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Prediction of the Values of the Chemical Constituents of the Gezira Groundwater Using GIS Techniques

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Abstract: This paper is concerned with establishing prediction models for the chemical composition of the groundwater in the Gezira area from the available recorded data. The area of study is approximately bordered by latitudes 13°-15.6° North and longitudes 32°-34.5° East.The inverse distance weighted (IDW) technique of the Geostatistical Analyst of the GIS has been employed to describe each individual chemical parameter of the Gezira groundwater by a mathematical continuous-surface function. The graphical representations of these mathematical functions in the GIS environment are eventually converted into colored-filled contours covering the whole area under study.The developed models can be used as primary predictors for estimating the expected values of the chemical constituents of the groundwater pertaining to any proposed drilling location in the Gezira area. The established GIS models are also used for the assessment of groundwater quality in the study area.
Key words: *Groundwater, Gezira area, contour models, chemical constituents, prediction, GIS techniques, the inverse distance weighted (IDW)*.

المستخلص: هذه الورقة تختص بإنشاء نماذج لتقدير التركيب الكيميائى للمياه الجوفية فى منطقة الجزيرة من المعلومات المسجلة المتاحة. منطقة الدراسة تقع تقريباً بين خطي عرض ١٣° - ١٥.٦° شمالا وخطي طول ٣٢° - ٣٤.٥° شرقا. وبلستخدام نظم المعلومات الجغرافية GIS ، تم إنشاء نماذج لتقدير المعالم الكيميائية للمياه الجوفية بالجزيرة. هذه النماذج يمكن إستعمالها للتقدير الأولي للقيم المتوقعة للمعالم الكيميائية للمياه الجوفية في المواقع الجديدة بالخريطة . تستخدم هذه النماذج ايضاً فى تقييم جودة المياه فى منطقة الدراسة.

1- Introduction

Groundwater is extensively utilized in Sudan for domestic, agricultural and industrial purposes. It derives its importance mainly from the fact that over 50% of the country lies within the desert or semi-arid zones where rainfall and run-off are scarce. Deep boreholes and shallow wells are generally preferred to the other sources of water in Sudan due to their attractive economic, technical and environmental characteristics. Thus, for example, thousands of wells have been drilled in the Gezira area irrespective of their presence near or far away from the two Niles, so as to maintain sustainable water supplies especially for areas remote from the present distribution network.

Due to the expansion of urbanization and agricultural activities in the Gezira area, well-documented information on the quality of its groundwater is becoming of major concern. Also the establishment of models for the prediction of the quality of the groundwater is likewise becoming very important to assist in the decision process whenever the drilling of a new well is undertaken.

This paper is concerned with employing relevant GIS techniques to establish a graphical interface for the chemical composition of groundwater in the Gezira area from the available recorded data. Also ArcMap of the GIS is used to create models of the chemical constituents of groundwater in the area.

2- Study Area

The area of study is the Gezira area and is approximately bordered by latitudes 13°-15.6° North and longitudes 32°-34.5° East (Fig.1).

The Gezira area is located in the central clay plains of the Sudan where the largest Irrigated Farm in Africa with a total area of 2.1 million feddans (a feddan =1.o38 acre) under one management [1], [2], [3]. The scheme is fed principally by gravity irrigation from Sennar dam.

3- Methodology

3.1 Data Collection and Organization

The chemical data collected for the mapping and modeling of the Gezira groundwater were obtained via the routine standard methods of chemical analysis. The various analyses were carried out in the Central Laboratories of the Ministry of Health in Khartoum. The methods adopted are described in the book of the "Approved Methods for the Physical and Chemical Examination of Water" by Hamence, (1960) and the manual of the Sudan Ministry of Health Laboratory [4].

The recent chemical data samples of the Gezira groundwater used for comparison with the model results were collected and analyzed in the laboratories of the Ministry of Physical Planning and Public Works (Gezira State Water Corporation). All the analyses were performed by a Palintest Photometer 7000 [5].

The chemical data gathered for modeling the Gezira groundwater were organized using Microsoft Excel and Database techniques. The data was classified into two database files representing the Nubian and Gezira aquifers. The individual database files were then converted into shape files (GIS format) with the aid of ArcView GIS 3.3. The shape files were utilized for the mapping and modeling of the chemical data with the aid of ArcGIS 9 (ArcMap) package.

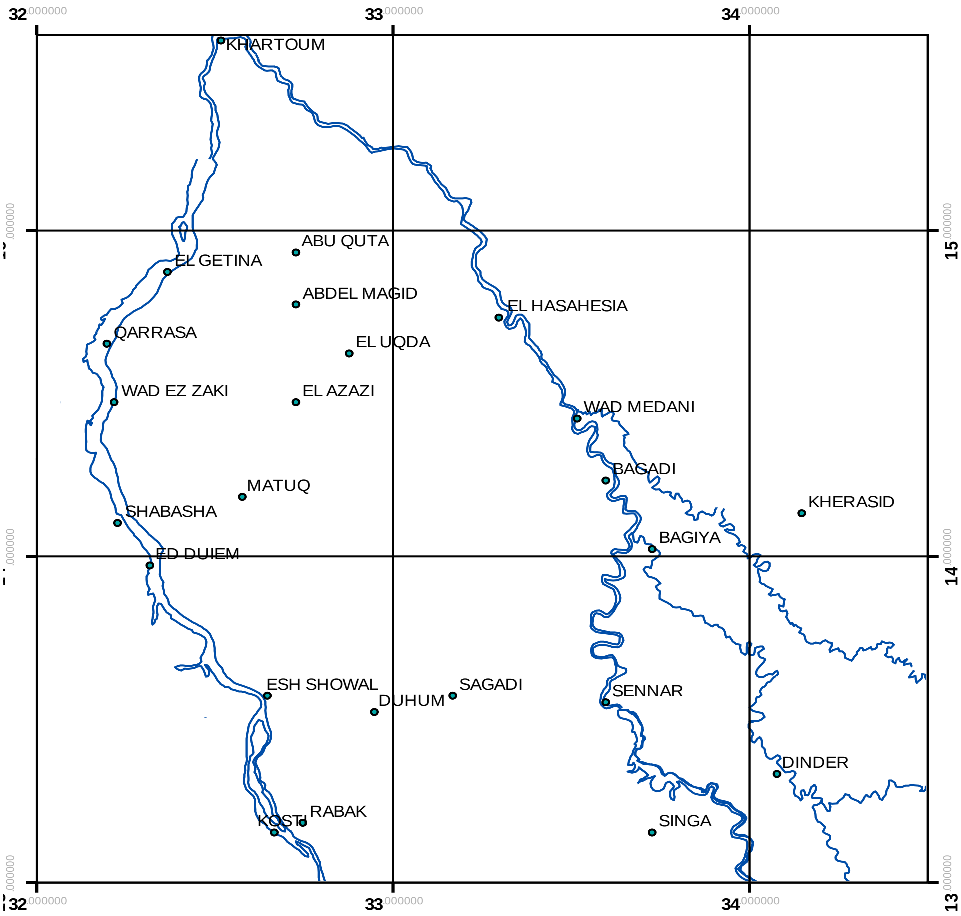

Figure1: Area of STUDY

3.2- Modeling Technique

The Geostatistical analyst is one of the GIS modeling packages, which has been developed by tightly integrating geostatistical tools within GIS modeling environments. The Geostatistical analyst utilizes samples collected from different locations in a landscape to interpolate a continuous surface. The surface is derived using the measured values from the sampled locations to predict values for each location in the landscape (ESRI, 2001) [6].

Two groups of interpolation techniques are provided by the Geostatistical analyst: deterministic and geostatistical. Both techniques rely on the basic assumption of similarity of nearby sample points to create the surface.

The deterministic techniques use mathematical functions only while the geostatistical rely on both mathematical and statistical methods for the creation of a surface. The salient advantage of the geostatistical techniques over the deterministic is their capability to assess the uncertainty of the predictions depicted by the surface. However, the sample values will not be part of the surface created by the geostatistical methods. This is not the case when a surface is created by what is called an exact deterministic method, where the predicted surface is forced to pass through the measured values of the sample points.

As a large number of samples (more than one thousand) was used in this study, it was found well-suited to employ an interpolator that would result in a surface maintaining the same sample values. The inverse distance weighted and the radial basis functions are exact interpolators, where the former is based on the extent of similarity while the latter is based on the degree of smoothness. Therefore the inverse distance weighted interpolator was chosen for modeling the chemical data since it was considered to satisfy both criteria of exactness and the assumption of similarity of chemical distribution in the vicinity of a prediction location.

The Inverse Distance Weighted Technique (IDW) is based on the assumption that things that are close to one another are more alike than those widely apart. To predict values for an unmeasured location, the IDW utilizes the measured values surrounding that location. The IDW assumes that each measured point has an influence on the prediction location that diminishes with distance. Thus, it gives greater weights to the measured points closer to the prediction location than those distant from it, hence the name inverse distance weighted. The surface is derived using the measured values from the sampled locations to predict values for each location in the landscape [6, 7].

4- Results and Discussion for Chemical Data Models

The main chemical parameters considered in this study were pH, TDS, E.C., Ca, Mg, Na, K, Alkalinity, $CaCO_3$, Na_2CO_3, Cl, F, SO_4, HCO_3, NH_3, NO_2, NO_3, SiO_2 and Albumin. Each parameter was represented by two database files, one for the Nubian aquifer and the other for the Gezira aquifer. Each file was formatted into three columns representing the identification and location of the well (longitude & latitude) and the value of the chemical parameter under consideration. Four extra database files for the depth and Static level of the sampled wells at the above mentioned aquifers were formed to correlate the model results with groundwater levels.

The individual database files were then converted into shape files (GIS format). The spatial data corresponding to each shape file would contain the geographic locations of the wells featured by points on the earth's surface, along with attribute information describing what these features would represent.

The IDW interpolator of the geostatistical analyst was employed to create surfaces or models for the shape files previously obtained. The resulting models for the Gezira and Nubian aquifers are depicted as colored filled contours GIS maps. Each map is appended with a legend, two additional layers of the two Niles and a rectangular extent of grid between latitudes 13° - 15.6° N and longitudes 32° - 34.5° E.

Figures 2, 3, 4, and 5 show respectively, the models of TDS (Total Dissolved Solids), and Na (sodium) distributions at the Gezira and Nubian aquifers in the area.

It should be noted that the resulting chemical models can be utilized in a GIS environment to yield interactive maps that maintain the same values of the measured sampled locations and give predictions between the sampled locations. The credibility of the established chemical models in predicting reasonable chemical values was checked by comparing their

results with the corresponding ones obtained from recent data. Both sets of results were found to fall in the same ranges.

5- Conclusions

The GIS facilities have been successfully employed to convert all the collected chemical data of the Gezira area into spatial form, resulting in an easy interactive system for representation of the data. The main advantage of such a data storage technique is the convenience with which the recording and retrieval of specific information is achieved as related to the exact geographical locations contained in the map. Also, the established map can be easily updated or supplemented with new data.

Using GIS techniques, estimation models for the chemical constituents of the Gezira groundwater have been conveniently devised. The developed models can be used as primary predictors for estimating the expected values of the chemical constituents of the groundwater pertaining to new locations in the map.

It has been found that the GIS tools and techniques can be utilized efficiently to produce a comprehensive map of the Gezira groundwater. The map is composed of all the collected data and the established models of the chemical parameters. The developed integrated map can be extended to include also the mapping of groundwater clusters, ionic ratios and saturation indices. The remarkable achievement of this integrated model will be attributed to its readiness to provide this huge information by just a click of a button on a requested location in the map.

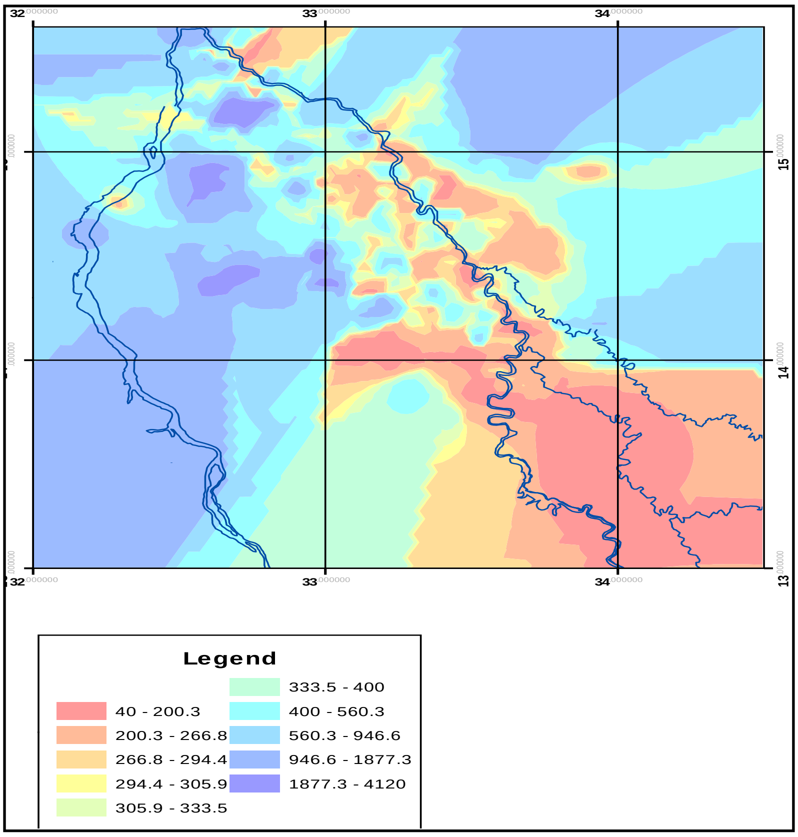

Figure 2: Model of Total Dissolved Solids (TDS) (Gezira Aquifer)

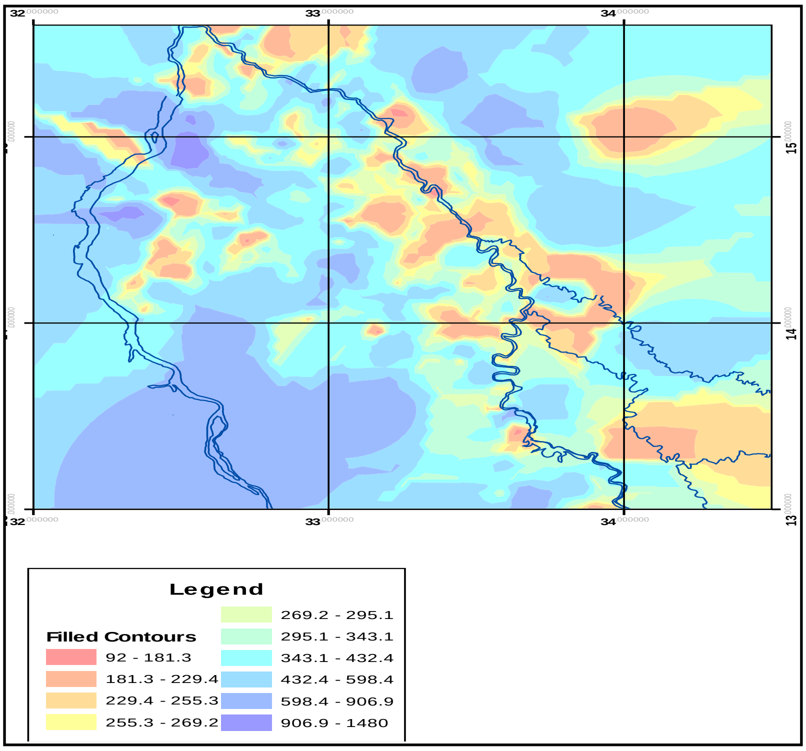

Figure3: Model of Total Dissolved Solids (TDS) (Nubian Aquifer)

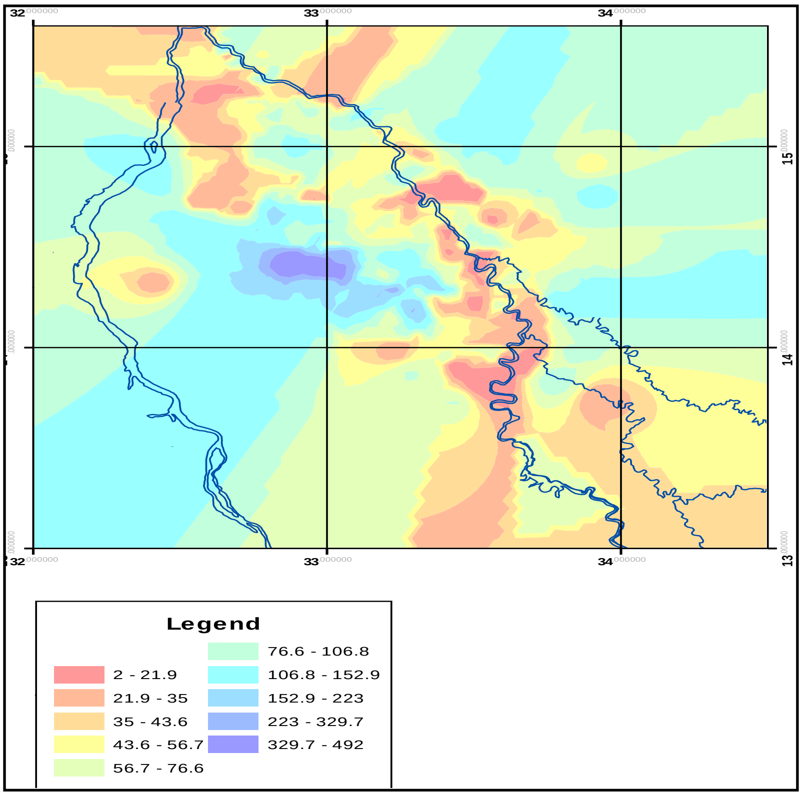

Figure4: Model of Sodium (Na) (Gezira Aquifer)

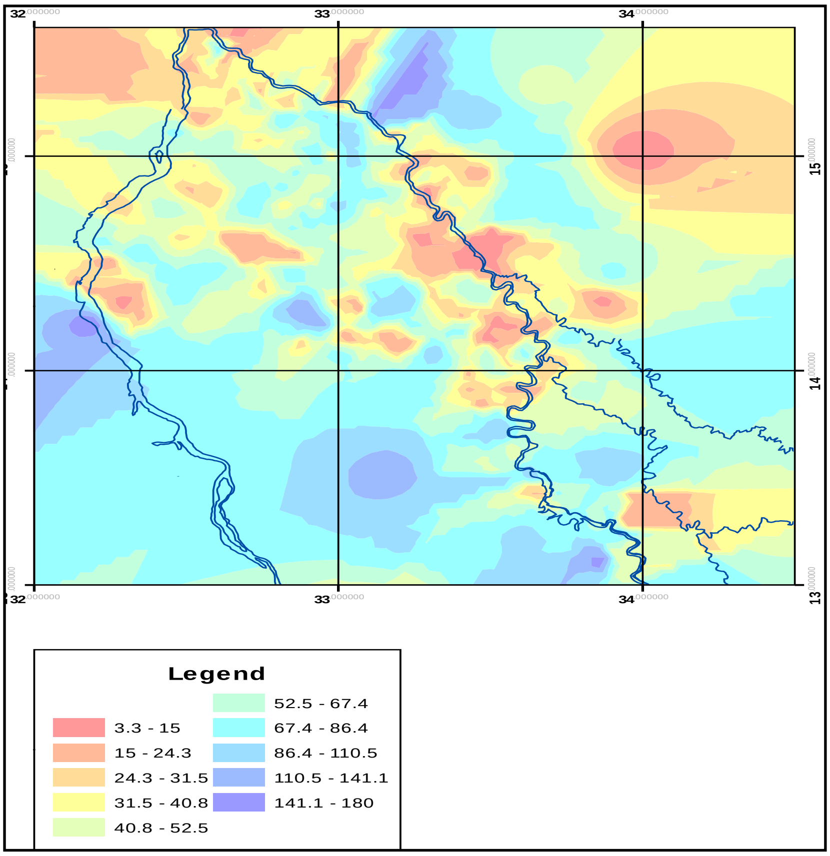

Figure5: Model of Sodium (Na) (Nubian Aquifer)

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