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RESEARCH ARTICLE

DEVELOPMENT OF A TOOL TO CALCULATE THE WATER QUALITY INDEX USING SPATIAL MODELING

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Abstract

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Water quality is crucial for balancing water demand and availability, and ensuring it meets human and environmental needs is essential for sustainable development. This study developed a Water Quality Index calculating tool (Arc G-WQI) using spatial modeling to determine subsurface water type and suitability for various purposes. The tool was developed using Python Programming Language and Model Builder for Esri ArcGIS desktop 10.6. Arc G-WQI allows secure and structured storage of data from analyses of field-collected samples in a geodatabase and accelerates WQI computation, allowing faster and more accurate classification. A case study was conducted to validate the tool's applicability in assessing groundwater quality. Groundwater samples were collected from 85 sites in the Ismailia Canal in the eastern Nile Delta. The Arc G-WQI-Tool stored WQ data in a geodatabase and created thematic information layers which are then utilised to create maps displaying water quality parameters distribution. Next, the groundwater quality index (WQI) was computed and a map of the WQI was created. According to the outcomes, groundwater in the southern and western parts of the research area is classified as "good water" appropriate for a variety of uses. However, groundwater in the research area's northeastern parts is classified as "very poor water" and could be used to cultivate salt-tolerant plants. The study concluded that the spatial tool can be a reliable technique for monitoring and managing groundwater quality in the water supply system.

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Introduction:-

In Egypt, water shortages and contamination are considered one of the greatest challenges affecting economic and social development operations. This is because of the increased demand for water, coupled with limited water resources. Effective water management is also a major challenge and requires integrated and comprehensive planning to address these issues and protect water for present and future generations. Water resources planning and management activities are usually motivated to solve the problems of water distribution and quality. Water quality is an important factor in balancing water demand and availability. Therefore, ensuring water quality that suits human and environmental needs is a critical component of integrated management and sustainable development.

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Water quality evaluation is a complex procedure that encompasses many physical and chemical characteristics as well as certain regulating variables.The monitoring method aims to determine water quality (WQ) conditions using water quality parameters (WQPs). This method necessitates multiple water samples, each of which is analysed to evaluate the concentrations of a variety of WQPs, which can be a source of uncertainty when determining WQ As a result, a water quality index (WQI) was created to assign a single number to reflect the quality of a water source by combining data on water quality parameters in simplified terms that the general public, not WQ professionals, can understand and evaluate.

WQI is a classification system that determines the combined effect of multiple water quality criteria on the comprehensive quality of water consumed by humans (Mitra and Asabe Member, 1998). Several researchers have recently successfully used WQI to evaluate water quality for domestic uses, irrigation, commercial uses, and other purposes depending on input variables and necessary performance [5, 29, 30, 32, and 34].

The primary purpose of this work was to employ spatial modeling to develop a Water Quality Index calculating tool (**Arc G-WQI**). Which is a planning tool that can generate spatial distribution maps for subsurface water quality index (WQI) parameters to assist decision-makers in determining the type of subsurface water, evaluating its suitability for various study area uses, and achieving the best use of water resources. This tool was created using Model Builder for Esri ArcGIS desktop 10.6 and the Python Programming Language. **Arc G-WQI** tool allows for the secure and structured storing of data from field-collected sample analysis in a geodatabase, as well as the acceleration of the WQI computation, allowing for faster and more accurate water quality categorization.

A case study was conducted to validate the **Arc G-WQI** tool's applicability in assessing the quality of groundwater sources. Groundwater samples were obtained at 85 various sites within the command area of the Ismailia Canal in the eastern Nile Delta. The samples have been analysed for the following physicochemical properties: pH, EC, TDS, Total Hardness, Total Alkalinity, Chloride, Fluoride, and Nitrate. The **Arc G-WQI**tool created in this study is used to store WQ data from sample analysis in a geodatabase and to create thematic information layers, which are then utilised to create maps displaying the distribution of various water quality parameters. After that, the groundwater quality index (WQI) was computed and a map of the WQI was created. According to the outcomes, groundwater in the southern and western parts of the research area is classified as "**good water**" appropriate for a variety of uses. However, groundwater in the research area's northeastern parts is classified as "**very poor water**" and could be used to cultivate salt-tolerant plants. As a result, it was concluded that the spatial tool developed can be a dependable technique for monitoring and managing groundwater quality in the water supply system.

Study Area

As illustrated in Figure (1), the Ismailia command area in the Eastern Nile Delta region was chosen for the study. The Ismailia Canal is one of the most important freshwater sources for the region's governorates of Kaliobia, Sharkia, Ismailia, Suez, and Port Said. The service area is roughly (819,665 acres (acre= 0.4047 hac)). It is also a major supply of water for irrigation expansion projects in the Eastern Nile Delta and Sinai.

Groundwater is used for domestic, industrial, and agricultural water supply and irrigation in the study area. Groundwater recharge in the study region is mostly accomplished through infiltration and downward seepage of surface water into the irrigated field from the Damietta branch and the connected branches. Rainfall on shed areas, which generates surface runoff through the desert wades, is another recharge source. Furthermore, upward leakage from the Oligocene and Miocene aquifers through the fault planes may refill the aquifer in the southern section of the study arefa.

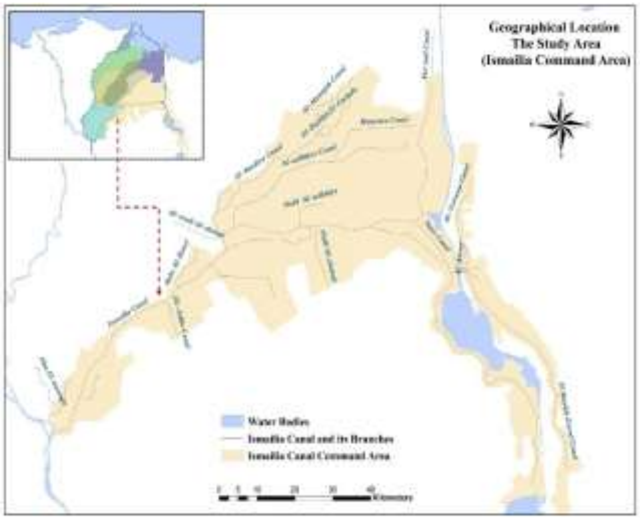


Figure (1):-Study Area Location.

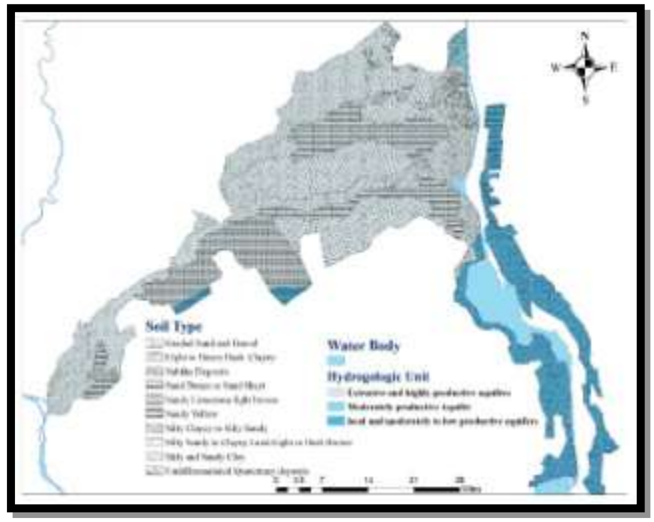


Figure (2):- Hydrogologic Unit.

Material and Method:-

The methodology used throughout the study, which includes the following six stages:

1- Physical and chemical analysis of collected samples, and obtaining data on water quality parameters (WQPs)
2- Geo database development that allows secure and structured storage of WQ data from sample analysis and creates thematic information layers
3- A geostatistical method uses an interpolation technique to forecast the water quality in other locations. Then, maps depicting the spatial distribution of all parameters created.
4- Description of the ArcWQI-Tool and stages of development
5- A case study was conducted to validate the tool's applicability in assessing groundwater quality.
6- Discuss the results, conclusions and recommendations

Groundwater samples were obtained at 85 various sites within the command area of the Ismailia Canal in the eastern Nile Delta. The samples have been analysed for the following physicochemical properties: pH, EC, TDS, Total Hardness, Total Alkalinity, Chloride, Fluoride, and Nitrate. Because water bodies are so large, collecting water samples at all locations is difficult. In this case, GIS is a powerful tool with a lot of potential for addressing environmental issues in several fields. The GIS interpolation techniques can predict the value of attributes at unsampled sites based on measurements collected at point locations within the same area. It is a collection of techniques or tools for predicting a variable's values that are distributed in space or time. Kriging, Spline, and inverse distance weighted (IDW) interpolation methods are used in several disciplines for environmental spatial assessment [3, 14, 22, 23] Those concluded that the IDW method is more credible and preferable to kriging and Spline in evaluating water quality due to its neighborhood attitude and radial base properties. As a result, IDW interpolation was utilised in this work to look at the sample data, construct variogram models, and generate geographical distribution maps of water quality parameters. The **Arc G-WQI**tool will then be developed. The following parts provide more information on the processes that were considered during the creation of the **Arc G-WQI**. As shown in Figure (4).It was constructed in four stages as the following:

- Groundwater quality parameters (GWQPs) were chosen after a thorough review of national and international literature, and weights were assigned to each GWQP based on their relative importance in terms of use and their respective value in total water quality. The G-WQI was calculated using twelve quality parameters: pH, TDS, TH, Ca_2^+, Mg_2+, Na+, K+, HCO3−, Cl−, NO3−, SO_4^2 -, and F−. Since TDS, fluoride, chloride, nitrate, sulfate, and sodium are the most significant factors for determining water quality, they were given the highest weight (5). Bicarbonate provides less information about the area's water quality and is given a low weight (1). Weights were assigned to magnesium, calcium, and pH (3), while total hardness and potassium (2) were based on their importance. The (Eq. 1) was used to compute the relative weights for each factor.

$$W_i = w_i \sum_{i=1}^{n} w_i \text{ Eq. } (1)$$

Where: $\mathbf{W_i}$ denotes relative weight, $\mathbf{w_i}$ denotes the weight assigned to each parameter, and n denotes the number of parameters.

- Then, (Eq. 2) was used to compute the quality rating range (Q_i). By multiplying the value of each parameter in the sample (C_i) by one hundred and dividing the result by it's special to standard (Si), WHO's a proposal.

$\mathbf{Q_i = (C_i * 100)/\ S_i Eq.\ \ (2)}$

- Finally, using (Eq. 3), the sub-index (SI_i) was calculated by multiplying relative weights (Wi) and quality rating range (Q_i) and then using equation (4), G-WQI was calculated.

$\mathbf{SI_i = W_i * Q_i Eq.\ \ \ (3)}$

G-WQI = $\sum$ **SIiEq (4)**

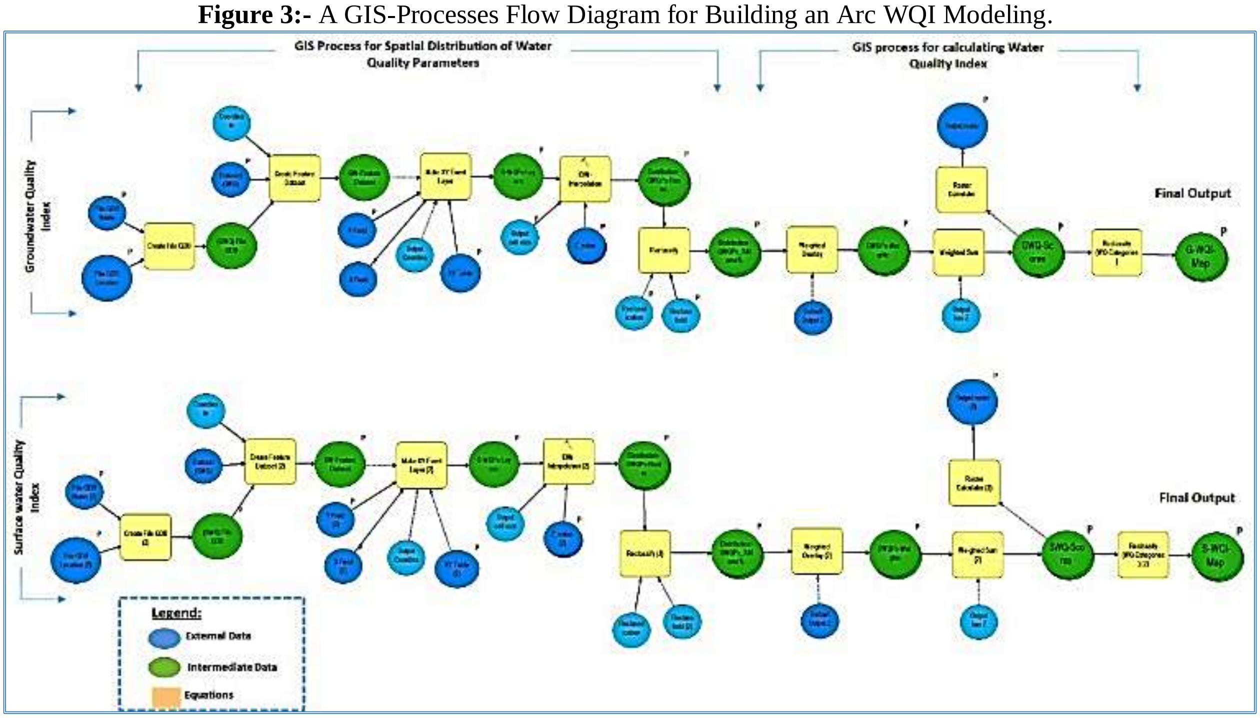
WQI classification as decreasing scale index, where the index value reduces as the contamination level decreases. WQI divides water quality into five groups based on hydro-chemical parameters: excellent water (EW), good water (GW), poor water (PW), very poor water (VPW), and unsuitable (UDP) as shown in Table 1.

Table (1):- Water Quality Index Classification.

WQI Range	Water Category
< 50	Excellent Water (EW)
50 - 100	Good Water (GW)
100 - 200	Poor Water (PW
200 - 300	Very Poor Water (VPW)
>300	Unsuitable (UDP)

Source: Rao, et al. [26], Vasanthavigar, et al. [37], Rao and Nageswararao [27].

Figure 3:- A GIS-Processes Flow Diagram for Building an Arc WQI Modeling.



Results and Discussion:-

In 2020, 87 groundwater samples were taken from the study area as a representative sample. Then, the pH, TDS, TH, Ca2+, Mg2+, Na+, K+, HCO3, Cl, NO3, and SO42 were measured in the samples. The developed modeling tool is run with the measured water quality data for ten selected parameters as inputs to calculate WQI and assess the groundwater's suitability for drinking and cultivation. The maps in Figures 5 and 6 offer a summary of the modeling results.

Spatial Distribution of Water Quality Parameters

These maps in Figure 4 represent the spatial distribution of water quality variables in the Ismailia Canal's command area. This can be explained as the following:

1. Based on the water analysis results for TDS, pH, and EC in 87 samples, the studied groundwater has acceptable physical qualities. This can be summarised as follows:
   - The pH of the groundwater aquifer ranges from 7.1 to 9. The pH values for all the samples analysed showed natural alkaline to slightly alkaline water conditions.
   - The electric conductivity (EC) varies between 300 Mmhos/cm and 10110 Mmhos/cm for the groundwater samples.
   - The samples' Total Dissolved Salts (TDS) range between 333 ppm and 8433 ppm.
2. Based on the results of water analysis of the concentrations of major anions in 87 samples, which can be summarised as follows:
   - The bicarbonate ion is the most common anion (HCO_3). It was found in groundwater samples at concentrations ranging from 2.5 ppm in well no. (25) to 656 ppm in well no. (67).
   - Anion chloride (Cl) is the second most abundant. The quantity of the groundwater samples ranges from 34 ppm in well no. (59) to 4260 ppm in well no. (84).
   - The lowest prevalent anion is sulfate (SO_4). Its content in groundwater samples ranged from 4 ppm in well no. (59) to 2180 ppm in well no. (84).
3. Based on the results of water analysis of the concentrations of major cations in 87 samples, which can be summarised as follows:
   - The most important cation is sodium (Na^+). Its content in groundwater samples ranged from 34 ppm in well no. (27) to 2507 ppm in well no. (80).
   - Calcium (Ca^{2+}) is the second most abundant cation in groundwater samples. Its concentration varies from 6 ppm in well no. (51) to 994 ppm.
   - Magnesium (Mg^{+2}) is the third most abundant cation in the groundwater samples in the study area. Its concentration varies from 2 ppm to 256 ppm in well no. (77).
   - The cation potassium (K^+) is the least abundant. It has a concentration of 2 ppm in wells 34, 30, 43, 48, 51, 56, and 26 ppm in well no. (10).

Water Types

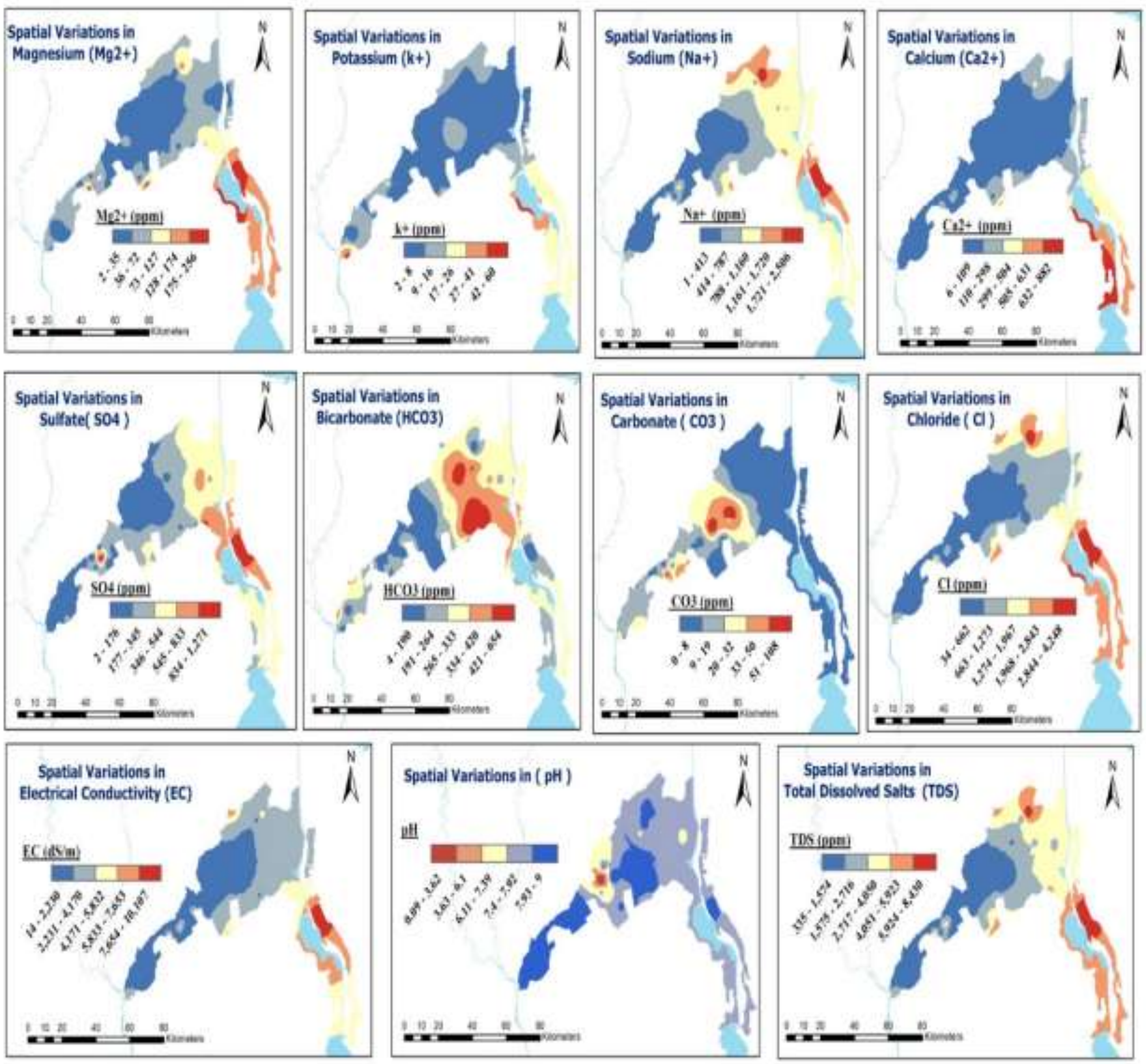
4. According to the analysis of the previous results, the classification of groundwater categories can be the following:
   - In the southwest part of the command area, the "+" hydrochemical processes, as well as the major cations (HCO_3) and anions (Ca, Mg), are dominant. This indicates the existence of fresh groundwater types with Ca-HCO3+ and Mg-HCO3+ in the area. This is due to the aquifer being continuously recharged by excess agricultural water.
   - To the southeast and west of the research area, there is a zone with fresh, sometimes brackish Na-HCO3+ and Na-Mix+ water types That Ca- and Mg- cations are still present indicates that the aquifer is less flushed than the southern part of the Delta.
   - There is no CI groundwater type in the northern area, which means the groundwater in this area is brackish to saline, yet the aquifer is still inundated with freshwater.
   - Near the coast, the groundwater of the Ca-C1-, Mg-Cl-, and Ca-C_{10} types is detected, indicating that freshwater is being replaced by saline water due to either seawater intrusion.
   - In the west and east of Temsah Lake, groundwater type's Ca-C1- and Ca-C10 are saline water present. The groundwater in this area differs completely from the Delta's water**.**

Water Quality Index

After that, it uses spatial distribution maps for water quality parameters (WQPs) as input data in a raster format. The groundwater quality index (G-WQI) is calculated in the Ismailia canal command areato assess the status of groundwater and its suitability for various purposes. Figure (5) shows that the G-WQI was defined as a scalar index with a diminishing scale (as pollution increases, the index values decrease). The results that appear illustrate the following:

- From the southern part and the western side of the research area, around 35% of groundwater samples are rated as "good water." In these groundwater samples, the concentrations of all hydro-geochemical parameters are less than the maximum recommended limit proposed by the standard WHO (1997). This area's groundwater is suitable for different uses.
- About 20% of the studied groundwater samples are found in the research area's middle part and are classified as "poor water," which can be used for household and agricultural uses with some restrictions.
- In the North and northeastern areas of the study zone, almost 20% of the groundwater samples are classed as "very poor water" and could be used to cultivate salt-tolerant plants.
- In the west and east of Temsah Lake and near the coast, about 25% of groundwater samples are classed as "unsuitable water" Because of seawater intrusion, the groundwater in this area is saline. As a result, it is unsuited for human or agricultural consumption.

Figure 4:- Spatial Distribution of Water Quality Parameters in Groundwater.



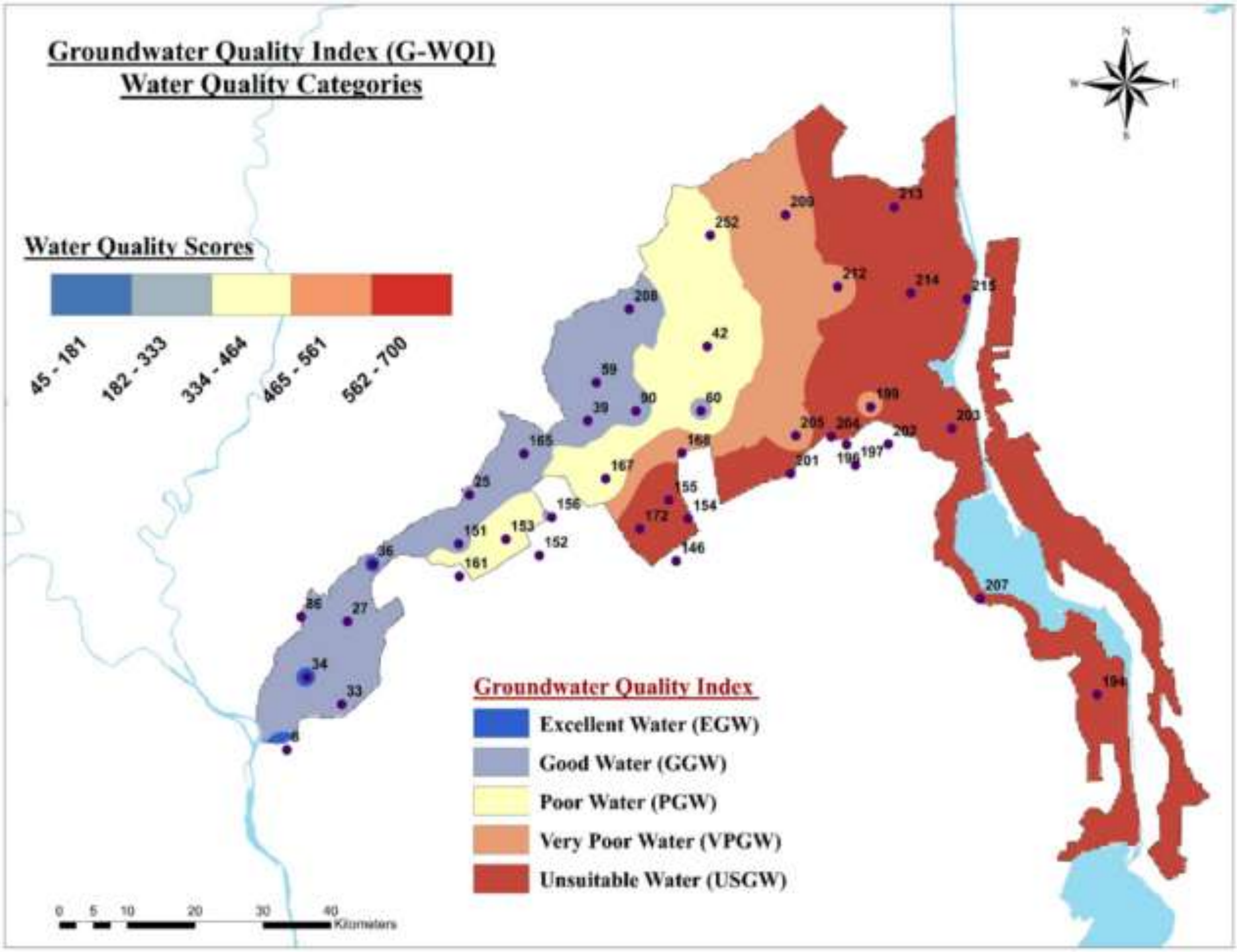


Figure 5:- Groundwater Quality Index Map (G-WQI).

Conclusions:-

In this study, a water quality index calculating tool (**Arc G-WQI**) was developed using spatial modeling to determine subsurface water type and evaluate its suitability for various purposes, for the Ismailia command area in the eastern Nile delta. This study produced an index map of groundwater water quality in the study area, as well as spatial distribution maps of different water quality parameters.

The results indicate that groundwater in the southern and western parts of the research area is classified as "good water" appropriate for a variety of uses. However, groundwater in the research area's northeastern parts is classified as "very poor water" and could be used to cultivate salt-tolerant plants. But In the west and east of Temsah Lake and near the coast, about 30% of groundwater samples are classed as "unsuitable water" Because of seawater intrusion, the groundwater in this area is saline. As a result, it is unsuited for human or agricultural consumption.

This research is critical for the sustainable use of groundwater resources through correct management. The use of spatial modeling techniques aids in the monitoring and management of groundwater quality in the water supply system, as well as providing a valuable and effective tool for monitoring, summarising, and reporting data to decision-makers in order to help them understand the quality of water within the study area and reach optimum use.

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