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Research Article

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Groundwater Quality Assessment for Drinking and Irrigation Purposes in Khartoum Area-Between the two Niles-Sudan

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ABSTRACT
The Nile and groundwater waters are the two sources for drinking and irrigation water in Khartoum corridors. The assessment of groundwater quality is of high priority for safe uses of water. The suitability of groundwater for drinking purpose was made by applying water quality index (WQI). For irrigation purpose the assessment was based on the Percentage of sodium, Sodium adsorption ratio (SAR), Permeability index (PI), Residual sodium carbonate (RSC), Kelly's ratio (KR), Magnesium adsorption ratio (MAR) and Chloro-alkaline indices (CAI). The water quality index (WQI) reveals that all groundwater samples are found between excellent and good category of water and appropriate for drinking purposes. It is indicated that 95% and 96% of groundwater samples are grouped as excellent water for Gezira and Sandstone aquifers respectively, the remaining samples grouped as Good water. Most of the characteristics of irrigation water which calculated for the groundwater of Sandstone aquifers are more suitable for irrigation than the groundwater for Gezira aquifers (%Na, SAR, PI %, RCS, MAR%, KR and CAI). In the Sandstone aquifers the water quality adjacent to the Blue Nile is of higher quality standers than groundwater quality adjacent to the White Nile.

Keywords: Groundwater, Water Quality Index, Drinking, Irrigation, Gezira, Sandstone Aquifer

Introduction

The quality of groundwater is essential as its quantity; in which both surface and groundwater contain salts in solution. The composition and type of rocks and soil in the catchment areas has a direct effect on water quality. The purposes of water use always govern the required quality of groundwater [1].

Nile water and groundwater are used to secure domestic, irrigation and industrial demands in Khartoum state. The groundwater covers about 54% of water needs while the surface water covers about 46% of daily water supply, which leads the significance of groundwater in Khartoum area. The population growth and the resulting city expansion, agricultural and industrial extensions will stress the water resources.

At current time, the groundwater suitability for drinking and irrigation purposes evaluation, are available through numerous methods. WQI is considered as one of the most efficient technique for groundwater quality evaluation. [2]. WQI, have ability to integrate data from multiple water quality parameters into mathematical forms, that determines the water quality level [3]. The groundwater suitability for irrigation purposes is reflected through some parameters such as soluble sodium percentage (SSP), sodium adsorption ratio (SAR), permeability index (PI), residual sodium carbonate (RSC), Kelly's ratio (KR), magnesium adsorption ratio (MAR) and Chloro-alkaline indices (CAI) which support the groundwater indices classifications.

Study Area

The study area is lies between the confluence of Blue and White Niles in central Sudan, thus the study area formed rectangle shape within the Khartoum sub basin. Generally, it is confined between latitudes 15º 37/03//and 15º 23/ 20// N and longitudes 32º 27/ 26// and 32º 40/ 28// E with an area of about 325Km^2, (Figure 1).

The sub-Saharan climate is characterized the region in which the dry season extend of about Nine months. The rainy season

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is extended from Jully to September and the peak of rains often occurs in August, with annual average rainfall is of about 120mm. The mean monthly temperature ranges from 20 C º to 45 C º, and the average mean annual relative humidity is 28% in rainy season [4]. The Blue Nile and White Nil are the main water courses in the study area.

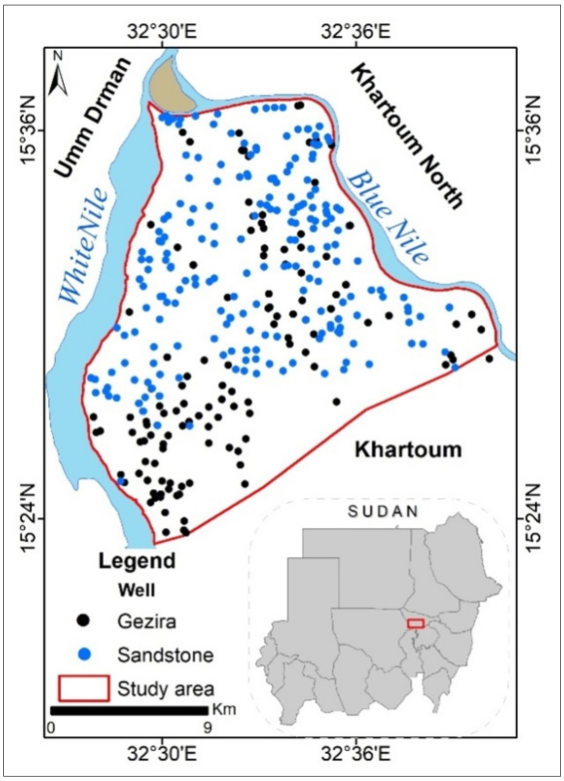

Figure 1: Location map of study area, showing wells distribution in Khartoum area

Geological and Hydrogeological Setting

Geologically the study area is located at the margin of the Khartoum basin. The Pan-African Basement Complex partly bounds this sedimentary basin and located at more than 500 m depth [5]. Commonly the rock units in the study area are presented by; Basement Complex (Pre- Cambrian), Nubian Sandstone Formations (Cretaceous), Volcanic Basalt (Tertiary), Gezira Formation (Quaternary) and superficial Deposits (Recent).

Basement complex rocks are including crystalline metamorphic rocks, foliated to non-foliated intrusive and extrusive igneous rocks [6]. The Basement Rocks Complex rocks were not recognized within the basin, either as outcrop or in boreholes. The basaltic Tertiary volcanic rocks were detected in some boreholes in the study area.

Cretaceous Nubian Sandstone Formations composed of mudstone, sandstone and conglomerate sequences [7]. The origin and age of sandstone in Khartoum basin is of fluviatile origin definite Cretaceous age. gives the lithological classification of the formation [8].

Volcanic rocks are mainly basalt intruded the Cretaceous sedimentary rocks formations which are attributed to Tertiary age. Currently, Tertiary volcanic was found in subsurface through drilling at the south east parts of Khartoum town; it is discriminate as very hard rock unit, gray to dark color.

Gezira Formation consists mainly of unconsolidated sediments composed of; clay, silt, sand and gravels which lies unconformably on Sandstone formations or directly on the basement complex at the peripheries of the basin, which they overlain by blown sand and other superficial deposits [9]. It is characterized by rapid facieses changes and thickness variations. The Gezira Formation subdivided into Upper and Lower Gezira Formation. The lower Gezira Formation is indicates Oligocen-Miocene age, while the upper formation is supposed to be of Miocene to Quaternary age. [10].

Superficial deposits represent the youngest geological units in the area. It made up of; clay, sandy clays and wind sand deposits. The older geologic formations are everywhere covered by recent superficial deposits.

The main water-bearing formations in the study area can be confidential into Gezira Formation and Cretaceous Sandstone Formations Aquifers. Gezira formation aquifers represent the upper part of water-saturated zone. It rests unconformity over the Sandstone aquifer. The Sandstone aquifers represent the most important groundwater system in the study area. Both aquifers are hydraulically interconnected to form one aquifer system particularly near the White Nile. The existences of mudstone and clay intercalations isolate the hydro-stratigraphic units in the area under consideration.

Objectives

The main objective of the current investigation is to determine the groundwater suitability for drinking and irrigation purposes in Khartoum area. This includes the determination of water quality index (WQI) and the parameters responsible for irrigation water quality. These are soluble sodium percentage (SSP), sodium adsorption ratio (SAR), permeability index (PI), Residual sodium carbonate (RSC), Magnesium adsorption ratio (MAR), Kelly's ratio (KR) and Chloro-alkaline indices (CAI).

Materials and Methods

The current Water quality studies are based on large amounts of collected data (122 wells from Gezira aquifer and 219 wells from the Sandstone aquifer), these wells are distributed evenly throughout the study area, (Figure 1). The methods of the investigation were describing different parameter obtained from three water analysis laboratories (Khartoum Water Corporation laboratory, Groundwater and Wadies General Directorate (GWWD) laboratory and Central Laboratory for Technical Services and Calibration (CLTSC)). The organization of the acquired data, is considered as the first stage in data processing, the data is sets into tables which checked for its ionic balance. Hence, all records with ion balance greater than 6 % were rejected; moreover. The calculations of summary statistic were taken in to consideration and portrayed in maps.

Water Quality Index (WQI)

Numerous methods are obtainable to evaluate the groundwater suitability for domestic use [11]. The WQI is examined as one of the most efficient techniques to evaluate groundwater quality [12]. The main advantage of WQI is its ability to integrate data from various water quality parameters into mathematical forms that determines the water quality level. To compute WQI, each parameter has been assigned a weight (wi) according to its relative importance in the overall water quality for drinking purpose as shown in Table (1).

Table 1: Showing the comparison between Sudanese Stander Metrology Organization (2015) with water samples in the study area with Relative Weight

Item	Gezira Aquifers	Sandstone Aquifers	SSMO	Weight (Wi)	Relative Weight (Wi)
Ph	6.7 – 9.3	6.2 – 9.6	6.5 – 8.5 Unit	4	0.075
T.D.S	120 – 2975	35.6 – 1012	1000 mg/l	5	0.094
TH	20 – 790	20 – 480	-	2	0.038
HCO_3	100 – 732	48.8 – 571	-	3	0.057
Cl	5 – 589.3	2.84 – 256	250 mg/l	4	0.075
SO_4	0.04 – 748	0.18 – 552.6	250 mg/l	4	0.075
NO_3	0.088 – 62.9	0.072 – 83.6	33 mg/l	5	0.094
NO_2	0.0001 – 1.2	0.001 – 2.9	2 mg/L	5	0.094
Na	8 – 810.3	2.171 – 303	250 mg/l	2	0.038
K	0.9 – 24.5	1.5 – 12.7	-	2	0.038
Ca	4 – 108	4.8 – 102.4	-	2	0.038
Mg	1.9 – 127.4	0.97 – 64.1	-	2	0.038
NH_3	0.012 – 5.3	0.01 - 6	1.5 mg/l	5	0.094
Fe	0.01 – 0.5	0.01 - 8	0.3 mg/l	4	0.075
Mn	0.081 – 0.6	0.002 – 0.409	0.27 mg/l	4	0.075
				$\sum wi = 53$	$\sum Wi = 1$

The relative weight (Wi) is computed by the following equation;

$$Wi = \frac{Wi}{\sum_{n-1}^{n} wi} \quad (1)$$

Where, Wi is the relative weight, wi is the weight of each parameter and n is the number of parameters.

Then the Quality rating scale (Qi) is determined for each parameter as:

$$Qi = (Ci/Si) X100 \quad (2)$$

Where Qi is the quality rating, Ci is the concentration of each chemical parameter in each water sample and Si is the WHO drinking water standard for each chemical parameter in mg/l.

The SI is first determined for each chemical parameter, which is then used to determine the WQI as per the following equation:

$$SI_i = W_i \; X \; q_i \quad (3)$$

Where, SI_i is the sub index of i^{th} parameter and Q_i is the rating based on concentration of i^{th} parameter.

Then the Water Quality Index (WQI) is calculated as follows:

$$WQI = \sum SI_{i-n} \quad (4)$$

Where SIi is the sub index of ith parameter and n is the number of chemical parameters.

According to table (2), WQI values are classified into five categories.

Table 2: Water quality index (WQI) ranges for possible usages [13].

(WQI) Value	Grade of Water Quality	Possible usages
0–25	Excellent	Drinking, Irrigation and Industrial
25–50	Good	Domestic, Irrigation and Industrial
51–75	Poor	Irrigation and Industrial
76–100	Very Poor	Irrigation
101–150	Unsuitable	Restricted use for Irrigation
>150	Unfit for Drinking	Proper treatment required before use.

Water Quality of Irrigation

In this study the groundwater indices classifications such as Percentage of sodium (%Na), Sodium adsorption ratio (SAR), Permeability index (PI), Residual sodium carbonate (RSC), Kelly's ratio (KR), Magnesium adsorption ratio (MAR), Chloro-alkaline indices (CAI) were calculated using the following equations (5) to (11) as:

$$SSP = \frac{Na^{+}+K^{+}}{Na^{+}+Ca^{++}+Mg^{++}+K^{+}} X100 \quad (5)$$

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{++}+Mg^{++})/2}} \quad (6)$$

$$PI = \frac{Na^{+}+\sqrt{HCO_3^{-}}}{\sqrt{Na^{+}+Mg^{++}+Ca^{++}}} X100 \quad (7)$$

$$RSC = (HCO_3^- + CO_3) - (Ca^{++} + Mg^{++}) \quad (8)$$

$$KR = \frac{Na^+}{Ca^{++}+Mg^{++}} \quad (9)$$

$$MAR = \frac{Mg^{++}}{Ca^{++}+Mg^{++}} X100 \quad (10)$$

$$CAI\text{-}I = \frac{[CL^- - (Na^+ + K^+)]}{CL^-} \quad (11)$$

The groundwater suitability for irrigation purposes according to the indices SSP, SAR, PI, RSC, KR and MAR classifications is shown in Table (3).

Table 3: The different indices for groundwater classification suitable for irrigation purposes [14-22].

(All ionic concentrations are in milli-equivalents per liter (meq/L) except for Na%, MAR and PI which are expressed in percentages)

Parameters	Range	Classification	Reference
Soluble Sodium Percentage (SSP%)	< 60 %	Excellent	[14]
	> 60 %	Poor	
Sodium Adsorption Ratio (SAR)	< 10 meq/l	Excellent	[15]
	10 - 18 meq/l	Good	
	18 - 26 meq/l	Fair	
	> 26 meq/l	Poor	
Permeability Index (PI%)	> 75%	Good for Irrigation.	[16]
	< 25%	Unsuitable for Irrigation	
Residual Sodium Carbonate (RSC)	<1.25 meq/l	Saf for irrigation	[17] & [18]
	1.25 - 2.5 meq/l	termed marginal	
	> 2.5 meq/l	unsuitable for irrigation	
Kelly's Ratio (KR)	< 1	Suitable	[19] & [20]
	> 1	unfit for irrigation	
Magnesium Adsorption Ratio (MAR%)	< 50 %	Excellent	[21] & [22]
	> 50 %	Harmful for soil	

Results and Discussion

Physical and chemical properties, achieved the determination of groundwater suitability for human use and irrigation as any altering factors that may have occurred as a results of human activity and microbial activities in soils [2]. World Health Organization (WHO) and many countries have published the guidelines for drinking water. Accordingly, comparisons between Sudanese Stander Metrology Organization (2015) with water samples in the study area are improved in table (1).

Water Quality Index (WQI) for Drinking Water

From the computation of WQI and according to table (2), 95.9% and 96.7% of groundwater samples are grouped as excellent water, for Gezira and Sandstone aquifers respectively, the remains are grouped as good water. In this study, water quality index (WQI) reveals that all groundwater samples are found under excellent and good category of water and appropriate for drinking purposes. Specifically, the WQI shows the excellent water in the area beside Blue and White Niles in Gezira aquifer. In Sandstone aquifer, the groundwater occurred adjacent to the Blue Nile is relatively excellent than water occurred adjacent to the White Nile. (Figure 2).

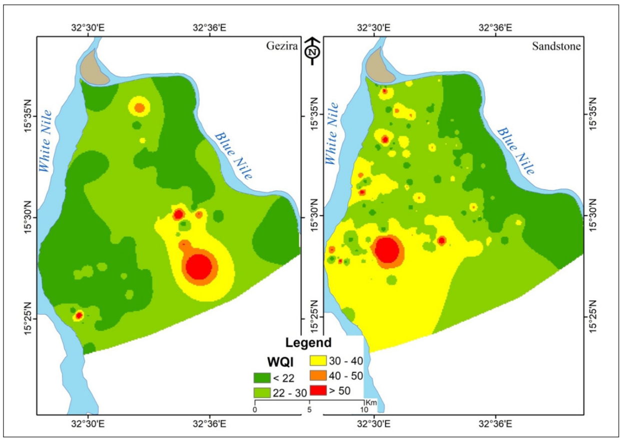

Figure 2: Spatial distribution of Water Quality Index (WQI) for Gezira (left) and Sandstone aquifers (right).

Quality of Irrigation Water

The Percentage of sodium (%Na) of the groundwater in the study area is relatively high in Gezira than Sandstone aquifers, table (4). The Wilcox, 1955 diagram relating sodium percent and EC, shows that 85% of the groundwater falls in the "Excellent to Good" range and 14% is distributed between the "Good to Permissible" and "Permissible to Dubabtful" ranges for the Gezira aquifers. In Sandstone aquifers the range of "Excellent to Good" represent 74%, "Good to Permissible", "Permissible to Dubabtful" represent 24% of groundwater (figure 3). This makes the groundwater for Gezira aquifers are suitable for irrigation purposes than the Sandstone aquifers.

Sodium adsorption ratio (SAR), values in the study area, shows that all the groundwater samples could be classified as excellent category and would be suitable for irrigation expect at three sites, which classified as good category (Saria Complex, Asim Albeile in Gezira aquifers and Mnsoura B1 in Sandstone aquifers), (Figure 4).

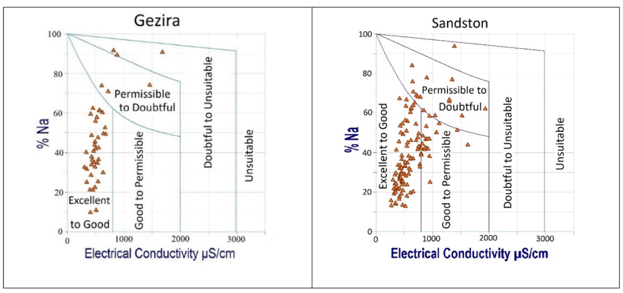

Figure 3: Wilcox diagram showing the suitability of groundwater for irrigation in Gezira (left) and Sandstone aquifers (right).

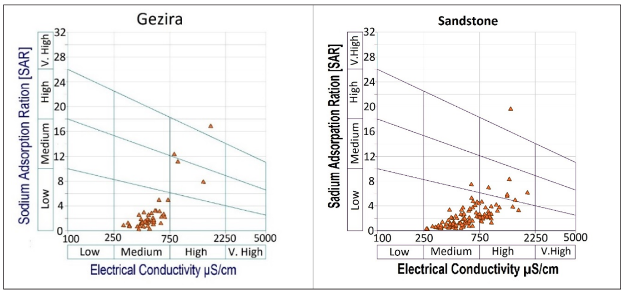

Figure 4: Wilcox diagram (SAR) showing the suitability of groundwater for irrigation for Gezira (left) and Sandstone aquifers (right).

The Permeability index (PI) values in the study area are high in sandstone than in Gezira aquifers, table (5). Based on Doneen's chart and the USSL diagram classifications, groundwater with PI greater than 75 % (PI > 75 %) are termed Class I, Class II is (25–75%) and Class III is (< 25%). According to this chart the groundwater in Gezira aquifers is more suitable for irrigation than sandstone aquifers, (Figure 5).

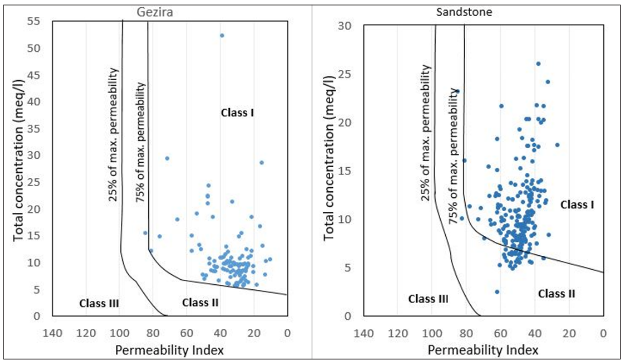

Figure 5: Permeability index diagram for Gezira (left) and Sandstone aquifers (right).

Residual sodium carbonate (RSC) values in this study for Gezira aquifers can classify 64% of the samples are safe for irrigation, 23 % are marginal and would require great care in its usages, the remaining 13% are unsuitable for use as irrigated water. In the sandstone aquifers 83% of the samples are safe for irrigation, 7% are marginal and would require great care in its usage. The remaining 11% are unsuitable for use as irrigated water.

Kelly's ratio (KR) results from this study shows 30% and 28% of samples have values greater than 1 (KR >1) for Gezira and Sandstone aquifers respectively. That means sandstone aquifer is more suitable for irrigation than Gezira aquifer with this parameter.

Magnesium adsorption ratio (MAR) results from this study show 88% and 96% of samples below 50 % in Gezira and Sandstone aquifers respectively. That means sandstone aquifer is more suitable for irrigation than Gezira aquifer,

Chloro-alkaline indices (CAI) in the study area, 15 and 24 of samples for Gezira and Sandstone aquifers respectively recorded positive CAI values with no exchange between Na + K ions with Ca and Mg, ions. The remaining are negative that give an indication of the occurrence of Exchange between Na and K ions in water with Ca and Mg in the host rocks.
The statistics of irrigation water quality parameters for the two aquifers are presented in table 4.

Table 4: Statistics summary of irrigation water quality parameters for Gezira and Sandstone aquifers.
(All ionic concentrations are in milli-equivalents per liter (meq/L) except for Na%, MAR and PI which are expressed in percentages).

	Gezira aquifer			Sandstone aquifer		
Parameter	**Min**	**Max**	**Average**	**Min**	**max**	**Average**
%Na	7	95	44	3	94	40
SAR	0.2	16	2	0.05	14	1.5
PI %	10	87	34	27	85	49
RSC	-10	10	1	-8	5	-0.6
MAR %	6	100	37	6	71	35
KR	0.07	22	1	0.03	15	0.9
CAI	-0.02	0.00079	-0.002	-0.015	0.0007	-0.002

Figure (6) generally shows the unsuitable groundwater for irrigation, was concentrated in the middle of the Study area for Gezira aquifers. Figure (7) shows the most suitable groundwater for irrigation concentrated in the area adjacent to Blue Nile river course in the study area for Sandstone aquifers.

Most of the characteristics of irrigation water which calculated for the groundwater of Sandstone aquifers are more suitable for irrigation than the groundwater for Gezira aquifers (table 4) except the permeability index (PI) which is high in Sandstone aquifers.

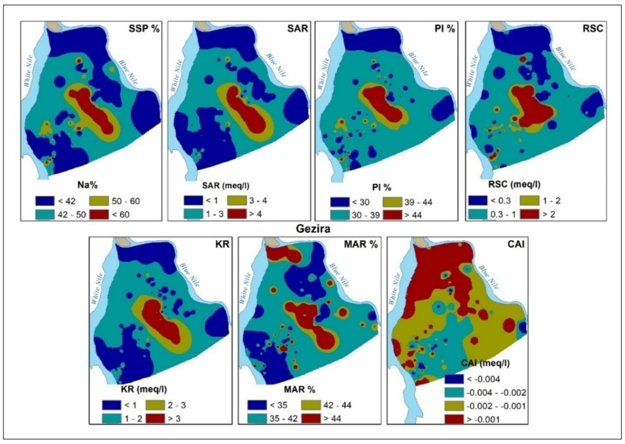

Figure 6: The spatial distribution of SSP, SAR, PI, RSC, KR, MAR and CAI for Gezira aquifers.

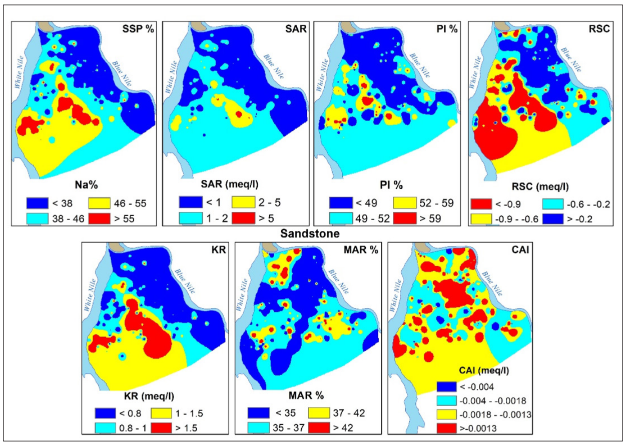

Figure 7: The spatial distribution of SSP, SAR, PI, RSC, KR, MAR and CAI for Sandstone aquifer.

Conclusions

The study area is lies between the confluence of Blue and White Niles, the study area formed rectangle shape within the Khartoum sub basin. The main rock units in the study area include Pre- Cambrian Basement Complex, Cretaceous Sandstone Formations, Tertiary Volcanic Basalt, Quaternary Gezira Formation and Quaternary to Recent superficial Deposits. The groundwater covers about 54% of total water needs in Khartoum area, it storage in both Gezira and Sandstone formations.

The main objective of the current investigation is to determine the groundwater suitability for drinking and irrigation purposes in Khartoum area. The methods of the investigation were describing different parameter obtained from three water analysis laboratories. Water quality investigations are based on large amounts of collected data (122 wells from Gezira aquifer and 219 wells from the Sandstone aquifer), these wells are distributed evenly throughout the study area.

The study results show that water quality index (WQI) for all groundwater samples are found under excellent and good category of water and appropriate for drinking purposes either for Gezira or Sandstone aquifers. The results of Wilcox diagram show 85% and 74% of groundwater samples for Gezira and sandstone aquifers respectively fall in excellent to good category. The Wilcox (SAR) diagram shows all groundwater samples classified as excellent category except three samples. The USSL diagram suggest all groundwater samples belonged to CI category for Gezira aquifers while it suggest the groundwater samples belonged to CI and CII categories for Sandstone aquifers. These indicating the two aquifers have low to medium salinity and low sodium hazard.

Most characteristics of irrigation water (%Na, SAR, PI %, RCS, MAR%, KR and CAI) point to the groundwater of sandstone aquifers is more suitable for irrigation than the groundwater for Gezira aquifers.

Generally, in Sandstone aquifers the area adjacent to the Blue Nile shows good quality for drinking and irrigation purpose, while the area adjacent to the White Nile shows relatively low quality for drinking and irrigation purposes. In Gezira aquifers, the groundwater is suitable for drinking and irrigation purpose except the south- middle part of study area, in which the groundwater is of low class for irrigation purpose.

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Ethical Approval: The manuscript is not now being submitted or under investigation in other journal for simultaneous consideration. The submitted work is original and not has been published elsewhere in any form or language.

Consent to Participate: The authors have no problem to participate the article with any partners based on the journal vision

Consent to Publish: The authors have approve to publish the article based on the journal revelation

Authors Contributions

This article is derived from the current Ph.D. Research Program conducting on Groundwater Resources Management in Khartoum area, the Capital of Sudan.

Braa Abdelwdood Ali Ahmed[1]is the hydro-geologist working in the Groundwater and Wadies general Directorate, Ministry of Irrigation and Water Resources, Sudan. This research is a part for her Ph.D. program.

Abdalla Eltom Mohamed Elsheikh[2], He is the co-author of this research, he is the main supervisor for the Ph.D. research. He is strongly participating in the all research phases; data collection, analysis and interpretation.

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