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Term Paper Draft

Applications of GIS in Hydrogeology: Recent Case Studies From Egypt

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1. Introduction:

Water is a crucial element for the survival of humans and the security of their urban and rural communities. Water-related issues and challenges are addressed through the discipline of hydrogeology which offers contributions such as locating new water resources, monitoring pollution in current resources, and monitoring flood zones. Recently, these contributions have become increasingly dependent on Geographic Information System (GIS) techniques.

This term paper addresses these applications by reviewing three case studies from Egypt. The benefits of utilizing GIS are numerous in this country which has areas of different characteristics. It has the longest river in the world as well as large arid areas. Subsequently, the geography of Egypt contributed to the diversity of researcher's approaches in utilizing GIS for Hydrological studies.

Three case studies are selected to be the scope of this term paper (Fig.1). Two selection criteria were followed to choose the case studies. Case studies have been published recently in the past four years. Also, these case studies utilize GIS to address different applications in hydrogeology. They addressed areas of research are locating prospect areas for new water resources, monitoring volumes of the available water resources in fresh lakes, assurance of the quality of the water in the rivers. Each case study will be viewed and discussed individually below.

Figure 1 : Location of the selected case studies. (Modified after Abdalla, 2012)

2. Case Study I: Assessing Water loss from Tushka Lakes:

2.1. Introduction:

The work conducted by Bastawesy et.al. (2008) aimed to study the water loss from lakes located west of the Aswan High Dam which was constructed on the Nile River (Fig.2). The water reservoir of this dam is known as Nassir Lake. Moreover, the water level at this lake has to be maintained below 178 m above the sea level for the safety of the dam structure. In 1978, 25 km long canal (Tushka Spilway) was created to transport the excess water to Tushka Depression when the lake's water level is beyond the safe limit mentioned previously.

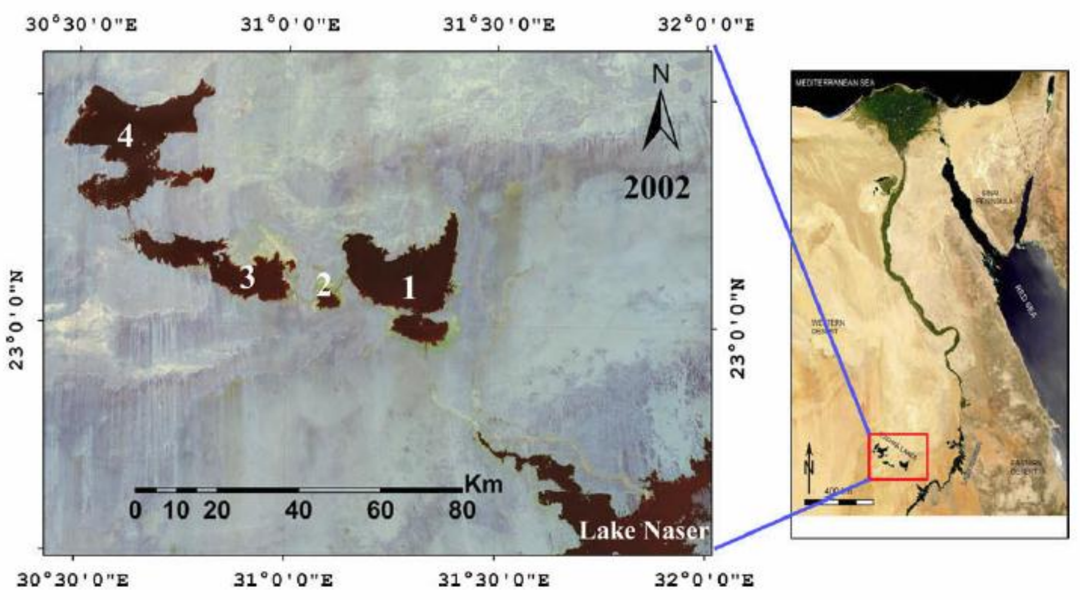

Figure 2 : Location of the Tushka lakes. The numbers are used to refer to the lakes in the text. (Bastawesy et.al, 2008)

This study focused on studying the four Tushka lakes that formed after 1998 (Fig.3). Comparison between the surface area and the volume of water between 2002 and 2006 is used

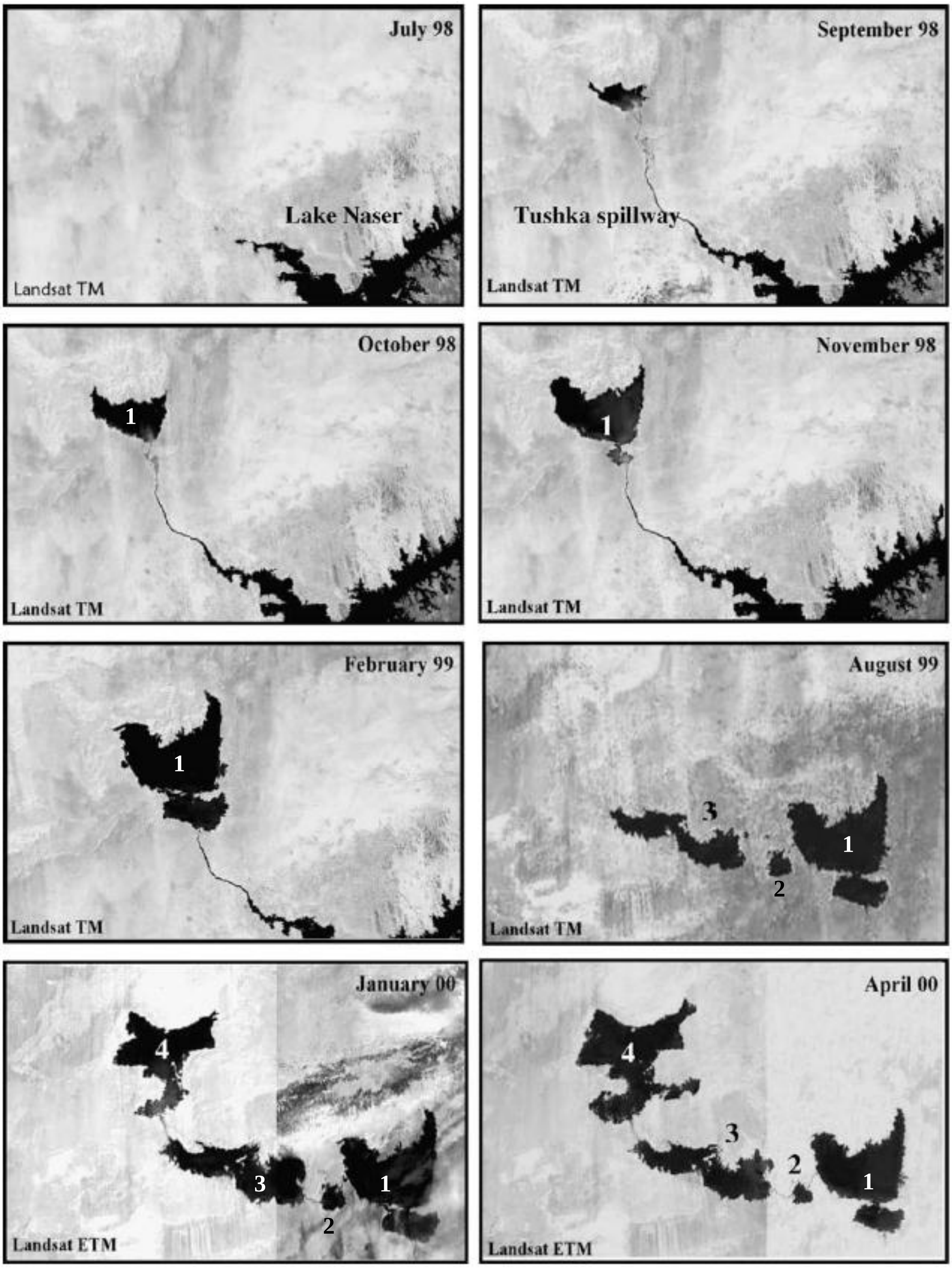

Figure 3 : Landsat images demonstrating the evolution of the Tushka Lakes between 1998 and 2000. Numbers correspond the the lakes numbers in the text. (Bastawesy et.al, 2008)

to derive the annual rate of water loss. Bastawesy and his co-others used these rates to project and predict the time of total loss of fresh water for each lake individually.

2.2. Methodology:

Data used in this study includes Three ASTER images acquired February 2002 and four SPOT-4 images acquired February 2006. The primary function of these images is to define the surface area of the four lakes during both periods. Universal Trans-Mercator (UTM) Zone 36 projection method is used to process these images. Contrast of the reflective infrared bands between the water and its surrounding land cover is utilized to isolate the pixels representing water in order to calculate the lake surface area. Applying this methodology on images from 2002 and 2006 reviled the area that has dried up in these four years (Fig.4). It is noteworthy that the cut off between water and land cover pixels is not straight forward especially in the transitional areas around each lake. Thus, a fixed threshold is used for all images to eliminate any discrepancies.

Moving from 2-D areal analysis to a 3-D volumetric analysis dictates the need to integrate the topography in order to resolve the geometry of lakes bottom floor. For this purpose, topographic maps of 1:100,000 scale were digitized to generate a digital elevation model to simulate the lakes floor. These maps were surveyed prior to the formation of these lakes. The model is then interpolated in ArcInfo Topogrid's module and integrated with satellite images.

2.3. Results:

The main outcome of work conducted by Bastawesy et.al. (2008) is the volumetric assessment of fresh water in Tushka lakes. Numerical values of area and volume attributes for each lake were calculated using the functions from ArcInfo Grid Module (Table.1). Moreover, the study modelled the water loss to estimate the times where each lake dries up completely. This is based on the assumption that the precipitation and flooding conditions continue as they were between 2002 and 2006 (Fig.5). Since Lake 2 was completely dry before making the estimation in the study, estimates provided are only for remaining three lakes. Their study predicts that Lakes 1, 3, and 4 will be completely dry in 2014, 2012, and 2020, respectively.

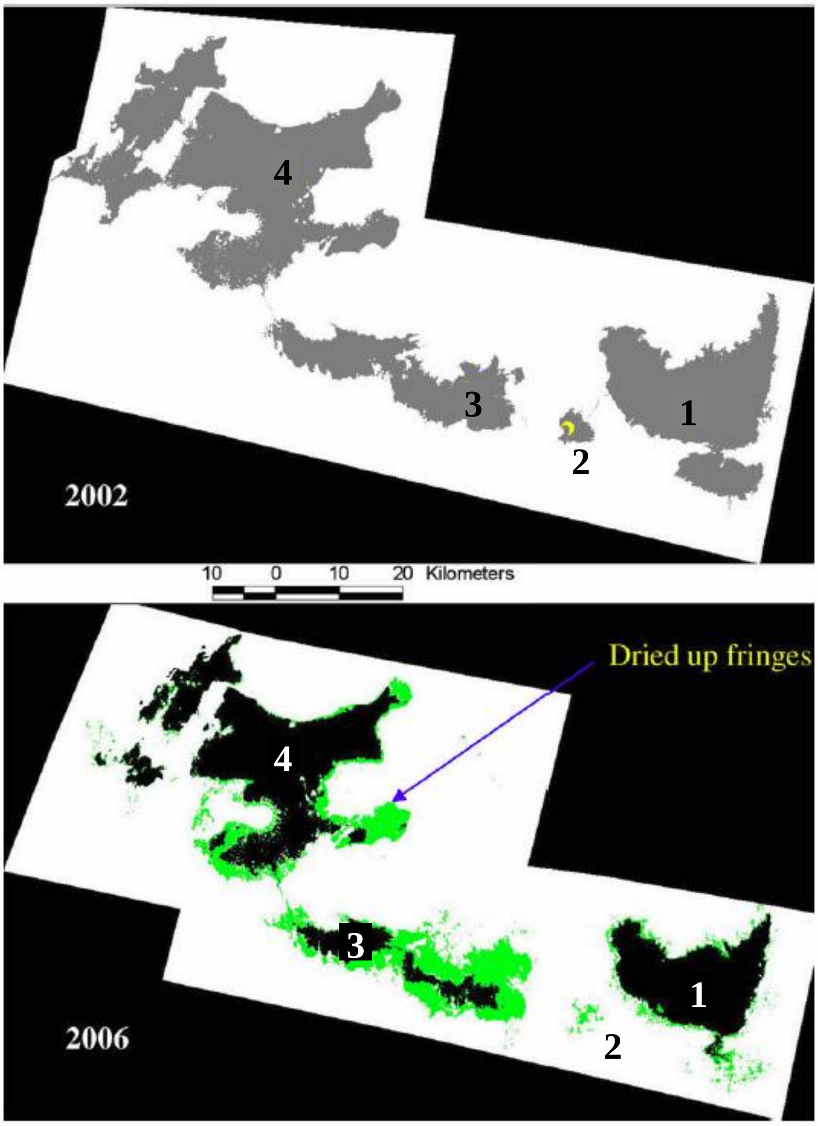

Figure 4 : Two maps showing the surface area of the four Tushka lakes in 2002 and 2006. (Bastawesy et.al, 2008)

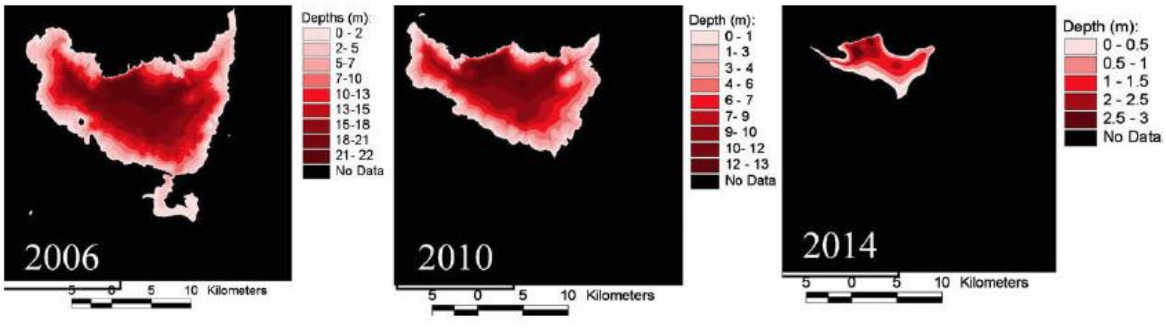

Figure 5 : Estimated area and bathematry of for Lake 1 in 2006, 2010, 2014. (Bastawesy et.al, 2008)

Table 1: Area and Volume calculation results for the years 2002 and 2006. (Bastawesy et.al, 2008)

	Area (km^2)		Volume (billion m^3)	
	2002	**2006**	**2002**	**2006**
Lake 1	499	286	6.78	3.45
Lake 2	20	0	0.044	0
Lake 3	265	101	2.21	0.44
Lake 4	807	550	16.23	8.78
Total	1591	937	25.264	12.67

2.4. Discussion:

The work conducted by Bastawesy et.al. (2008) represents an example of utilizing the ArcGIS package to integrate two types of spatial data in order to apply specific calculations. These calculations are important in assessment of water resources sustainability evaluation. GIS proved to be an excellent tool for areal and volumetric determination.

In this report, a recent satellite image from 2013 is used to test the predictions made by

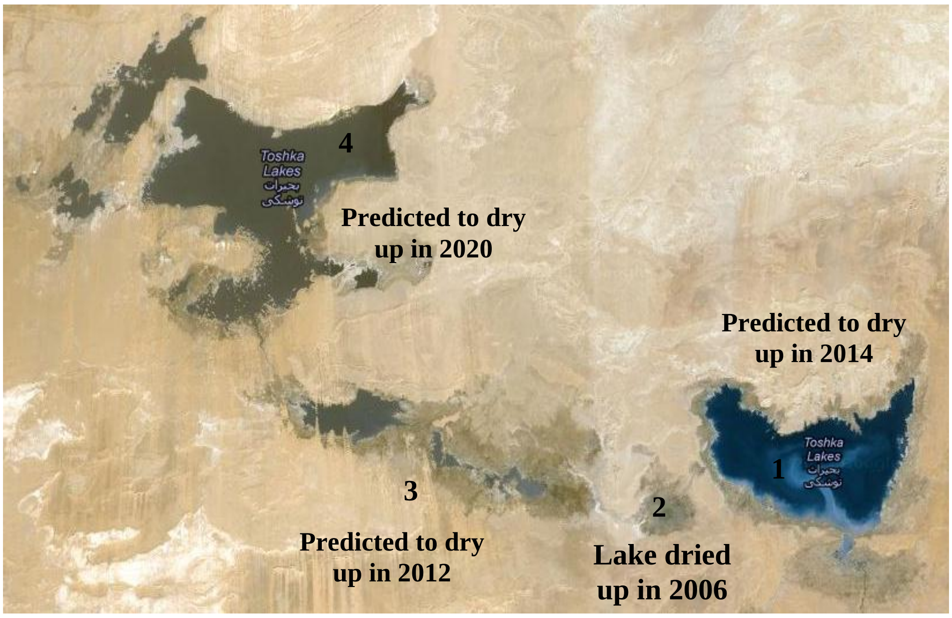

Figure 6 : Predictions made in 2008 are posted on recent Satellite images acquired in 2013. (Google Maps, accessed on 4/11/2013)

Bastawesy et.al (2008). Because of the unavailability of the data and DEM model used their comparison is only qualitative. Lake 3 which was predicted to dry up completely by 2012 still has water column and is not completely dry (Fig.6). This suggests the either the water loss rate used by Bastawesy et.al (2008) is overestimated or water charging this lake has increased since the time of the that study.

3. Case Study II: Characterizing the water pollution in the Nile Delta:

3.1. Introduction:

The study published by Shaban et.al. (2010) focused on a different aspect of hydrogeology that is more oriented toward environmental assessment. Egypt depends highly on it water supply from the Nile river since the annual precipitation rates are fairly low. This demonstrates the importance of the quality of the Nile water to the country. Thus, monitoring the water quality and the type of pollutants is essential requirement to maintaining this important water resource.

Authorities including the Egyptian Ministry of Water Resources and Irrigation (MWRI) have been following various strategies in order increase the amount of the reused drainage water which has reached 7.07 billion cubic meters per year in 2010. Nonetheless, one of the obstacles toward reaching this goal is the spreading of different types of pollutants in different parts of the river drainage system. Effluents from sewage systems and industries find its way to the river water either by lack of complying with the regulations or partial treatment (non-complete treatment). Excessive use of pesticides and fertilizers is an additional source of water pollution in agriculture areas.

Shaban et. al. (2010) aimed to develop a tool for planning and implementing the reuse of the river drainage water for irrigation in the Nile Delta area. This was accomplished by classifying the pollution levels and type of the drainage water by utilizing a statistical clustering approach.

These clusters are in turn visualized by using GIS to generate thematic maps of pollution in the entire Nile Delta.

3.2. Methodology:

The water quality is characterized by Shaban et.al. (2010) through comparing a set of eight water quality parameters that covers biological, physical, and chemical components. These parameters are Biological Oxygen Demand (BOD mg/l), Total Suspended Solids (TSS mg/l), Nitrate (NeNO3 mg/l), Iron (Fe mg/l), pH, Total Dissolved Salts (TDS mg/l), Sodium Adsorption Ratio (SAR) and Dissolved Oxygen (DO mg/l). A dataset composed of monthly readings of these parameters spanning the interval from 1997 to 2007 is incorporated for further analysis.

The Two-Step Multivariate Cluster Analysis (TSMCA) procedure is used to classify the data point into cluster sharing similar parameters ranges. The main concept behind this analysis technique is to classify homogeneous subgroups (sharing similar characteristics) of data points in a dataset by minimizing the Within-group and maximizing Between-group variations. The sequential clustering approach scans the records one by one to judge if this record belongs to a previously defined cluster or it belongs to a new cluster. Then, the clusters are manipulated to meet the desired number of clusters. The defined clusters by this analysis are then imported to be visualized using a GIS technique.

ArcGIS 9.1 Desktop software package is utilized to incorporate a collection of maps at the scale of 1:50,000 for the Nile Delta region, the coordinates of the monitoring locations on the drainage system. The maps were digitized into two layers; the main drains were combined in one layer whereas another layer is dedicated for the branch drains. Locations of the water quality monitoring stations is as defined by the Global Positioning System (GPS) were entered then jointed to the representing segment (Fig.7).

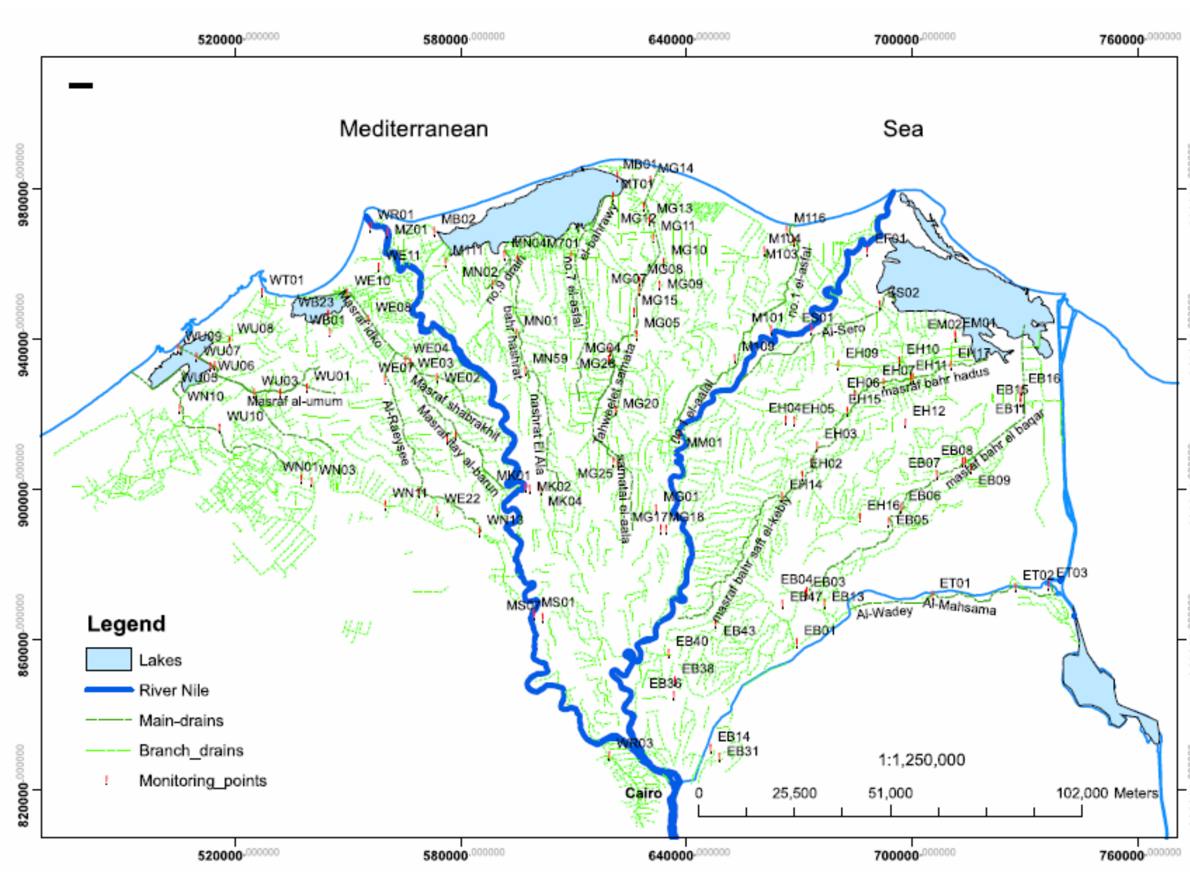

Figure 7 : Locations of main drains, branch drains, and monitoring stations in the Nile Delta area. (Shaban et.al., 2010).

3.3. Results:

The Two-Step Multivariate Cluster Analysis (TSMCA) revealed six different clusters (Fig.8):

- Cluster 1: high biological pollution, low salt constituents, moderate nutrients and iron concentration.
- Cluster 2: high biological pollution, moderate salt and iron constituents and low nutrients
- Cluster 3: low biological pollution and salt constituents, moderate nutrients and high iron concentrations
- Cluster 4: low biological pollution, high salt and iron constituents and moderate nutrients
- Cluster 5: very low biological pollution, moderate salt and iron constituents and high nutrients

- Cluster 6: moderate biological pollution and salt constituents, low nutrients, and high iron concentration

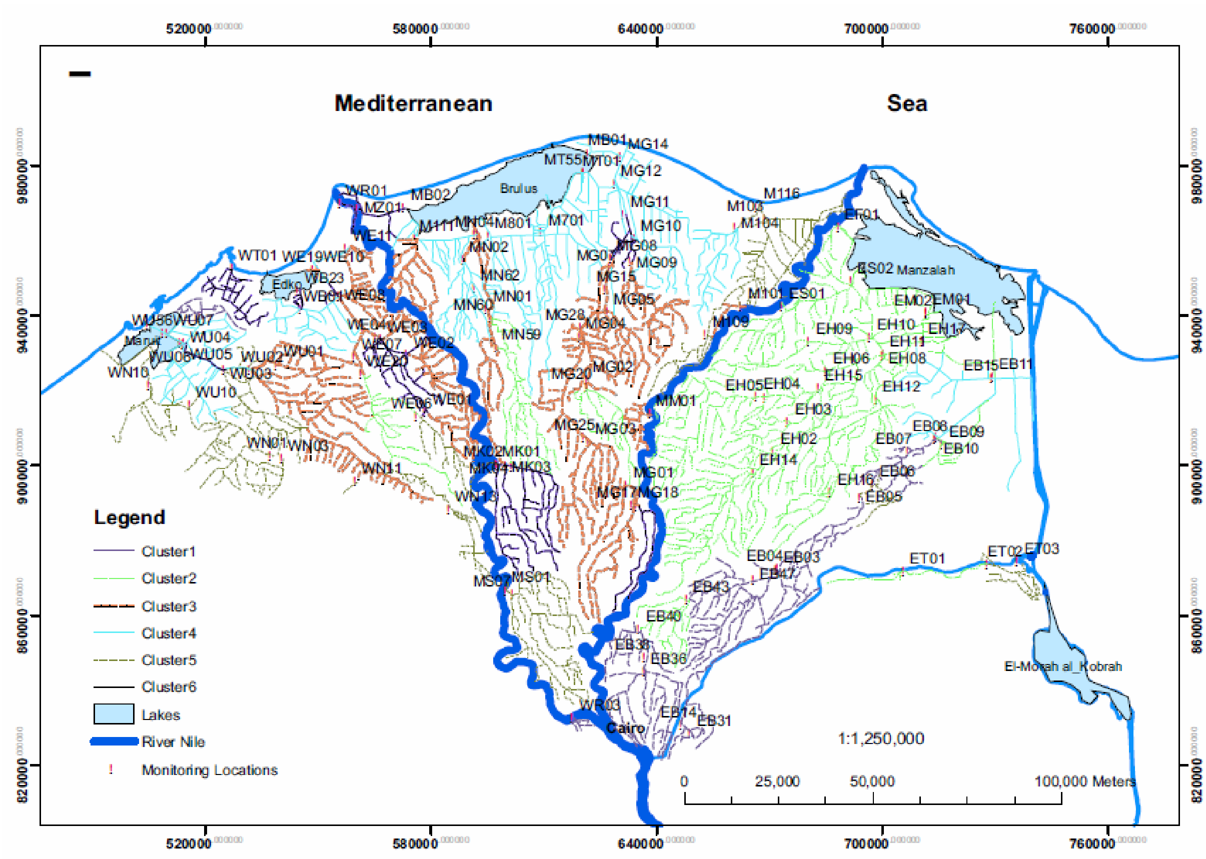

Figure 8 : Locations of main drains, branch drains, and monitoring stations in the Nile Delta area visualized though ArcGIS. (Shaban et.al., 2010).

4.3. Discussion:

It has been shown that GIS is very powerful tool for data visualization. In this case study, the statistical approach can successfully clasisfy the drains into clusters. However, it important for the porpose of this study to have the clusters visualized. For example, cluster 3 (borwn color) ocupies areas that are geographically separated (Fig.8). The reasons behind the pollutants distrubution needs to be studied further. This could be achieved by adding layers of areas with no sewage water treatment, or heavy industies for camparison. The final reasults shwon in Figure 8 are very helpful in focussing more monitering efforts in clusters of high pullotion. Furthermore, it also help identifiying areas of best water quality where the gevernment efforts should be targetted towred preserving the water quality.

4. Case Study III: prospecting for ground water, Eastern Desert, Egypt:

4.1. Introduction:

This work conducted by Abdalla (2012) integrates various types of data through GIS in order to define area of high ground water potential. The study area is located in the vicinity of Wadi El Laqeita in the Central Eastern Desert (Fig.9). Development of this land for agriculture purposes relies on its potential for having enough water resource under the ground. The main objective of this is to find features that relate or control ground water through analysis of remote sensing data.

Figure 9 : Location of the study area in the central Eastern Desert. (Abdalla, 2012)

4.2. Methodology:

Data used by Abdalla (2012) is composed of two main types. One is Satellite images that were acquired by the Landsat 7 satellite and Landsat7 ETM+ images with 30 m resolution provided by the Global Land Cover Facility. The base map of the study area was generated using these images. Then, these images were processed through ENVI v 4.7 software for lithological discrimination of the different types of rocks and land cover. The other type of data is from Shuttle Radar Topography Mission (SRTM data) which was processed to create a continuous digital elevation model (DEM) for the study area.

The ArcGIS 9.3.1 software package is utilized to extract different parameters where each parameter was isolated in a separate layer. The parameters which are explained in the following paragraph are ground slope, lineaments, topography, stream networks and geological maps. The advantages from utilizing GIS are the manipulation and analyzing abilities such as superposition and integrate the thematic layers as needed.

Five layers were generated where each layer corresponds to a thematic map of a single parameter (Fig.10). These parameters includes: (1) slope, which dictates if the water is transported quickly to other places or stays on the ground allowing the water to infiltrate into the ground, (2) stream network, which controls the transportation direction of the water on surface, (3) lineaments, which provide excellent pathways for water to percolate vertically into the ground to charge the ground waters, (4) lithologic or rock type, which controls the degree and rate to which the water infiltration process. (5) Topographic map, since the water is less likely to be stored in high elevation area.

Each of these five layers was divided into three or four classes based on the potential. For example, the slope layer (Fig.10,b) is divided into three classes: low potential (high slope causes water to runoff on the ground to other areas downstream), moderate potential, high potential(low slope allows time for water to remain in the area and percolate into the ground).

After these maps where generated and classified individually into classes, each map is multiplied by a rank number which expresses the importance of this layer for ground water potential (Table 2). Furthermore, in each map the classes were assigned values according to their importance as well (Table.2). A final ground water potential map (GWP) is generated mathematically from the five input layers using values of Map Wight (W) and Capability Value (CV) for each class according the following expression:

$$GWP = \sum W_i * CV_i$$

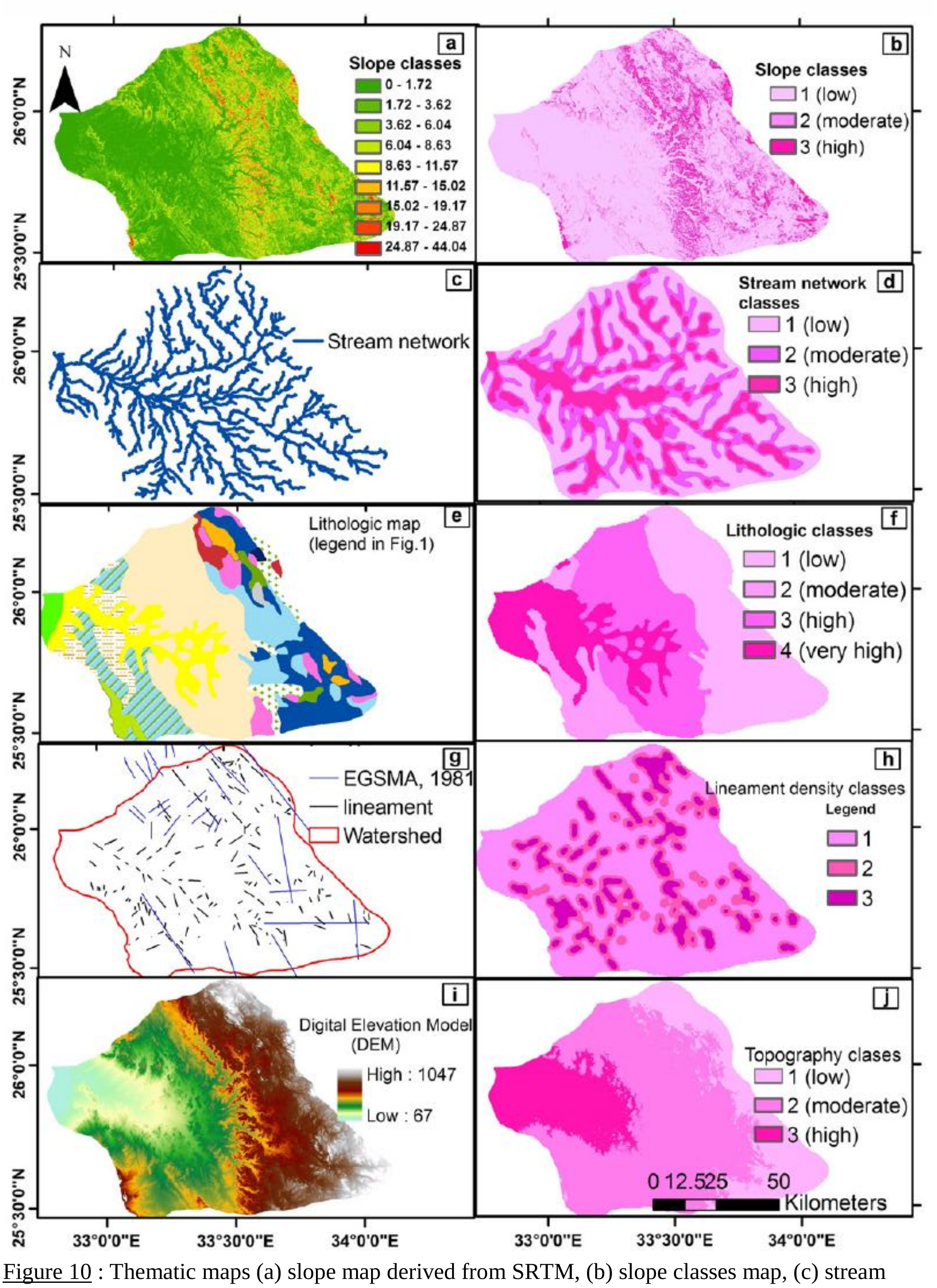

Figure 10 : Thematic maps (a) slope map derived from SRTM, (b) slope classes map, (c) stream network map, (d) stream density map, (e) simplified geology map modified after EGSMA (1981), (f) geologic map assigned weight factor depending on capability for holding water, (g) lineament map, (h) lineament density map, (i) Digital Elevation Model of the study area and (j) DEM classified map assigned weight factor depending on water infiltration. (Abdalla, 2012)

Layer #	Thematic layer	Map rank	Map weight (Wi)	Class ranges	Degree	Rank	Capability value
1	Slope	2	0.15	0–5	High	3	0.6
				5–10	Moderate	2	0.33
				10–44.041798	Low	1	0.16
2	Stream networks	3	0.23	0–0.30	Low	1	0.16
				0.30–0.50	Moderate	2	0.33
				0.50–0.848	High	3	0.5
3	Lithology	2	0.15	Basement	Low	1	0.1
				Sedimentary sequence	Moderate	2	0.2
				Nubian sandstone	High	3	0.3
				Wadi deposit	Very high	4	0.4
4	Lineament	3	0.23	0–20	Low	1	0.16
				20–40	Moderate	2	0.33
				40–0.62997	High	3	0.5
5	Topography	3	0.23	67–270	High	3	0.5
				270–450	Moderate	2	0.33
				450–1047	Low	1	0.16

Table 2: Thematic map Layers properties. (Abdalla,2012)

4.3: Results:

The results are simply presented in one map showing the ground water potential (Fig.11). Nonetheless, this one map was generated by integration of different layers in a mathematical approach that treats each layer according to its importance for the ground water potential. The results suggest that the western part of the study area has generally higher potential for gound water. In addition, moderate potential in the eastern part of the study area is located on lineament and drainage channels (Fig.11).

4.4: Discussion:

The procedure followed in this study represents an innovative solution for ground water potential assessment through GIS. It proved to be an excellent, inexpensive solution which utilized the capacities of ArcGIS package to analyze data that were already collected for other purposes. This procedure is applicable to other areas given the availability of satellite images and topography which are usually available. However, the challenge is that these data is acquired by different official agencies that hold the access rights which dictates the need for data sharing and integration.

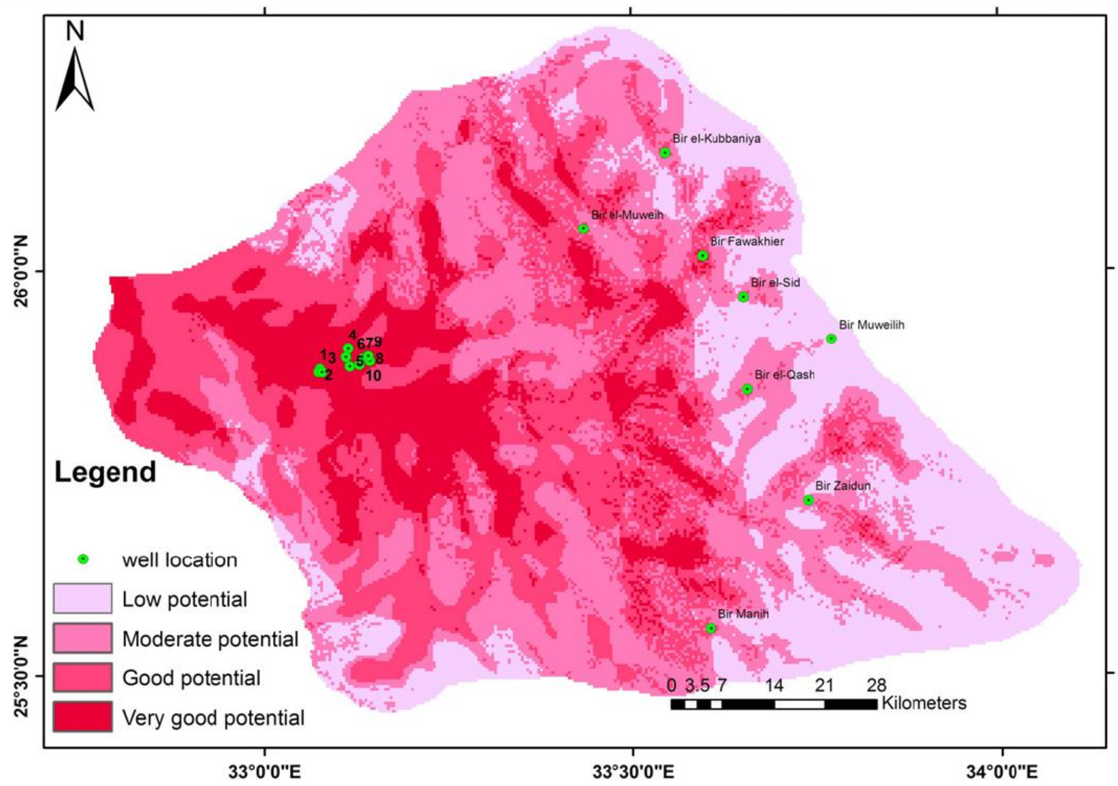

Figure 11 : Groundwater prospect map of the study area.(Abdalla,2012)

5. Conclusion:

Geographic Information System (GIS) has been proven to be extremely helpful and essential tool in hydrogeological investigations. The three case studies reviewed in this report clearly show the capabilities and the added value by the discipline of GIS in finding new water resources, understanding the water quality distribution geographically, and assessment of their sustainability. This report that GIS is important application for hydrogeological studies where it can be easily used and integrated with other disciplines such as statistics as shown in the Nile Delta case study.

6. References:

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