Original

Assessment of Drinking Groundwater Quality Using Water Quality Index in Elfasher, North Darfur State, Sudan

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Received: 3/02/2023
Accepted: 16/03/2023

Abstract

Groundwater is the major supply of drinking water and additional uses in Darfur state, Sudan. This study aims at evaluating the groundwater quality in that area by applying water quality index method (WQI). Forty water samples were collected during the dry and wet seasons.

Field tests were carried out for Temperature, pH, Electrical Conductivity and Total Dissolved Solids (TDS) whereas other chemical parameters of water quality for these samples were carried in the Ministry of Health laboratory, in El Fasher city.

The chemical parameters determined included chloride, nitrates, nitrite, floride, sulphates, sodium, potassium, calcium, magnesium, manganese, ammonium, bicarbonate and total hardness. The mean and standard deviation of the examined physiochemical parameters of these samples were found as follows:

The mean concentration and the standard deviation of pH, EC, TH, TDS, TUR, NO_3^-, Mg^{2+}, Ca^{2+}, Na^+, CO_3^{2-}, K^+, HCO_3^-, SO_4^{2-}, Cl^-, F^-, and NH_4^+ in study area was 7.26 ± 0.26, 864.2 ± 352.5 µS/cm, 172.3 ± 66.7 mg/l, 428.4 ± 178.5 mg/l, 4.4±8.8NTU, 37.1 ± 40.1 mg/l, 18.6 ± 17.1 mg/l, 57.5 ± 32.8 mg/l, 39.9 ± 25.2 mg/l, 115.5 ± 56.0 mg/l, 8.7 ± 4.9 mg/l , 231.1 ± 112.4 mg/l, 29.9 ± 22.2 mg/l, 45.8± 63.3 mg/l, 0.27 ± 0.26 mg/l and 0.27±0.28 mg/l in dry season, respectively

ISSN: 2948-300X (print) 2948-3018 (0nline)

Whereas the concentration of the above parameters in the wet season was: pH 7.76 ± 0.37, EC 1244.9 ± 436.1 µS/cm, TH, 242.1± 89.2 mg/l, TDS 618.6 ± 212.4 mg/l, Turbidity (TUR) 6.20±11.9 mg/l, NO_3^- 54.1 ± 67.0 mg/l, , Mg^{2+} 19.7± 17.6 mg/l, Ca^{2+}57.8 ± 32.8 mg/l, Na^+45.1± 26.3 mg/l, CO_3^{2-} 133.4 ± 53.6 mg/l, K^+ 10.6 ± 5.3 mg/l, HCO_3^-266.9 ±107.2 mg/l,SO_4^{2-} 42.5 ± 25.2 mg/l, Cl^- 26.2 ± 29.8 mg/l, F^- 0.49 ± 0.26 mg/l, NH^+_4 0.48 ± 0.34 mg/l .

According to the WQI, the majority of the ground water samples is chemically appropriate for drinking.

The WQI values for these samples ranged from 19.93to 129.00 in the dry season and from 30.49 to 161.80 in the wet season. Wet season samples show poorer water quality than dry season samples due to the greater quantity of dissolved solids. This is because groundwater moves and seeps more during the rainy season.

Keywords: Groundwater quality- Physicochemical parameters- Weighted Arithmetic method-WQI

Introduction

Water quality is seen as a crucial indicator of environmental changes linked to social and economic growth (1). Because of the current worldwide surface water shortage, groundwater usage has become increasingly important. Groundwater quality in many parts of the world has been severely impacted by population growth, excessive pumping, protracted droughts, and poor management (2).

Rock-water interaction and oxide-reduction reactions that occur as water percolates through the aquifers are the main causes of changes in groundwater quality. In addition to these activities, groundwater motion transports toxic and nontoxic contaminants, waterborne pathogens, and other key water quality factors from the recharge area to the discharge area through aquifer (3).

The Water Quality Index (WQI) is a method for determining and rating the acceptability of drinking-quality groundwater (4). The water quality index (WQI) is regarded as a mathematical instrument that considerably reduces the complexity of data sets pertaining to water quality and offers a single classification value that indicates the level of pollution or the quality condition of a body of water.

WQI also is a single, dimensionless number that, by combining measurements of selected factors like pH, nitrate, and heavy metals, provides a concise assessment of the overall status of water quality. Horton 1965 established this method in to use mathematical equations to assess the river's water quality..

It is a significant factor in determining the quality of groundwater and whether it's fit for human consumption. Multiple water quality factors are numerically summarized by the (WQI), a single value expression (1). Horton and (5) proposed the (WQI), which assigns a score to a water sample based on estimated physico-chemical parameters.WQI is a simple and effective method of explaining the quality level of water to the general public and relevant agencies (6).Water samples' WQI values, which range from 0 to 50, indicate excellent water quality. Water samples having WQI results between 50 and 100 are considered to be of good quality. If the WQI score is greater than 100, the water is deemed to be of low quality and unsafe to drink.

Study Area

Elfasher (North Darfur state) is situated between the latitudes of 13037'N and 25022'E, at an altitude of roughly 740 m above mean sea level, and over an area of over 140 km^2.It is located over a subterranean complex and seems to have been built around a fula, a small depression that collects and stores surface water from the drainage system and Wadi Haloof. The primary drainage canal from the town during the wet season is Wadi El Ku, which flows from north to south (7).It is distinguished by its sandy soil as opposed to the clay soils around the seasonal wadies, within the arid and semi-arid climatic zone, where water is scarce (8).There are three IDP camps and rural areas account for more than 60% of the population (Abo Shouk, Al Salam, and Zamzam).Figure (1) displays a geological map of the study area. Figure (2) displays the geological cross-section of the research area's subsurface and water samples sites are illustrated in Figure (3).

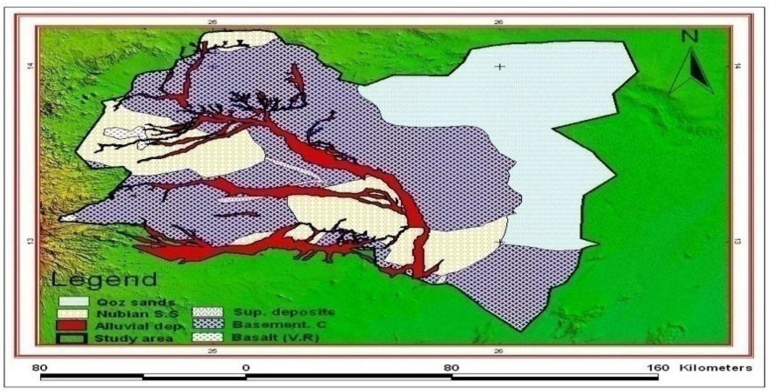

Figure 1: Geological map of the study area.

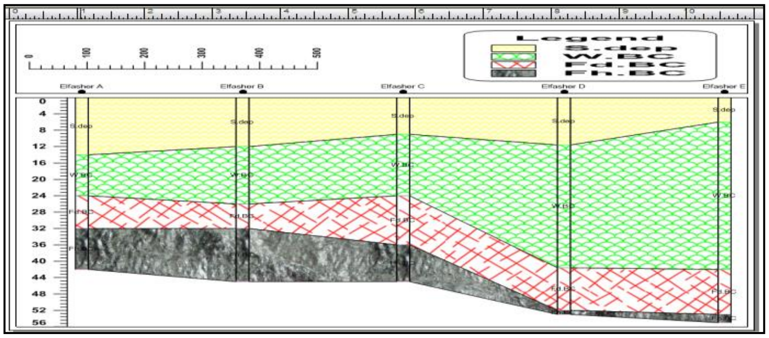

Figure 2: Geological cross-section through the subsurface of the study area.

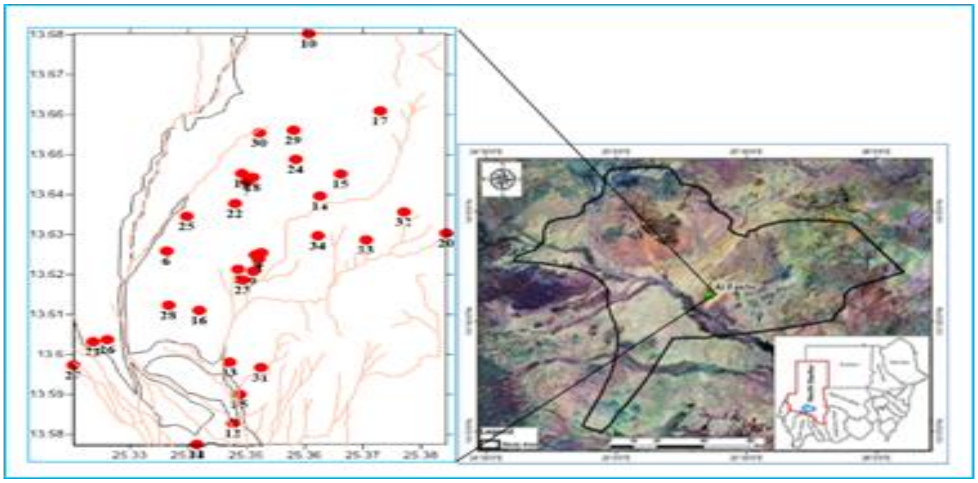

Figure 3: Water samples sites.

Materials and Methods:

Sample collection:

Samples were collected during dry and rainy season 2016-2017. The geographic coordinates of the sampling points were recorded using a GPS model called German 76. The determinations of the physiochemical analysis of all samples taken were carried out in a laboratory that belongs to the Ministry of Health, North Darfur State, in ElFasher city. All water samples were analyzed according to standard methods (9).

Forty samples were collected in two seasons from water wells distributed throughout the study area for physiochemical analysis. For chemical tests, water samples were collected in a one-liter plastic bottle after washing and cleaning from the same source of water and transferred to laboratories for chemical analysis.

Sample Analysis:

To assess the quality of the ground water, this study used sixteen physicochemical parameters. The determination of pH was done by pH meter, Electrical conductivity by conductivity meter (Palin test water proof 800) and Total dissolved solids (TDS) by using TDS meter (Palin test water proof 800). The Hardness was calculated by (Palin test Photometer model 7500) this photometer was used to determine the concentration of all chemical parameters except sodium was determined with flame emission photometry.

WQI Estimation:

The calculations were done according to the standards set by Sudanese Standard Metrology Organization (SSMO, 2016) for drinking water quality standards and (WHO, 2011). The (SSMO 2016) was used as a main criterion for evaluation, while the (WHO, 2011) was applied in the case there are no permissible limits set by the Sudanese standard for parameter. In this study, 16 physicochemical factors were taken into account while calculating the WQI. Relative weight (wi) is assigned based on their perceived effects on primary health and relative significance in overall water quality. The parameters NO_3, NO_2, TDS, Cl, SO_4 and NH_4 are given the greatest weights of 5 because of their major importance in water quality assessment. And the parameters F, pH and Mn given 4, TH and Ca are given 3, and K, Na, Mg, EC given 2, while HCO_3 and are given the lowest weights of 1 because it does not play crucial role in the assessment of water quality (10).

The weighted arithmetic WQI method (11) was applied to ascertain water suitability for drinking purposes. In this method, water quality rating scale, relative weight, and overall WQI were calculated by the following formulae:

The computation of the relative weight (Wi) is given in equation below (1):

$$\mathrm{Wi} = \mathrm{wi}/\sum_{i-1}^{n} \mathrm{wi}$$

Where:

Wi refers for the relative weight,

wi for the weight of each individual parameter, and

n for the total number of groundwater parameters a quality rating scale

(qi) for each parameter is assigned by dividing its concentration in each water sample by its respective standard according to the guidelines laid down in the SSMO(2016)and WHO(2011) and the result is multiplied by 100 using equation (2):

$$\mathrm{qi} = (\mathrm{Ci}/\mathrm{Si}) \times 100$$

Where:

qi is the quality rating

Ci is the concentration of each chemical parameter in each water sample in milligrams per liter Si is the Sudan drinking water standard for each chemical parameter in milligrams per liter according to the guidelines of the (SSMO, 2016) and (WHO, 2011) (12).

For computing the WQI, the SI is first determined for each chemical parameter, which is then used to determine the WQI as, per the following equation as per the expressions in (3, 4):

$$SIi = Wi \times qi$$

Where:

SIi is the sub-index of water quality (SI) for each physicochemical parameter,

Qi is the rating based on concentration of parameter, n is the number of parameters.

$$WQI = \sum_{i=1}^{n} SIi$$

Howladar et al., 2018 classified the water quality into five categories as excellent, good, poor, very poor, and unsuitable for human consumption based on WQI values as showed in Table2.

Table (1): Weight and relative weight of each parameter used for WQI determination

Parameters	Stander value (SSMO 2016)	Weight(wi)	Relative Weight $Wi = wi/\sum_{i-1}^{n} wi$
PH	8.5	4	0.07
TDS	1000	5	0.09
EC	1400	2	0.04
TH	500	3	0.05
NO3	33	5	0.09
NO2	2	5	0.09
Cl	250	5	0.09
SO_4	250	5	0.09
F	1.5	4	0.07
Na	250	2	0.04
K	12	2	0.04
NH_4	1.5	5	0.09
Ca	100	3	0.05
Mn	0.27	4	0.07
Mg	50	2	0.04
HCO_3	500	1	0.02
		$\sum wi = 57$	$\sum_{i-1}^{n} wi = 1$

Table (2): Water quality classification for drinking purposes based on the WQI values (10)

WQI	**Rating Class**
<50	Excellent
50–100	Good
100.1–200	Poor
200.1–300	Very Poor
> 300	Unsuitable for drinking

Results and Discussion

The groundwater samples from the selected city was analyzed for physical and chemical parameters such as pH, TDS, EC, TH, NO_3, NO_2, Cl, SO_4, F, Na, K, NH_4, Ca, Mn, Mg & HCO_3. The results showed in some points the quality level and contamination of groundwater due to the leaching process.

Most of the ground water samples in seasons were found in the range of excellent values in dry season and good in wet season and some points was poor category showed in Table2 and Table3 respectively, In this study the computed WQI values ranges from 19.93to 129.00 during dry season and from 30.49 to 161.80 during wet season. According to (13) classification scheme, the results showed in Table 3 and 4 for dry and wet season respectively. The percentage of water samples that falls under different quality except some points showed in Table 5. The high value of WQI at these wells has been found to be mainly from the higher values of nitrate, manganese and calcium in the groundwater. Nitrate pollution is one of the most significant sources of groundwater pollution, as is well recognized. Nitrate (NO_3) and nitrite (NO_2) ions, which are nitrogen compounds, are found in groundwater. Compared to nitrate, nitrite is more harmful to both animal and human health. Since nitrates are very soluble in water, they can quickly pass through soil and into the water supply (14). The fertilizers and domestic wastes are main sources of nitrogen-containing compounds and they are converted to nitrates in the soil.

The wet season samples exhibit poor quality in greater percentage (10 %) when compared with dry season (2.5%) Figure (4), this may be due to effective leaching of ions into soil with run. The anther source of ground water contamination during the rainy season may be the percolation of water through various layers of soil, seepage and moving of water during rain and dissolving of minerals from litho logical composition, and the addition of other pollutants from anthropogenic activities in areas.

Table (3): Calculated Water Quality Index and their classification of the samples in Dry Season

Sample	WQI	Water type	Sample	WQI	Water type
1	56.59	Good	21	19.93	Excellent
2	57.25	Good	22	28.67	Excellent
3	50.94	Good	23	24.53	Excellent
4	57.40	Good	24	41.99	Excellent
5	53.36	Good	25	38.64	Excellent
6	45.73	Excellent	26	30.72	Excellent
7	46.05	Excellent	27	26.27	Excellent
8	52.89	Good	28	58.55	Good
9	49.74	Excellent	29	31.64	Excellent
10	36.32	Excellent	30	28.91	Excellent
11	34.85	Excellent	31	37.30	Excellent
12	43.78	Excellent	32	23.37	Excellent
13	129.00	Poor	33	39.52	Excellent
14	66.44	Good	34	32.75	Excellent
15	46.42	Excellent	35	24.14	Excellent
16	52.81	Good	36	61.51	Good
17	48.00	Excellent	37	41.56	Excellent
18	46.03	Excellent	38	88.31	Good
19	46.32	Excellent	39	36.78	Excellent
20	39.58	Excellent	40	38.20	Excellent

Table (4): Calculated Water Quality Index and their classification of the samples in Wet Season

Sample	WQI	Water type	Sample	WQI	Water type
1	69.73	Good	21	32.18	Excellent
2	70.20	Good	22	36.37	Excellent
3	65.88	Good	23	33.59	Excellent
4	78.46	Good	24	69.00	Good
5	76.41	Good	25	48.09	Excellent
6	67.22	Good	26	38.56	Excellent
7	65.43	Good	27	36.50	Excellent
8	61.07	Good	28	80.62	Good
9	64.90	Good	29	41.06	Excellent
10	60.30	Good	30	36.05	Excellent
11	69.53	Good	31	49.50	Excellent
12	65.59	Good	32	30.49	Excellent
13	161.80	Poor	33	52.01	Good
14	109.27	Poor	34	39.18	Excellent
15	78.82	Good	35	35.60	Excellent
16	84.94	Good	36	64.08	Good
17	104.84	Poor	37	48.68	Excellent
18	80.84	Good	38	140.40	Poor
19	66.47	Good	39	39.97	Excellent
20	50.73	Good	40	40.67	Excellent

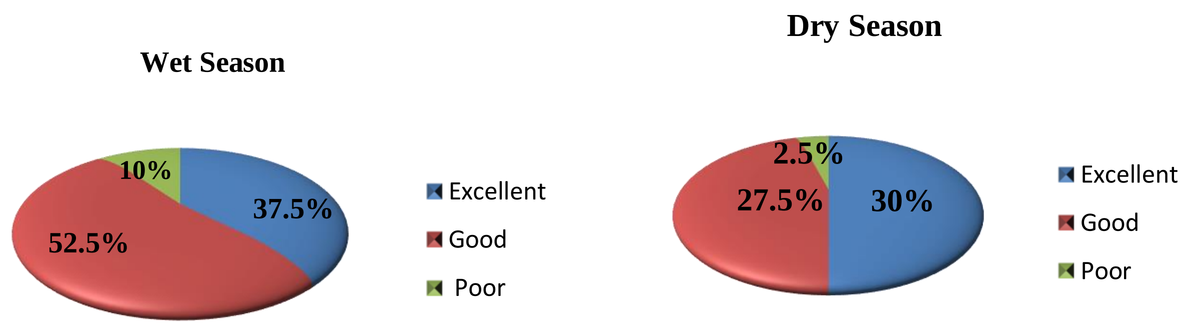

Figure.4: WQI Categories of samples (%) in dry and wet seasons

Table (5): Water quality classification based on WQI value

WQI value	Water quality	Percentage of water samples (Dry Season)	Percentage of water samples (Wet Season)
<50	excellent	70 %	37.5 %
50–100	good water	27.5 %	52.5%
100.1–200	poor water	2.5 %	10 %
200.1–300	very poor water	-	-
> 300	unsuitable Water for drinking	-	-

Conclusion

According to the completed WQI, the majority of the study area's groundwater is chemically appropriate for drinking. Animal waste, sewage, anthropogenic activities, and natural influences are the main causes of contamination that cause variations in groundwater quality. Therefore, it is advised to employ suitable pollution control measures and conduct regular groundwater level monitoring. Whereas study results of different seasons reveal changes in the WQI. The WQI showed that water of dry seasons is suitable for drinking purposes, whereas during the wet season, the WQI increases due to the fact that water in this season moves and thus it may wash pollutants during its movement.

High value of WQI at these wells has been found to be mainly from the higher values of nitrate, chloride and manganese in the groundwater. The analysis reveals that the some groundwater points of the area needs degree of treatment before consumption, and it also needs to be protected from the perils of contamination. Making decisions can be based on the water quality index measurement method, which is the best and most effective way to evaluate the suitability of groundwater for drinking.

Acknowledgments

The authors would like to thank all the laboratory technicians of the water lab in Elfasher city that participated in field sampling. And special thanks to Dr. Adam Khalifa Mohamed for his help and advice to finish the present work.

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