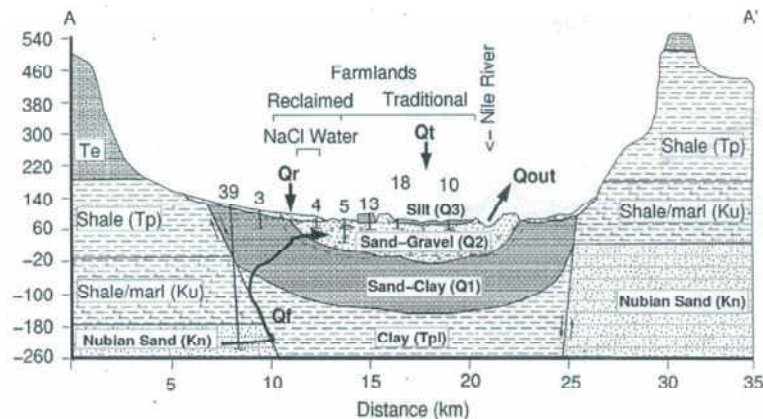


Fig. 7: Hydrogeologic cross-section for Esna Region

Change detection map was produced, which reflects the change in reclaimed lands, and it was observed a lot of changes in development areas especially on the border of the old land. The change in land reclaimed area was estimated with 44%. The total cultivated area based on groundwater reach to about 1000 fed., and located in the north and south of the western fringes as shown in the change detection map.

The numerical groundwater flow simulation package modflow was used to predict the expected drawdown and water balance in the future as a result of groundwater development in the area. The study concluded that the most critical areas which have been affected by remarkable lowering in the groundwater level especially in the new cultivate land

Hydrogeology: Two principal groundwater aquifers are present in the study area, the Quaternary aquifer of the Nile Valley, and the Cretaceous Nubian Sandstone found near the surface 50 km or more away from the valley. The Quaternary aquifer consists of gravel, sand and silt deposited by the River Nile in a structural low formed during Oligo-Miocene rifting related to the opening of the Red Sea [5]. Egyptian geologists have interpreted the depression to be a fault graben in the Esna area [2]. The bedrock walls of the graben are comprised of Cretaceous to Eocene marine shales, carbonate and sandstone.

The distribution of hydrostratigraphic units in the study area has been investigated through geophysical surveys and borehole studies [2]. The graben fill is of greatest importance to this study, and the RIGW studies indicate a deeper sand-clay zone ("Plio-Pleistocene aquifer" or Q₁ on Figure 7) overlain by gravel-sand ("Quaternary aquifer" or Q₂). These are the principal

aquifers within the Nile graben, and are overlain by silty overbank deposits (silt-clay, Q₃) acting as a semi-confining layer above the aquifers. Thick late-Tertiary marine clay (T_{pl}) underlies the Quaternary aquifers, forming an essentially impermeable base.

Bedrock in the vicinity of the graben consists of marine sediments of Cretaceous to Eocene age, including carbonates, marls and shales. These units act as aquitards, except for the deeper Cretaceous Nubian Sandstone (K_n), which forms a regional aquifer beneath much of Egypt. The Nubian Sand lies several hundred meters below the Nile valley floor in the study area (Figure 7). Research wells penetrating the Nubian Sand show artesian pressure along most of the Nile valley [2] and salinity above 1000 ppm. Some leakage is postulated from the Nubian Sand aquifer upward along graben-bounding faults.

Groundwater flow is primarily toward the river from the valley walls, with a slight northward (downriver) gradient present (Figure 8). A barrage, or low-head-dam built across the Nile at Esna in 1960 causes the steeper gradients just downstream. The profile line used for modeling below is essentially perpendicular to isopach lines, and therefore two-dimensional cross-sectional modeling along this line is a valid approximation of the system.

Ground Water Flow Model: The numerical modeling is a powerful and helpful tool for the analytical solution, especially when the area of model has variability and complicated in the hydrogeological conditions as acquired in the study area. In addition, it is used for forecasting the effect of development proposed scenarios on the groundwater levels after 50 years. To satisfy this objective the latest version of numerical modeling software (Visual Modflow 4.2) was used.

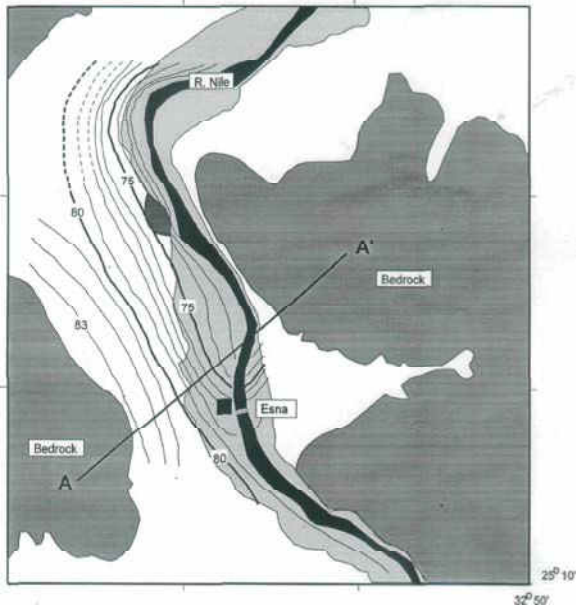


Fig. 8: Potentiometric surface in the vicinity of Esna

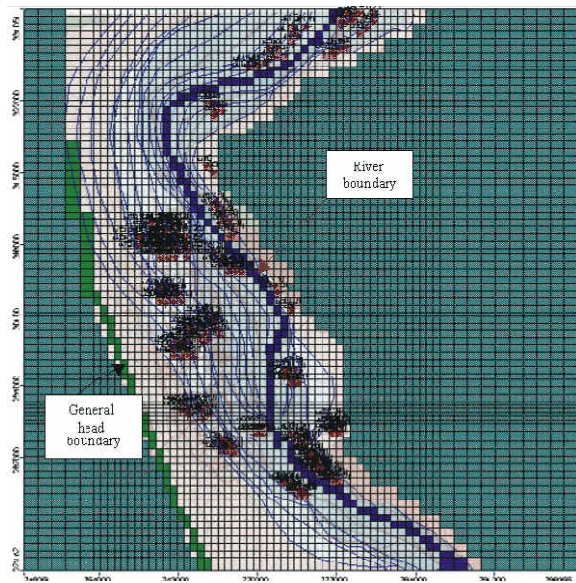


Fig. 9: Conceptual and boundary conditions of the study area

The Simulation Code: Visual MODFLOW4.2 is a multi-dimensional, finite difference, block-centered, saturated groundwater flow code. It is a fully integrated package combine Modflow, Modpath and MT3D, where MT3D is used to forecast future concentrations of TDS.

Geometry of Modeling Area and Input Data: The regional groundwater model covers west Esna map sheet with longitudinal length 75km. The modeled area was divided

into 82 cell in north south direction and 50cell in east west direction, each cell cover area 900km. The model includes two layers (one semi-confined aquifer). The first layer is consist of clay its thickness varies from 0 to 8m, and the second layer is the quaternary aquifer which consists of sand and gravel with some intercalation of clay, its thickness varies from 100m to 150m.

Input Data: The input data of the model based on: 1) Geometry of the aquifer system including the top layer; 2) Hydraulic Parameters of the Aquifer System (Transmissivity, Storativity, Vertical and Horizontal hydraulic conductivity); 3) The average rate of hydraulic conductivity of the clay layer reach to 0.05m/day, while it varies between 60-100m/day for quifer layer area [6]. The average rate of recharge is ranging between 0.0001 – 0.0005 m/day in flood plain, whereas the main discharge in the model area, is groundwater extraction for various uses which reach to about 2.14×10^9 m³/day at 1990 [7], while it increased to about 2.719×10^9 m³/year at 2011 due to new development. The total amount of discharge distributed all over the area through grouped sinks; 4) Topography; 5) the hydraulic parameters of the River and main canals and drains (water level, wetted perimeters, and resistance).

Boundary Conditions and Conceptual Model: The boundaries of the regional model are selected to coincide with natural hydrogeological conditions. The boundary conditions are defined as follows: 1) River Nile is considered river boundary; 2) the western boundary coincides with a general head boundary for the pizometric level -81m (with respect to m.s.l)(Figure 9).

Calibration: The calibration process is executed through 2 phases, first phase: steady state conditions at 1990 using the existing pizometric head contour map [2]. The second phase: unsteady state condition for regional model during the period from 1990 to 2011 accoding to continous development and new development areas obtained from change detection map.

The calibration process has been done through several trials by adjusting the recharge parameters and hydraulic resistance to generate piezometric head, which are in agree with measured values. Figures (10 and 11) show the calibrated pizometric head at 1990 and 2011 respectively.

Calibration Results: Results of the model is considered satisfactory where the difference between the computed and measured heads from hydrogeological map of west

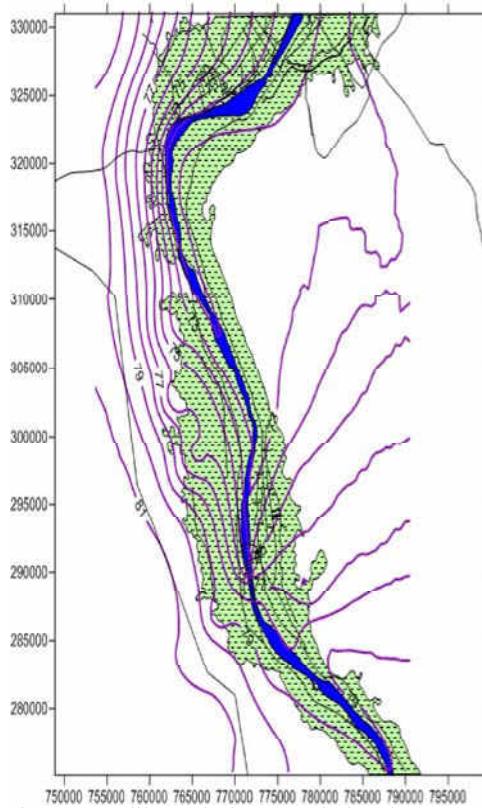


Fig. 10: Calibrated Piezometric head at 1990

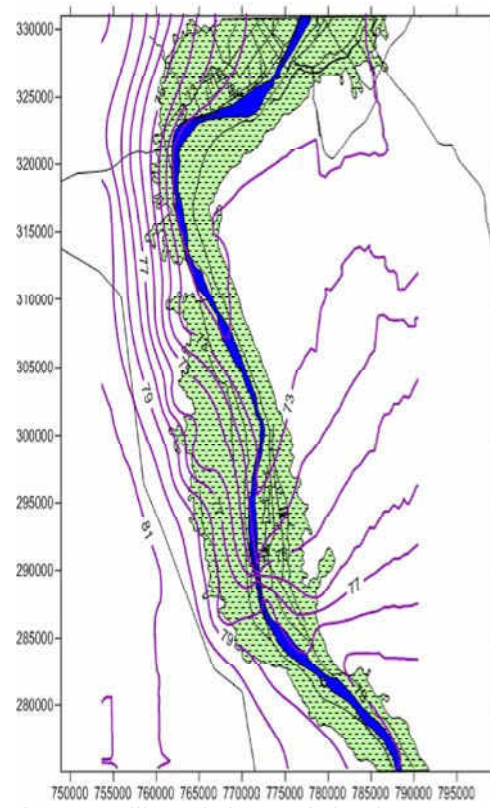


Fig. 11: Calibrated piezometric head at 2011

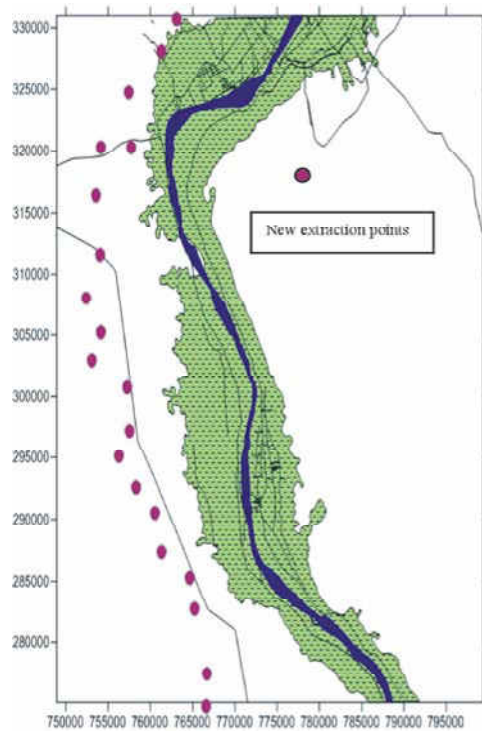


Fig. 12: location of new extraction points in the study area

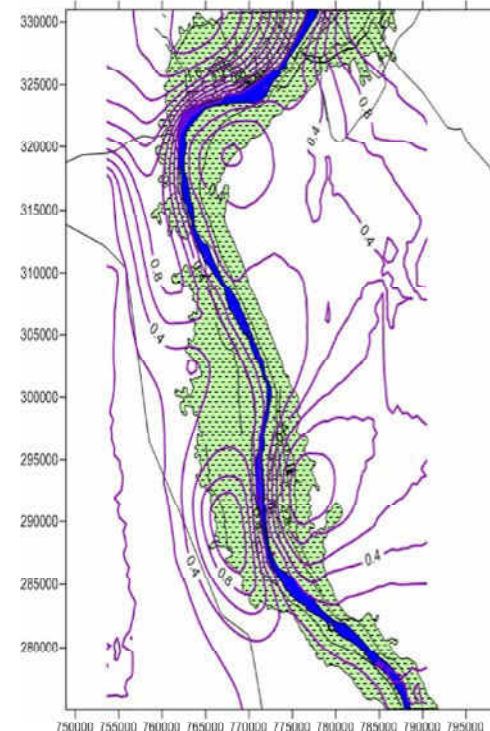


Fig. 13: Drawdown in groundwater piezometric head from 1990 to 2011

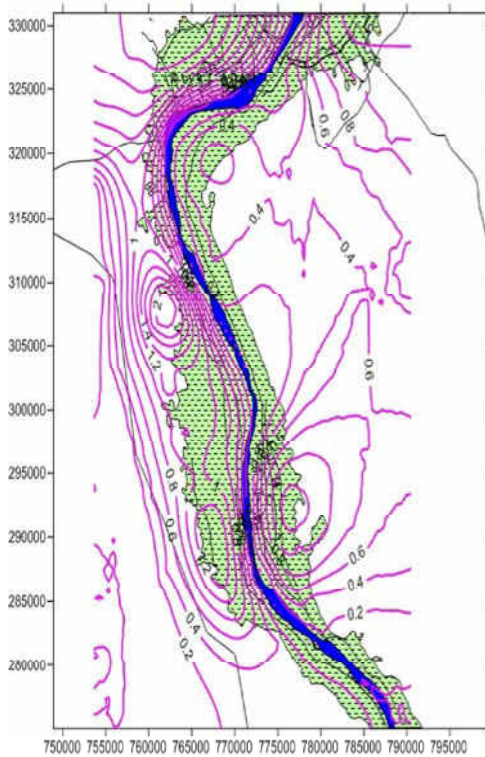


Fig. 14: The drawdown from 1990 to 2040

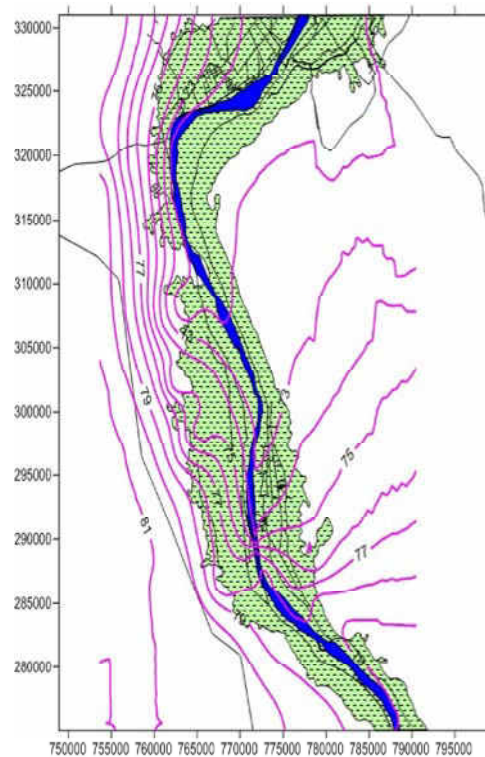


Fig. 15: The predicted piezometric head 2040

Esna [2] was limited. The figures (10 and 11) illustrate the calibrated piezometric levels contours map in year 1990 (first stage of development) and 2011 (due to continuous development and new reclaimed areas through change detection map). The groundwater extraction points due to the new reclaimed areas concentrated in the south and north part of the western fringes of the study area as shown in figure 4. The total increasing in Groundwater extraction at 2011 reach to $(2.719 \times 10^9 \text{ m}^3/\text{year})$

Groundwater flow model illustrate the impact of these increasing in reclaimed area on groundwater. The average drawdown of groundwater due to the continuous development and new reclaimed areas ranges from 0.5m to 2.5m. Figure 10 represents the difference in groundwater levels between year 1990 and 2011

CONCLUSION

- Landsat TM images represent as important tool to illustrate the land use and land cover maps. Change detection map was produced to reflect the changes in different human activities in the study area.
- New development areas were calculated from the produced landuse map 2011. Groundwater numerical

model was used to evaluate the impact of these development on groundwater aquifer in the study area.

- Two Land use maps for the study area were produced with high accuracy using remote sensing technique through Erdas imagine software
- From Landuse maps for the study area showed a lot of changes in development areas especially on the border of the old land. The change in land reclaimed through change detection map was estimated with 44%.
- The numerical groundwater flow simulation package modflow was used to predict the expected drawdown and water balance in the future as a result of new development on groundwater in the study area.
- The average drawdown of groundwater due to the continuous development and new reclaimed areas ranges from 0.5m to 2.5m through the period from 1990 to 2011.
- The study concluded that the most critical areas which have been affected by remarkable lowering in the groundwater level are in new cultivate land

Recommendations: There is still much to be done in the future studies through the following recommendations:

- Applying different kind of change detection technique (post classification comparison, image deference and image ratio) on the new development areas to compare between the results.
 - Continuous monitoring for western Esna development areas by using different kind of satellite images to protect groundwater resources from depletion and deterioration.
 - It is recommended also to apply well license system in order to avoid groundwater deterioration at ESNA and also follow the regional plan of aquifer development.
 - Study the scenarios of applying conjunctive use of surface and ground water recourses in order to prevent the increase of water
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