



## Using Analytical Hierarchy Process Integrated with Geographic Information System and Remote Sensing (AHP/GIS/RS) for Mapping Groundwater Potentiality in West El-Minia Area, Upper Egypt

Sadek, M.A.<sup>1</sup>; Ewes, R.S.<sup>2</sup>; Hussien, R.A.<sup>1</sup>; Mohamed, F.A.<sup>1</sup>

Received: 29/03/2021

Accepted: 23/05/2021

DOI: 10.21608/jntas.2021.69947.1035

E.mail:rashahussien76@yahoo.com

### **ABSTRACT**

Water resources management is considered a major socio-economic issue and a central component for future development; this implies an increasing demand for exploration of groundwater of high potentiality to cope with the excessive needs. In this work, Analytic Hierarchy Process (AHP) which is a widely used Multi-Criteria Decision Analysis (MCDA) has been used with Geographic Information System and Remote Sensing for classifying and mapping zones that intrinsically control and reflect groundwater recharge potentiality in the western area of El Minia Governorate, Upper Egypt. Six parameters of high attributes to groundwater recharge potentiality (Geology, Geomorphology, Slope, Lineaments Density, Drainage Density, and land use/land cover) have been selected. Assigned weights based on their relative importance to groundwater recharge, the weights were compared in a pair-wise matrix, the Eigen values were determined and the consistency ratio was calculated to validate the assigned weights; the ranges of these parameters are classed and rated. Overlay analysis was done to integrate the thematic layers of the parameters in Arc GIS domain for the development of a groundwater recharge potential map which has been verified using stable isotopic content ( $\delta^{18}\text{O}$  and  $\delta\text{D}$ ) of 67 groundwater samples collected from the study

### **KEYWORDS**

*Groundwater recharges Potentiality, Analytic Hierarchy Process, ArcGIS/RS, Environmental Stable Isotopes, El Minia, Egypt.*

1. Egyptian Nuclear and Radiological Regulatory Authority (ENRRA).
2. Egyptian National Authority for Remote Sensing and Space Sciences (ENARSS).

area. Three groundwater recharge potentiality zones; (high, intermediate and low) have been delineated in a recharge potentiality map. The demarcated zones numerically integrate the geological, surficial factors and anthropogenic impacts on groundwater recharge and introduce a base for sustainable development of groundwater in the study area.

## INTRODUCTION

**W**ater resources management is considered a major socio-economic issue and a central component for future development. Egypt suffers from exceeding shortage of water resources while population rate and agricultural deficit progressively increases. One of the pillars of the strategic natural plan is to secure adequate water resource (on both quantitative and qualitative term) and to sustain its development and appraise its exploit. This implies an increasing demand for exploration of groundwater of high potentiality to cope with the excessive needs. Exploring of the groundwater conditions with the determination of the factors affecting it is of a prime importance and considered a global issue for the sustainable development projects under aridity conditions, hence it can extremely contributes to compensate the gap between food and continuous population growth. Recently, remote sensing and (Geographic Information System) GIS applications are considered to be a key to providing data for assessment of the current groundwater situation as well as, forecasting its future development. On the other hand, all the traditional methods are very expensive and time consuming for an accurate investigation of groundwater recharge potential of a region (Nampak *et al.*, 2014; Sander *et al.*, 1996). Coupling Geographical Information System (GIS) based modeling with Remote Sensing data (RS) and Geo-hydrological investigation has the ability to predict groundwater recharge potential zones with very high

efficiency (Nag and Ghosh, 2013; Agarwal and Garg, 2016; Fagbohun, 2018). Many statistical and mathematical techniques are used along with RS and GIS in different studies for getting more effective results in groundwater investigation as Analytical Hierarchy Process (AHP) (Badamasi *et al.*, 2016; Patra *et al.*, 2018; Chakraborty *et al.*, 2018; Murmu *et al.*, 2019; Maity and Mandal, 2019). The analytical hierarchy process (AHP) is one of the multi-criteria decision-analysis (MCDA) tools developed by Saaty (2003). The application of AHP model along with RS and GIS techniques is more popular all over the world due to its validity (Ramanathan, 2001; Chowdhury *et al.*, 2010; Siva *et al.*, 2017; Pinto *et al.*, 2017; Chakraborty *et al.*, 2018). In this research, the AHP/RS/ArcGIS technique verified by stable isotopes has been used to map the groundwater recharge potentiality zones in the whole watershed of El Minia area. As currently, Egypt launches a strategic plan to accommodate the water and food deficit by extension of agricultural lands to the desert areas, which are located at the periphery of traditionally cultivated lands in the Nile Delta and Valley (the study area belongs to this area). The identification of groundwater recharge potential zones in this area is helpful for the conservation and sustainable development of groundwater aquifers. The occurrence of groundwater in Quaternary aquifer in the Nile valley and in either fissured carbonate rocks or fossil paleowater aquifers outside Nile valley requires crucial and comprehensive understanding of its recharge source, renewability, potentiality, flow regimes and quality. This necessitates a detailed investigation of the hydrogeological system of the areas allocated for the desert reclamation projects including geological, geophysical, geochemical, and remote sensing techniques. Some of the methods are more effective, accurate, time and cost effective. Previous studies have used the traditional methods to select the most suitable sites for groundwater recharge in local zones in the study area (Ismail *et al.*, 2017).

### Site description of the study area

#### Geology and hydrogeology

The area of study lies in the western reaches of El-Minia Governorate at mid Upper Egypt, (**Fig. 1a**). It extends between longitudes 29° 9' 37.41" and 30° 58' 5.49" E and latitudes of 27° 32' 28.13" and 28° 47' 6.36" N. Its surface elevation and slope increase from east to west. It is characterized by an arid to semiarid climate (limited rainfall <20 ml/y) hot summer and warm winter (average temp. 20°C and 40°C respectively). Surface evaporation rate reaches about 10 mm/d. The mean monthly relative humidity during day time ranges from 62% in May to 29% in December (**Korany et al., 2008**). El Minia area and its western peripheries was previously subjected since 1980 to scattered and sporadic small scale hydrogeological and hydrogeochemical studies by many authors among them are; **Abou Heleika and Niesner (2009)**; **El Kashouty (2010)**; **Shabana (2014)**; **Ghoubachi (2017)**; **Al Temamy and Abu Risha (2016)**. The groundwater in the study area is exploited from three main aquifers according to (**Fig. 1b**).

**The Quaternary aquifer** which has a wide distribution in Nile Valley and the adjacent areas at the foot slope of the Eocene plateaus, this aquifer is composed of alluvium deposits (coarse, thick sand and gravel beds intercalated with clay lenses) covered by a semi-confining bed of silt and clay decreasing in thickness westward, it is recharged by seepage of Nile water and irrigation canals as well as infiltration of irrigation water return.

**The Eocene aquifer** is basically represented by limestone rocks differentiated into formations of variant lithofacies and intercalation nature. It underlies the alluvium aquifer, overlies the Nubian sandstone aquifer (**Al Temamy and Abu Risha, 2016**) and occupies the western sides of the study area. The groundwater of the Eocene aquifer occurs under unconfined conditions and gets its recharge by percolation of local seepage from the Quaternary aquifer

and upward leakage from the underlying Nubian sandstone aquifer.

**The Oligocene sandstone aquifer** which is mainly composed of calcareous sandstone with clay intercalation, its thickness increases westward of the study area and comes in contact with Eocene aquifer along fault planes shows a generalized hydrogeological cross section in the study area.

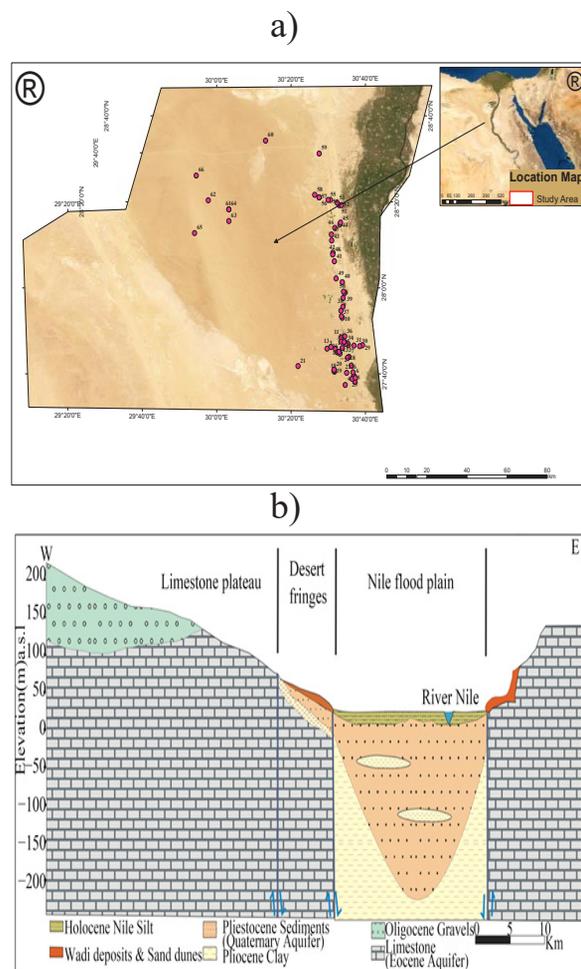


Fig. (1): a) Location map of the study area; b) General hydrogeological cross-section in El Minia area (RIGW, 1992).

### MATERIALS AND METHODS

The present work presents an attempt to incorporate a systematic integration of remotely sensed geo-data with available hydrogeological data to provide a cost-effective and rapid tool for the groundwater recharge potential zones delineation in El Minia region

using Multi Criteria Decision Analysis (MCDA) as Analytic Hierarchy Process (AHP) for assigning numerical weighing values for principle factors that control groundwater recharge potentiality (according to their relative importance). In this paper; the geospatial techniques are used to overlay and inte-

grate the weighed thematic layers of recharge factors and to demarcate the zones of different potentiality. A schematic sketch describing the overall processes and steps in this work is illustrated in the flow chart (Fig. 2).

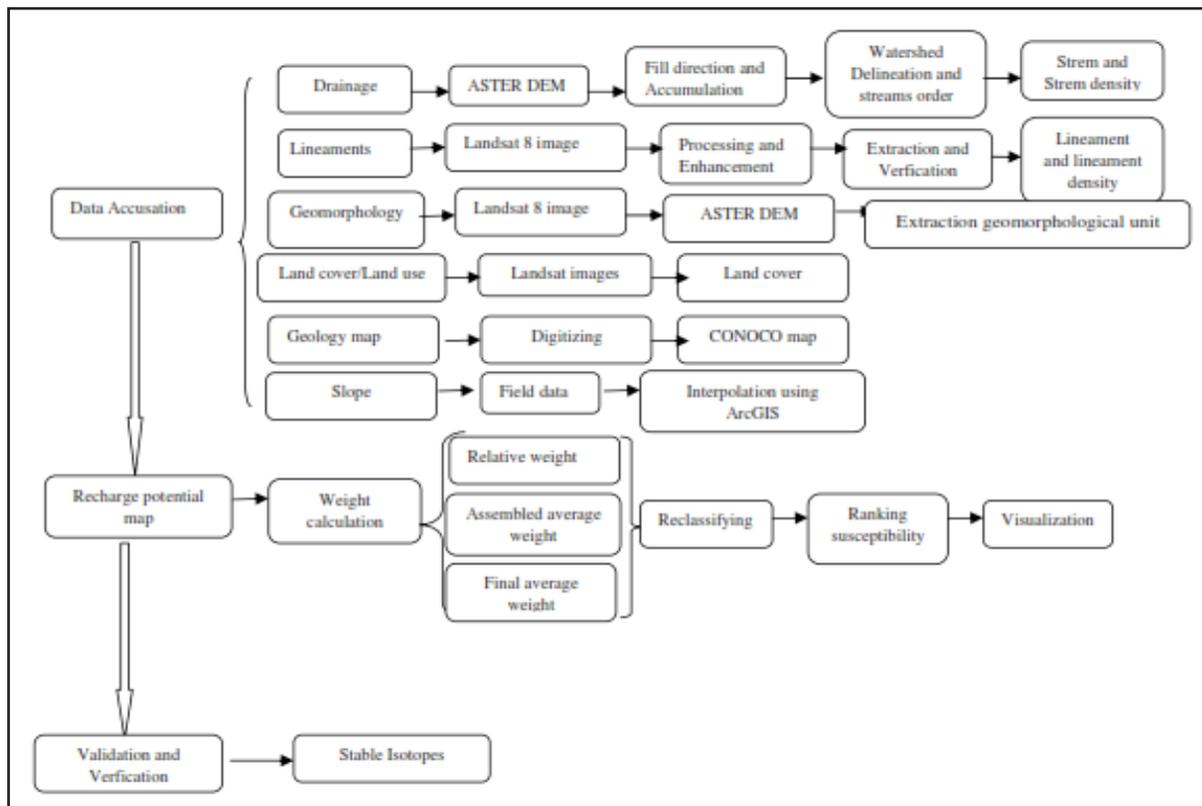


Fig. (2): Schematic sketch showing the methodology applied in this work.

The following three steps are used to delineate the potentiality zones in the study area.

### *Selection and preparation of thematic layers for groundwater recharge potential (RS/GIS).*

The factors that are believed to intrinsically influence and control recharge in the study area have been selected (Geology, Geomorphology, Slope/Degree, Lineaments Density, Drainage Density, Land Use/Land cover). Several satellite images, maps and field traced data have been used to prepare thematic layers for these factors (Fig 3). Geology and geomorphology maps of the study area have been ob-

tained from the Geological Survey of Egypt. Arc GIS10.3 software has been employed to digitize the maps intended for further analysis. SRTM DEM has been used to prepare the slope and drainage density maps. Landsat 8 data of 30 m spatial resolution has been obtained from USGS official website (<https://earthexplorer.usgs.gov/>) and classified in Erdas Imagine software for mapping land uses of the area. The Digital Elevation Model has been established and the data were refined by applying the hillshade feature to develop lineament map.

**Deriving the weights for the groundwater recharge potential thematic layers (AHP/ANP)**

The developed thematic layers are subdivided into features or scales that have relative significance for the layers that might contribute groundwater recharge process (Potentiality). All the themes and their features were assigned weights and normalized weights based on Saaty (2003). The maximum value is given to the feature with highest groundwater recharge potentiality and the minimum being to the lowest potential feature. Consequently, all factors are

compared in a pairwise comparison matrix. To control and test the consistency of the assigned weights, a consistency Ratio (CR) is calculated according to the following equations. Where ( $\lambda_{max}$ ) is the maximum eigenvalue, (CI) is the Consistency Index, n is number of factors, (RI) is the Random Consistency Index that is based on the number of factors according to Saaty Random Scale. If the value of CR is less than 0.1, the judgment of weights is acceptable and consistent.

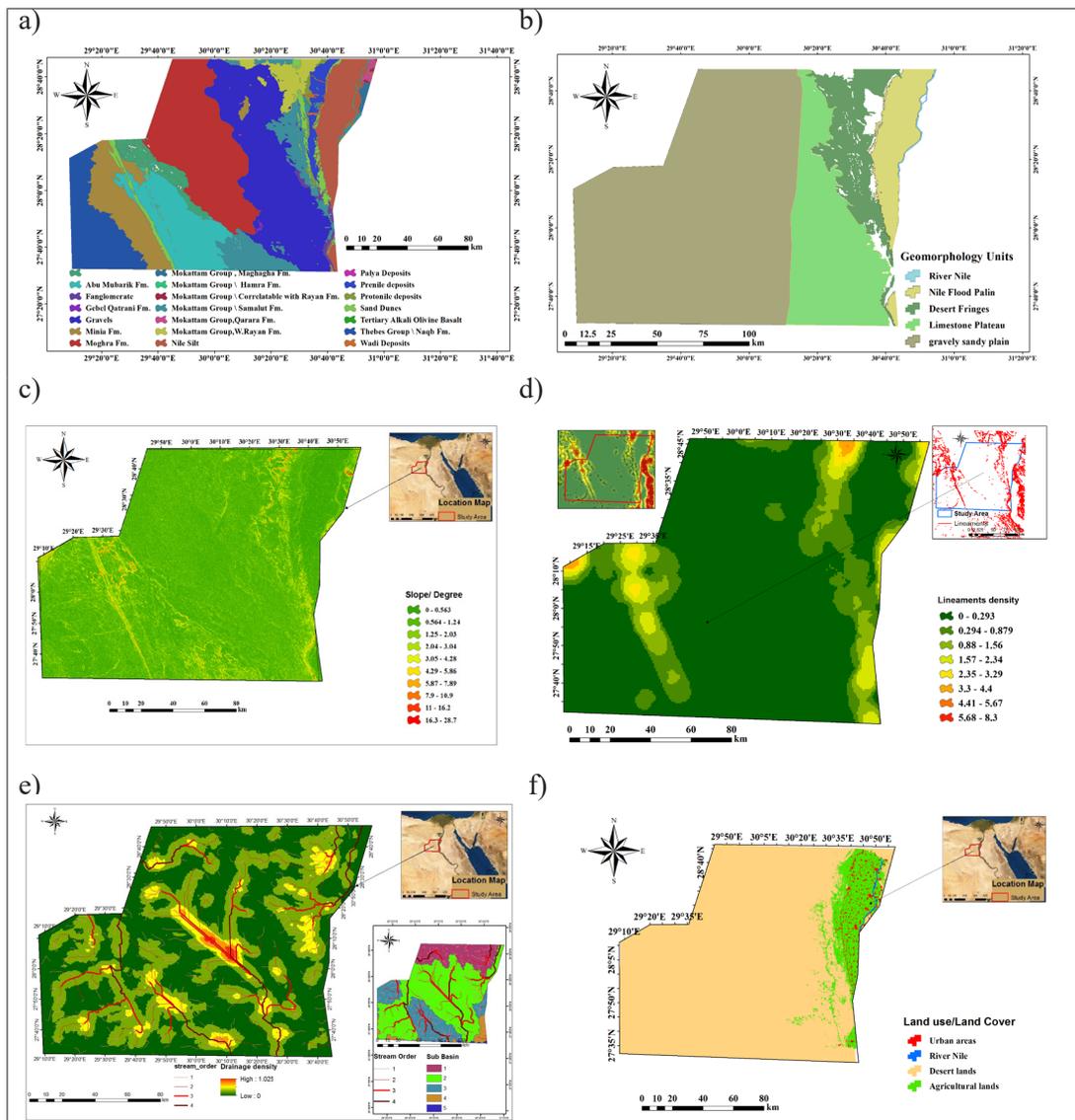


Fig. (3): Thematic maps of the selected parameters (a: Geology, b: Geomorphology, c: Slope, d: Lineament Density, e: Drainage Density, f: Land use/Land cover).



The consistency Ratio (CR) of this research is calculated and was found equal to 0.016 which means that the judgment of the pairwise comparison matrix is consistent. Hence, the assigned weight for Geology, Geomorphology, lineament, slope, land use / land cover, and drainage density are 0.343, 0.21, 0.21, 0.079, 0.124 and 0.04 respectively.

### Reclassifying thematic maps

The six thematic layers and sub-layers presented in (Fig 3) have been reclassified based on the consistently verified weights indicated in Table (3). Each layer has been reclassified into four recharge potentiality classes (Very Low, Low, Intermediate and High) based on the natural breaks of the data as shown in (Fig 4a – f).

**Table (3) : Rates and Weights of Factors Influencing Potentiality.**

|                             | Class   | Reclassified values | Potentiality categories | Weight |
|-----------------------------|---|---------------------|-------------------------|--------|
| <b>Geology</b>              | Wadi deposits, gravel, sand Pre Nile, Proto Nile, conglomerates                         | 4                   | High                    | 0.21   |
|                             | Moghra Fm, Qatara Fm, Qatrani Fm  | 3                   | Intermediate            |        |
|                             | Limestone (El Minia Fm, Samalut Fm, Maghagha Fm, W. El Rayan Fm, Al Marsad Fm, Nagb Fm) | 2                   | Low                     |        |
|                             | Basalt, Silt, Qarara clay, Playa  | 1                   | Very low                |        |
| <b>Geomorphology</b>        | Nile Flood Plain  | 4                   | High                    | 0.343  |
|                             | Old alluvial plain  | 3                   | Intermediate            |        |
|                             | Desert fringes  | 2                   | Low                     |        |
|                             | Tableland   | 1                   | Very low                |        |
| <b>Slope Degree</b>         | 0-2   | 4                   | High                    | 0.079  |
|                             | 2-4   | 3                   | Intermediate            |        |
|                             | 4-8   | 2                   | Low                     |        |
|                             | >8  | 1                   | Very low                |        |
| <b>Lineament Density</b>    | 0.0-1   | 1                   | Very low                | 0.21   |
|                             | 1-2   | 2                   | Low                     |        |
|                             | 2-4   | 3                   | Intermediate            |        |
|                             | 4-8   | 4                   | High                    |        |
| <b>Drainage Density</b>     | 0.0-0.25  | ٤                   | High                    | 0.04   |
|                             | 0.25-0.5  | ٣                   | Intermediate            |        |
|                             | 0.5-0.75  | ٢                   | Low                     |        |
|                             | 0.75-1  | ١                   | Very low                |        |
| <b>Land use/ Land Cover</b> | Nile River  | 4                   |                         | 0.124  |
|                             | Agriculture   | 3                   |                         |        |
|                             | Urban Land  | 2                   |                         |        |
|                             | Desert Land   | 1                   |                         |        |

- **The Geology** several studies were carried out in order to investigate the geological settings of El Minia upper Egypt by many authors among them Said (1990); Khalifa (1981); Mansour

**and Philobos (1983); Abdel Aziz (1994) and Abdel Baki (2013).** Based on previous data and field investigations, the study area is characterized by a lithostratigraphic succession related to

Eocene and post Eocene (Oligocene, Pliocene & Pleistocene and Holocene). The Eocene rocks are dominated by limestone sediments differentiated into several formations ((e.g. Maghagha, Samallut, Minia, Wadi El Rayan) based on the lithofacies nature and intercalation. The post-Eocene rocks include: (1) Oligocene sands and gravels which are exposed in the west and north-western part of the study area (Qatrani Formation, Qattara, Moghra). (2) Pliocene dark clays and undifferentiated sands, (3) Pleistocene al-

luvial deposits (sand, gravel with clay lenses), (4) Holocene Nile silt and clay. Consequently, the geological map has been classified as shown in (Fig 4a) according to recharge opportunity, the wadi deposits sands and gravels) that dominate the wadis courses and channels and the undifferentiated alluvial deposits that cover the flood plain have a good recharge potential. The massive limestone of the Eocene and Cretaceous rocks has low recharge potentiality.

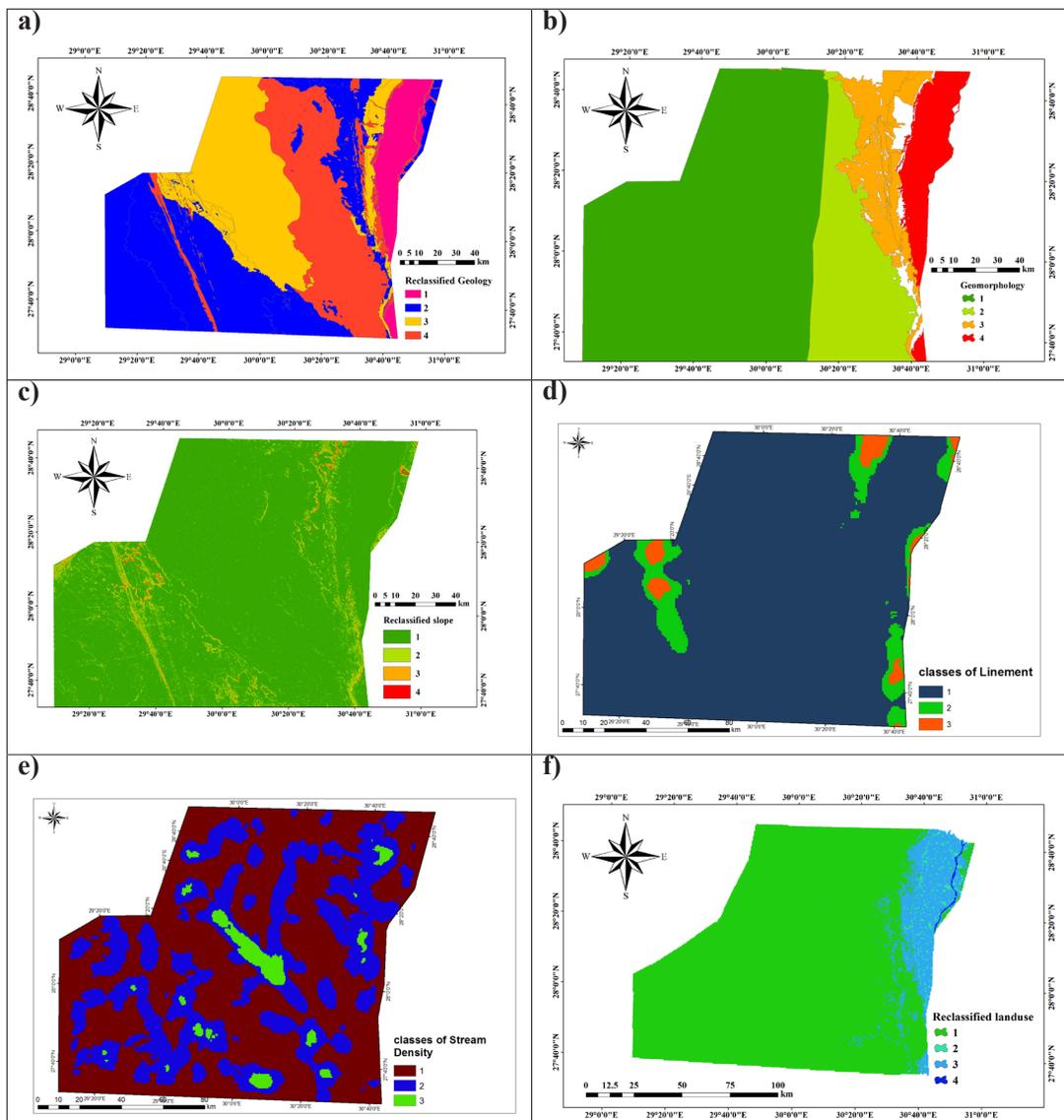


Fig. (4): Reclassifying Thematic Maps of the Selected Parameters (a: Geology, b: Geomorphology, c: Slope, d: Lineament Density, e: Drainage Density, f: Land use/Land cover).

- The Geomorphology** Three major geomorphologic units appear in the study area (from east to west) young flood plain & old alluvial plain and desert fringes & Table land). **Fig. (4b)**, their potentialities to control groundwater recharge are indicated in **Table (5)**. The young flood plain is occupied by Holocene silt and clay at the extreme east, bordered by Nile River with elevation in the range of 60m (amsl). It represents the agricultural areas which are irrigated with surface water diverted from the Nile and from main canals. The old alluvial plain and desert fringes dominated by Pleistocene sands and gravel, it shows undulated topographic and terraces features and includes the new desert reclamation lands as well as scattered urbanized areas, it is irrigated by surface water and groundwater. The lower Eocene plateau and table land at the extreme west, it has an elevation in the range of 250m (amsl) with respect to the River Nile, it is structurally formed, undulated with steep cliff and scarp, it is composed of limestone covered with alluvial deposits of sands and gravels and appearance of Sandunes and isolated hills in the eastern bounds.
- The Slope is** a vital parameter that controls groundwater occurrence and movement. Slope is inversely proportional to infiltration rate. Thus, areas which are slightly slopes are areas of slow surface water runoff, high residence time and high infiltration and recharge. In addition, areas which are extremely slopes are in general areas of fast runoff, less infiltration and low recharge of aquifers. The variation of slope in the study area is mapped and presented (**Fig. 4c**), it is classified into four categories; the gentle slope range (0-2m) is classed as high for groundwater recharge, the moderate and poor ranks of recharge are rated to slope ranges (2-4m) and (4-8m) respectively, the very poor recharge potential category is rated to the slope (>8m) which has high surface runoff with little chance for infiltration and recharge.
- The lineaments density** is an expression of underlying geological structures such as a faults, joints or fractures or lithologic contacts. Lineaments play significant role in groundwater exploration particularly in hard rock terrain (**Bahuguna et al. 2003**). Areas that have high lineament density indicate high secondary porosity that referred as good groundwater recharge potential zones. In the present study, the lineaments density map, (**Fig 4d**) is classified into four categories very low ranged from (0.0-1), low from (1-2), moderate from (2-4) and high from (4-8) correspondingly represent zones of very low, low, moderate and high recharge potentiality respectively.
- The Drainage density** it is inversely proportional to permeability; high permeability causes high infiltration, low runoff and low drainage density, on contrary, low permeability causes low infiltration, high runoff and high drainage density. In the study area, the drainage density ranges from 0 to 1.025, classified into four categories very low from (0.0-0.25), low from (0.25-0.5), moderate from (0.5-0.75) and high from (0.75-1) (**Fig.4e**). The low drainage density is dominated in permeable low topographic zones of high infiltration potential, while high drainage density is common in less permeable, high topographic areas of low infiltration and recharge potential.
- The Land use/Land cover mapping is** a good indication of the potentiality of groundwater as water availability is the major factor that determines the land use pattern. In addition, surface water bodies, like rivers, ponds, etc., can act as recharge zones, enhancing the groundwater recharge potential in the neighborhood. Vegetation cover benefits groundwater recharge by loosening the top soil prevents direct evaporation of water and sometimes prevents water loss by ab-

sorbing the water by roots. It is very well known that area covered by vegetation increases infiltration, whereas roads and concrete pavement and buildings reduce infiltration. (Fig.4f) shows the major land use/land cover types in the study area. The main classes are Agricultural lands, urban areas and Desert lands. The distribution of land use is expected to enhance groundwater recharge depending on the underlying soil and geologic conditions.

### Groundwater recharges potential zones map and validation

The raster calculator tool of ArcGIS software is used to integrate the AHP weighted/ rated thematic layers into an overall groundwater recharge potentiality map that has been geospatially generated for the study area, Fig (3). Three zones have been demarcated in Fig. (4) Indicating the different intrinsic groundwater recharge potentiality in the study area; zone 1 (6.5843Km<sup>2</sup> ~ 7%), zone 2 (10.546 Km<sup>2</sup> ~10%) and zone 3 (82.869 Km<sup>2</sup>~ 83%) of high, intermediate and low potentiality, respectively. The eastern area is dominated by a good recharge potentiality, it covers an area of at the Nile flood plain which is characterized by features accelerating groundwater recharge (e.g. gentle slope, plain morphology, lower groundwater depth and agricultural land use irrigated by Nile water and irrigation canals), the positive impacts of these features override the negative impacts of the overlying silts and clays that retard vertical infiltration, while seepage along the whole aquifer contact with surface water participate to recharge. The general massive and undulated nature of the limestone plateau to the west of the study area; its high slope degree, barren land use and higher groundwater depth render it of low groundwater recharge potentiality. The little chance of surface water infiltration to the limestone aquifer in the western plateau zone is (to some extent) compensated by upward recharge from deep paleowater aquifers through lineaments and fractures. The des-

ert fringes represent the intermediate transfer zone between the flood plain to the east and the limestone plateau to the west; it is bounded by the plateau escarpment and have undulated ground and terraces morph, it is categorized as a zone of moderate potentiality (more favorable than the plateau and less favorable than flood plain).

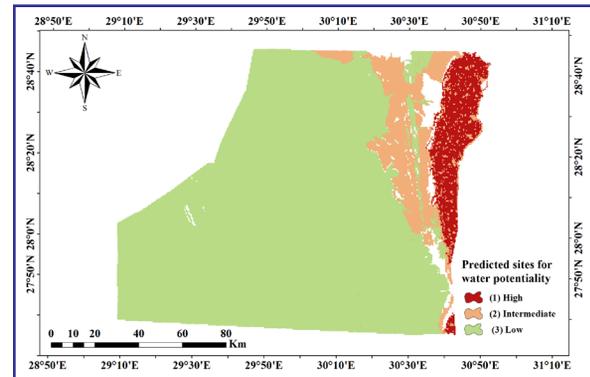


Fig. (5): Groundwater recharge potential zones map.

Validation of groundwater recharge potential map against field data investigation was applied by many authors (Prasad *et al.*, 2008; Abdalla, 2012; Khodaei and Nassery, 2013). In this study, Environmental stable isotopes data were used to validate groundwater recharge potentiality map. As oxygen-18 and deuterium content of water resources are parts of the water molecule itself, they are received in the original recharge environment and typically reflect the local conditions at time of formation as well as subsequent variation in the hydrogeological system. The different sources of recharges (rain, rivers, seas, and lakes ....etc.) have specific isotopic compositions that label them and fingerprint the atmospheric and hydrologic conditions under which they are formed. The sources of groundwater recharge in Egypt (Rain water, River Nile, Paleowater of western desert and irrigation return) has highly differentiated and distinguishable isotopic content that helps to fingerprint the contribution of different recharge sources in a given aquifers. The extreme isotopic enrichment in the study area ( $\delta^{18}O = +3\%$ ) is indicative of high l groundwater recharge

potential from present day active Nile water the extreme isotopic depletion ( $\delta^{18}\text{O} = -10\text{‰}$ ) is indicative of non-active low potential recharge from paleowater, the ( $\delta\text{O}-18$  values in between  $+3\text{‰}$  and  $-10\text{‰}$ ) represent a proportional mixing ratio between the two sources and intermediate range of groundwater recharge potentiality.

The plot of  $\delta^{18}\text{O}$  vs.  $\delta\text{D}$  of 67 groundwater samples collected from the study area, against Global Meteoric Water Line (GMWL) (Craig, 1961) and major recharging sources in Egypt (Fig 6) classifies the samples into three distinct groups (group 1, group 2 and group 3) which combines the samples aerially distributed in the groundwater recharge potentiality zones of Fig. (1a) (zone 1, zone 2, zone 3) respectively.

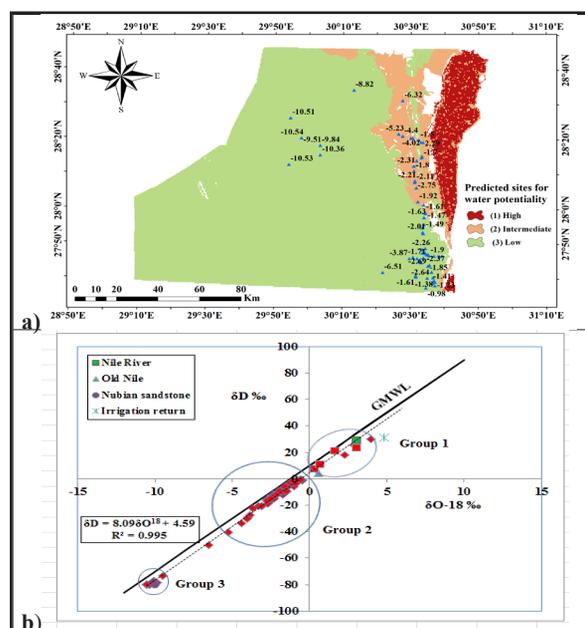


Fig. (6): a)  $\delta\text{O}-18$  in ‰ values in the study area, b)  $\delta\text{O}-18$  vs.  $\delta\text{D}$  relationship in ‰ for the study area.

Group 1 combines the samples which are located adjacent to Nile River and bordered by it, these have enriched isotopic composition of  $\delta^{18}\text{O}$  and  $\delta\text{D}$  ranging from 0.33 to 3.98‰ and 7.27 to 29.85‰ respectively, this location enhances recharging from the Nile River corresponding to high potentiality zone. Samples of Group 2 combines samples which

are located at the western part of the Nile River and characterized by slightly depleted values of  $\delta\text{O}-18$  and  $\delta\text{D}$  ranging from  $-6.51\text{‰}$  to  $-0.66\text{‰}$  and from  $-49.97$  to  $-0.68\text{‰}$  respectively. The relatively weak enrichment in heavy isotopes could be explained by proportional mixing of Nile water with upward leakage of paleowater that renders recharge potentiality moderate. Group 3 samples are located in the far western part of El Minia and has very depleted isotopic composition of  $\delta\text{O}-18$  and  $\delta\text{D}$  values varied from  $-10.54$  to  $-9.51\text{‰}$  and from  $-79.97$  to  $-73.63\text{‰}$  respectively, suggesting that non renewability zone with no recent recharge and low potential zone that have completely contribution of the deeper Nubian sandstone aquifer through fractures and faults in the study are.

## CONCLUSION

In the present study, The Analytical Hierarchy Process (AHP) which is one of the Multi Parameters Decision Approach (MPDA) has been integrated with Remote Sensing and Geographic Information System (RS/GIS) to identify the areas of different groundwater recharge potential in West El-Minia Area, Upper Egypt. Six thematic layers for the factors influencing groundwater recharge were prepared including (Geology, Geomorphology, Slope, Lineaments Density, Drainage Density, and Land Use/Land cover). All the themes and their features or scales were assigned weights and normalized weights based on Saaty approach. Overlaying the different thematic maps, the final groundwater recharge potential map was produced which is validated using isotopic content ( $\delta^{18}\text{O}/\delta\text{D}$ ) of 67 groundwater samples collected from the study area. Integrating the multi decision parameters in the GIS / SI mapping provided a single platform for mapping, visualizing, combining, analysis and decision-making regarding groundwater recharge potentiality in the study area, which could provide a basis for better groundwater management plan The approach used in this work is proved effective, it overrides complexities, cost-

ing and time consuming of collective investigations (geological, geophysical, geochemical,...) required to predict groundwater recharge potential zones.

## ACKNOWLEDGEMENTS

It is a pleasure to acknowledge the support provided by Egyptian Nuclear and Radiological Regulatory Authority (ENRRA) as well as the International Atomic Energy Agency, (Isotope Hydrology Section and Research Contract Administration Section)

## FUNDING

This work was financially supported by IAEA Coordinated Research Project (CRP) no F33025, 2018-2021.

## REFERENCES

- **Abdalla, F. (2012):** Mapping of groundwater prospective zones using remote sensing and GIS techniques: a case study from the Central Eastern Desert, Egypt. *J. Afr. Earth Sci.*, 70: 8.
- **Abou Heleika, M. and Niesner, E. (2009):** Configuration of the limestone aquifers in the central part of Egypt using electrical measurements. *Hydrogeol J.*, 17(2): 433.
- **Agarwal, R. and Garg, P. (2016):** Remote sensing and GIS based groundwater potential & recharge zones mapping using multi-criteria decision making technique. *Water Resour. Managt.*, 30: 243.
- **Al Temamy, A.M. and Abu Risha, U.A. (2016):** Groundwater interaction and potential inferred from geoelectrical and hydrogeological techniques in the desert fringe of Abu Qurqas area, El Minia, West Nile, Egypt. *J Geol.*, 60: 75.
- **Badamasi, S.; Sawa, B.A. and Garba, M.L. (2016):** Groundwater potential zones mapping using remote sensing and geographic information system techniques (GIS) in Zaria, Kaduna State, Nigeria. *Am Sci Res J Eng Technol Sci.*, 24(1): 51.
- **Bahuguna, I.M.; Nayak, S.; Tamilarasan, V. and Moses, J. (2003):** "Groundwater Prospective Zones in Basaltic Terrain using Remote Sensing", *Jour of the Indian Society of Rem Sens.*, 31(2): 107.
- **Brunelli, M. (2015):** Introduction to the Analytic Hierarchy Process. Springer, Amsterdam.
- **Carver, S.J. (1991):** Integrating multi-criteria evaluation with geographical information systems. *Int. J. Geogr. Inf. Syst.*, 5 (3): 321.
- **Chakraborty, R.; Pal, S.C.; Malik, S. and Das, B. (2018):** Modeling and mapping of groundwater Potentiality zones using AHP and GIS technique: a case study of Raniganj Block, Paschim Bardhaman, West Bengal. *Modeling Earth. Sys. Environ.*, 4 (3): 1085.
- **Chowdhury, A.; Jha, M.K. and Chowdary, V.M. (2010):** Delineation of groundwater recharge zones and identification of artificial recharge sites in West Medinipur District, West Bengal using RS, GIS and MCDM techniques. *Environ. Earth. Sci* 59 (6): 1209.
- **Conoco (1987):** Geological Map of Egypt, Scale 1:500,000. Luxor Sheet, the General Petroleum Company, Cairo.
- **Craig, H. (1961):** Isotopic variations in meteoric waters. *Science*, 133: 1702.
- **Dabralla, S.; Bhatt, B.; Joshi, J.P. and Sharma, N. (2014):** Groundwater suitability zones mapping a GIS application. Hyderabad, India, the international archives of the photogrammetry. Remote Sens. Spatial Inform. Sci p. 7.
- **Das, S.; Pardeshi, S.D.; Kulkarni, P.P. and Doke, A. (2018):** Extraction of lineaments from different azimuth angles using geospatial techniques: a case study of Pravara basin, Maharashtra, India. *Arab. J. Geosci.*, 11: 160.
- **El Sayed, E. A. (1987):** Hydrogeological evaluation of the groundwater resources in El Minia district, Egypt. M.Sc. Thesis, Geol. Dept., El Minia Univ., 115p.

- **El Kashouty, M. (2010):** Modeling of the limestone aquifer using isotopes, major, and trace elements in the western River Nile between Benisuief and El Minia. Fourteenth International Water Technology Conference, Cairo, Egypt; 941.
- **Ezzat, A.M. (1974):** Regional Hydrogeologic conditions. Ministry of agriculture and land reclamation, Cairo, Egypt.
- **Fagbohun, B.J. (2018):** Integrating GIS and multi-influencing factor technique for delineation of potential groundwater recharge zones in parts of Ilesha schist belt, southwestern Nigeria. *Environ. Earth Sci.*, 77: 69.
- **Ghoubachi, S.Y. (2017):** The hydrogeological characteristics of the Nubian Sandstone System in Sahl Karawein Area and Its Vicinities, El-Farafra Oasis, Western Desert, Egypt. *Ann. Geol. Surv. Egypt.*, 36: 175.
- **Hajkowicz, S. and Higgins, A. (2008):** A comparison of multiple criteria analysis techniques for water resource management. *Eur. J. Oper. Res.*, 184 (1): 255.
- **Hung, L.; Batelaan, O. and De Smedt, F. (2005):** Lineament extraction and analysis, comparison of LANDSAT ETM and ASTER imagery. Case study: suoimui tropical karst catchment, Vietnam, Remote sensing for environmental monitoring, GIS applications, and geology V. *Int. Soc. Optic. Photon.* 59830T.
- **Ismail, E.A.; El-Sayed, E.; Sakr, S. and Youssef, E. (2017):** Characteristic of groundwater potentialities in West Nile Valley South, Minia Governorate, Egypt. *Arabian. J. of Geosci.*, 10: 23.
- **IWACO/RIGW. (1986):** Feasibility of vertical drainage in the Nile valley, Minia Pilot area. Ministry of irrigation, Cairo, Egypt.
- **Khalifa, M.A. (1981):** Geological and sedimentological studies of west Beni Mazar area, south El-Fayum province, Western Desert, Egypt. Ph.D. Thesis.
- **Khodaei, K. and Nassery, H.R. (2013):** Groundwater exploration using remote sensing and geographic information systems in a semi-arid area (Southwest of Urmieh, Northwest of Iran). *Arab. J. Geosci.*, 6: 1229.
- **Korany, E.; Sakr, S.; Darwish, M. and Morsy, S. (2008):** Hydrogeologic modeling for the assessment of continuous rise of groundwater levels in the quaternary aquifer, Nile valley, Egypt: case study. *Intern. Conf. Geol. Arab World (GAW8)*, Cairo University, pp 703.
- **Maity, D.K. and Mandal, S. (2019):** Identification of groundwater potential zones of the Kumari river basin, India: an RS & GIS based semi-quantitative approach. *Environ. Devt. Sust.*, 21(2): 1013.
- **Mansour, H.H. and Philobos, E.R. (1983):** Lithostratigraphic classification of the surface Eocene Carbonates of Nile Valley, Egypt. A review. *Bull. Fac. Sci, Assuit Univ.*, 12 (2c).
- **Murmu, P.; Kumar, M.; Lal, D.; Sonker, I. and Singh, S.K. (2019):** Delineation of groundwater potential zones using geospatial techniques and analytical hierarchy process in Dumka district, Jharkhand, India. *Groundwater for Sustainable Development*. <https://doi.org/10.1016/j.gsd.2019.100239>.
- **Nag, S. and Ghosh, P. (2013):** Delineation of groundwater potential zone in Chhatna Block, Bankura District, West Bengal, India using remote sensing and GIS techniques. *Environ. Earth. Sci.*, 70: 2115.
- **Nampak, H.; Pradhan, B. and Manap, M.A. (2014):** Application of GIS based data driven Evidential belief function model to predict groundwater potential zonation. *J. Hydrol.*, 513: 283.
- **Patra, S.; Mishra, P.; Mahapatra, S.C. and Mishra, S.K. (2016):** Modeling impacts of chemical fertilizer on agricultural production: a case study on Hooghly district, West Bengal, India. *Model. Earth Syst. Environ.*, 2 (4):180.

- **Pinto, D.; Shrestha, S.; Babel, M.S. and Ninsawat, S. (2017):** Delineation of groundwater potential zones in the Comoro watershed, Timor Leste using GIS, remote sensing and analytic hierarchy process (AHP) technique. *Appl. Water. Sci.*, 7: 503.
- **Prasad, R.; Mondal, N.; Banerjee, P.; Nandakumar, M. and Singh, V. (2008):** Deciphering potential groundwater zone in hard rock through the application of GIS. *Environ. Geol.*, 55: 467.
- **Ramanathan, R. (2001):** A Note on the Use of the Analytic Hierarchy Process for Environmental Impact Assessment. *J. of Environ. Manag.*, 63: 27.
- **RIGW, Research Institute for Groundwater. (1992):** Hydrogeological Map of Egypt, Scale 1:100,000. 2nd Edition, Map Sheet of El-Minia.
- **Saaty TL (1977)** A scaling method for priorities in hierarchical structures. *J. Math. Psychol.*, 15: 231.
- **Saaty, T.L. (1980a):** Group decision making and the AHP. In: Golden, B.L., Wasil, E.A., Harker, P.T. (Eds.), *The Analytic Hierarchy Process*, Berlin, Heidelberg: Berlin, Heidelberg.
- **Saaty, T.L. (1980b):** *The Analytic Hierarchy Process*, xiii ed. McGraw-Hill International Book Co., New York.
- **Saaty, T.L. (2003):** Decision-making with the AHP: why is the principal eigenvector necessary. *Eur. J. Oper. Res.*, 145: 85.
- **Said, R. (1981):** The geological evaluation of the River Nile. Springer verlag New York, 151p.
- **Said, R. (1990):** The geology of Egypt. A.A. Balkema/Rotterdam/Brookfield, 734p.
- **Shabana, A.R. (2014):** Geology of water resources of Wadi El Tarfa, Eastern Desert, Egypt. *Egy. J. geol.*, 58: 41.
- **Sander, P.; Chesley, M. M. and Minor, T.B. (1996):** Groundwater assessment using remote Sensing and GIS in a rural groundwater project in Ghana: lessons learned. *Hydrogeol. J.*, 4 (3): 40.
- **Siva, G.; Nasir, N. and Selvakumar, R. (2017):** Delineation of groundwater potential zone in Sengipatti for Thanjavur District using analytical hierarchy process. IOP Conf Ser. *Earth. Environ. Sci.*, [https:// doi. org/10.1088/1755-1315/80/1/0120613](https://doi.org/10.1088/1755-1315/80/1/0120613).
- **Strougo, A. (1986):** Mokattamian stratigraphy of eastern Maghagha-El Fashn district, Mid. East Res. Cent. Ain Shams Univ. *Sci. Res. Ser.*, 33.
- **Tantawy, M.A. (1992):** Isotopic and hydrochemical application to the surface and groundwater assessments in El Menia district, Ph. D. Thesis, Fac. of Sci., El Minia Univ. 263p.