QUALITY ASSESSMENT USING ANALYTICAL METHODS AND SPATIAL DISTRIBUTION OF GROUND WATER ATTRIBUTES IN FAISALABAD DISTRICT, PUNJAB PAKISTAN

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ABSTRACT

Water is vital for all living beings and is crucial for sustaining human civilization, ecosystems, and food security. Groundwater, constituting 30% of the world's freshwater, serves as a primary drinking water source. However, rapid industrialization has led to groundwater pollution, caused by various hazardous chemicals discharged by industries. To assess the quality of groundwater in Faisalabad district's industrial zone, a study collected samples from 40 locations and used physiochemical analysis and IDW interpolation techniques to create groundwater quality maps, revealing minimum and maximum values of pH (7.175 to 8.899 mg/l), TDS (182.90-444.5 mg/l), sulphate (80.08-449.77 mg/l), nitrite (0.00004-2.998 mg/l), chloride (5.439-388.55 mg/l), calcium (10.125-347.24 mg/l), sodium (7.254-1378.8 mg/l), potassium (3.126-44.156 mg/l), Total hardness (80.05-983.77 mg/l) in Faisalabad. Researchers employed GIS (Geographic Information System) to analyze the spatial distribution of various physico-chemical parameters. The study utilized ARC GIS 10 software to create spatial variation maps. The investigation focused on groundwater quality mapping in Faisalabad, aiming to identify suitable water sources for agriculture and drinking. Unfortunately, the findings indicated unfavorable groundwater conditions for these purposes. To make the water safe for human consumption and control pollution, improvements in treating industrial and sewage effluents are necessary.

Keywords: Ground water, physio-chemical parameters, industrial waste water, spatial distribution maps, inverse distance weighted (IDW)

Introduction

1.1 Introduction to Water Importance and Sources:

Water is most important for all living plants, animals and human beings (Rosa et al., 2020). More than a third of the water consumed worldwide originates from underground sources, supplying approximately 42%, 36%, and 27% of the water used for agricultural, domestic, and industrial purposes, respectively (Döll et al., 2012).

1.2 Groundwater and Hydrological Cycle:

Groundwater is a key irrigation source in Pakistan, along with surface water and rainwater, all dependent on the ever-changing hydrological cycle (Allen & Ingram, 2002). Pakistan's economy heavily relies on the agriculture sector, fulfilling irrigation water needs through groundwater (Natasha et al., 2020). Excessive groundwater pumping for agriculture and industry lowers levels and degrades drinking water quality (Umar et al., 2022). Water scarcity crisis intensifies due to declining water availability, population growth, and changing climatic conditions in multiple regions (Sarwar et al., 2021).

1.3 Groundwater as a Vital Resource:

Groundwater is a crucial global resource, supplying 50% of potable water, 40% of industrial water, and 20% of irrigation needs (Molden, 2013). Assessing and maintaining groundwater quality is crucial to prevent declining quantity and quality due to inadequate management (Gharbia et al., 2016). Effective groundwater quality management requires reliable quantitative data on groundwater behavior. Investigating the spatial behavior of groundwater quality is crucial for credible interpretations and accurate estimations, involving geostatistics approaches to establish relationships between sample distances, directions, and various quantities (Eslami, Dastorani, Javadi, & Chamheidar, 2013).

1.4 Industrial Pollution and Groundwater Contamination:

Faisalabad, a major industrial city in Pakistan, faces a critical environmental issue due to the disposal of large amounts of organic and inorganic waste, including heavy metals, into natural water sources. This poses significant risks to the environment, groundwater, surface water, and human, plant, and animal health (Pavithra, Devi, Suneetha, & Rani, 2017). After gaining independence, Faisalabad rapidly advanced in diverse industries like paper, leather, textile, sugar, vegetable oil, dying, soaps, and detergents (Association, 1926). The area's major industry is textile production with 200 small- and large-scale units, involving various toxic chemicals and generating significant volumes of toxic wastewater, including heavy metals and poisonous dyeing ingredients (Srinivasan, Bhavan, & Krishnakumar, 2014). Improper wastewater management leads to contaminated groundwater with chemicals and heavy metals, causing numerous diseases when used for drinking and irrigation. Approximately 40% of Pakistan's diseases are attributed to polluted water consumption (Ashraf, 2015).

1.5 Water Quality Parameters and Water Quality Index (WQI):

Geostatistical analysis uses statistical models to explore spatial data and create groundwater quality maps (Yidana, Banoeng-Yakubo, & Akabzaa, 2010). The Water Quality Index (WQI) is a powerful tool to convey water body quality information by converting extensive data into a single numerical value, benefiting citizens and policymakers (Singh & Hussian, 2016).WQIs are commonly used to assess water quality, but their effectiveness is limited by resource constraints and decision-making complexity (Payton, Khubchandani, Thompson, & Price, 2017). Horton's method defines the US Water Quality Index (WQI) based on widely used metrics like pH and dissolved oxygen, also adopted in Asia, Africa, and Europe, with additional parameters like chloride and alkalinity. Brown et al. proposed a similar index based on parameter weights. Recently, experts and researchers have explored several modifications to WQI tools (Dwivedi, Tiwari, & Bhargava, 1997). Various methods used for evaluating water chemistry and quality in rivers, with water indexes proving to be the most efficient in communicating information to stakeholders and the public (Salcedo-Sánchez, Garrido Hoyos, Esteller Alberich, & Martínez Morales, 2016).WQI simplifies data from various sources into one value, expressing the overall status of a water system logically (Ferahtia, Halilat, Mimeche, & Bensaci, 2021). Water quality index (WQI) is a rating representing the combined impact of various water quality parameters Deininger (Scottish Development Department, 1975) enhanced the initial WQI concept introduced by a previous researcher (Horton, 1965).

1.6 Inverse distance weighted (IDW):

The IDW method, a widely used geostatistical interpolation technique, predicts target parameters in hydrology science (Rostami, Isazadeh, Shahabi, & Nozari, 2019). It was developed for mapping and predicting spatial distribution maps, such as water quality parameters (Aminu, Matori, Yusof, Malakahmad, & Zainol, 2015).

1.7 GIS and Groundwater Monitoring:

GIS is a valuable tool for hydrologists, aiding in water resource management by capturing, analyzing, and presenting location-linked data efficiently. It stores and manages both spatial and non-spatial information (Sana'a Odat, Azzam, & Dominik, 2015). GIS is an evolving technology that requires efficient data processing and expertise for unified environmental simulation models, utilizing methods like internet, Global Positioning Systems, and Remote Sensing (Alshehri & Abdelrahman, 2023). GIS simplify mapping sampling areas, enabling water quality mapping with informative and user-friendly results (Singh & Hussian, 2016). ArcGIS Geostatistical Analyst creates continuous surface maps from sample points, aiding in visualizing and analyzing spatial phenomena, such as groundwater quality distribution. It efficiently analyzes complex spatial data for mapping groundwater properties (Omran, 2012). Its advantages in groundwater monitoring include effective storage and analysis of spatial and temporal data, depicting pollutant-source relationships, visualizing water quality changes, and managing river basins through buffer zones based on water quality criteria. It is useful for groundwater modeling, analyzing variations in groundwater quality over decades, and developing conceptual groundwater models with additional layers of information (R. Goyal & Arora, 2004).

Researchers applied geostatistical analysis using kriging and Inverse Distance Weighting (IDW) interpolation (S. K. Goyal, Chaudhary, Singh, Sethi,

& Thakur, 2010) GIS is used to identify parameter values and perform zonal statistics at administrative or geophysical boundaries. It integrates spatial and temporal data for assessing quality parameters, including groundwater, in various land uses (Ding et al., 2016). (Banerjee, Ahmed, Bhuyan, & Baruah) Geographic data and GIS were used to assess groundwater quality in Gulbarga City, Karnataka, India. Water samples from 76 boreholes and open wells across the city were tested for physicochemical attributes and compared to standards, resulting in groundwater quality maps for the entire study area.

In the present work, not only groundwater quality assessment has been carried out by different statistical tools but groundwater quality is also mapped with spatial distribution of population to understand percentage of population falling under unacceptable groundwater quality area. This could be useful to planners for water resources planning of the area.

The objectives of the study were to: (1) offer an overview of current groundwater quality and (2) establish the spatial distribution of groundwater quality measures such as electrical conductivity EC, Calcium Ca^{+2}, Potassium K^{+} , Magnesium Mg^{+2}, Sulphate SO_4 , Total Dissolved Solids TDS, Chloride Cl , pH, Sodium Na^{+} , Bicarbonates HCO_3 and (3) to map irrigation water quality in the study area (Faisalabad district) in order to identify places with the best quality for irrigation within the study area by using Geographical Information System GIS and Geostatistics techniques. This study will help engineers, decision-makers, and managers manage groundwater quality control operations.

2. RESEARCH METHODOLOGY

Groundwater tests from various locations in Faisalabad were analyzed using scientific techniques to assess the impact of pollutants. Samples were collected from 40 sites along different roads and nearby areas, approximately 5 to 6 km apart, for evaluating their physicochemical properties.

2.1 Material

Beakers, Forceps, Smooth –tipped, Graduated Cylinders, Dish Tongs, Gooch Crucibles, Vacuum Pumps, Crucible tongs, 100, 250 and 500 ml volumetric flasks, 10 and 20 ml pipettes, 250 ml conical flask, pH indicator papers, 10 and 100 ml measuring cylinders, Burettes, Stand, Dropper, Glass funnel, Burette stand, Stirrer, wash bottle, membrane filtration, petri dishes, Forceps, and Reference cell were used for the water quality parameters (Omer, 2019).

2.2 Chemicals

Distilled water, Buffer solutions of pH 4 and pH 7, EDTA, Dilute hydrochloric acid solution, Sodium hydroxide solution, Dilute sodium hydroxide solution, NH_3CL, Eriochrome Black-T, Magnesium Carbonate, Ammonia Buffer, 90% Ethyl alcohol, standard silver nitrate titrant, Potassium chromate indicator solution, Sodium hydroxide, Acetic acid, Potassium nitrate, Brucine-sulfanilic acid reagent, Sulfuric acid solution, Sulfuric acid solution, Stock solutions of sodium and potassium were used for analysis of water quality parameters (Gorde & Jadhav, 2013).

2.3 Instruments

The incubator, flame photometer, thermometer, UV-VIS spectrophotometer, pH meter, Electric oven, Magnetic stirrer, orbital shaker, Octagon sieve, weighting balance were used in ground water quality parameter analysis (Dohare, Deshpande, & Kotiya, 2014).

2.4 Sampling Methods and Labeling of the samples

Groundwater pollution surveyed in residential and rural areas using standard methods, collecting samples in 2-liter polypropylene containers washed with nitric acid and demineralized water before sample collection (Wagner, 1995). Each example was coded enough and imprint code on testing bottles by indelible marker at two spots, recorded all the data with respect to name of the examining area, source and date of assortment in field book to keep away from any disarray and mistake (Sundaram et al., 2009).

2.5 Sampling Sites

Faisalabad, Pakistan, dubbed the "Manchester of Pakistan," is the third-most-populous city, cover 1300 sq km (coordinates: 31° 25' 7.3740" N, 73° 4' 44.7924" E). Forty samples collected from various areas in the district, about 5-6 km apart, displayed notable physiochemical analysis differences (Ullah et al., 2022).

Figure 2.1: *Faisalabad map*

2.6 Collection and Examination of samples

Groundwater samples were collected from forty locations in Faisalabad after flushing the bore wells/hand siphons. The samples were carefully collected, sealed, and preserved at room temperature for testing (Davis & Carpenter, 1990). Groundwater tests from various locations were analyzed for contamination levels and presence of physicochemical parameters and heavy metals. Parameters included color, odor, taste, pH, TDS, total hardness, and various elements like Ca, Mg, Na, K, Cl, NO3, SO4, Cl2, and coliforms (Gholizadeh, Melesse, & Reddi, 2016).

2.7 Standard Methods Adopted For Ground Water Analysis

Groundwater samples from different locations were analyzed for pollution levels using standard methods outlined in the 17th edition of the APHA, AWWA, and WPCF guidelines. Physicochemical parameters were measured to assess pollution levels (Halden, Happel, & Schoen, 2001). pH and TDS were measured using the Electrometric and electrode methods, respectively, while heavy metals were determined through various calibration-based methods using standard metal solutions after acidification and filtration of water samples in glass volumetric flasks (Masura, Baker, Foster, & Arthur, 2015).

Table 2.1: *Standard values of ground water parameter*

S.no	Parameter	Standard Value
1	Power of hydrogen(pH)	6.5 -8.5
2	Total Dissolved Solid (TDS)	500
3	Total Hardness (TH)	250
4	Calcium(Ca)	100
5	Magnesium(Jefferies)	50
6	Sodium (Na)	100
7	Nitrite (NO_2)	1.0
8	Sulphate (SO_4)	250
9	Chloride (Cl)	250
10	Potassium (K)	10
11	Chlorine (Cl2)	0.1
12	Total coliform	0/250 ml
13	E/fecal coliform	0/250 ml

2.10 Experiment

2.10.1 Color analysis

The colors of water samples was observed by naked eye. The visual method is the simplest since it consists of a water sample being compared to a series of colored slides or tubes (Jaquet & Zand, 1989).

2.10.2 Odour analysis

Filled the 500 ML flask with around 200 ML of sample. Close the stopper. Shake the well at room temperature. Opened the flask and smell at the mouth of the flask (Callejón, Ubeda, Ríos-Reina, Morales, & Troncoso, 2016).

2.10.3 Taste analysis

Take some water in separate clean bottle and shake it well. Then taste a sip of water noted its taste (Du et al., 2022).

2.10.4 pH analysis

pH was measured with an OHAUS ST2100 pH meter using hydrogen ions activity and potentiometric measurement. Calibration was done with pH 4 and pH 7 buffers before recording readings from a 50ml sample in a clean beaker (Gorde & Jadhav, 2013).

2.10.5 TDS (Total Dissolved Solids) analysis

A conductivity meter electrode was employed to measure TDS (Total Dissolved Solids) in a shaken 50 ml sample. The resulting value was recorded in mg/L after rinsing the electrode with distilled water (BIS, 2012).

2.10.6 Calcium analysis

In the calcium hardness determination, 1.5 ml of Ca^{2+} buffer and a spatula of calcium indicator were added to a 50 ml sample. Titration with 0.01N EDTA was done promptly due to the indicator's instability in alkaline conditions (Sedlak & von Gunten, 2011).

2.10.7 Magnesium analysis

For magnesium hardness determination, 1.5 ml of Mg^{2+} buffer was added to a 50 ml sample. The indicator was added, and titration with 0.01N EDTA was performed promptly due to indicator instability in alkaline media (Sarda & Sadgir, 2015).

2.10.8 Total hardness analysis

For total hardness determination, a 1.5 ml Mg^{2+} buffer was added to a 50 ml sample, followed by adding the indicator. Prompt titration with 0.01N EDTA was done due to indicator instability in alkaline media (Zafar, Mobeen, Ghani Rahman, & Iqbal).

Table 2.2: *Classification of ground water on the basis of total hardness*

Sr.no	Total hardness concentration (mg/L)	Classification
1	0-60	Soft
2	61-120	Moderately Hard
3	121-180	Hard
4	>180	Very Hard

2.10.9 Chloride analysis

The sample was diluted and titrated against silver nitrate with potassium chromate indicator until a color change occurred, and the titrant amount was recorded (Gupta, Vishwakarma, & Rawtani, 2009).

2.10.10 Nitrite analysis

Nitrates were measured using a spectrophotometric method at 550 nm wavelength. Standard concentrations of 2 and 20 were used with nitrate buffer, and readings were recorded for samples with a volume of 50 ml (Boyd, 1990).

2.10.11 Sulphate analysis

Photometer cell with distilled water set at 525nm wavelength and reading at 100. Sample with sulphates turbidity reagent added, measured in 2nd cell, and difference in readings recorded (Jaquet & Zand, 1989).

2.10.12 Sodium analysis

Sodium ions were quantified using a flame photometric method at 589 nm wavelength. Highly concentrated samples were diluted if indicated by high conductivity, and standardized equipment analyzed each sample individually using 1 ml for analysis (Carpenter, 1993).

2.10.13 Potassium analysis

Potassium was quantified using a flame photometric method at 766.5 nm wavelength. Highly concentrated samples were diluted, and 1 ml of each sample was analyzed using a frame spectrophotometer (Nasir et al., 2016).

2.10.14 Free Chlorine analysis

A photometer was calibrated at 410nm with distilled water as 100 reading. Then, 25ml sample with 5 drops of Free Chlorine Reagent was measured, and the difference in readings was noted (White, 1975).

2.10.15 Total coliform analysis

Sterilize equipment. Filter 250ml sample, incubate Petri Dish with media for 24 hours at 35°C. Count red colonies with metallic sheen for total Coliform bacteria presence. Ignore other spots (Daud et al., 2017).

2.10.16 E-coliform/ Fecal coliform analysis

Sterilize equipment. Pour media into Petri Dish. Filter sample. Incubate at 35°C for 24 hours. Observe red colonies with metallic sheen (Total Coliform). Incubate at 41°C for 24 hours. Observe blue colonies with metallic sheen (Fecal Coliform/E. coli). Count colonies, ignore other spots (Zainab et al., 2021).

2.11 Geographic Information System Method

The study employed GIS to create shape files of Faisalabad, Pakistan, and generate spatial distribution and water quality index maps for comparing groundwater physicochemical properties in industrial areas. Microsoft Excel 2013 facilitated data importing into ArcGIS, the preferred software for spatial analysis over other GIS options (Rashid, Asad, Nasir, Chaudhary, & Sattar, 2018).

2.11.1 ArcGIS (10) Software

ArcGIS 10 software and Spatial Analyst modules were used to analyze groundwater quality parameters (e.g., hardness, pH, TDS) and create a quality map using GPS data and Inverse Distance Weight interpolation (Aleem et al., 2018).

2.11.2 IDW

DW interpolation uses a power function to predict surfaces based on nearby sample points, emphasizing local variations. The precision of IDW is influenced by the number of closest neighboring samples and the chosen power value (Mirzaei & Sakizadeh, 2016).

3. RESULTS AND DISCUSSION

Groundwater is a crucial water source for both urban and rural areas due to limited access to clean surface water. However, it faces challenges like high fluoride causing skeletal issues and elevated nitrate leading to methemoglobinemia, mainly due to inorganic chemical pollution, poor sanitation, and waterborne diseases in agricultural nations.

3.1 Variation of Physico-chemical characteristics

The resulting maps and results showed that which areas had groundwater that was fit for drinking and other uses.

Table 3.1: *Variation of physico-chemical characteristics of groundwater of Faisalabad*

Sr.no	Variables	Minimum	Maximum	Mean
1	pH	7.1	8.8	7.95
2	TDS	182	3444	1813
3	Calcium	10.1258	347.242	178.68
4	Magnesium	10.407	139.90	75.1535
5	Total hardness	80	983	531.5
6	Chloride	5.439	388.55	196.99
7	Nitrite	0.00004	2.998	1.499
8	Sulphate	80	449	264.5
9	Potassium	3.167	44.156	23.6615
10	Sodium	7.254	1378.81	693.032
11	Total coliform	9	Unlimited	Unlimited
12	E/fecal coliform	12	1	6.5

Groundwater assessments were analyzed to determine maximum, minimum, and average values using GIS software. Concentration values were classified according to WHO (2004) drinking water guidelines.

3.2 Values of physico-chemical parameters for ground water samples

The water quality parameters of groundwater samples were presented in Tables 4.2 and compared to WHO's recommended limits.

Table 3.2: *Values of physio-chemical parameters for ground water samples*

Sample no.	Longitude	latitude	pH	TDS	Ca	Mg	TH	Chloride	Nitrite	SO_4	K	Na	Free chlorine	Total coliform	E/fecal coliform
1	72.9022104	31.4777383	8	740	45	55	330	60	0	190	17.2	124	NA	NA	NA
2	72.961647	31.4589691	8.3	1250	110	45	480	150	0	310	12.4	324	NA	NA	NA
3	73.0223307	31.4385938	8.7	2560	170	140	890	310	2	400	22	900	NA	NA	NA
4	73.0487678	31.4063112	7.6	3250	340	75	920	300	2	420	30	1050	NA	NA	NA
5	73.08475714	31.43308707	8.1	1360	100	60	460	45	0	290	12.4	360	NA	NA	NA
6	73.100888	31.4587392	8.1	330	25	12	90	10	0	140	4.3	48	NA	NA	NA
7	73.1203924	31.5019454	8	1040	96	60	490	250	0	270	10.5	255	NA	NA	NA
8	73.1646687	31.5277881	8.6	2810	180	120	840	390	2	390	20	1010	NA	NA	NA
9	73.1970706	31.530487	8.8	200	10	12	80	25	0	140	4.3	11	NA	4 colonies	2 colonies
10	73.23074643	31.48178943	8.6	580	45	27	220	48	0	200	11.8	113	NA	NA	NA
11	73.2108012	31.473404	7.5	180	30	10	100	30	0	150	4	4	NA	NA	NA
12	73.2853704	31.5048553	7.4	1880	108	60	590	260	1	400	14.5	540	NA	9 colonies	5 colonies
13	73.0891807	31.4169429	7.6	890	70	50	390	85	0	240	13.7	110	NA	NA	NA
14	73.08145	31.42045	7.8	950	90	30	400	40	0	240	18.6	196	NA	NA	NA
15	73.0866893	31.447299	8.2	3300	150	90	870	300	3	440	22	980	NA	NA	NA
16	73.070642	31.429668	8.2	580	48	40	280	40	0	200	12.7	90	NA	NA	NA
17	73.07078259	31.41577064	7.1	660	60	30	270	80	0	200	15.7	112	NA	NA	NA
18	73.07888889	31.42916667	7.4	790	28	42	240	90	0	210	12	198	NA	5 colonies	2 colonies
19	72.990164	31.35899856	8.1	3460	190	120	950	380	3	450	32	1380	NA	Unlimited	12 colonies
20	73.1089689	31.41684306	7.8	3040	300	55	900	310	2	410	29	940	NA	3 colonies	1 colony
21	73.143996	31.3987056	7.9	2260	152	125	870	260	2	390	24	635	NA	NA	NA
22	73.17495089	31.394823	7.6	3070	320	60	950	310	2	420	24	1070	NA	NA	NA
23	73.09714	31.42999	8	2010	120	80	670	115	1	350	25	590	NA	NA	NA
24	73.185196	31.35883	7.4	1320	100	50	470	250	0	275	10.4	316	NA	7 colonies	3 colonies
25	73.1054	31.4030888	8.1	3460	190	120	950	380	3	450	31	980	NA	NA	NA
26	73.12781	31.381	7.5	1770	130	70	550	80	1	330	44.4	376	NA	NA	NA
27	73.0737312	31.4829822	8.6	2490	160	100	800	370	2	390	22	1200	NA	NA	NA
28	73.13769	31.45949	7.5	3220	350	70	990	350	2	435	5	25	NA	NA	NA
29	73.03264	31.30215	8	270	16	13	90	5	0	160	5.2	24	NA	NA	NA
30	72.99911	31.21681	8.1	220	24	15	120	20	0	90	3.1	13	NA	9 colonies	4 colonies
31	73.02769	31.31567	8.4	180	12	15	90	20	0	150	10	58	NA	NA	NA
32	72.9707969	31.0705855	7.4	490	45	32	250	40	0	180	16	202	NA	NA	NA
33	73.373	31.349	8.8	490	145	30	910	15	0	100	16.5	189	NA	NA	NA
34	73.316	31.313	8	3350	182	72	560	300	0	430	12.7	1150	NA	NA	NA
35	73.331	31.26	8.9	2100	320	132	100	35	0	175	18.5	520	NA	NA	NA
36	73.355	31.179	8.4	3420	60	65	750	380	1	80	33	45	NA	NA	NA
37	73.09	31.147	8.7	2270	190	140	930	74	1	390	28	70	NA	NA	NA
38	73.182	31.105	7.6	1730	17	25	620	155	0	220	24	860	NA	NA	NA
39	73.197	31.001	7.9	1150	26	90	80	280	0	190	31.6	960	NA	13 colonies	9 colonies
40	73.132	30.924	8.1	640	330	130	860	330	3	430	42	1320	NA	NA	NA

3.3 Physical parameters:

Water's diverse properties impact human health, necessitating careful measurement of its quality due to potential significant consequences from even slight alterations.

3.3.1 Odor, color, taste

The drinking water quality is assessed based on odor, taste, and color. The prescribed limits for odor, color, and taste are colorless, unobjectionable taste, and odor. In this study, odor and color were found to be within limits, but most samples had objectionable taste due to contamination. The taste analysis did not meet WHO standards, possibly due to elevated levels of sodium, chloride, manganese, iron, or low pH, causing taste and odor issues. Serious pollutants from man-made chemicals may also affect water quality, particularly in areas near landfills and industrial sites. Changes in chemical usage for water treatment systems in public water systems could also impact taste or smell.

3.4 Chemical parameters

Chemical parameters of ground water includes the pH, TDS, Calcium, Magnesium, Potassium, sodium, Total hardness, chloride, Nitride, Sulphate, Free chlorine, Total coliform, E/fecal coliform analysis.

3.4.1 Map for pH

pH measures acidity or alkalinity, with a range of 0-14. pH values below 4.0 taste sour, and above 8.5 taste alkaline. The recommended pH range is 6.5-8.5. The groundwater samples in Faisalabad had pH values ranging from 7.175 to 8.899. A pH map was created using ArcGIS 10, showing various pH levels across the district. pH values above 7 were found, possibly due to runoff picking up chemicals from industries, raising the pH. High pH water can cause scaling in water heating systems and skin issues. pH variations may also result from soil and mineral content, influenced by waste disposal.

Figure 3.1: *PH map for Faisalabad city*

3.4.2 Map for TDS

Groundwater TDS levels indicate inorganic substance disintegration in water. Groundwater usually has higher TDS compared to surface water, acting as a salinity indicator. TDS in groundwater results from Calcium, Magnesium, Sodium, Potassium, Bicarbonate, Chloride, and Sulfate presence. Drinking water TDS limit is 500 mg/L, but most samples exceed this. The TDS map of Faisalabad region illustrates different ranges, suggesting pollution sources like agricultural activities and domestic wastewater discharge, which can have health implications. Increased electrical conductivity corresponds to higher TDS, potentially leading to health issues like cancer and coronary heart disease.

Figure 3.2: *TDS map for Faisalabad city*

3.4.3 Map for Calcium

Calcium is abundant in water and plays a crucial role in water solidification. In Faisalabad, calcium levels in groundwater samples ranged from 10.12 to 347.24 mg/L, exceeding WHO's recommended limit in some cases. The calcium map using Arc GIS 10 shows different ranges of calcium levels in the district. Some samples were within the permitted limit, while others were above it, potentially leading to hardness in water due to calcium carbonate. High calcium levels are associated with sewage and calcium-rich rocks. Drinking calcium-rich water regularly may lead to heart disease and kidney stone formation.

Figure 3.3: *Calcium map for Faisalabad city*

3.4.4 Map for Magnesium

Magnesium is a prevalent component in natural water, contributing significantly to water hardness. Its levels vary in groundwater studies but are generally lower than calcium hardness. A study in the Faisalabad district found magnesium levels ranging from 10.40 to 139.90 mg/L, some exceeding the WHO limit. Arc GIS 10 created a magnesium map indicating different levels. Samples within 10.40 to 24.79 mg/L were within limits (green), while higher ranges were represented by various colors. Magnesium levels over 90 mg/L are considered very hard, sourced from rocks and industries. Excessive magnesium intake can lead to severe health consequences.

Figure 3.4: *Magnesium map for Faisalabad city*

3.4.5 Map for Total hardness

Water hardness is caused by multivalent metallic cations, primarily calcium and magnesium, found in soil and rock formations. It hinders soap foam production and requires more soap for washing. The study conducted in Faisalabad showed total hardness concentrations ranging from 80.05 to 983.77 mg/L. Arc GIS 10 was used to create a total hardness map with different color hues representing various hardness ranges. Some samples were within the permitted limit (80.05 to 180.47 mg/L), while others exceeded it. Groundwater tends to be harder than surface water due to its solubilizing property with rocks containing gypsum, calcite, and dolomite. Contamination from sewage and runoff can also contribute to hardness. Drinking this water could lead to health issues due to high calcium concentrations causing kidney stone formation and heart diseases.

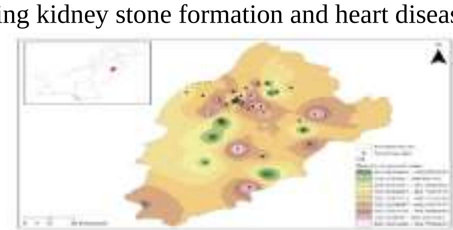

Figure 3.5: *Total hardness map for Faisalabad city*

3.4.6 Map for Chloride

Chloride, present in various water sources, is usually found in low concentrations in fresh water, with acceptable levels below 250 mg/L. It is used to identify groundwater contamination from wastewater. In some regions, evapotranspiration can increase chloride and salinity levels, affecting plant water absorption. The study conducted in Faisalabad found chloride concentrations ranging from 5.43 to 388.55 mg/L, with some readings exceeding the WHO limit. The presence of chloride in groundwater can be attributed to various sources, including sewage discharge, industrial waste, and erosion of chloride-containing minerals. Excess chloride intake can lead to health issues, such as kidney stones and metabolic acidosis.

Figure 3.6: *Chloride map for Faisalabad city*

3.4.7 Map for Nitrite

Nitrite particles are typically present in low concentrations and are found in waste treatment plant effluents at generally low levels due to the existence of nitrogen in other forms. Nitrite serves as an intermediate in the oxidation of ammonia to nitrate. Groundwater samples from Faisalabad ranged from 0.000040 to 2.99 mg/L of nitrite, with a maximum allowable limit in drinking water being 1.0 mg/L. The Arc GIS 10 program was used to create a nitrite map, showing different nitrite levels in various areas of Faisalabad. The presence of nitrite in water samples indicates potential sewage contamination, and its reaction with organic compounds can produce carcinogenic nitrosamines. The low nitrate levels in the research area suggest limited agricultural activity near the sampling sites.

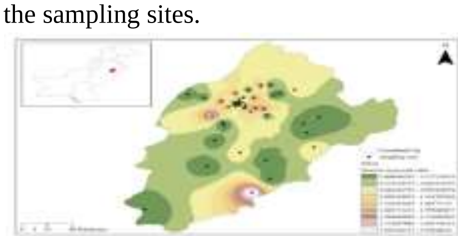

Figure 3.7: *Nitrite map for Faisalabad city*

3.4.8 Map for Sulphate

Sulphate is a common anion found in water bodies due to various natural minerals. It contributes to water hardness and mineral content. The permissible limit of sulphates in drinking water is 250 mg/L. A study in Faisalabad found sulphate concentrations ranging from 5.439 to 388.55 mg/L, with some exceeding the limit. ArcGIS 10 was used to create a sulphate map showing different concentration ranges. The presence of sulphates in water can be attributed to industrial processes and other sources, and high concentrations may have soothing effects but can lead to dehydration. Drinking water with sulphate levels over 250 mg/L is not recommended.

Figure 3.8: *Sulphate map for Faisalabad city*

3.4.9 Map for Potassium

Potassium is an essential nutrient found in both plant and animal tissues, primarily sourced from the diet, particularly fruits and vegetables. Intoxication through ingestion is rare due to its rapid discharge from the body. The study in Faisalabad revealed varying levels of potassium in groundwater samples, some within the permissible limit (3.126 to 7.685 mg/L) and others exceeding it. The ArcGIS 10 software was used to create a map showing different potassium ranges in the region, represented by distinct colors. The wide range of potassium concentrations in water samples could be attributed to inadequate groundwater management and potential contamination. Excessive intake of potassium can overwhelm kidney functions and lead to fatal kidney failure.

Figure 3.9: *Potassium map for Faisalabad city*

3.4.10 Map of Sodium

Sodium is a significant cation found in most fresh waters, and while it's generally considered safe at normal levels from food and drinking water, high intake can be hazardous for people with certain health conditions. In the Faisalabad district, groundwater samples showed sodium levels ranging from 7.254 to 1378.813 mg/L. Some samples exceeded the WHO limit of 250 mg/L, while others were within an acceptable range. The sodium map created using ArcGIS 10 depicted different sodium levels with various color tones. Excessive sodium intake from water in areas with intensive agriculture can lead to health issues, and water with more than 100 mg/L sodium is not recommended for those on a low-sodium diet.

Figure 3.10: *Sodium map for Faisalabad city*

3.4.11 Map for free Chlorine

Chlorine is widely used for dating old groundwater, produced through atmospheric interactions and mixed with natural air chloride before being deposited on the land surface. Groundwater recharge carries chlorine into the subsurface where dating takes place. Groundwater age is estimated by measuring the radiometric decay and chlorine reduction from recharge water. However, variations in groundwater chlorine levels complicate the process. In a study in Faisalabad, chlorine levels in drinking water were below the WHO limit of 0.1 mg/L, with readings ranging from 0.0 to mg/L in groundwater assessments.

3.5 Bacterial parameters

Bacterial parameters of ground water includes the *total coliform and E coliform and fecal coliform* analysis.

3.5.1 Map for Total coliform *E/ Fecal Coliform*

Coliform microbes are divided into Aggregate and Fecal Coliform based on their origin. The Fecal Coliform, mainly Escherichia coli (E. coli), is found in the intestines of mammals and humans, as well as in waste and soil. Detection of these microorganisms in treated water helps assess water sanitation. The presence of Fecal Coliform in well water may indicate recent contamination by human or animal waste, possibly carrying harmful organisms. Drinking water should ideally have zero Total Coliform colonies per 100 milliliters, but some samples from Faisalabad exceeded the WHO limit. Contaminated water sources can lead to gastrointestinal illnesses and other health issues.

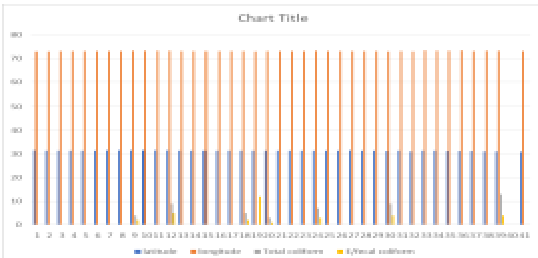

Figure 3.11: *Total coliform and E/Fecal coliform graph for Faisalabad city*

Conclusion:

Groundwater is the primary water supply for Faisalabad district, serving domestic, agricultural, and industrial needs. Its quality is vital for various uses, following standards set by authentic agencies. However, groundwater is mostly contaminated due to irresponsible behavior and population growth. Previous studies didn't assess its quality, so this work aimed to indicate the water quality status. Groundwater samples were collected from different areas in Faisalabad and analyzed for various physicochemical parameters using standard methods. Results indicated poor water quality with high pH, TDS, hardness, chloride, nitrite, and bacterial levels. A GIS tool was utilized to map the spatial distribution of these parameters using ARC GIS 10 software. The findings suggest the urgent need for improving water treatment to make it suitable for drinking and irrigation purposes, as well as controlling groundwater pollution caused by industries and sewerage.

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