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A Correlation Matrix of Groundwater Quality Parameters along the Red Sea Coast

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Abstract: Groundwater samples, collected from different locations along coastal zone in the Red Sea State (RSS), Sudan, were analyzed for their physicochemical characteristics. Twenty six samples from borehole locations of groundwater were investigated. The investigation focused on the determination of physicochemical parameters such as electrical conductivity (EC), pH, total dissolved solids (TDS), chloride, sulphate, fluoride, sodium, calcium and some other parameters. Groundwater suitability for domestic and irrigation purposes was examined in comparison with World Health Organization(WHO) guidelines for drinking water quality and Indian Drinking Water Standards (BIS), which indicate that the groundwater in most areas, are not suitable for domestic and agriculture purposes. Statistical properties of the physiochemical parameters were computed. The correlation coefficients between the different water quality parameters were computed and organized in a matrix form. TDS and EC are perfectly correlated to chloride, $CaCO_3$ and sodium and significantly correlated to fluoride, calcium and magnesium. Thus, the major exchangeable ions were found to be correlated positively indicating the origin of major cations to be dissolution/precipitation processes.

Keywords: *Correlation Matrix; Groundwater; Physiochemical Parameters; Red Sea State*

1. INTRODUCTION

The chemical composition of groundwater is a measure of its suitability as a source of water for human consumption and for other purposes, and it also influences ecosystem health and function [1]. Groundwater is widely used as a source for drinking water supply and irrigation in food production [2]. It is a vital component of global water cycle and environment. As such, groundwater provides water to rivers, lakes, ponds, and wet lands helping to maintain the ecosystems [3]. The chemical composition of groundwater is controlled by many factors including the composition of precipitation, mineralogy of the watershed and aquifers, climate and topography. These factors can be combined to create various water types that change in composition spatially and temporally. Despite the large volume of water that covers the surface of the earth, only 1% is inland or fresh and easily available for human use [4].

The concentrations of different chemicals usually have strongly skewed distributions with a few very high values and a large number of low ones showing varying statistical behavior of water quality data. Despite recent works on the subject, the statistical treatment of environmental data is far less frequently applied. Spatial mapping of variables with groundwater data is also of great interest and practical importance. The correlation between water quality parameters are usually computed and organized in matrix form. The matrix provides a way of easily comparing correlations. It shows the virtue of having a correlation which is comparative, (i.e., is not dependent on the units of the parameters, and determining clusters of variables that co vary).

Quality of groundwater reflects input from the atmosphere, soil and water-rock reactions as well as pollutant sources such as mining, land activities, agriculture, acidic precipitation, and domestic and industrial wastes. The major ions as natural tracers have become a common method to delineate flow paths in aquifers [5]. Natural filtration of groundwater removes organic matter and microscopic life, where it remains as salts in solution [6]. In general, Groundwater pollution has become a globally major subject of public concern. This can be noticed in some recommended water standards, such as that at a high TDS concentration where, water becomes saline. Water with a TDS above 500 mg/l is not recommended for use as drinking water according to Environmental Protection Agencies. Water with a TDS above 1500 to 2600 mg/l (EC greater than 2250 to 4000 µmho/cm) is generally considered

problematic for irrigation use on crops with low or medium salt tolerance.

Seawater intrusion is also a problem of coastal areas. When groundwater is abstracted from near sea aquifers, seawater proceeds into the groundwater and the quality deteriorates with respect to salinity. Seawater intrusion becomes evident, when basically the Chloride concentration of the groundwater increases over time. However, Chloride concentration is not an indicator that can be solely relied on, and other geochemical parameters need to be verified.

Thus, it is important to detect change and early warnings of change both unnatural systems and that resulting from pollution. The present paper concentrates on the physiochemical parameters in the Red Sea State (RSS), in the eastern part of Sudan, investigating of the statistical behavior of groundwater quality data.

2. MATERIALS AND MTHODS

Red Sea State in Sudan occupies an area of 218,887 km^2 and is located in north-eastern Sudan, bordering Egypt to the North, Nile Valley State to the West, Kassala State and Eretria to the south and the Red Sea to the East (Fig. 1). The State is sub-divided into eight districts. Port Sudan, latitude 19^o 37` longitude $37^o$ 13`, is the capital city of the state and the urbanized residential and commercial centre. The coastline of Sudan on the Red Sea is about 750 km long. The dominant coastal forms are silty beaches, rocky headlands and salt marshes, commonly bordered with mangroves. Water clarity is generally high due to the lack of sedimentation. The coastal strip is 20 to 50 km wide, flat and crossed by seasonal channels, known locally as khor, that run off the hills lying to the west. There are two major alluvial fans in the coastal zone: Arba'at Delta, located just north of Port Sudan, and Tokar Delta, located about 150 Km south of Port Sudan. The present study deals with groundwater samples collected along the coastal zone between Arba'at Delta and Tokar Delta.

The selected sampling locations, mainly used for drinking, household purposes and irrigation purposes, were identified. The groundwater samples from the assigned locations were taken from manually operated boreholes. A total of 26 samples were collected from the locations along the coastal zone, (Fig. 1), using spot sampling procedure. The taste of the samples was noted at the sampling point itself. The tastes of the samples were brackish to saline. The samples were saved for laboratory examination to determine the physical and chemical parameters. These include electrical conductivity (EC), pH, total dissolved solids (TDS), chloride, $CaCO_3$, sulphate, ammonia, fluoride, sodium, calcium, iron, manganese and magnesium. Standard procedures were used for the experimental tests. The results were compared to WHO guidelines [7] and BIS standards [8].

The anthropogenic facilities usually influencing the environmental stresses are industrial, wastewater, fluid and solid wastes originating in the residential areas and industrial plants pose a significant threat to the aquifer systems. These factors are not affecting ground water in the study area. The simple linear correlation analysis has been carried out to find out correlation between any two tested parameters representing the significance of correlation at 5% level.

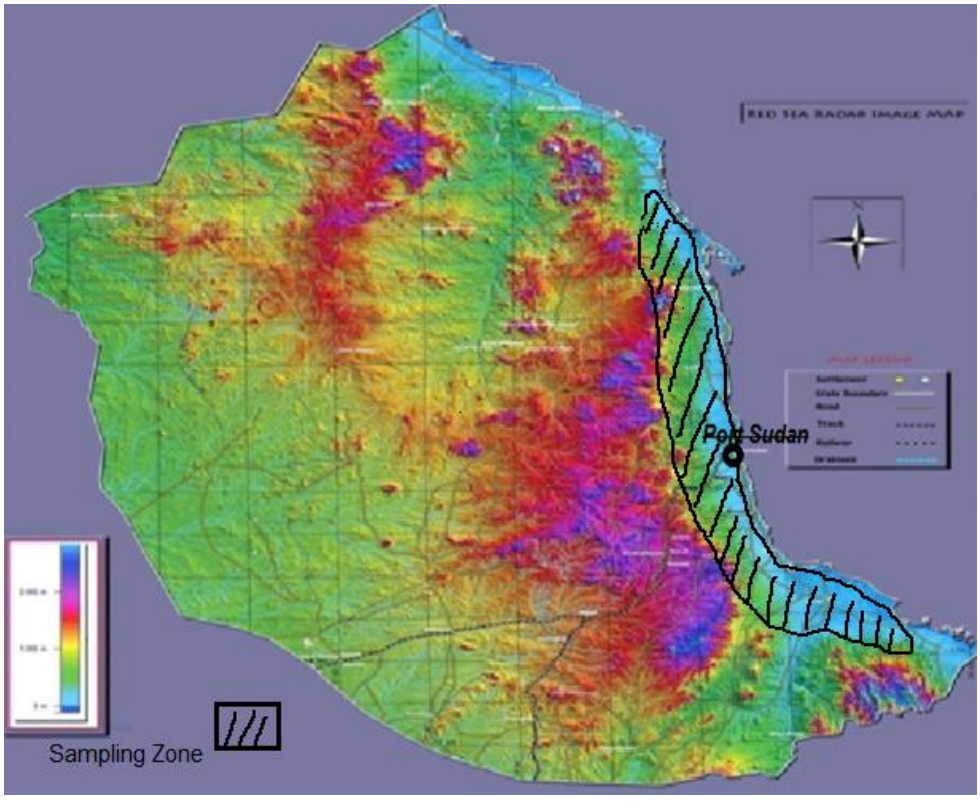

Fig. 1. Red Sea State

3. RESULTS AND DISCUSSION

All the water samples were mainly collected from boreholes surrounded by plants, trees or houses. The values of the physical and chemical parameters are tabulated along with their statistical properties in Table 1. The observed parameters are skewed from normal distribution and have Kurtosis coefficient oscillating around the normality. PH is considered an important ecological factor providing important information on many types of geochemical equilibrium or solubility calculation. It is an important parameter in water body since most of the aquatic organisms are adapted to an average pH and do not withstand abrupt changes. The collected water samples have pH within the permissible limits. The chloride content of water samples collected lies within permissible limits in few of the samples. Samples analyzed are found to have high concentration of chloride content and exceeds the permissible limit proposed by BIS and WHO. Chlorides are important in detecting the contamination of ground water by waste water. Total alkalinity, as $CaCO_3$, of water samples lies in the range beyond the limits except in few locations. The value of alkalinity in water provides information on types of natural salts present in water. The cause of alkalinity is the type of the mineral which is dissolved in water from soil. The various ionic species that contribute to alkalinity include bicarbonate, hydroxide, phosphate, borate and organic acids.

Most collected samples have moderately high values of sulphate exceeding the permissible limit recommended by BIS and WHO. Ammonia in water samples lies in range not exceeding the permissible limit. The majority of the samples have Sodium concentration exceeding the permissible limit. Calcium and fluoride in water samples collected lies within the permissible limit. Iron, manganese and magnesium of the samples collected lies in accepted limit. It is shown that various parameter concentrations differ considerably in various locations. The samples were not suitable for drinking and domestic use. Comparison of groundwater parameters with WHO Guidelines and Indian Drinking Water Standards (BIS) are shown in Table 2.

The correlation coefficients (r) between various water quality parameters were calculated and the values of the correlation coefficients are presented in Table 3. The significance of the observed correlation coefficients have been tested by using t-test. Out of the total correlations found between the two parameters, 33 were found to be significant at 5% level of significance ($r > 0.659$). Among these significant correlations, three are negative (inverse) correlations. Since the correlation coefficient test gives the interrelationship between the parameters, correlation coefficients were calculated. Results of correlation analysis showed that chloride and $CaCO_3$, chloride and sodium, $CaCO_3$ and sodium, TDS and EC have almost perfect correlation. Correlation analysis also showed that chloride, $CaCO_3$, fluoride, sodium, calcium and

Table 1. Descriptive statistics of groundwater parameters

Parameter	Unit	Max.	Min.	Mean	St. Dev.	Skew	Kurt.
Chloride	mg/l	6048.00	194.94	1523.17	2230.95	2.38	5.74
CaCO3	mg/l	3250.00	240.00	956.11	1141.40	2.28	5.38
Sulphate	mg/l	1314.38	128.97	453.22	437.44	2.06	4.63
Ammonia	mg/l	1.30	0.00	0.34	0.50	1.80	3.40
Fluride	mg/l	1.08	0.24	0.57	0.28	1.28	2.78
Sodium	mg/l	2687.00	125.00	668.83	996.16	2.37	5.69
Calcium	mg/l	260.00	55.00	124.17	75.87	1.31	1.81
Iron	mg/l	0.40	0.10	0.20	0.13	0.89	-0.78
Manganese	mg/l	0.40	0.06	0.16	0.12	1.94	4.01
Magnesium	mg/l	54.24	10.59	31.22	16.55	-0.08	-0.99
T.D.S.	mg/l	11910.00	790.00	3615.00	4116.98	2.30	5.49
E.C.	µmho/cm	14300.00	1230.00	4296.67	4984.15	2.27	5.32
pH		7.50	6.35	6.97	0.41	-0.39	-0.11

Table 2. Comparisons of groundwater parameters with WHO Guideline, and Indian Drinking Water Standards (BIS)

Parameter	Unit	Max.	Min.	Mean	WHO	BIS
Chloride	mg/l	6048.00	194.94	1523.17	250	250 - 1000
CaCO3	mg/l	3250.00	240.00	956.11	500	300 -1000
Sulphate	mg/l	1314.38	128.97	453.22	400	200 - 400
Ammonia	mg/l	1.30	0.00	0.34	0.5	
Fluride	mg/l	1.08	0.24	0.57	1.5	1.5
Sodium	mg/l	2687.00	125.00	668.83	200	
Calcium	mg/l	260.00	55.00	124.17		75 - 200
Iron	mg/l	0.40	0.10	0.20	0.3	0.3 - 1.0
Manganese	mg/l	0.40	0.06	0.16	0.1	0.1 - 0.3
Magnesium	mg/l	54.24	10.59	31.22	50	
T.D.S.	mg/l	11910.00	790.00	3615.00	1000	
E.C.	µmho/cm	14300.00	1230.00	4296.67	1400	
pH		7.50	6.35	6.97	6.5 - 8.5	6.5 - 8.6

Table 3. Correlation coefficients between different water quality parameters

	Chloride	CaCO3	Sulphate	Ammonia	Fluride	Sodium	Calcium	Iron	Mangan -ese	Magnes -ium	T.D.S.	E.C.	pH
Chloride	1.000	0.994	-0.024	-0.260	0.886	0.997	0.917	-0.428	-0.227	0.722	0.997	0.994	-0.093
CaCO3		1.000	0.009	-0.264	0.922	0.998	0.944	-0.525	-0.318	0.791	0.997	0.999	-0.080
Sulphate			1.000	0.889	-0.060	-0.011	0.213	-0.257	-0.351	0.271	-0.025	0.033	-0.687
Ammonia				1.000	-0.409	-0.272	-0.059	0.116	0.090	-0.102	-0.270	-0.236	-0.644
Fluride					1.000	0.916	0.896	-0.693	-0.562	0.829	0.896	0.921	0.553
Sodium						1.000	0.929	-0.477	-0.295	0.753	0.996	0.998	0.920
Calcium							1.000	-0.684	-0.376	0.885	0.932	0.949	-0.157
Iron								1.000	0.745	-0.917	-0.479	-0.519	-0.117
Mangan -ese									1.000	-0.630	-0.246	-0.318	0.238
Magnes- ium										1.000	0.762	0.786	0.052
T.D.S.											1.000	0.995	-0.047
E.C.												1.000	-0.115
pH													1.000

magnesium have significant correlations with most of the other parameters. TDS and EC are also perfectly correlated to chloride, $CaCO_3$ and sodium and significantly correlated to fluoride, calcium and magnesium. Thus, the major exchangeable ions were found to be correlated positively indicating the origin of major cations is due to dissolution/precipitation processes. The high Sodium and Chloride contents detected in most of the samples may indicate the existence of chloride salts dissolution. At higher pH values, there is repulsion between OH- ions and fluoride, F-, ions. The leachability of F- ions is not significantly related to pH medium.

4. CONCLUSIONS

Analysis of the groundwater quality parameters for different locations along part of the coastal zone in the Red Sea State (RSS) shows that only few parameters are well within the permissible limits. Most of the thirteen physiochemical groundwater quality parameters are above the desirable limit. Results also show that, the analyzed groundwater samples are alkaline in nature and hard, but in few locations the groundwater is relatively soft and falls within the safety limits as prescribed by WHO and BIS. In general, the groundwater samples analyzed are not suitable for domestic and drinking purpose requiring treatments to minimize the contamination. The range of the variation, the mean, the standard deviation, the skewness and the kurtosis of each parameter were presented.

Statistical techniques are efficient ways to display complex relationships among many objects. Computational analysis of data set of hydro-chemical constituents in the groundwater suggests that the aquifer is mainly controlled by T.D.S. Sodium, Chloride and E.C. due to the higher concentration values of these parameters in most of the location investigated. In addition, correlation matrix could be used in selecting the proper treatment procedures in order to minimize the contaminations of groundwater. In particular, the correlation coefficients help in identifying the relationship between the parameters and the pH medium

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