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Groundwater Quality Monitoring in Selected Areas of District Buner, Khyber Pakhtunkhwa, Pakistan

Naveedullah

Associate Professor, The university of Agriculture Peshawar,

Email: naveedullah@aup.edu.pk

Fawad Ali

M.Sc (Hons) Scholar, The university of Agriculture Peshawar.

Syed Iftikhar Hussain Shah Kazmi

Assistant Professor, The university of Agriculture Peshawar,

Email: i.kazmi@aup.edu.pk

Muhammad Ehsan Rahim

MS Scholar, The university of Agriculture Peshawar,

Email: ehsanrahim8@aup.edu.pk

Haider Ali Khan

MS Scholar, The university of Agriculture Peshawar,

Email: Khanhaiderkhan123@gmail.com

Hassam Ullah Kakar

MS Scholar, The university of Agriculture Peshawar,

Email: hassamullahkakar@gmail.com

ABSTRACT

The problem of water quality is becoming ever more serious as freshwater resources are severely degraded globally. Groundwater is the major source of drinking, domestic, agricultural, and industrial purposes in the undeveloped countries including Pakistan. The current study was carried out to evaluate the groundwater quality and its suitability for drinking and irrigation purposes. The results of the physicochemical parameters were compared with the existing data of Pakistan Council of Research in Water Resources (PCRWR). Standard methods were used to analyze groundwater samples. The result reveals that the pH of all the samples were above 7 (alkaline). However electrical conductivity (EC_w) of the 92.84% samples were found non-saline. Turbidity of the (13%) 11 samples exceeded the permissible limit of 5 NTU in drinking water. In case of irrigation water, Sodium concentration with a mean value of 21.05 mgL^{-1} of the 5% samples were above the safe limit. However, the sodium concentration in drinking water were within the permissible limit. In irrigation water potassium concentrations with a mean value of 3.82 mgL^{-1} of the 10.92% samples were above the safe limit.

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Similarly, in drinking water the potassium concentration of the 9.24% samples were above the permissible limit. Calcium concentration with a mean value of 39.96 mgL^{-1} of all the samples were within the permissible limit. It was noted that magnesium concentration with a mean value of 39.16 mgL^{-1} of (38%) samples were within the maximum limit and suitable for drinking purpose. Carbonate and bicarbonate with a mean value of 0.53 mgL^{-1} and 123.87 mgL^{-1} respectively were within the safe limit. However, it was noted that in irrigation water bicarbonate concentration of the (8%) samples exceeded the safe limit. Both in irrigation and drinking water sulphate and chloride concentration were within the safe limit. The result of heavy metals Cu, Fe, Zn, Ni, Cr and Pb were compared with the existing data of Pakistan Council of Research in Water Resources (PCRWR). No major change in heavy metals concentration were observed and that all the samples were within the safe limit. The findings of this study are pivotal for effective groundwater management. Excessive marble industries are present in the study area; therefore, it is necessary to reduce metal contamination via proper disposal and treatment of marble wastewater, for which the government should take serious action in the study area.

Keywords—

INTRODUCTION

Water is a precious and necessary natural resource that covers 70% of the earth's surface. The ocean is the main source of water, making up about 97% of the total, while the remaining 3% is available in fresh form, only 3% is appropriate for human use (Habiba *et al.*, 2012). Expansion, and intensified agricultural practices have placed immense pressure on the finite fraction of the global water reservoir. This limited resource is now experiencing mounting depletion and contamination, transforming water quality into a pressing concern with far-reaching implications not only for public health but also for the environment. Almost 80% of the people use unsafe and imprudent water in rural areas. Similarly, about 2.1 billion individuals do not have access to clean and safe water. Seven hundred children under five years of age die from diarrhea on daily basis and during last year about 2/3 of the world's population faced a severe shortage of water (UNO world water day 2019). The physicochemical properties of water, along with its consistent quality, are key variables governing health. Water plays a crucial role in safeguarding the health of all living beings. (Nawab *et al.*, 2018). In developing countries, largely open ground is polluted by direct trash disposal, posing a major hazard to human health and ecosystems. (Tariq *et al.*, 2006). Water availability in Pakistan is steadily diminishing because 70% of the population relies on groundwater for direct and domestic needs, pointing towards a potential water scarcity issue. In Pakistan, both water scarcity and pollution are getting worse. Industrial wastewater is the primary cause of water contamination. Marble is an important building material and is vital to the country's economic growth and development. (Mulk *et al.*, 2011). Beyond its financial implications, the marble industry is a significant contributor to waste production, with approximately 70% of marble being discarded during various processes, including mining, cutting, and polishing. (Aukour and Al-Qinna, 2008). In several places across the country, the industrial sector lacks wastewater treatment plants

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and infrastructure for wastewater effluent control. It is worth mentioning that most industrial cities in Pakistan, especially Khyber Pakhtunkhwa, lack sufficient wastewater treatment facilities. Water wastes cause surface and groundwater pollution, posing a threat to agricultural production and biodiversity (Nasrullah *et al.*, 2006). The direct discharge of effluents from marble businesses into various water bodies is the primary source of water pollution in Buner District. This pollution poses health risks to people, livestock, and aquatic animals, while also reducing crop yields and diminishing the area's scenic beauty. (Khan *et al.*, 2012). The marble industries are mostly concentrated in the southeastern part of the district.

A groundwater quality study was carried out in the southeastern part of district Buner. The proposed study will compare data to assess changes in the physicochemical quality of groundwater, including trace metal concentrations in the study area. To our knowledge, this is the first study to evaluate the groundwater quality in an industrial-residential region of district Buner, Pakistan. Groundwater serves as a major source of domestic and agricultural water supply, often being utilized without treatment. With the ongoing processes of urbanization and industrialization, this vital source faces significant environmental threats, impacting both agricultural and domestic sectors. In Pakistan, most of the industries dispose their waste effluents directly into the nearby drains, rivers, streams, ponds, ditches, and open or agricultural land which pollute the overall environment including surface and groundwater (Azizullah *et al.* 2013). Given its importance in both domestic and agricultural contexts, regular monitoring becomes crucial. Groundwater serves as a major source of domestic and agricultural water supply, often being utilized without treatment. With the ongoing processes of urbanization and industrialization, this vital source faces significant environmental threats, impacting both agricultural and domestic sectors. The *Pakistan Council of Research in Water Resources* carried out study in 2008 in district Buner to check the physio-chemical parameters in groundwater. The current study aims to investigate groundwater quality in 2020 to determine whether any changes have occurred over the years.

Objectives

- To evaluate groundwater quality and its suitability for irrigation and drinking.
- To determine heavy metals concentration in the groundwater samples.

REVIEW OF LITERATURE

Din *et al.* (2022) examined the quality of groundwater for irrigation and drinking in the Hangu district, Khyber Pakhtunkhwa Pakistan. Groundwater samples were collected from different locations, including springs, bore wells, excavated wells, and tube wells, and the study analyzed physicochemical parameters like turbidity, magnesium (Mg^{+2}), sodium (Na^{+}), fluoride (F), chloride (Cl), nitrate (NO_3), and sulfate. Most of the physicochemical characteristics were found to be in accordance with the World Health Organization (WHO) permissible limits. Rehman *et al.* (2018) assessed the groundwater quality of three Tehsils in the District of Dera Ismail Khan. Source identification was conducted through various water sources, including tube wells and hand pumps, using established procedure and geographical diversity. Some of the water

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quality measures that were found to be over WHO guidelines were Total Dissolved Solids and Sulfate.

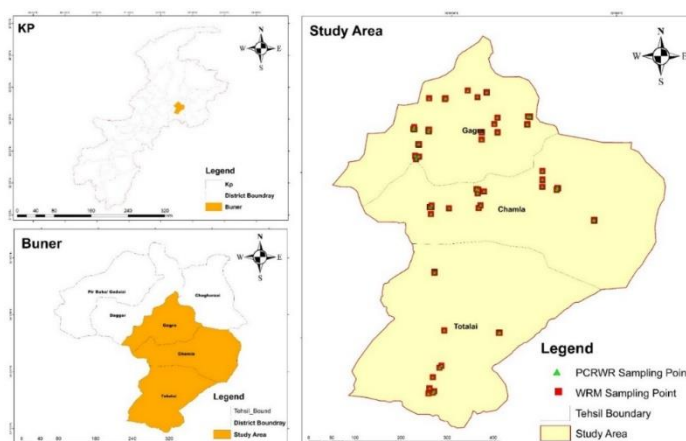
Khan *et al.* (2018) investigated the effect of withdrawal on groundwater table levels and water quality parameters in District Karak. The ground surface water table levels, well discharge and Electrical Conductivity (EC_w) were also determined. The pH of the water ranged from 8.2 to 8.9, while the EC_w ranged from 0.4 to 4.7 dSm^{-1} . The study found that groundwater in seven communities had an EC_w higher than the WAPDA (1974) suggested acceptable level, and the Sodium Adsorption Ratio was within an acceptable range.

Muhammad *et al.* (2015) examined the physicochemical characteristics and heavy metal concentrations of the drinking water quality in Narangi district Swabi, Pakhtunkhwa, Pakistan. Samples of water were collected from springs, dug wells, tube wells, and hand pumps. Lead (Pb) was discovered to be beyond the WHO permitted limits, whereas nitrite (NO_2) was found to be above the WHO standard in physicochemical characteristics. In many parts of the world, contaminated drinking water is the primary factor in health issues and is responsible for catastrophic illnesses such as stomach cancer, kidney failure, and neurological disorders. The authors found that the presence of Pb and NO_3 in the drinking water of the selected areas could pose a health risk.

Jabeen (2013) assessed the environmental geochemistry of Pakistan's Attock and Haripur Basins. Using an Atomic Absorption Spectrometer, water, soil, and plant samples were collected to analyze physio-chemical parameters as well as heavy and trace elements. Furthermore, several statistical approaches for data interpretation were developed, demonstrating that geogenic and human activities were the main causes of water pollution in the region. The authors also used ArcGIS to perform geographic information system-based geographical distribution of samples and parameters.

MATERIALS AND METHODS

Buner is a district in the Malakand Division of Pakistan, located at 34.3943° N and 72.6151° E in the Khyber Pakhtunkhwa Province. Buner is bordered to the north by Swat District, to the west by Malakand Agency, to the south by Mardan District, and to the east by Hazara Division. District Buner covers an area of 1,865 square kilometers and has a population of 506,048 people (Khan *et al.*, 2012). Forests cover about 32,102 hectares of the total area of District Buner. The total available land area in District Buner is 172,096 hectares, out of which 111,733 hectares are uncultivated land, counted as forests. In the study area, approximately 150 marble industries operate, providing jobs and income for the local community (Khan *et al.*, 2012).



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Eighty-Four (84) groundwater samples in clean plastic bottles were collected from Tube wells, dug wells, hand pumps. The sampling points were the same where PCRWR collected data during 2008 and labeled sample code and geographic coordinates, source of sampling point in the study sites. The collected water samples were then analyzed for heavy metals, physical and chemical parameters in the water quality laboratory of the Soil and Environmental Science and the Department of Water Resources Management, the University of Agriculture Peshawar.

The suitability of water quality for irrigation and drinking purposes was determined based on the following criteria: FAO (1985) criteria were employed for irrigation, and WHO (2011) criteria were used for drinking water. FAO did not specify clear criteria of some parameters in irrigation water for those parameters, Robbins (2013) criteria were utilized.

Table 1 Guidelines for Irrigation and Drinking Water.

Parameters	Units	Allowable Limits	
		Irrigation Water (Robbins, 2013)	Drinking Water (WHO, 2011)
pH	-	6.5-8.4	6.5-8.5
EC _w	(μS/cm)	< 0.7 Not saline, > 3.0 sever for Irrigation	
Turbidity	(NTU)	--	<5 NTU
Sodium	mgL ⁻¹	51	200
Potassium	mgL ⁻¹	9.75	12
Calcium	mgL ⁻¹	120	100
Magnesium	mgL ⁻¹	51.03	150
Sulphate	mgL ⁻¹	--	250
Carbonates	mgL ⁻¹	7	--
Bicarbonates	mgL ⁻¹	--	500
Chloride	mgL ⁻¹	--	250

Table 2 Maximum Recommended Concentration of some Trace Elements.

RESULTS AND DISCUSSIONS

Element	Units	Allowable Limits	
		Irrigation Water (Robbins, 2013)	Drinking Water (WHO, 2011)
Iron	mgL ⁻¹	5.0	0.3
Zinc	mgL ⁻¹	2.0	5
Copper	mgL ⁻¹	0.20	1.5
Lead	mgL ⁻¹	5.0	0.05
Nitrate	mgL ⁻¹	--	10
Chromium	mgL ⁻¹	0.10	0.05
Fluoride	mgL ⁻¹	--	1.5

Concentration of Physical and Chemical Parameters in Groundwater

Determination of pH

The pH values ranged from 7.1 to 7.98, with a mean value of 7.46. The standard deviation of the pH data was 0.20 in (Figures 4.1 and 4.2). All the locations have a pH greater than 7, indicating alkalinity. In 2008, most location were alkaline, but a few samples were acidic. Their pH slightly changed to alkaline in 2020.

A pH greater than 7.5 can affect crop growth and reduce the availability of some trace elements, such as copper and zinc (Virginia Brunton and Ourimbah, 2011). A lower pH can cause nutritional problems and damage to irrigation instruments. Overall, there was no threat to irrigation water or drinking water due to pH, as the standard range for pH, according to FAO and WHO criteria, is 6.5 to 8.5.

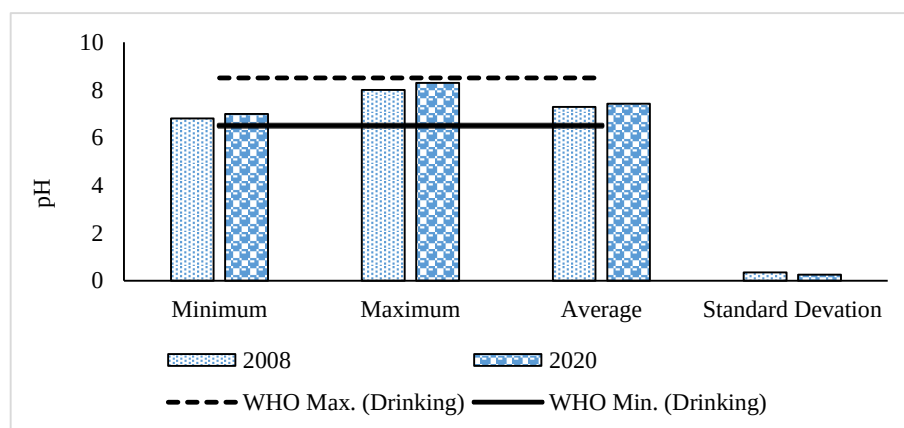
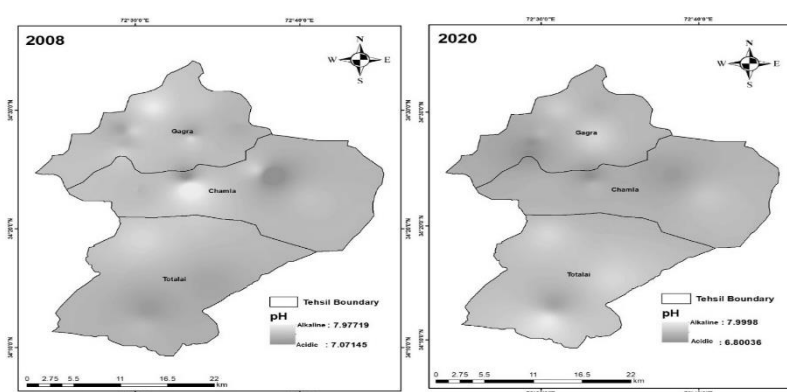


Figure 4.1 pH Classification of the Groundwater Samples.



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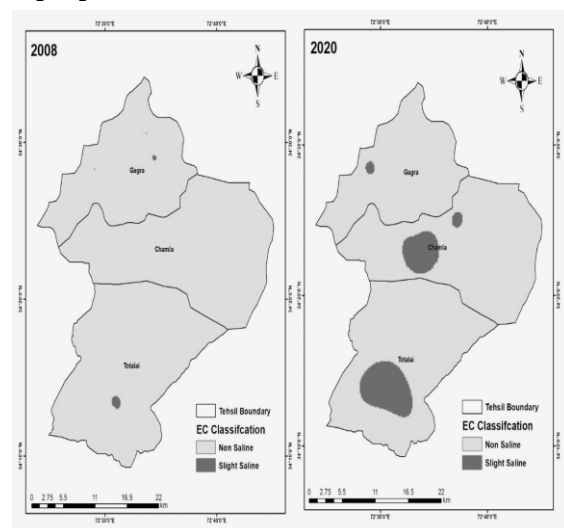
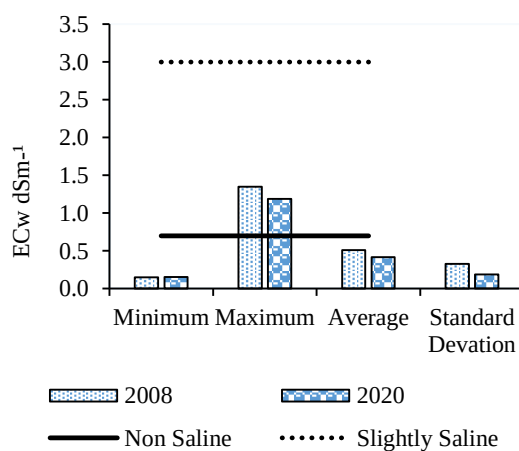
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Figure 4.2 Spatiotemporal Variation of pH in the Study Area.

Electrical Conductivity (EC_w)

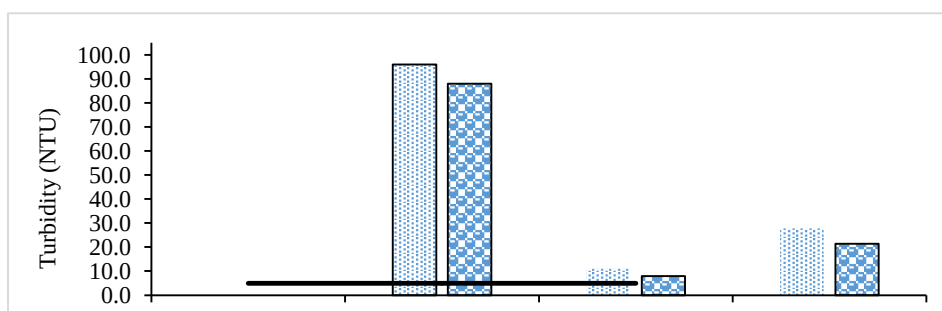
Figures 4.3 and 4.4 present the EC_w (electrical conductivity of water) values of the study area, which ranged from 0.16 dSm^{-1} to 1.15 dSm^{-1} , with an average of 0.42 dSm^{-1} . The statistical analysis showed that the standard deviation of EC data was 0.19. Out of 84 locations, 92.84% were found to be non-saline, 7.14% were slightly to moderately saline, and no samples were severely saline. A comparison study shows that in the study area, including villages such as Amnawar, Swari, Bajkata 4, Ghurghosto 1, and Sura 4, the EC_w values were in the slightly to moderately saline range, which is considered non-severe, in the 2008 study.

Continuous use of saline groundwater for irrigation may lead to soil salinity, which ultimately reduces crop yield and affects soil properties.



Turbidity

Figures 4.5 and 4.6 show the values of turbidity in the locations, which ranged from 0.01 to 88 (NTU), with an average value of 7.97. The standard deviation of turbidity data was 21.44. It was noted that in 2008, some areas had turbidity levels above 5 NTU, which remained the same in 2020. However, samples from specific locations, such as village BAJKATA WS3, WS4, BAJKATA SHINGRAI WS1, DAKARA WS1, WS2, WS3, WS4, TOTALAI WS3, TOTALAI WS4, NAGRAI WS1, WS2, exhibited turbidity levels exceeding the Maximum Recommended Concentration for Drinking Water.



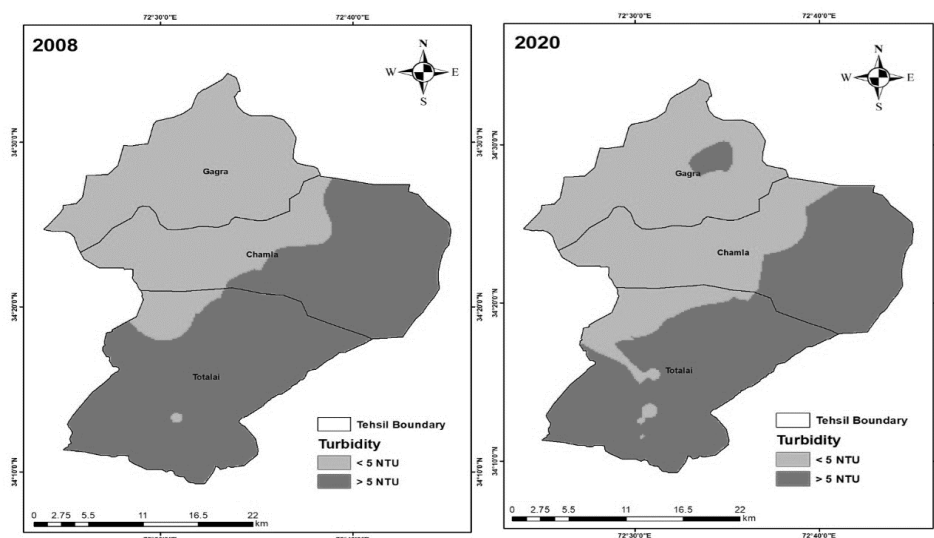
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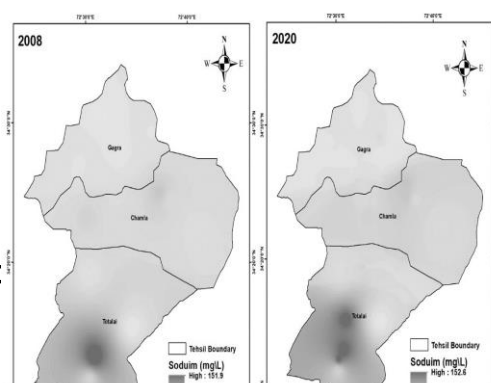
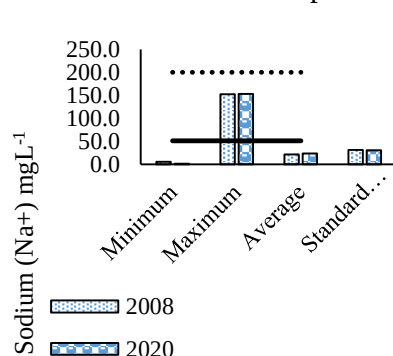


Cations Concentration in Groundwater

The groundwater in the research site was examined for the concentrations of several cations, including Sodium, Potassium, Calcium, and Magnesium, and the results were compared to FAO and WHO criteria.

Sodium (Na^+)

The sodium concentration ranged from 5 mgL^{-1} to 152 mgL^{-1} , with an average of 21.05 mgL^{-1} . The standard deviation of the sodium data was 31.10 mgL^{-1} (Figure 4.7). When comparing the results from 2008 with those from 2020, it was found that four locations from village Ghurghosto had concentrations above the safe limits for irrigation. Furthermore, when comparing the results with the WHO drinking water quality standards, all the locations were within the permissible limits. Sodium occurs naturally in water because of corrosion or saline water intrusion. Sodium accumulates in the soil by irrigating sodium concentrated water, which causes infiltration and drainage problems. Javed (2014) reported similar results in his study conducted in Tehsil Kohat and found that most of the samples had concentration above the safe limit.



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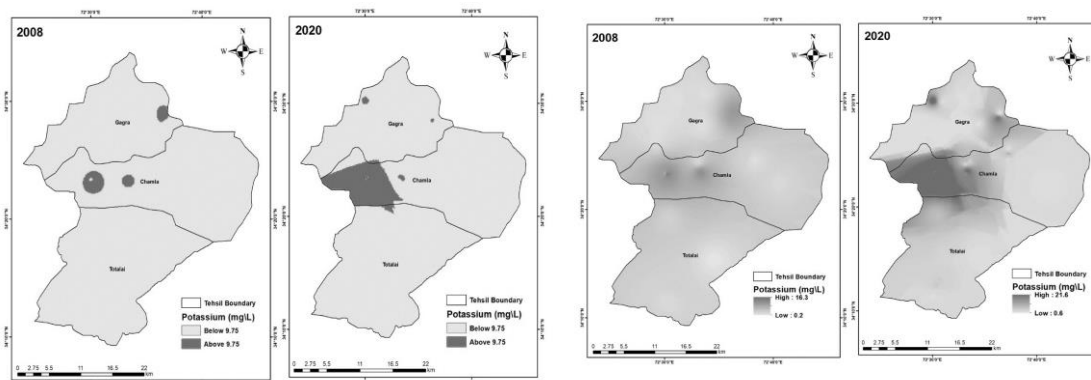
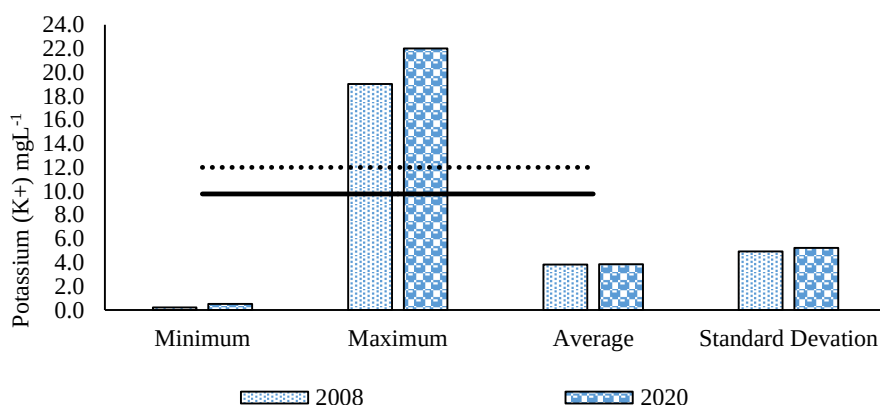
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Potassium (K^+)

Figures 4.8, 4.9, and 4.10 indicate potassium concentration in the groundwater samples. Potassium levels in the study area ranged from 0.20 mgL^{-1} to 22 mgL^{-1} , with an average of 3.84 mgL^{-1} and the standard deviation was 5.21. When comparing the results with irrigation water quality guidelines, it was found that 13 locations (15%) had potassium concentrations above the safe limit. Frequent application of high Potassium in irrigation water may cause the hydraulic conductivity of the receiving soils (C.J Smith 2014). Similarly, 11 locations (13%) had potassium concentrations outside the permissible range for drinking purposes. The impact of high potassium intake can cause vomiting diarrhea shortness of breath and kidney damage. (WHO)



Calcium (Ca^{++})

Figure 4.11 represents calcium value in the groundwater samples. Calcium concentration in the study area ranged from 16 mgL^{-1} to 96 mgL^{-1} with mean value of

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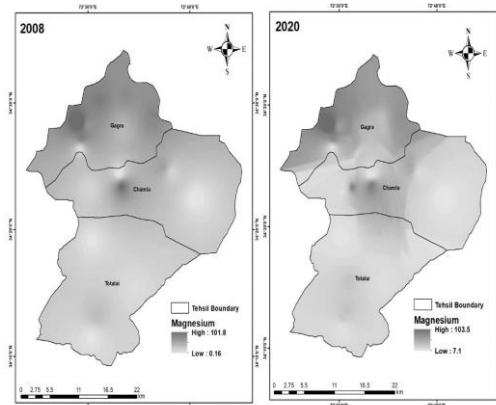
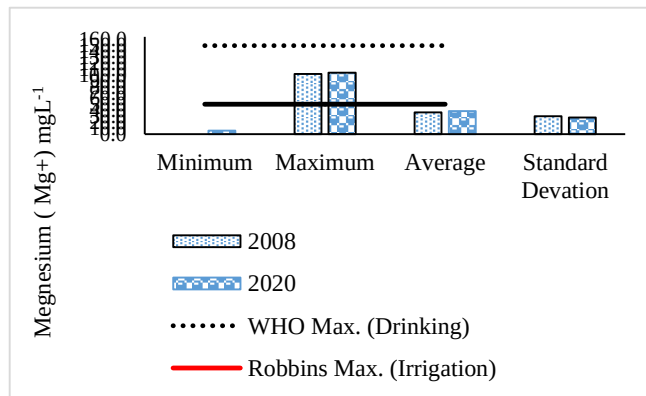
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39.96 mgL⁻¹. Statistical analysis showed that standard deviation was 19.38. Calcium in the study area was found within normal range for irrigation and drinking.

Magnesium (Mg⁺⁺)

Figures 4.11 and 4.12 show the magnesium concentration in groundwater samples. Magnesium levels in the study area ranged from 6 mgL⁻¹ to 104.37 mgL⁻¹, with an average of 39.16 mgL⁻¹. The standard deviation of magnesium (Mg⁺) was 28.35. 38% samples of magnesium concentration for irrigation were found to be within the maximum limit. It is worth mentioning here that all the locations were safe for drinking purposes in both the 2008 and 2020 studies." Soil irrigated with magnesium concentrated water may adversely affect its productivity (Ayers and Westcot, 1985).

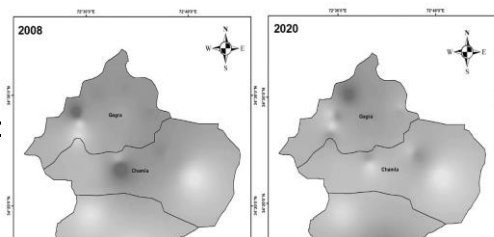
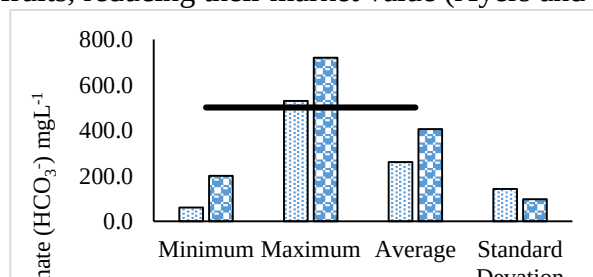


Carbonate (CO₃²⁻)

Carbonate levels in the study area ranged from 0.28 mgL⁻¹ to 16 mgL⁻¹, with an average of 0.53 mgL⁻¹. The standard deviation of the carbonate data was 1.61. When comparing the results with FAO guidelines, it was found that all the locations had carbonate concentrations within the normal range, for irrigation and drinking water.

Bicarbonate (HCO₃⁻)

Figures 4.13 and 4.14 present bicarbonate concentrations in groundwater samples. Bicarbonate levels in the study area ranged from 200 mgL⁻¹ to 720 mgL⁻¹, with a mean of 406.02 mgL⁻¹. Statistical analysis showed that the standard deviation of bicarbonate data was 29.62. When comparing the data from 2008 with that from 2020, it was found that seven locations exceeded the maximum recommended concentration for irrigation, and 8 locations (9%) had bicarbonate concentrations above the safe limit for drinking in the study area. According to Sarkar and Hassan (2006) higher amounts of bicarbonate with high Residual Sodium Carbonate (RSC) values can create permeability problems. Although bicarbonate has no toxic effects on crops, in sprinkle irrigation, irrigating crops with bicarbonate-concentrated water can produce white scale on the leaves and fruits, reducing their market value (Ayers and Westcot, 1985)."



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Chloride (Cl^-)

Chloride levels in groundwater samples in the study area ranged from 0.30 mgL^{-1} to 203 mgL^{-1} , with a mean of 20.70 mgL^{-1} . The standard deviation of chloride data was 19.03. All the locations from both 2008 and 2020 were within the safe range for chloride concentration, which was below 250 mgL^{-1} (WHO standard).

Sulphate (SO_4^{2-})

The values of sulfate concentrations in groundwater samples ranged from 4 mgL^{-1} to 92.36 mgL^{-1} , with an average of 20.70 mgL^{-1} . Statistical analysis showed that the standard deviation was 19.03, and the coefficient of variation was 91.98%. All the locations from both 2008 and 2020 were within the safe range for sulfate concentration, which was below 250 mgL^{-1} for drinking water (WHO standard).

Determination of Heavy Metals

Heavy metals, including Cu, Fe, Zn, Pb, Ni, and Cr, in the groundwater samples were analyzed using an American Society for Testing and Materials (ASTM) standard and the (APHA, 1995) method, employing a Flame Atomic Absorption Spectrometer (FAAS) (Perkin Elmer Analyst 200) and a Beckman DK 2 Spectrophotometer. The results indicated that the concentrations of these specific heavy metals were within permissible ranges for both drinking and irrigation purposes.

CONCLUSIONS

It is concluded that, overall, the water quality analysis suggests that the groundwater in the study area generally meets acceptable standards for both irrigation and drinking purposes. However, some samples showed elevated levels of certain parameters, emphasizing the importance of continued monitoring and management efforts to ensure safe and suitable water quality for the locals. The average pH of the groundwater samples was within the normal range, indicating slightly alkaline water. Electrical conductivity (EC_w) results suggested that the groundwater was mostly non-saline, with only six locations (7%) showing slight to moderate salinity, and none were severely saline. Turbidity levels were generally low, with most areas having values below 5 NTU. Only eleven locations (13%) exceeded the Maximum Recommended concentration for turbidity in drinking water. Sodium concentration in the samples met irrigation water quality guidelines, with only four locations (5%) from Ghurghosto village exceeding safe limits. All samples complied with drinking water quality standards. Potassium concentration results indicated that thirteen locations (10.92%) exceeded safe limits for irrigation, and eleven locations (9.24%) were outside

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permissible ranges for drinking purposes. Calcium levels in the study region were generally within the normal range for irrigation and drinking water. Magnesium concentrations in thirty-two locations (38%) exceeded maximum limits for irrigation, but all locations were safe limits for drinking water. Carbonate concentration was within the normal range for all the locations. Bicarbonate concentrations in seven locations (8%) were above the limits for irrigation and eight samples (9%) that for drinking water, exceeding recommended concentrations. Sulfate, and chloride concentrations in the groundwater locations were all within normal limits according to standards. Heavy metal analyses, including copper (Cu), iron (Fe), zinc (Zn), lead (Pb), nickel (Ni), and chromium (Cr), were performed and found to be within acceptable limits.

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