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Case Study **Open Access**

Assessment of Groundwater Vulnerability – A Case Study

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Abstract Two DRASTIC models have been used in this study, which are generic and pesticide to get the groundwater vulnerable levels to pollution in the Nile aquifer along Assiut governorate. Groundwater vulnerability maps were produced using Geographic Information Systems (GIS). It has been found in map of generic DRASTIC model that the most of the study area is covered by moderate vulnerable and high vulnerable; where 55.2 % of the area is moderately vulnerable and 35.4 % has high level of vulnerability. However in the vulnerability map generated by pesticide DRASTIC model, the results concluded that about 64% of the study area has an extreme to high vulnerability to contamination, 34.6% has a moderate vulnerability and small areas occupy about 1.4% and has a low vulnerability.

Keywords *Groundwater Vulnerability; Generic DRASTIC; Pesticide DRASTIC; Geographic Information Systems (GIS)*

1. Introduction

There is a rising awareness of monitoring groundwater pollution since consumption of groundwater in agriculture, industry, and domestic use has increased. Due to the high-cost of groundwater contamination monitoring in huge parts, the usage of modeling methods such as DRASTIC model with GIS has become a must to assess groundwater potential to pollution. Groundwater resources of Assiut, Egypt face a very serious problem which is contamination from agricultural and urbanization activities. In the previous decades, researchers working in groundwater pollution assessment have focused on limited areas in Assuit governorate by using traditional methods such as chemical and bacterial analysis (Sobih et al., 1988) [1]; Abdel-Lah and Shamrukh, 2001 [2]), and electrical resistivity measurement (Bakheit et al., 1993 [3]; Ebrahim, 1997 [4]; Sebaq et al., 2003 [5]; Mohamaden et al., 2009 [6]). Ebrahim (1997) [4] used Schlumberger geoelectrical depth soundings and horizontal geoelectrical profiling to determine the distribution of the contaminated and uncontaminated zones of groundwater in (El-Madabegh) area, northwest of Assiut city. Sebaq et al. (2003) [5] used surface geoelectrical methods for delineation of groundwater pollution in Beni Ghaltib area, northwest of Assiut city. Mohamaden et al. (2009) [6], carried out Forty-two vertical electrical soundings (VES.'s), using Schlumberger array in Assiut area in order to elucidate hydrogeological information and delineate subsurface structural elements. However in this paper groundwater pollution potential is being studied all over Assiut governorate though using newly updated method represented in DRASTIC model and geographic information systems (GIS).

A groundwater vulnerability analysis classifies areas where groundwater is possible to be polluted as an effect of different activities. The purpose of vulnerability investigation is to protect groundwater quality through spotting the light on those vulnerable areas by decision makers. Groundwater vulnerability can be assessed throughout three different ways: (1) site-specific evaluation by hydrogeologists, (2) pesticide destiny, and (3) index methods [7]. DRASTIC model has been chosen as one of the most well-known index methods because it is more flexible and economic.

DRASTIC model has been developed by the U.S. Environmental Protection Agency in 1987 as an implement to evaluate groundwater vulnerability. The word DRASTIC is an acronym formed the initial letters of the seven factors which are used for determining relative rankings. (D) refers to Depth to water, (R) refers to net Recharge, (A) refers to Aquifer media, (S) refers to Soil media, (T) refers to Topography, (I) refers to Impact of the vadose zone media, and (C) refers to hydraulic Conductivity of the aquifer [8]. For GIS is “a powerful set of tools for storing and retrieving at will, transforming and displaying spatial data from the real world for a particular set of purposes” [9], it has been used for assessing groundwater vulnerability based on DRASTIC model.

The factors used to assess groundwater vulnerability differ according to available data. Schmidt (1987) [10] used five factors to develop a GIS weighting model which are type of bedrock, depth to bedrock, depth to water table, soil characteristics, and surficial deposit characteristics. Nebert and Anderson (1987) [11] used another five factors which are land cover, soil media, precipitation, geological properties, and shallow aquifers to evaluate groundwater contamination potential through pesticides by GIS to build a database. Petersen et al. (1991) [12] applied GIS to assess non-point pollution using topography, farm animal density, soils, precipitation, land cover, and a rainfall-runoff factor. Atkinson et al. (1992) [13] used seven factors representing the DRASTIC model and a GIS to evaluate groundwater vulnerability. Zhang et al., (1996) [14] used DRASTIC model and GIS to determine groundwater pollution potential through applying several parameters which are groundwater depth, net recharge, Aquifer media, impact of vadose zone, soil media, topography, and hydraulic conductivity.

Al-Adamat et al., (2003) [15], used GIS and DRASTIC model to generate groundwater vulnerability map and risk map by including six factors out of seven DRASTIC factor except the hydraulic conductivity of the aquifer because of sufficient quantitative data shortage, while Thapinta and Hudak (2003) [16] used five factors including soil media, topography, land use map, depth to water, and rainfall in Geographic information systems (GIS) to estimate groundwater vulnerability to pesticide pollution. GIS as a technique can be used alone or accompanied by other image processing software such as ILWIS "Integrated Land and Water Information System" and ERDAS imagine "Earth Resources Data Analysis System". Rahman (2008) [17] used Arcview 3.2a as GIS software with (ILWIS 3.0) to determine the groundwater vulnerable zones in shallow aquifers using the DRASTIC model. It is obvious that GIS play a significant function in assessing and expecting the groundwater pollution potential.

2. Study Area

Assiut governorate is considered as a part of the Nile Valley, Egypt. It reaches the northern edge of Sohag Governorate at latitude 27°37′ N and extends the southern edge of El-Minia Governorate at latitude 26° 47′ N. It is bordered between longitudes 30° 37′ - 31° 34′ E, as shown in Figure 1. The total area of Assiut governorate is 25,926 km^2. The length of the River Nile along Assiut governorate area is approximately 125 km, and the valley width varies between 16 and 60 km [18].

The study area includes populated and agriculture areas in Assiut governorate cover up an area of about 2674.54 km^2. River Nile divides the study area into a western and an eastern part. In general, the land surface in the fringes of both parts slopes towards the River Nile. The sharp declination is the main feature of the fringes of the study area because of the limestone plateau which limits the area from the east and the west, except of the Northwestern part that has a moderate slope [19]. There are some wadies joined with the study area like: Wadi El-Assiuti and Wadi El Ibrahimi in the central east, Wadi Abu Shih in the south east.

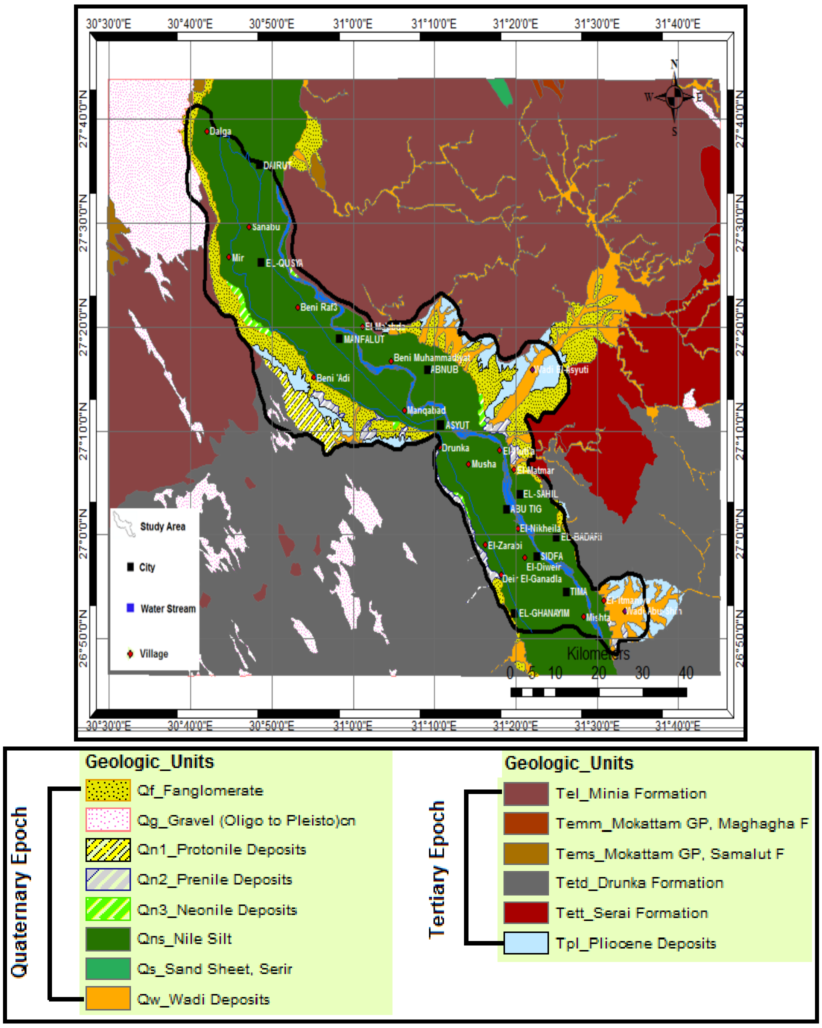


Figure 1: *Geological Map of Assiut Region* [20]

3. Methodology

In recent decades, modeling has grown to be an essential tool for managing groundwater resources, predicting the current and future conditions impact on groundwater and pollutant movement and assessing aquifer susceptibility.

3.1. The DRASTIC Model

DRASTIC is "an empirical groundwater model that estimates groundwater contamination vulnerability of aquifer systems based on the hydrogeological settings of that area" [8]. DRASTIC uses a statistical ranking system that gives relative weights to different factors. Each one of DRASTIC factors is specified a certain weight according to its relative importance in affecting pollution possibility. The standard ratings vary between 1 and 10 while weights between 1 and 5.

The DRASTIC Index [DI] can be expressed numerically through calculating algebraic sum of the ratings and weights outcomes of each factor (see Equation 1). Whenever DI value is higher, groundwater becomes more vulnerable [8].

$$DI = D_r D_w + R_r R_w + A_r A_w + S_r S_w + T_r T_w + I_r I_w + C_r C_w \quad (1)$$

Where; r: rating of the factor & w: weight assigned to the factor

In the following Table 1, weights significance for factors in general and pesticide DRASTIC models have been assigned [8].

Table 1: *Weights of DRASTIC Factors* [8]

Factors	Weight Significance	
	General DRASTIC	**Pesticide DRASTIC**
Depth to water (D)	5	5
Net Recharge (R)	4	4
Aquifer Media (A)	3	3
Soil Media (S)	2	5
Topography (T)	1	3
Impact of Vadose Zone (I)	5	4
Hydraulic Conductivity (C)	3	2

3.2. Implementation of DRASTIC Model using GIS

The DRASTIC model has been applied to create the map of groundwater vulnerability of Nile aquifer along Assiut governorate. Two DRASTIC models have been used by adopting their weights and ratings which generic DRASTIC model and pesticide DRASTIC model. The water wells data has been used to get the DRASTIC factors values. From these wells data, three parameters have been gotten which are depth to water (D), permeability, and hydraulic conductivity (C). Permeability layer will overlay with geology layer and water depth layer to attain aquifer media (A) and impact of vadose zone (I) respectively. The topography (T) has been produced from the Digital Elevation Model (DEM) of Assiut area. However, no data was available for soil media S, landuse layer has been employed instead of soil media. In regard to recharge (R) of the Nile River quaternary aquifer, Dawoud, M.A., Ewea, H.A., (2009) [19] mentioned that "it ranges from 0.5 to 0.8 mm/day in the old agriculture land and ranges from 1.0 to 1.5 mm/day in the desert fringes for new reclaimed lands".

Application of GIS technique for implementation of DRASTIC model of River Nile quaternary aquifer along Assiut governorate is described as follows:

a) Identification of Data Layers

This paper spotlighted on seven factors influencing movement of contaminants to groundwater. The following table illustrates the data format for each variable.

Table 2: *List of Data Layers Affected in this Paper*

Data Layer	Variables Affected	Data Feature	Conversion into GIS Format
Depth to water (D)	Depth of water wells map	point	Resulted as surface raster format
Net Recharge (R)	Annually Recharge rate map	polygon	Converted from vector to raster
Aquifer media (A)	Permeability of Aquifer media map + Geological map	point + polygon	Resulted as surface raster format
Soil media (S)	Land use map	polygon	Converted from vector to raster
Topography (T)	Digital Elevation Model map (DEM map)	polygon	Already in raster format
Impact of vadose zone (I)	Permeability of soil media map+ Depth to water map	point	Resulted as surface raster format
Hydraulic conductivity (C)	Hydraulic conductivity map	point	Resulted as surface raster format

b) Add X, Y Data

This method is applied to add a new object to an analysis of any GIS project [21]. Firstly, longitude and latitude of groundwater wells at Assuit governorate must be added to GIS software by this tool. Three factors were tabulated as numbers and related to x and y coordinates which considered as point feature; these factors are depth to water, permeability, and Hydraulic conductivity. This theme contained forty four points representing depth to water, permeability, and Hydraulic conductivity of wells as shown in Figure 2.

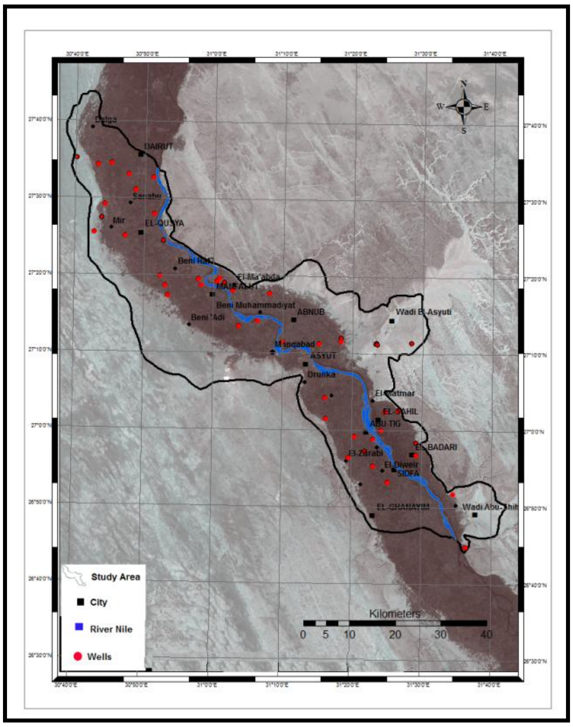


Figure 2: *Well Location Map Overlaid Assiut Satellite Image* [16]

c) Management of Data Layers

Every one of data layers affected groundwater vulnerability has to manipulate by three main methods as the following [22].

1) Data layer must be converted from vector feature such as point, line, or polygon, to raster data because the last one is relatively easier than vector data.
2) The data layers in the form point feature must be converted into surface raster gird by interpolation methods such as kriging or inverse distance weighting (IDW).
3) All data layers need to be factorial data by reclassification method. This method is used in order to unify the criteria that will be applied on all layers and to diminish the number of classes of each data layer.

d) Rasterization of Vector Data

Rasterization is defined as "the process of converting a polygon feature theme from vector to raster data structure" [23]. By this process polygons were converted to grid cells or pixel. The cell values belonging to each polygon are equal to each others.

e) Interpolation of Point Data

Interpolation can be known as "the function used to predict unknown values of any geographic point data to generate a continuous surface from sampled point values" [24]. There are three interpolation methods included in GIS software. They are Inverse Distance Weighted (IDW), Spline, and Kriging. It is not important what method is applied, whenever the data samples are more, the results are more dependable [24]. In this paper, IDW interpolation method was applied for interpolating all parameters which are included in physicochemical analysis of wells. IDW calculates the value of all pixels by computing the average of a set of sample points in a point feature theme. The computed average value is depending on the values of sample point and the distance between point to be estimated and other points. Thus, the closer the sample points to the cell which to be calculated, the more effect on the interpolated value [25].

f) Reclassification of Data Layers

The reclassification process can be elucidated as "replacing input cell values with new output cell values" [24]. In this paper, every data layer has been reclassified according to a general scale illustrating its effect to cause groundwater pollution. This scale includes ten classes for each data layer ranging from 10 to 1 where 10 is the highest potential to pollution and 1 means the lowest pollution potential. Spatial analyst included in ArcGIS software has been used to reclassify all data layers as shown below in the following clarification.

– Depth to water was reclassified by the obtained data wells into seven classes as shown in Table 3:

Table 3: *Reclassification of Depth to Water (D)*

Depth, m	Rating
0.02 - 1.5	10
1.5 - 4.5	9
4.5 - 9.5	7
9.5 - 15.2	5
15.2 - 22.9	3
22.9 - 30.5	2
30.5 - 42	1

The pollution potential is inversely proportional with depth of wells, thus the highest depth was assigned by 1 and the lowest depth was assigned by highest rating 10.

– Net Recharge (R): recharge has been reclassified into two classes as shown in Table 4.

Table 4: *Reclassification of Net Recharge (R)*

Land Use	Recharge, mm/Day	Rating
Old agriculture lands	0.5 to 0.8	8
Desert fringes (new reclaimed lands)	1.0 to 1.5	9

The two classes took rating 8 and 9 according to DRASTIC rating standard which determined by (Aller, et al., 1987) [8] as shown in Table 5.

Table 5: *DRASTIC Rating Standard [8]*

Recharge (inch/year)	Rating	Recharge (mm/year)	Rating
0 – 2	1	0 – 51	1
2 – 4	3	51 – 102	3
4 – 7	6	102 – 178	6
7 – 10	8	178 – 254	8
>10	9	>254	9

– Aquifer media: To identify aquifer media precisely, permeability and geology of aquifer were used to reclassify it. Moulton, (1992) [26] summarized that Quaternary alluvial deposits were given higher DRASTIC ratings than Tertiary sedimentary deposits, and young deposits were given higher ratings than old deposits. Table 6 and Table 7 illustrate the classes of permeability and geology of aquifer respectively.

Table 6: *Reclassification of Permeability*

Permeability, Millidarcy	Rating
7.98 – 2876.96	2
2876.96 – 5232.61	4
5232.61 – 8924.22	6
8924.22 – 15165.9	8
15165.9 – 28256.5	10

Table 7: *Reclassification of Geology Types*

Geology Type	Age	Rating
Nile Silt (Qns)	Quaternary	10
Fanglomerate (Qf)	Quaternary	9
Wadi deposits Qw	Quaternary	8
Neonile deposits Qn3	Quaternary	7
Prenile deposits (Qn2)	Quaternary	6
Protonile deposits (Qn1)	Quaternary	6
Pliocene deposits (Tpi)	Tertiary (Pliocene)	5
Samalut Fm. (Tems)	Tertiary (Middle Eocene- Mokattam group)	1
Minia Fm. (Tei)	Tertiary(Middle Eocene)	4
Drunka Fm. (Tetd)	Tertiary(Lower Eocene- Thebes group)	3
Seria(Thebes) Fm. (Tett)	Tertiary(Lower Eocene- Thebes group)	1

– The soil data layer has been reclassified by its landuse, which can be categorized into six groups as shown in Table 8. Due to lack of soil data, landuse map was used instead of soil layer. The new reclaimed lands were assigned highest rating because the degree of pesticide usage is high and the soil of new reclaimed lands has higher permeability than old agriculture lands.

Table 8: *Reclassification of the Soil Data Layer*

Landuse	Rating
New reclaimed lands	8
Water	7
Old agriculture lands	6
Islands	6
Buildings	5
Desert,	3

– The topography data layer has been reclassified by percent slope of land surface as shown in Table 9.

Table 9: *Reclassification of Percent Slope Layer*

Range, %	Rating
0 – 2 (very flat)	10
2 – 6 (flat slope)	9
6 – 12 (medium slope)	5
12 – 18 (steep slope)	3
>18 (very steep slope)	1

– The Vadose Zone for the purposes of the Nile aquifer vulnerability map incorporates soil permeability and depth to water. The equation used incorporates the factors believed to be important to the Vadose Zone as shown in Equation 2 [27].

$$\text{Impact of Vadose Zone} = \text{Soil Permeability} + \text{Depth to Water} \qquad (2)$$

The more the impact of vadose zone, the more rating of pollution potential as clarified in Table 10.

Table 10: *Ranges and Ratings for Vadose Zone Impact*

Ranges	Rating
4 – 5	2
5 – 7	4
7 – 10	6
10 – 12	8
12 - 17	10

– Hydraulic conductivity is strongly related to contamination potential; the higher the hydraulic conductivity, the higher contamination potential [8]. Hydraulic conductivity in the study area varies between 9 and 164 m/day. Table 11 shows that five categories of hydraulic conductivity are existed.

Table 11: *Ranges and Ratings for Hydraulic Conductivity*

Ranges	Rating
9.1 – 12.5	2
12.5 – 28.5	4
28.5 – 40.5	6
40.5 – 81.5	8
81.5 – 163.9	10

a) Analysis of Data Layers

This process is the last step of GIS technique in this paper to analyze data through overlaying all layers. Overlay process is defined as "the spatial operation in which a thematic layer is placed over another to form a new layer" [23]. During this process, all data layers have been overlain to produce a groundwater vulnerability map.

By these actions, all cells values in each layer were multiplied by their weight. The total result of adding the values of one layer that place at the same location to the values of the others was an output expressing DRASTIC index (DI).

4. Results and Discussion

The vulnerability results will be presented in the following steps.

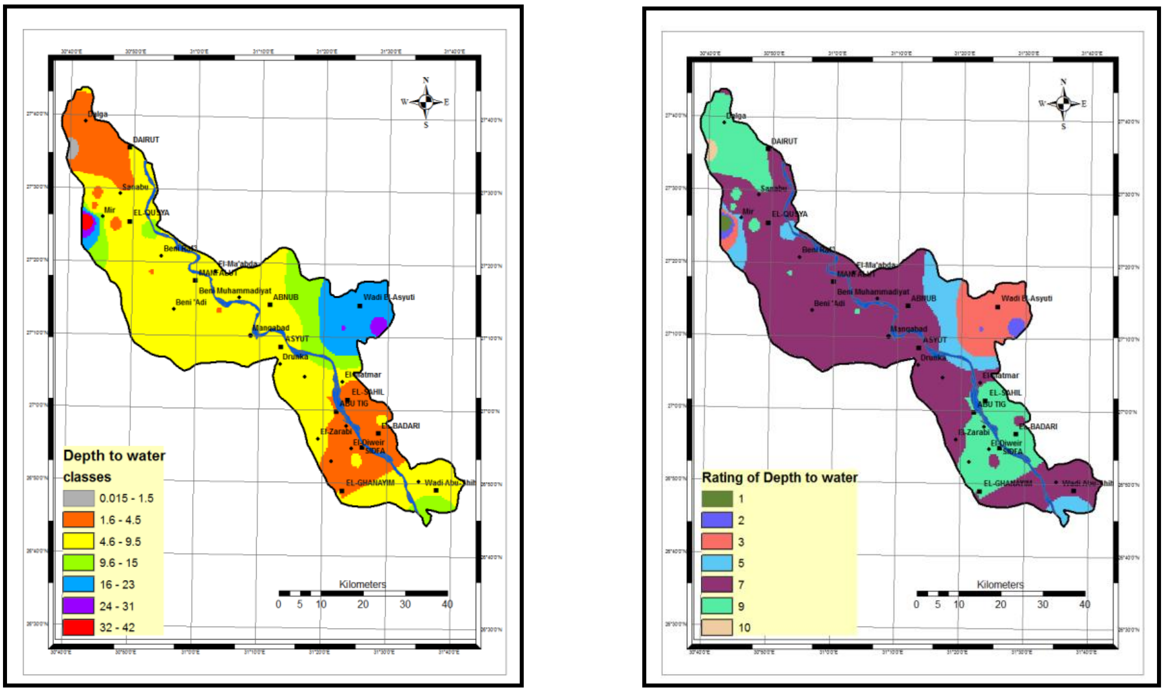
4.1. Ratings for the DRASTIC Factors

a) Depth to Water (D)

This layer was classified into seven classes as shown in Figure 3b. Spatial analyst (reclassify tool) was then applied on depth to water layer to reclassify it into 7 classes ranging from 1 (the highest depth) to 10 (the lowest depth). The majority of study area varies between two categories; the first one ranges from 1.6 to 4.5 m which has rating equal 9, the second category ranges from 4.5 to 9.5 m assigning 7 as rating value.

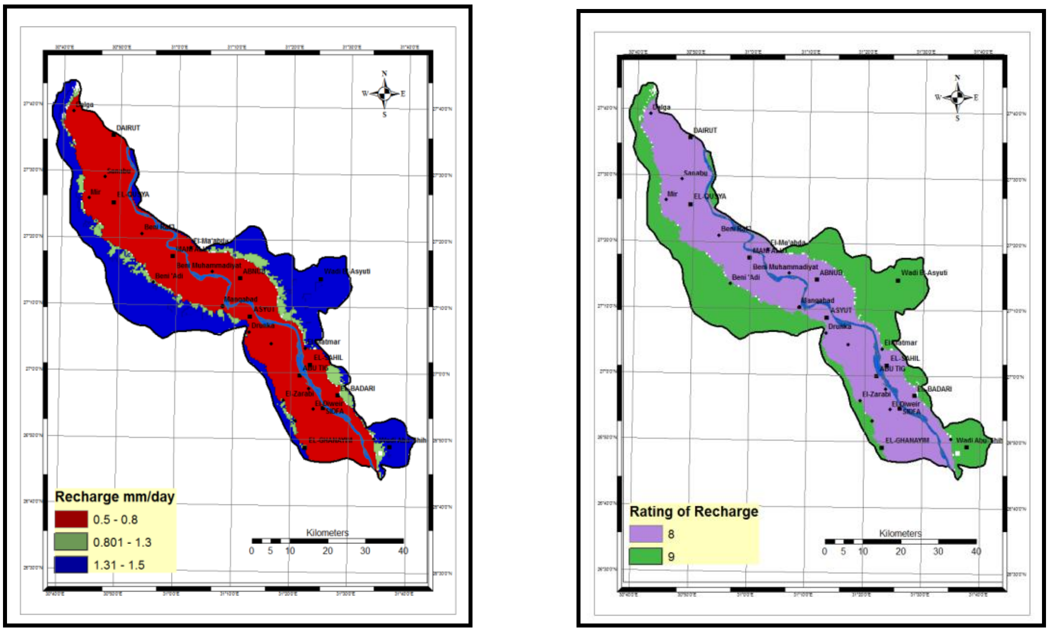
b) Net Recharge (R)

The spatial distribution layer of net recharge of the Nile aquifer has been reclassified into two classes. The two classes assigned rating 8 and 9 according to DRASTIC rating standard as shown in Figure 4a and Figure 4b.



(a) Raw Data *(b) After Reclassification*

Figure 3: *Spatial Distribution Map of Depth to Water*

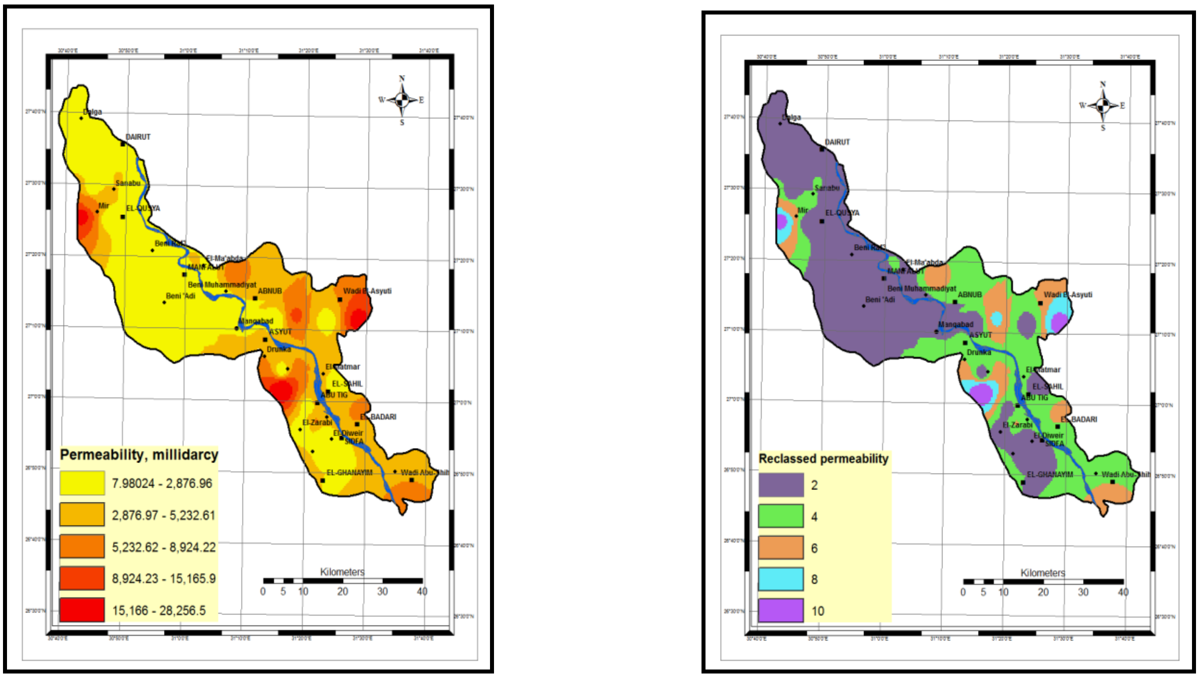


(a) Raw Data *(b) After Reclassification*

Figure 4: *Spatial Distribution Map of Net Recharge of the Nile Aquifer*

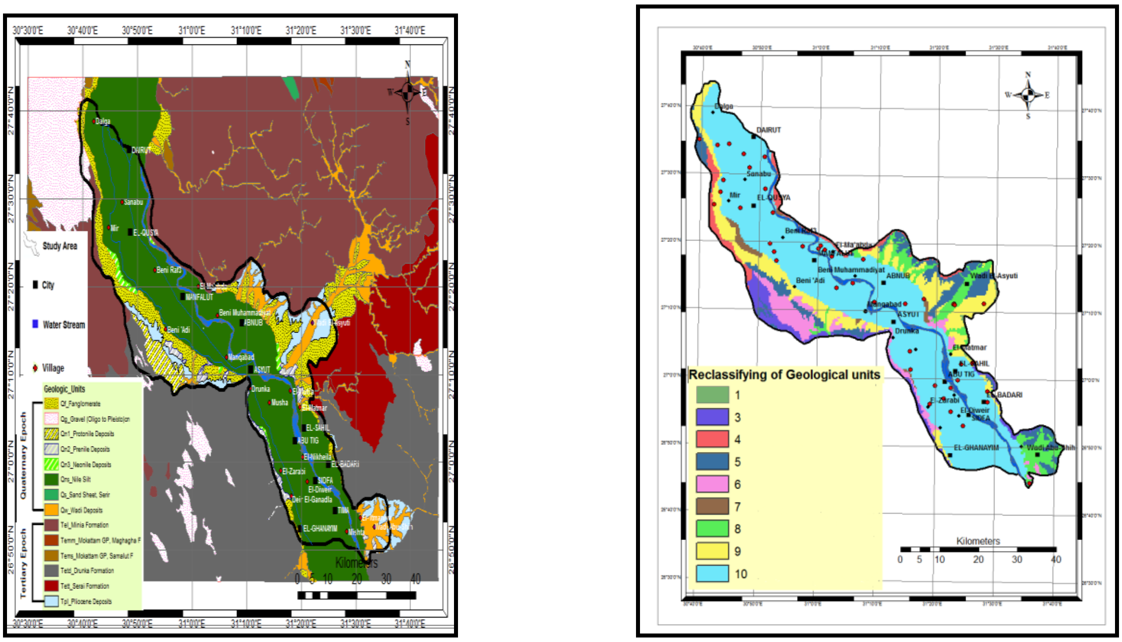
c) Aquifer Media (A)

To categorize aquifer media accurately, permeability and geology layers of the Nile aquifer in the study area were combined together to produce layer representing the aquifer media (A). The permeability layer was reclassified as shown in Figure 5b and the geology map was converted from vector to raster and then reclassified as shown in Figure 6b. After reclassifying of permeability layer and geology layer, they were combined together by raster calculation tool - which including in spatial analyst - to get integrated view of aquifer media as shown in Figure 7.



(a) Raw Data *(b) After Reclassification*

Figure 5: *Spatial Distribution Map of Permeability of the Nile Aquifer*



(a) Original Map *(b) After Reclassification*

Figure 6: *Geology Map of Assiut Region*

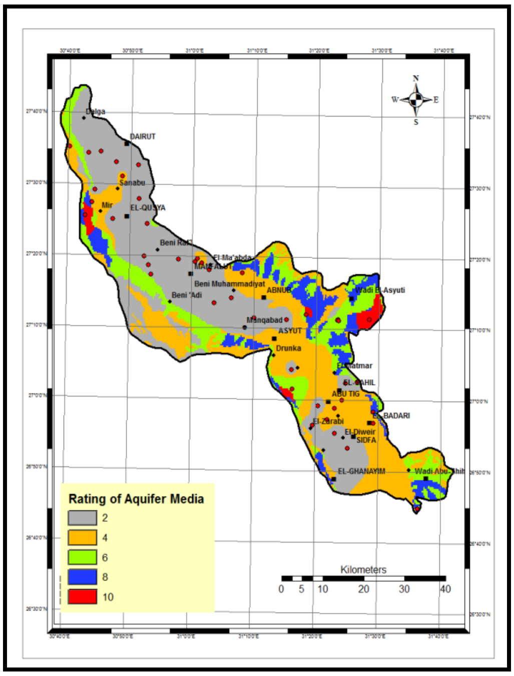


Figure 7: *Geology Layer Incorporated with Permeability Layer in Study Area*

d) Soil (S)

For the reason that there is lack of soil data, landuse map was used instead of soil layer. The soil data layer was reclassified by its landuse, which can be categorized into six groups as shown in Figure 8. Landuse map has been reclassified according to rating shown in Table 8, the highest rating was distinguished the new reclaimed land since high degree usage of pesticides in it. The desert land has been assigned with lowest rating because annually rate of rain is very low in the way that it doesn't affect the groundwater properties in desert lands.

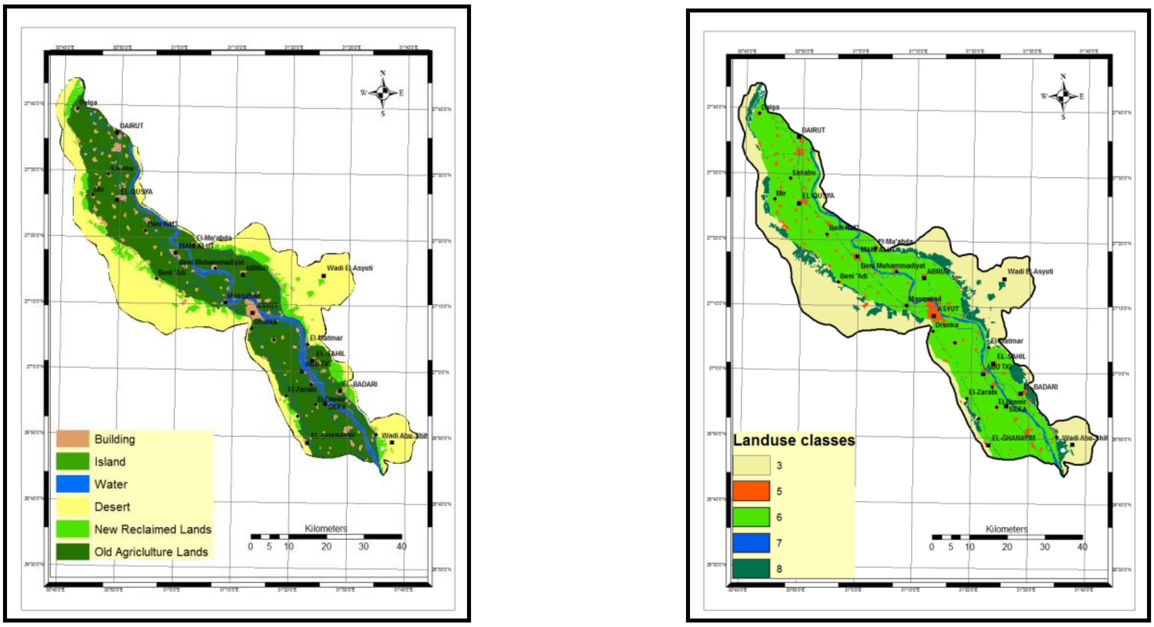
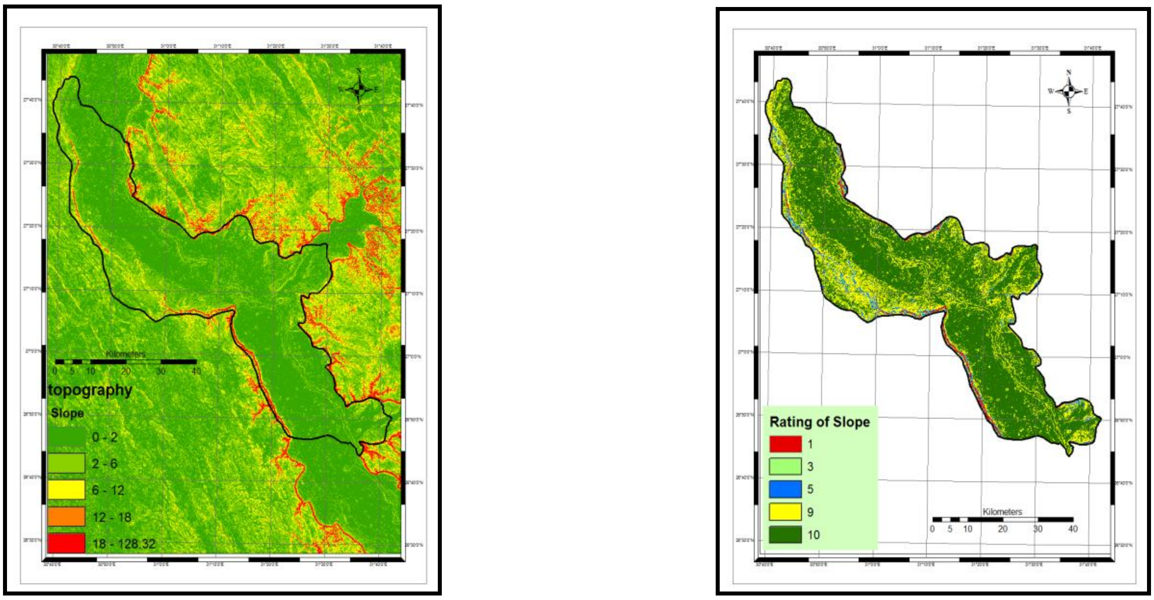


Figure 8: *Landuse Map of Study Area*

e) Topography (T)

The slope data layer represents topography map of study area. The slope map can be produced as percent from digital elevation model (DEM) of Assiut area using spatial analyst tool in ArcGIS 9.3. Classification of slope including five classes which are: very flat slope (0-2), flat slope (2-6), medium slope (6-12), steep slope (12-18), and very steep slope (18-128.32) as shown in Figure 9a.

Slope map has been reclassified by percent slope of land surface as displayed in Figure 9b. The reclassification of slope was based upon the rule that "The higher the slope, the lower the rating". Accordingly, the cell which is very flat slope was assigned 10 rating, whereas, the cell has very steep slope was assigned rating 1.

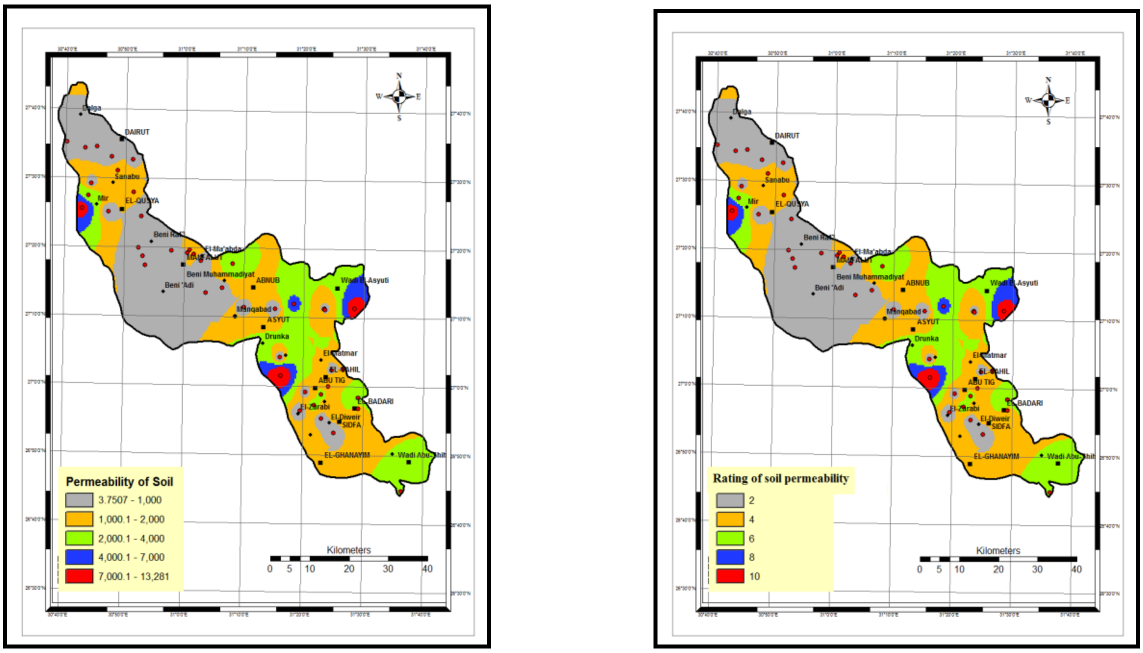


(a) Raw Data *(b) After Reclassification*

Figure 9: *Slope Map of Study Area Generated from DEM*

f) Impact of Vadose Zone (I)

The Vadose Zone for the purposes of the Nile aquifer vulnerability map incorporates soil attenuation type and depth to water. Depth to water has previously been displayed in Figure 3a and Figure 3b, but soil attenuation type is unavailable; hence soil permeability is used. Figure 10a demonstrates the soil permeability map of study area.



(a) Raw Data *(b) After Reclassification*

Figure 10: *Soil Permeability Map of Study Area*

Soil permeability map was reclassified according to "the higher the permeability, the higher the potential of pollution". Impact of vadose zone layer has been created as shown in Figure 11.

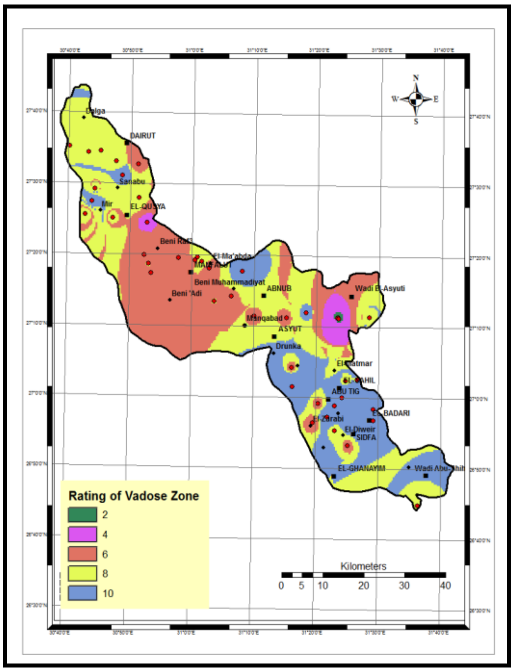
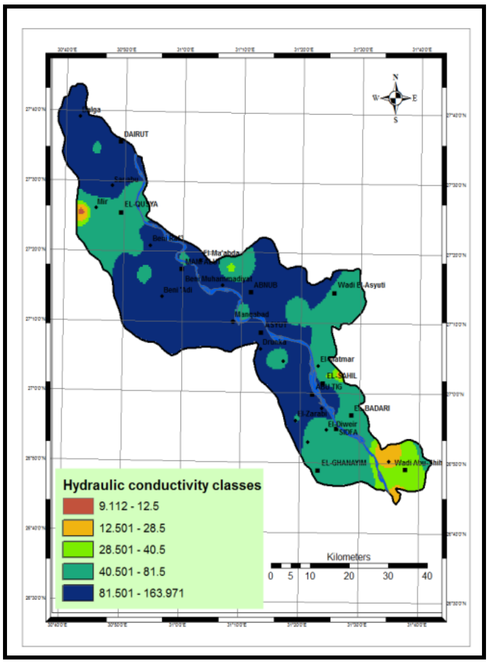


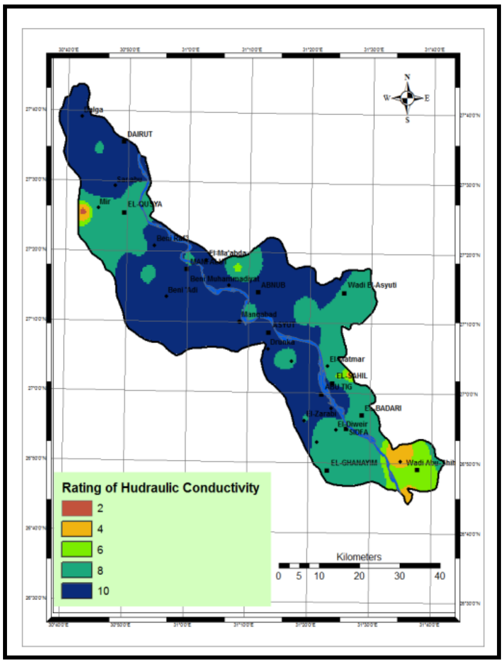
Figure 11: *Impact of Vadose Zone Layer After Incorporating and Reclassification*

g) Hydraulic Conductivity (c)

There are five categories of hydraulic conductivity index values. According to DRASTIC standard rating these values were assigned for the rating where a higher rating is referring to a higher hydraulic conductivity; i.e., high hydraulic conductivity values ranked as 10, and lower values as 1 as displayed in Figure 12a and Figure 12b.



(a) Raw Data



(b) After Reclassification

***Figure 12**: Spatial Distribution of Hydraulic Conductivity of Study Area*

4.2. Generation of Vulnerability Map

To create vulnerability map, the DRASTIC Index [DI] must be computed by summation of the products of ratings and weights of each factor as shown in Figure 13. If the value of DI is becoming higher, the relative pollution potential or aquifer vulnerability will be greater. The weights and ratings were adopted as specified in the generic DRASTIC model and pesticide DRASTIC model to generate two vulnerability maps.

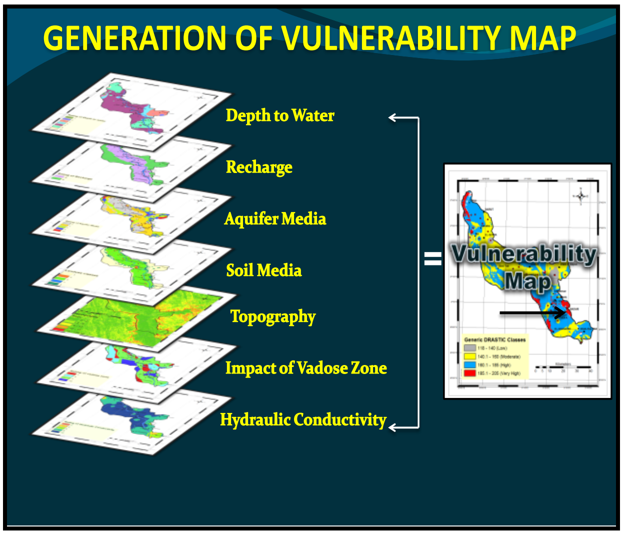


***Figure 13:** Generation Process of Vulnerability Map*

a) Groundwater Vulnerability Implemented By Generic DRASTIC Model

The vulnerability map generated by generic DRASTIC Model as shown in Figure 14, while Table 12 demonstrates the summary of vulnerability level and the areas percent of each class.

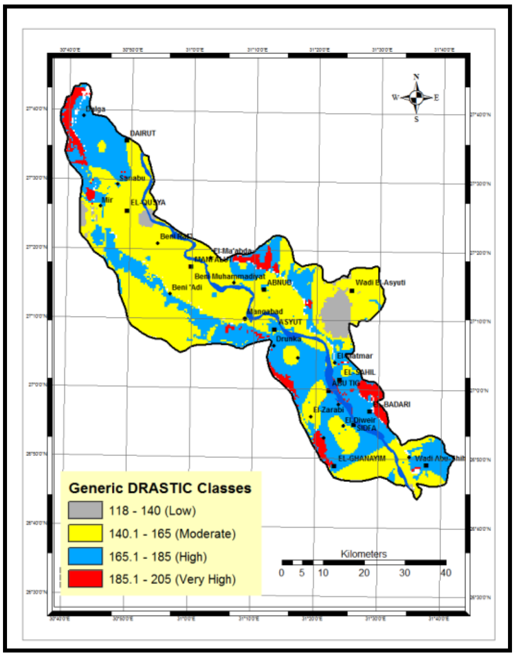


Figure 14: *Vulnerability Map of Nile Aquifer in Study Area Generated By Generic DRASTIC Model*

Table 12: *Summary of Vulnerability Classes*

Generic DRASTIC		
Legend	**Vulnerability level**	**Area %**
118 – 140	Low	3.8
140.1 – 165	Moderate	55.2
165.1 -185	High	35.4
185.1 - 205	Very high	5.6

From Figure 14 and referring to the legend illustrated in Table 12, it is found that about 3.8 % of the total area of Assiut governorate has low vulnerability level; on the other hand, 5.6 % of the total area is considered as very vulnerable level. The majority of study area is in between moderate vulnerable and high vulnerable; where 55.2 % of the area is moderately vulnerable and 35.4 % has high level of vulnerability.

With regard to Figure 14, it is seen that high vulnerability levels are concentrated on the south of the study area including districts of Sodfa, Abo-teej, and the western side of Assiut city towards Arab Al-Madabegh. As well as there are small areas in the eastern side on both east Abnoub city and Beni Muhammadyat city have high vulnerability level. Also, the high vulnerable areas can be clearly seen in the northern area beginning from Dayrout ending with Sanabuo village.

While the very high vulnerable areas are located on the eastern fringes of Al-Badary district as well as the western fringes of Al-Ghanayem and Dayrout districts. However, the northern areas beginning with Sanabuo ending with Assiut has moderate levels including Al-Qusya, Manfalut, and the western part of Abnoub district.

b) Groundwater Vulnerability Implemented By Pesticide DRASTIC Model

With regard to the groundwater vulnerability map illustrated in Figure 15 and Table 13, it is shown that about 64% of the study area has an extreme to high vulnerability to contamination, 34.6% has a moderate vulnerability and small areas occupy about 1.4% and has a low vulnerability.

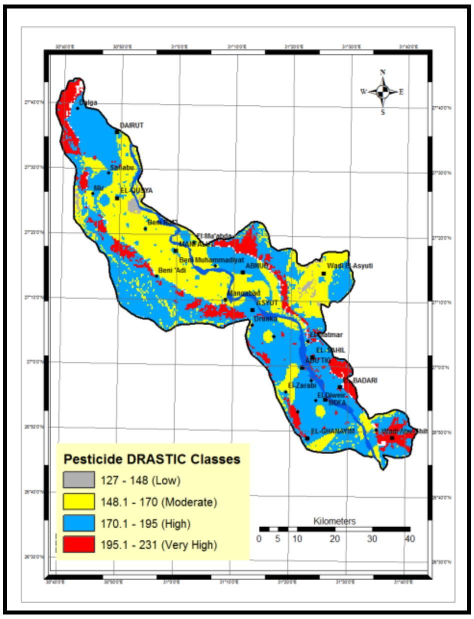


Figure 15: *Vulnerability Map of Nile Aquifer in Study Area Generated by Pesticide DRASTIC Model*

Table 13: *Summary of Vulnerability Classes*

Pesticide DRASTIC		
Legend	**Vulnerability level**	**Area %**
127 - 148	Low	1.4
148.1 - 170	Moderate	34.6
170.1 - 195	High	52
195.1 - 231	Very high	12

According to land use activities, it can be clearly seen that most areas which considered new reclaimed land are of very high vulnerability, while those which classified old agriculture lands vary between moderate to high vulnerability. The moderate levels areas lie in between the northern area of the governorate including Assiut, Manfalut, and Al-Qusya districts. Nevertheless, high vulnerable areas fully appear in the southern part of the study area including Sodfa, Abu-Teej, Al-Badary, Al-Sahel districts and the southern part of Assiut city.

5. Conclusion

Vulnerability Map of Nile aquifer along Assiut governorate was created by applying the DRASTIC model within GIS technique to find out the groundwater vulnerable zones to contamination. The vulnerability map generated by generic DRASTIC Model, demonstrates that about 3.8 % of the total area of Assiut governorate has low vulnerability level; on the other hand, 5.6 % of the total area is considered as very vulnerable level. The majority of study area is in between moderate vulnerable and high vulnerable; where 55.2 % of the area is moderately vulnerable and 35.4 % has high level of vulnerability. With regard to the groundwater vulnerability map generated by pesticide DRASTIC Model, it is shown that about 64% of the study area has an extreme to high vulnerability to contamination, 34.6% has a moderate vulnerability and small areas occupy about 1.4% and has a low vulnerability. According to land use activities, it can be clearly seen that most areas which considered new reclaimed land are of very high vulnerability, while those which classified old agriculture lands vary between moderate to high vulnerability.

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