FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 9 No. 5, May, 2025, pp 43 - 51
DOI: https://doi.org/10.33003/fjs-2025-0905-3358

PHYSICO-CHEMICAL ASSESSMENT OF SURFACE AND GROUNDWATER QUALITY IN SAVANNAH SUGAR COMPANY, NUMAN AND ITS ENVIRONS, ADAMAWA STATE, NIGERIA

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ABSTRACT

This research is aimed at evaluating surface and groundwater quality around the Savannah Sugar Company, Numan, and its environs. The analysis indicated that total hardness ranged from 43.9-91.0 mg/L and DO ranged from 4.2-11.3 mg/L, BOD ranged from 6.6-116.0 mg/L, and COD 10.4-139 mg/L, while Nitrate varied from 4.1-80.1 mg/L. Spatial analysis indicated a significant concentration of nitrate and iron at the northwestern flank of the study area. pH varied from 5.3 to 9.2, Electric conductivity (EC) 178-605 µS/cm; TDS ranged from 115-401 mg/L. Fe, Cu, Mn, Zn were below WHO/FMEnv limits, with iron (Fe) reflecting an average of 0.3 mg/L; while others were <0.1 mg/L, except for localized high concentrations of iron and nitrate. For the surface water samples, the following results represent the quantitative values of the physico-chemical parameters analyzed: pH ranged from 5.3 to 9.4, EC ranged from 181-773 µS/cm, while TDS ranged from 122-512 mg/L. The cation Na^+, K^+, Ca^{2+}, Mg^{2+} and anion HCO^{3-}, Cl^-, $SO4^{2-}$, ranged from 40.2-98.7 mg/L, DO 4.0-11.1 mg/L, BOD 28.1-98.5 mg/L, and COD 41.0-141.3 mg/L. Nitrate ranged from 38.4 to 84.9 mg/L. Fe, Cu, Pb, Mn, Zn, and F were significantly below WHO/FMEnv limits; iron (Fe) varied from 0.1-5.6 mg/L. However, high Fe and nitrate were also observed in the northwestern part of the study area. Generally, the surface and groundwater quality fall within the WHO/FMEnv permissible limit for drinking water.

Keywords: Physico-chemical, Groundwater, Surface water, Savannah sugar, Water quality

INTRODUCTION

Water pollution has emerged as a significant global challenge, driven by the continuously expanding global population and its increasing demand for access to clean water. (Alfonso-Muniozguren et al., 2018; Gil-Pulido et al., 2018; Zhu et al., 2018). Effluent, a major contributor to water pollution, encompasses discharges from sewage treatment plants and wastewater released from domestic, industrial, and agricultural facilities. (Li et al., 2016; Suresh & Nagesh, 2015). To mitigate the impact of effluent discharge, discharge limits and various regulations have been established both locally and internationally. Numerous studies have focused on water treatment before discharge into surrounding environments. (Zhao et al., 2013; Emenike et al., 2017; Durotoye et al., 2018; Ogbiye et al., 2018). Wastewater recycling is increasingly recognized as an alternative water management strategy to alleviate pressure on water resources due to rapid and sustained population growth. (Zahedi et al., 2018). The application of water is extensive and multifaceted. In Nigeria, the National Environmental Standards and Regulations Enforcement Agency (NESREA) has enacted regulatory acts governing the optimal use and discharge of water and wastewater. (Eslami et al., 2017). However, a persistent problem is the common practice of discharging untreated waste from industries and processing facilities into open drainage systems or rivers. Leachates produced from continuous decomposition processes infiltrate underlying aquifer systems, resulting in the contamination of streams, rivers, boreholes, and hand-dug wells used for drinking water by factories and other individuals. (Ozdemir et al., 2018; Abiola, 2021).

These pollutants contaminate surface and groundwater, a natural habitat for aquatic life, both directly and indirectly. It is crucial to acknowledge that less than 1% of freshwater, approximately 0.0069% of all water on Earth, is readily accessible and pure for direct human consumption (Chapelle, 2003; Nyagwambo, 2006). The physico-chemical analysis of both surface and groundwater is essential for effectively assessing the impact of domestic and industrial activities on these water sources. The discharge of wastewater from industry is particularly detrimental to the environment, contributing to river pollution (Kundzewicz et al., 2007; Zhou et al., 2016; Sandoval & Tiburan, 2019; Ismail et al., 2020). In Africa, particularly Nigeria, many industries discharge effluents directly into open water bodies, such as canals, rivers, and streams, without undergoing treatment, and the these waste products e.g. from sugar processing factories is often discharge into the open bodies of water (Itchfield, 1980; Adelegan, 2002, 2006). The water used for cleaning frequently becomes waste, further degrading water quality. Physical properties, such as color and odor, and chemical parameters, including chlorides (Cl), sulfates, pH, Chemical Oxygen Demand (COD), and nitrogen, are critical parameters for determining water quality (Beyene et al., 2019; Iqbal et al., 2020; Lenhart et al., 2002). Industry effluents are characterized by high concentrations of suspended solids (SS), including particles of organic and inorganic waste (Akange et al., 2016; Ozdemir et al., 2018; Abiola, 2021). Sixty percent (60%) of the insoluble and biodegradable waste represents the influent discharge of industry effluent, while 25% commonly originates from colloidal solids (Cadmus et al., 1999). Furthermore, the discharge of untreated agricultural, domestic, and industrial wastewater introduces numerous microorganisms, including pathogens, which can lead to waterborne diseases such as cholera, typhoid, and diarrhea (Lively, 1974; Chaudhary et al., 2017). Therefore, this research is aimed at assessing the surface and groundwater quality around the Savannah Sugar Company in Numan and the environs.

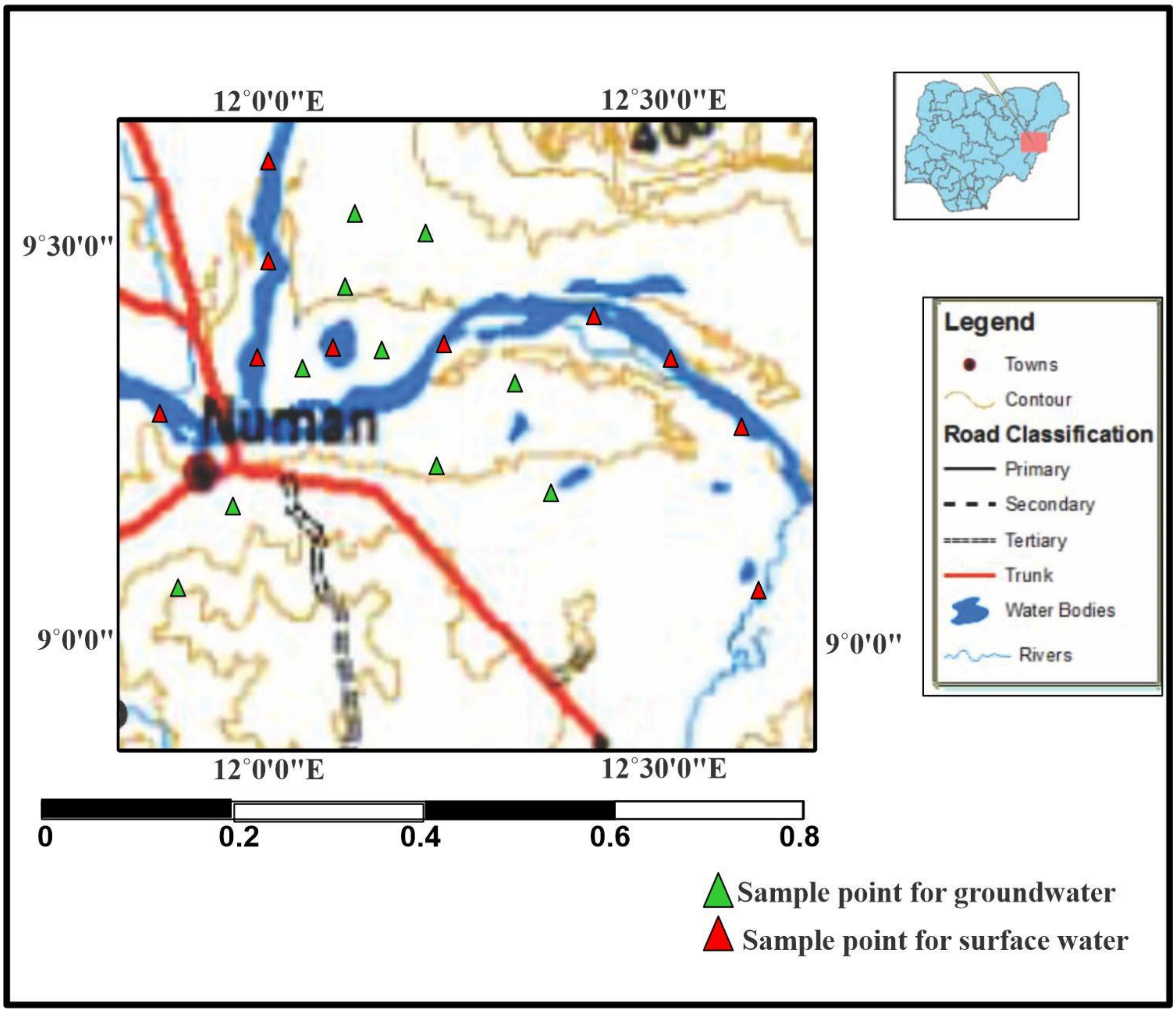

Figure 1: Topographic map of the Study area, modified after (Finthan et al., 2023)

MATERIALS AND METHODS

Location, Extent, and accessibility

The study area is located in Yola arm sub-basin of the Upper Benue Trough, it falls approximately between Latitude 9˚ 0'0" N-9˚ 30'0" N and longitude 12˚0˚0" E-12˚ 30'0" E (Figure .1). The basin host both marine and continental sediments, the study area can be accessed through trunk "A" roads, minor roads, footpaths, animal tracts, and along farmlands. The study area is characterized by exposure to hills ranging from the Lamurde anticline, Lunguda basalt, Ashafa, (2009) and breathtaking landscape scenery in the country with areas as low as 50 m and as high as 70 m above sea level Ashafa, (2009).

Surface and groundwater sampling

A total of 20 water samples were collected, ten (10) surface water samples, and ten (10) groundwater samples from hand-dug wells and boreholes (Fig. 6). The sampling technique that was employed for the reseach is a combination of exploratory and random sampling, where water samples were collected, generally aimed at checking the presence or absence of contamination. (Swyngedouw & Crepin, 2008). Before collecting the samples, the sample containers were rinsed with the samples to be collected. Physical parameters such as pH, temperature, TDS, and EC were measured at the point of sample collection using a Pen pH meter (Model C_T 6021, country of make), and an EC_5 portable conductivity meter. HCO_3, $CO_3^{2-,}$ and total hardness were equally measured onsite using the titrimetric method. Samples were collected from existing water sources, which according to Schmoll, (2013) Method form the most reliable samples for chemical analysis. Coordinates were taken at each sampling point.

Laboratory Analysis

The chemical parameters analyzed at the Adamawa State Water Board include Ca^{2+}, Mg^{2+}, K^+, Na^+, SO_4^{2-}, Cl^-, DO, and COD. BOD, F^-, NO_3^-, NO_2^-, TSS, SO_2^-, Total Nitrogen, Total hydrocarbon, Ni, Cd, Cr^{+6}, Fe^{2+}, Cu^{2+}, Pb, Mn^+, Zn and Co. These parameters were analyzed using a HACH digital Spectrophotometer (Model DR 2040, USA).

RESULTS AND DISCUSSION

Groundwater Quality Assessment

The physico-chemical assessment of groundwater samples indicates a range of characteristics, as presented in Table 1). The pH values varied from 5.3 to 9.2, with an average value of 7.4, indicating an overall neutral groundwater condition that falls within a permissible limit established by the Federal Ministry of Environment (FMEnv) and the World Health Organization (WHO), respectively (Duggal et al., 2017; Beyene et al., 2019; Karuppannan & Serre Kawo, 2020; Markus et al., 2022). Electrical conductivity (EC) and total dissolved solids (TDS) ranged from 178 to 605 µS/cm and 115 to 401 mg/L, respectively, with all recorded values remaining within permissible limits. Cation concentrations were as follows: sodium (Na^+) ranged from 0.4 to 37.7 mg/L, potassium (K^+) from 5.3 to 60.8 mg/L, calcium (Ca^{2+}) from 30.0 to 76.1 mg/L, and magnesium (Mg^{2+}) from 6.6 to 40.1 mg/L. All cation concentrations were within the established regulatory thresholds according World Health Organization (WHO) (Beyene et al., 2019; Zacchaeus et al., 2020; Markus et al., 2022). Anion concentrations were: bicarbonate (HCO_3^-) ranging from 187 to 536 mg/L, chloride (Cl-) from 2.0 to 81 mg/L, and sulfate (SO42-) from 8.4 to 43.1 mg/L, all of which were within acceptable limits according to the World Health Organization. (Duggal et al., 2017; Beyene et al., 2019; Karuppannan & Serre Kawo, 2020; Markus et al., 2022). Total hardness of the groundwater varies from 43.9 to 91.0 mg/L, which is also within a recommended range. Dissolved oxygen (DO), biochemical oxygen demand (BOD), and chemical oxygen demand (COD) concentrations have values that range from 4.2 to 11.3 mg/L, 6.6 to 116.0 mg/L, and 10.4 to 139 mg/L, respectively. Nitrate concentrations varied from 4.1 to 80.1 mg/L, with a mean value of 3.4 mg/L, which is within the acceptable limit.

Spatial distribution analysis (Fig. 3) revealed elevated nitrate concentrations in the northwestern and southwestern portions of the study area, specifically around Numan, Gudinyi, and Kola areas. Heavy metals observed included iron (Fe), copper (Cu), manganese (Mn), zinc (Zn), and fluoride (F), with concentration that varied from of 0.03 to 1.7 mg/L, 0.0 to 0.3 mg/L, 0.0 to 0.1 mg/L, 0.0 to 1.2 mg/L, and 0.0 to 0.9 mg/L, respectively. Mean concentrations were: 0.3 mg/L for Fe, 0.1 mg/L for Cu, 0.01 mg/L for Mn, 0.4 mg/L for Zn, and 0.08 mg/L for F. All mean heavy metal concentrations were below permissible limits set by World Health Organization (WHO) (Duggal et al., 2017; Beyene et al., 2019; Karuppannan & Serre Kawo, 2020; Markus et al., 2022). (Fig. 2 & 3) illustrate that elevated nitrate and iron concentrations were observed in the northwestern region of the Kola, and the Gudenyi and Numan areas. Overall, the groundwater samples analyzed were found to be within the permissible chemical quality requirements for human consumption as stipulated by the World Health Organization (WHO).

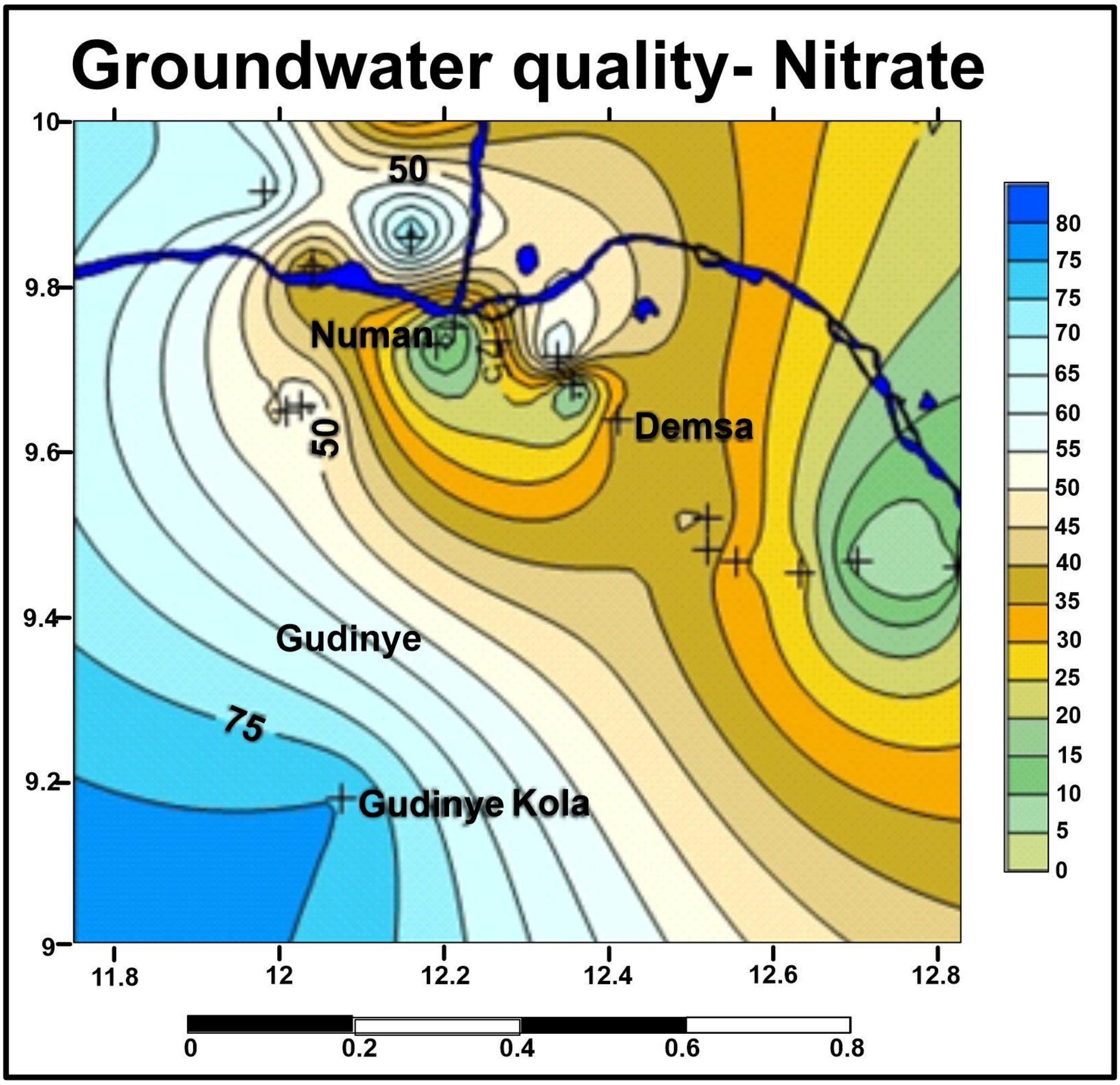

Figure 2: Spatial Distribution of Nitrate Concentration in Groundwater of Numan

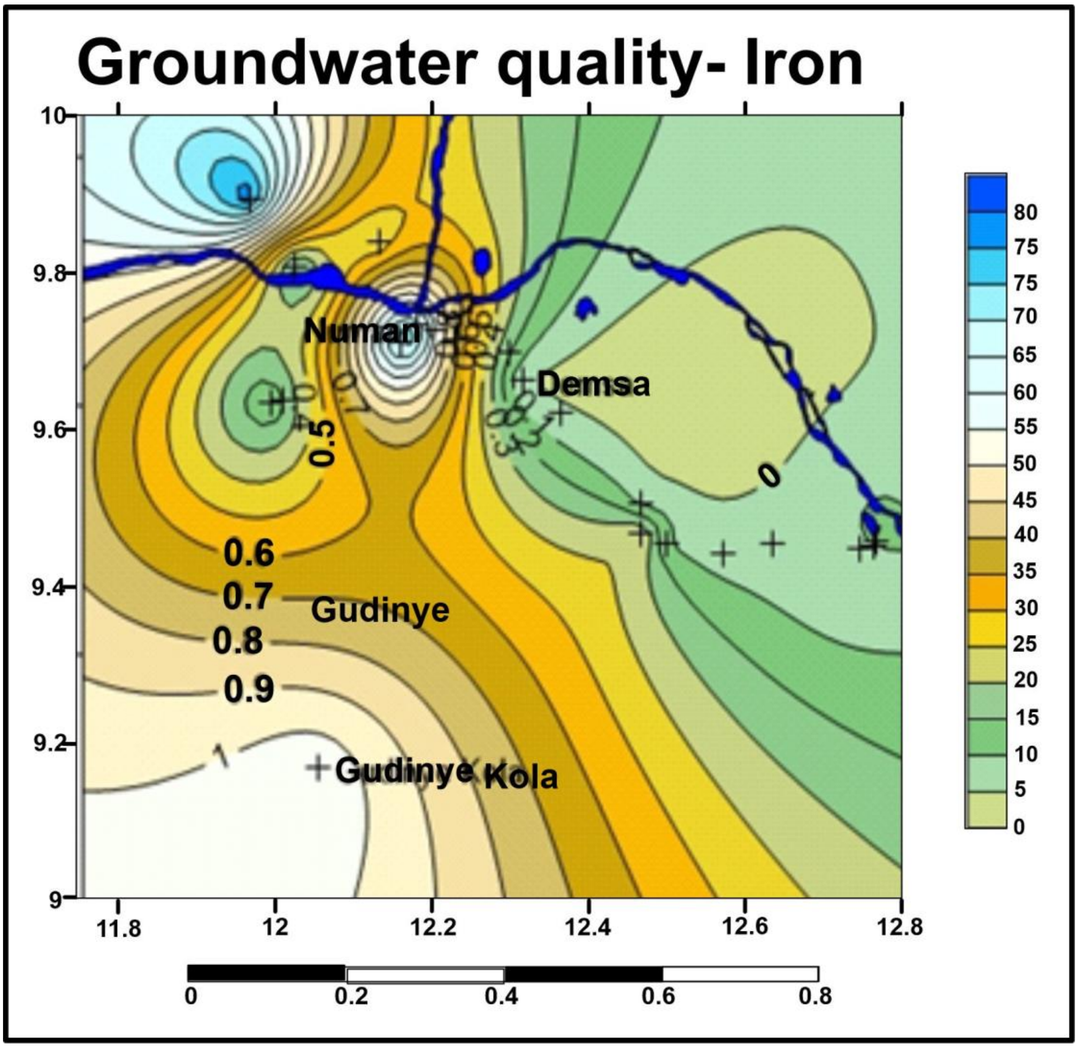

Figure 3: Spatial Distribution of Iron Concentration in Groundwater of Numan

Surface Water Quality Characteristics

Physico-chemical analysis was conducted to determine the characteristics of surface water samples (Table 2), the result revealed a pH range from 5.3 to 9.4, with an average value of 7.7. This mean value indicates a neutral condition for the surface water, which falls within a permissible limit according to the World Health Organization (WHO) (Duggal et al., 2017; Beyene et al., 2019; Karuppannan & Serre Kawo, 2020; Markus et al., 2022). Electrical conductivity (EC) and total dissolved solids (TDS) ranged from 181 to 773 µS/cm and 122 to 512 mg/L, respectively, all of which were below acceptable thresholds. Cation concentrations were as follows: sodium (Na^+) ranged from 0.9 to 39.8 mg/L, potassium (K^+) from 5.8 to 16.4 mg/L, calcium ($Ca^{2+)}$ from 28.7 to 59.8 mg/L, and magnesium (Mg^{2+}) from 10.3 to 49.1 mg/L. These values were all within the recommended limits set by the Federal Ministry of Environment (FMEnv) and the World Health Organization (WHO) (Sawyerr et al., 2017; Beyene et al., 2019; Zacchaeus et al., 2020; Markus et al., 2022). Anion concentrations were: bicarbonate (HCO_3^-) ranging from 174 to 523 mg/L, chloride (Cl^-) from 29.7 to 101.5 mg/L, and sulfate ($SO4^{2-}$) from 10.8 to 35.4 mg/L. The whole of the anion concentrations is within the World Health Organization's (WHO) permissible limit for consumption. The analysis also showed that the total hardness of the surface water samples ranges from 40.2 to 98.7 mg/L, also falling within the permissible limit for consumption according to the World Health Organization (WHO). The chemical oxygen demand (COD), Biochemical Oxygen Demand (BOD), and Dissolved oxygen (DO) concentrations were recorded as 4.0 to 11.1 mg/L, 28.1 to 98.5 mg/L, and 41.0 to 141.3 mg/L.

The concentrations for the Nitrate vary from 38.4 to 84.9 mg/L, with an average value of 5.9 mg/L, which is in tandem with the permissible limit according to the World Health Organization (Sawyerr et al., 2017; Beyene et al., 2019; Zacchaeus et al., 2020; Markus et al., 2022). The heavy metals detected from the surface water are: (Fe), copper (Cu), lead (Pb), manganese (Mn), zinc (Zn), and fluoride (F). The individual concentration for the elements ranges from 0.1 to 5.6 mg/L for Fe, 0.0 to 0.3 mg/L for Cu, and 0.0 to 0.004 mg/L for Pb. Manganese, zinc, and fluoride concentrations ranged from 0.002 to 0.09 mg/L, 0.001 to 1.1 mg/L, and 0.0 to 0.7 mg/L, respectively. Except for iron, all heavy metal concentrations were below acceptable limits (Zacchaeus et al., 2020; Markus et al., 2022). High iron concentrations are recorded around River Benue and Numan areas (Fig. 4). High concentration of nitrate concentrations has been observed at northwestern part of the study area, e.g. Kola, Gudenyi, and Numan areas (Fig. 5). In general, the surface water met the WHO chemical quality requirements for human consumption, with the notable exception of areas exhibiting elevated iron and nitrate concentrations as depicted in the spatial distribution maps.

Table 1: Result of the groundwater samples collected from the study area

Samples ID	pH	TH mg/l	DO mg/l	EOD mg/l	BOD mg/l	F mg/l	$N0_3^-$ mg/l	$N0_2^-$ mg/l	K^+ mg/l	TSS mg/l	Na^+ mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	SO_4^{2-} mg/l	Cl^- mg/l	SO_2^- mg/l	TN mg/l	THC mg/l
S1	5.9	60.11	5.12	65.07	41.4	0	27.62	0	13.42	63.8	1.1	44.62	12.67	16.92	10.63	0	39.14	0
S2	8	68.03	8.14	43.8	30.5	0.011	30.16	0	12	53.6	0.66	37.88	32.08	14.48	26.11	0	40.01	0
S3	6.44	68.42	6.14	46.5	30	0.012	37.83	0	16.1	57.8	3.12	39.9	25.01	29.41	31.82	0	41.02	0
S4	6.73	74.51	5.44	89	57.8	0.101	40	0	12	82	4.07	40.11	31.77	11.28	28.63	0	49.66	0
S5	8	61.4	10.21	25	22.75	0.06	38.52	0	9.3	43.7	1	50.01	9.08	12.42	31	0	48.97	0
S6	9.2	57.27	11.25	10.4	6.6	0.01	8.67	0	8.6	18.9	0.59	41.12	17.53	8.9	1.98	0	13.42	0
S7	8.4	78.63	6.18	58	35.4	0.015	63.98	0	9.4	63	17.56	48.63	23.42	21.07	42.66	0.001	77.52	0
S8	8.41	80.16	9.41	67.5	43.8	0.1	28.5	0	11.03	61.21	1.025	76.11	6.57	9.71	31.4	0	39.08	0
S9	5.3	77	8.8	30	22.1	0.04	9	0.001	13.01	34.73	0.805	69.83	6.87	10.23	20.16	0	15.62	0
S10	5.8	66.86	8	36.5	23.4	0.02	8.53	0.002	12.03	44.8	0.89	60.97	7.53	8.81	22.82	0	19	0

Table 2: Result of the surface water samples collected from the study area

Samples ID	T°C	PH	CO_3^{2-}	HCO_3^{2-}	EC	TDS	NTU	Ni	Cd	Cr^{+6}	Fe	Cu^{2+}	Pb^{2+}	Mn^-	Zn	CO
Sw 1	23	5.9	1.1	176	181	122	0.948	0	0	0	0.107	0.041	0	0.002	0.001	0
Sw 2	27	8	1.4	391	467	315	6.75	0	0	0	1.299	0.11	0	0.024	0.7	0
Sw 3	24	6.44	2.4	301	387	261	11.43	0	0	0	0.486	0.109	0	0.014	0.216	0
Sw 4	27	6.73	3.4	368	399	269	20.05	0	0	0	4.692	0.119	0	0.016	0.804	0
Sw 5	28.4	8	1.1	398	400	268	5.25	0	0	0	0.162	0.22	0	0.007	0.069	0
Sw 6	31.1	9.2	2.4	523	773	512	10.57	0	0	0	0.466	0.186	0.001	0.021	1.1	0
Sw 7	26.11	8.4	2.4	497	527	353	3.52	0	0	0	0.405	0.3	0	0.091	1.09	0
Sw 8	27	8.41	6.4	438	488	328	34.15	0	0	0	5.62	0.26	0	0.085	1	0
Sw 9	24.3	5.3	3.2	178	192	134	0.27	0	0	0	0.16	0	0	0.002	0.007	0
Sw 10	27.2	5.8	2.4	174	183	126	17.54	0	0	0	0.401	0.013	0.001	0.007	0.307	0

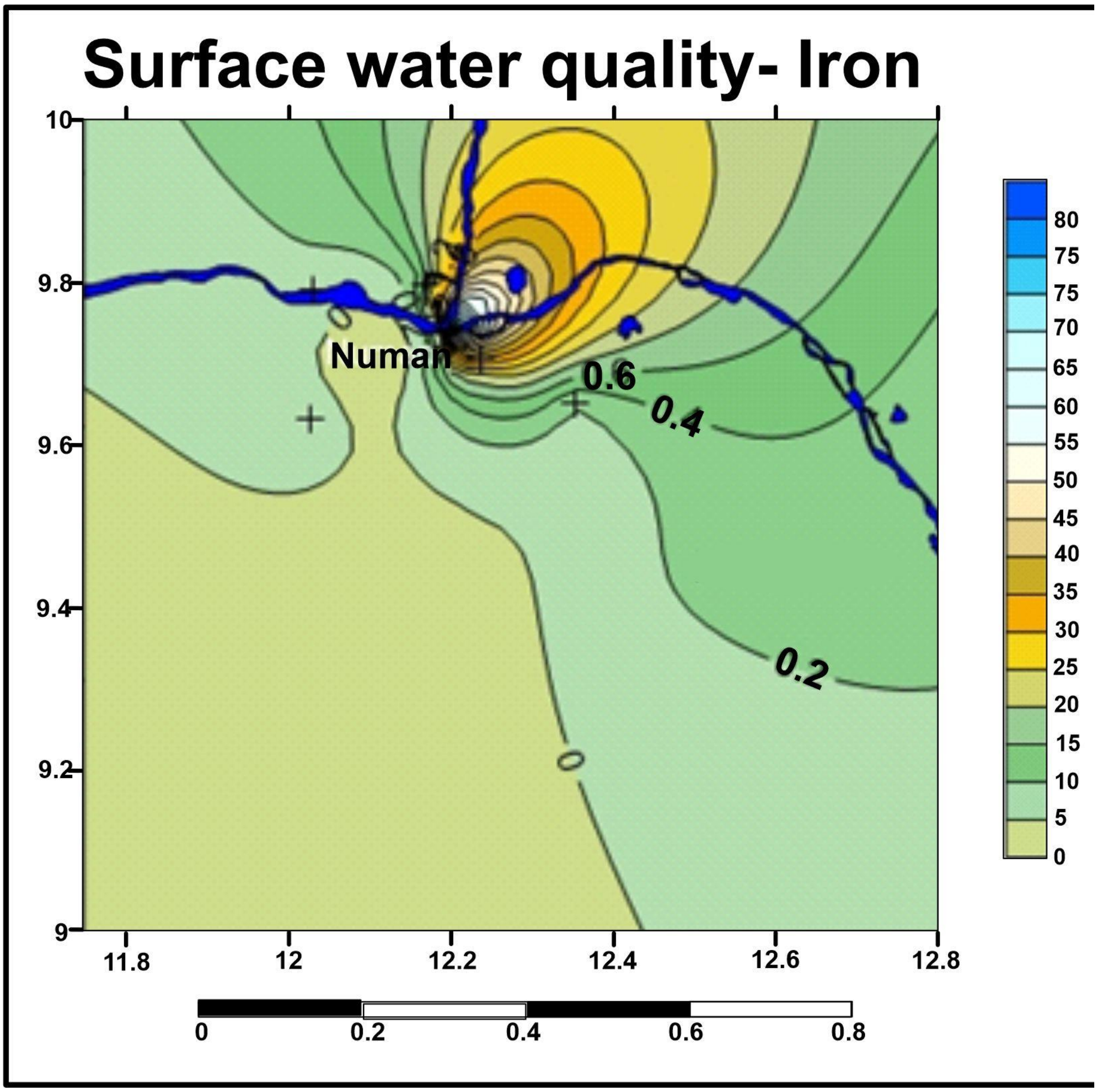

Figure 4: Spatial Distribution of Iron concentration in Surface water of Numan

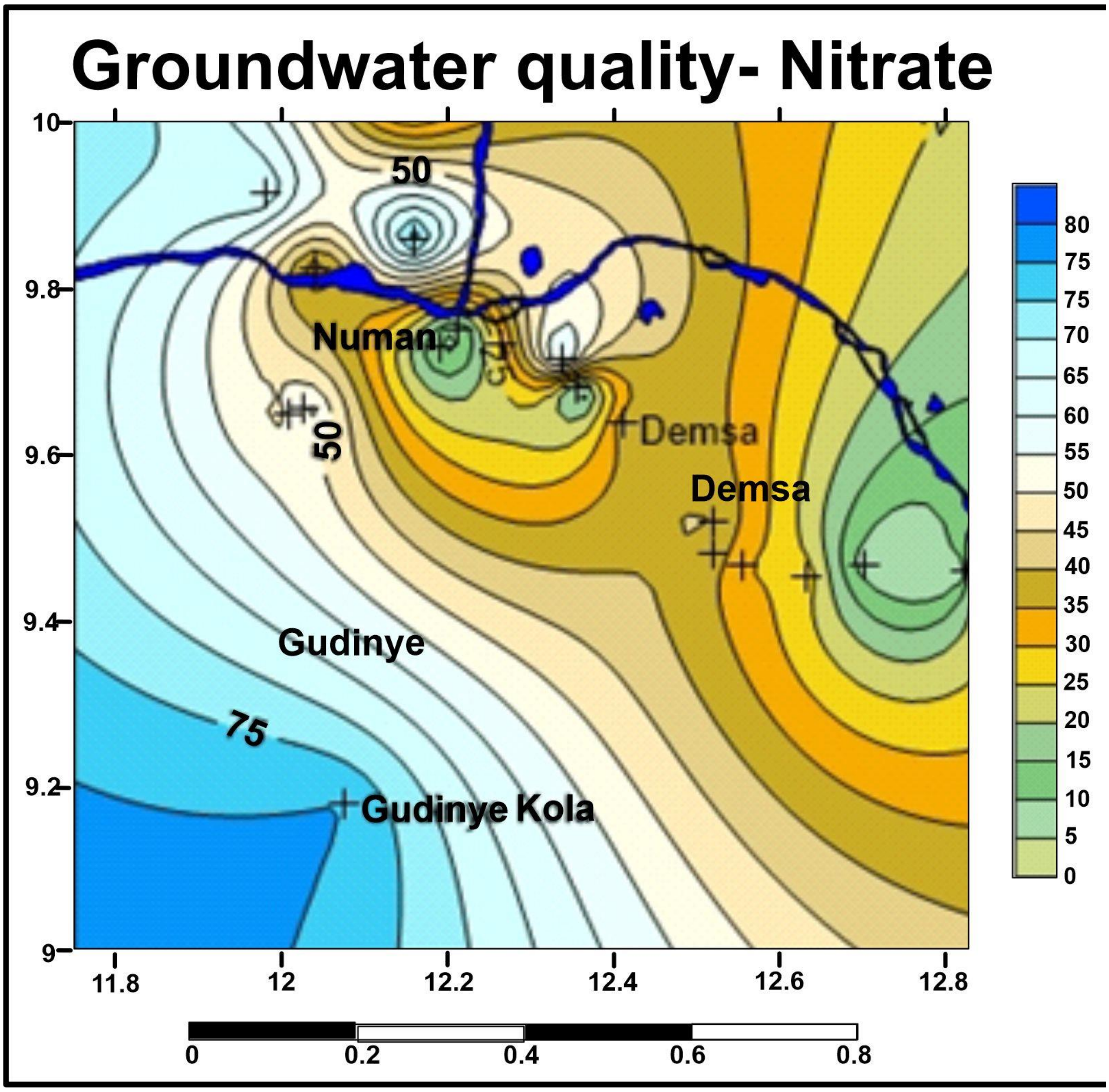

Figure 5: Spatial Distribution of Nitrate concentration in Surface water of Numan

CONCLUSION

This study focused on the assessment of surface and groundwater quality, revealing generally acceptable conditions for human consumption according to WHO and FMEnv standards. While most physicochemical parameters (pH, EC, TDS, major ions, hardness, DO, BOD, COD) fell within permissible limits, localized areas exhibited concerning trends. Specifically, high nitrate concentrations (state the range) were observed in the northwestern region of the study area. Although average heavy metal concentrations (Fe, Cu, Mn, Zn, F) were within permissible limits for the WHO, high nitrate and iron concentrations (state the range) were observed in the northwestern area encompassing Kola, Gudinyi, and Numan. However, the identified spatial variations in nitrate and iron necessitate careful monitoring and frequent investigation into potential sources to ensure long-term groundwater safety and sustainability.

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