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REVIEW ARTICLE

GIS-BASED ASSESSMENT OF GROUND WATER QUALITY FOR DRINKING PURPOSE BY WATER QUALITY INDEX APPROACHES IN BAHAWALPUR, PUNJAB

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ABSTRACT

Groundwater pollution is a significant environmental issue globally, particularly in large cities, and trace heavy metals are the most significant groundwater pollutants. Pakistan is particularly affected by groundwater contamination, which poses a major threat to public health. Many industrial facilities in Pakistan discharge untreated wastewater into nearby drains, which has a direct impact on the quality of surface water, soil, and groundwater. Bahawalpur, the 11th most populous city in Pakistan, is the focus of this research, which examines how residential areas in the city affect groundwater. The research area was carefully studied, and groundwater sampling locations were collected from 45 distinct locations throughout Bahawalpur's residential area. Groundwater samples were then analyzed for various parameters, including pH, turbidity, electrical conductivity, total dissolved solids, calcium, magnesium, iron, total hardness, total alkalinity, and chloride content. The results of these tests were compared to World Health Organization (WHO) recommendations, and the outcomes of the elements were displayed using ArcView GIS v10.7.1 and raster interpolation with IDW. The study found that the concentration of pollutants in groundwater exceeded the permitted level, and the water quality index for drinking water was determined to be only 65 percent in terms of pH, turbidity, electrical conductivity, iron, calcium, magnesium, total dissolved solids, total alkalinity, and total hardness. The characteristics of the groundwater did not comply with WHO standards. These findings suggest that there is a pressing need to address water pollution in Bahawalpur. The data collected and analyzed in this study could be used to design and construct a filtration plant facility to reduce water pollution in the area.

KEYWORDS

Contaminants, IDW, Interpolation

1. INTRODUCTION

The human-environment relationship is symbiotic, with a delicate balance required for mutual prosperity. The environment offers shelter and resources while also acting as a waste receptacle. Urbanization and industrial growth have heightened awareness about the connection between the environment, public health, and pollution. However, human activity often disrupts this balance, leading to environmental contamination. For humans, the environment serves three vital roles. It provides housing and amenities, supports agriculture and other resources, and absorbs the consequences of human actions. Ensuring that resource consumption aligns with the ecosystem's ability to replenish them is crucial. Unfortunately, this balance is frequently ignored, resulting in environmental pollution. Emerging countries face a grave threat from pollution, whether in the form of soil, water, or air contamination. Industrial pollution worldwide deteriorates soil, water, and air quality, endangering human, plant, and animal health. Water is indispensable for all life, with only a small fraction of it suitable for human use. Groundwater is vital for economic growth and has experienced a decline in supply due to population growth, inadequate storage, and pollution. Groundwater, a renewable resource, serves as a primary source of drinking water and irrigation. While sweet groundwater is accessible in some regions, its quantity and quality have depleted significantly, especially in densely populated areas. Population growth and industrial expansion have increased the demand for groundwater, affecting its availability and quality. Contaminants from urban areas and open sewers contribute to groundwater pollution. Worldwide, groundwater extraction exceeds 750-800 km3 annually, making up a substantial portion of the fresh water supply. The growing demand for fresh water in urban and industrial settings, coupled with inadequate waste management, poses a serious threat to groundwater quality and availability. This necessitates careful monitoring and action to ensure the sustainability of this essential resource.

1.1 Groundwater Contamination

Wastewater in Pakistan totals 4.43 billion cubic meters annually, with 3.06 BCM from municipal sources and 1.37 BCM from industries (IUCN, 2006). This poses a severe problem, adversely affecting freshwater resources, human health, and agriculture. Industrial effluents, especially untreated ones, harm surface and groundwater quality, while urban agricultural soils often rely on untreated city effluents for irrigation (Ghafoor et al., 2005). The indiscriminate release of materials from growing industries and populations leads to environmental contamination. Raw sewage in unlined drains causes soil salinity, sodicity, and metal ion toxicity in agriculture (Aziz, 2001). Groundwater pollution, particularly in urban centers like Faisalabad, Sialkot, and Lahore, is exacerbated by industrial wastewater, pesticides, and fertilizers (Rizwan and Riffat, 2009). In many underdeveloped regions, 60% of the population lacks access to safe drinking water, with groundwater contamination causing widespread health issues (Ullah et al., 2009). Wastewater contaminants, including heavy metals, pose significant risks to the ecosystem. Heavy metals,

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defined as elements with an atomic weight exceeding 23 and a density over 5 grams per cubic meter (Duff, 2002), are of growing concern due to their non-biodegradable nature and long-term environmental persistence.

1.2 Environmental Policy

In 1977, Pakistan initiated its first environmental protection legislation (Abbas, 2010), with subsequent federal and provincial institutional and policy changes. Key regulations, including the Pakistan Environmental Protection Act of 1997 and the Pakistan Environmental Protection Ordinance of 1983, were established in 1993, along with National Environmental Quality Standards (NEQS) for various pollutants. However, these regulations suffered from inadequate enforcement, and stringent enforcement alone did not guarantee effectiveness. On September 3, 1997, the National Assembly passed legislation to prevent pollution and promote sustainable development. NEQS limits were modified in 2000, but they need further updates to facilitate the establishment of effluent treatment plants. The National Environmental Protection Plan (NEAP) aimed to enhance environmental quality and general well-being in Pakistan through collaboration between government agencies and civil society (Luken, 2000). Untreated or partially treated wastewater for agricultural use lacks regulatory oversight. BOD and COD levels should adhere to specific limits, but limited resources hinder testing and treatment by WASA and municipal authorities, resulting in the sale of wastewater to farmers in violation of current environmental laws.

1.3 Global Positioning System (GPS)

The Global Positioning System (GPS) is a space-based global navigation satellite system, offering precise position and time information when at least three GPS satellites are in view (Hofmann-Wellenhof et al., 2007). Comprising 24 satellites, it's maintained by the United States and provides essential data for Geographic Information Systems (GIS). GIS, an integrated system for geographical data management, aids in water quality assessment and prediction (Chang, 2016). It offers a three-dimensional perspective on water quality fluctuations, combining statistical analysis, cartography, and database technology. The Inverse Distance Weighted (IDW) tool within GIS predicts unmeasured values by considering the proximity of measured elements (Singh and Verma, 2019). This approach is instrumental in transforming discrete data into continuous data. In the context of water quality assessment, the GIS-based Water Quality Index (WQI) is widely used, offering three-dimensional insights into water quality trends (Chang, 2016). It's been applied in various countries, including Pakistan, to evaluate groundwater quality. Bahawalpur City grapples with water quality issues, affecting health, agriculture, and the environment. The release of domestic and industrial wastewater compounds these problems, leading to waterborne illnesses, soil damage, and ecological harm. The city, with a population of over a million, has diverse industries, but untreated wastewater discharge has deteriorated groundwater quality. Public awareness, stakeholder collaboration, and comprehensive groundwater quality assessments are essential for addressing and mitigating contamination sources. The research aims to fulfill several key objectives. Firstly, it seeks to conduct a comprehensive examination of the physical and chemical attributes of groundwater within the study area. Additionally, the research aims to assess the quality of this groundwater by calculating a water quality index specific to the study area. Furthermore, it endeavors to pinpoint areas of elevated risk within the study region by employing Geographic Information System (GIS) techniques. Through these research endeavors, a deeper understanding of the groundwater in the study area and the potential risks associated with it will be achieved.

2. LITERATURE REVIEW

2.1 Importance

Drinking water quality is a crucial public health issue, and this study focuses on assessing the suitability of groundwater for drinking purposes in Bahawalpur, Punjab. The study uses a GIS-based approach, which allows for a comprehensive analysis of spatial patterns and correlations between different water quality parameters, providing valuable insights for water resource management. The use of water quality index (WQI) approaches provides a standardized framework for assessing water quality, making it easier to compare water quality across different locations and over time. The results of the study can inform decision-making for policymakers, water managers, and other stakeholders involved in ensuring access to safe and clean drinking water. The study contributes to the body of knowledge on water quality assessment and management, particularly in the context of groundwater, which is an important source of drinking water in many parts of the world.

2.2 Resources and Wastewater Reuse

This research is primarily concerned with determining the groundwater quality for drinking purpose and pollution issues related to contaminated groundwater. About half of all groundwater in urban areas comes from sources, wells and holes, with over 150 million U.S. and one trillion Asians relying on groundwater supplies (Clarke et al., 1995). Mashhadi and Muhammad (2000) searched the groundwater level in Islamabad is decreasing as a result of continual groundwater extraction. This drop in groundwater level indicates that groundwater extraction outpaces groundwater recharging. Field and Haines (2000) studied the breakdown of rocks causes a high concentration of suspended solids in groundwater. 'Salt's nature and concentration are influenced by the environment, mobility, and groundwater supply. Kahlown et al. (2002) studied the primary source of domestic and commercial water is groundwater in Pakistan. Due to the usage strain on groundwater, the level of groundwater in many cities has decreased. In some locations, the water table has plummeted more than 10 meters. As a result, the continual usage of groundwater has an impact on groundwater quality. Foppen (2008) concluded that Groundwater pollution can come from above or below the surface of the ground. Contaminants may pass through many layers of soil or other materials before they reach groundwater if they are spread over the land surface or enter the soil near the water table. Zaadnoordijk et al. (2004) worked on Recovery of ground water quality across the system and its flow characteristics, such as time being spent between penetration and exfiltration, may affect the quality of groundwater. A local residency period of tertiary might reach many decades even on a small scale. Rashed et al. (1995) studied the influence of wastewater discharged into the quality and energy efficiency of groundwater will afterwards be enormous. In places with scarce source water and above-renewal rates, the re-energization of groundwater by application of wastewater can, despite its inadequate quality, provide considerable financial and natural support. In this sense, it might be seen as an advantage in some cases. As a result, there is a clear contradiction between the advantages of groundwater recharge and the costs of groundwater contamination. 50-70% of irrigation water may penetrate to the groundwater reservoir in some areas. Hamazah et al., (1997) conducted study on utilization of groundwater is ascending in parched and semi-dry pieces of the globe, and the variances of the precipitation and a lack of new water is huge for Pakistan, which is the world's drier nation, and was seen as water shortage and water shortage soon. Ahmed (1998) determined the impacts of contamination on the climate in Islamabad and Rawalpindi were analyzed, and example from surface and groundwater holds was inspected. The results reveal that in ground water and surface water cadmium is lower, as tests for surface water have a somewhat low mineral content than normal water. Emmanuel et al., (2002) searched the Chemical compounds, notably medication residue and organ halo genic chemicals, which are spilled from septic tanks and discharged into the natural environment, are the major source of contamination of the multitude environment, particularly groundwater and soil.

Heaney et al. (1982) Studied the amount of calcium absorbed by the digestive organs is typically limited, a large amount of calcium ingested over a short period of time is unlikely to cause damage. However, if you consume too much calcium over a lengthy period of time, your blood calcium levels may rise (hypocalcaemia). Urinary tract calculi, hypocalcaemia, bone suppression, remodeling, and calcification in artery walls and sofa tissues like as the kidney can all be caused by this. The extraordinary absorption of calcium in the rocks beneath the earth causes them to be calcareous. The absorption of calcium in groundwater is greater than in surface water, according to research. Bhutta et al. (2005) concluded that only at the Muncher Lake surface storage tank in the province of Sindh were calcium levels found to exceed the permitted limits. According to the PCRWR rural research, 28% of the groundwater samples are calcium-based and only 5% had calcium levels over the allowed limits. Ghafoor et al. (1996) Concluded that Lower Chenab Canal, which irrigates roughly 80% of Faisalabad's land, is the cities only supply of canal water for irrigation. Farmers are forced to utilize groundwater or raw sewage to produce vegetables and crops in order to fulfill water demand. Fischer (1993) studied Land use planning, environmental control and management, departments and the navigation of motor vehicles all have an important role to play in policy analysis for geographic information systems. Rashed et al. (1995) finds the impact of wastewater chloride concentration on groundwater quality and recharge in wastewater-irrigated areas is anticipated to be significant. The concentrations of oxygen sulphate, total dissolved solids, and dissolved solids in groundwater are significantly greater than in wastewater. The leaching and drainage of wastewater used to irrigate crops in the aquifer can help replenish the groundwater. In some places, irrigation water can percolate to an aquifer at a rate of 50-70 percent. Mahmood (2006) concluded that Groundwater contaminants are divided into two categories: those created or contributed by human activity, and those that happen naturally. Petroleum and synthesized organic compounds, (pesticides, solvents, petroleum products, etc.) are contributed by human activities, as is leachate discharge into pond, and minerals like as calcium, iron, and selenium exist naturally as minerals. Maqbool (2007) concluded that many issues of groundwater contamination are caused by human activities, and contaminants are introduced to groundwater from a variety of sources. The procedure of groundwater supplies for the removal of municipal and industrial wastes is the most significant cause of groundwater pollution.

Ullah et al. (2009) worked on groundwater quality in a modern Pakistani metropolis, such as Sialkot, was determined by collecting 25 groundwater tests from various locations. pH, electrical conductivity (EC), all out disintegrated strong (TSS), and all out chlorine were among the 22 physical and compound characteristics broken down. The results were contrasted and the Pakistan Standard Quality Control Authority (PSQCA) and World Health Organization recommendations drawn up (WHO). The Contrast and similitude Bunch Analysis Contingent (CA) covers 4 areas from all physical space destinations. The results have shown that groundwater cannot be seen as great in the investigative region. By using the Geographic Information System, the water quality standards for spatial dispersion guidelines were developed. The circulation maps played a substantial role in demonstrating the quality parameters of groundwater and its soil water frameworks in terms of their environmental status, which exceed the cutoff points drawn up by the WHO, and in recognizing the Sialkot regions. Where promising water treatment innovation can be identified. Tahir (2000) concluded that a strong source of defilement and mechanical pollution in irrigated areas include toxic synthetic substance from modern effluents, material color, nitrogen composts, pesticides, arsenic and various synthetic materials. Ahmad (2000) studied in Sialkot, a large portion of the population gets their needs met, as well as the needs of their animals, from regular water sources. As a result of drinking contaminated water from tanneries, 82 percent of people contracted diseases such as cholera, diarrhea, typhoid, and other illnesses. The tannery odor lingers and might be transferred to natural pecking order. Kahlown and Majeed (2003) concluded that a human activity is the primary source of water pollution. The irregular mechanical waste, civic and indigenous trash in waterways, streams, lakes, and other water bodies are the essential workouts. Tariq et al. (2006) the study examined the conceivable impact of such waste streams on groundwater tests in tubing wells in the nearby of Estate, including temperature, pH. Electrical conductivity and the total solids disintegrated into the tube. This assessment examined the various types of modern Hayatabad Industrial Estate in Peshawar. These results suggested that effluents from various companies display varied characteristics and are likely to cause contamination of groundwater. Habib et al. (2007) concluded that Twenty-twenty-two examples from the region included an assessment of ground water tanning owing to tannery effluent, assessed with physiochemical parameters such as pH, Electrical Conductivity, Total Dissolved Solids, calcium and magnesium chlorides. Compared to the WHO criteria for drinking water, the convergence of these variables. The findings indicated that tanners constitute a primary source of soil water contamination and a major cause of soil water contamination in the research region.

Adekunle (2009) the groundwater contamination of a contemporary request was investigated using physiochemical and organic characteristics. Three wells in the contemporary region were evaluated. The absolute suspended solid and all-out broken-down solid were both quite high, according to the findings. The pH estimate varies between 6.8-7.4 whereas the EC is between 161 and 731. In groundwater, the quantities were significantly higher for Cl, Ca and Mg. The concentration of broken up oxygen ranged from 6 to 9 mg/L. The impression gained revealed that the contemporary effluents had a negative impact on the wells inside the mechanical plant. Siddiqui and Sharma (2009) studied a definitive investigation of the groundwater of regarding regions uncovered that the water isn't adequate' for consumption. A further investigation was carried out into the long-term impacts in Indian mechanical Kattedan of upgrading of groundwater quality. The findings of water testing have shown that water is unsuitable to be drunk in modern Kattedan and a cause of water pollution. Ghafoor et al., (2005) conducted a study of deficiency of water system supplies, metropolitan farming soils are typically inundated with untreated city effluents for developing agribusiness crops, for the most part vegetables. The waste water from both traditional and contemporary areas is combined in a single sewage system, and the resultant effluent is referred to as crude emanating. It is used by ranchers as a wellspring of water and as a supplement. Aziz (2001) concluded that various materials are discharged into sewage as industrialization and population grow. Prior research indicated that the crude coming from these sources is transported into unlined channels, causing difficulties such as soil saltiness/sodicity, groundwater tainting, and metal particle poisonousness for agriculture. Metal particle focus in crude emanating from various urban communities of Pakistan is relied upon to have fundamentally the same as science attributable to as industry blend and removal of profluent from various sources into a similar waste framework. Ghafoor et al. (1996) concluded that Lower Chenab Canal, which floods over 80% of Faisalabad's property, is the city's lone source of channel water for the water system. Ranchers are forced to use crude sewage to grow crops and vegetables in order to satisfy harvest water requirements. He et al. (2005) studied Changes in hereditary material and tumors in animals have been triggered as the convergence of heavy metals has increased. They have the potential to cause damage in hereditary cosmetics, notably in female and male germ cells, as well as in animals and humans. Khan et al. (1996) they're thought to be a collection of toxins that impact human health via bio amplification in plants. Heavy metals were discovered to be combined in soil before they were absorbed into ground water and then soil particles were absorbed. The ingestion of unclean food and polluted water accumulate these heavy metals in individuals. Plants and animals have distinct comparative conditions.

2.3 Geographic Information System (GIS) and Water Quality Index (WQI)

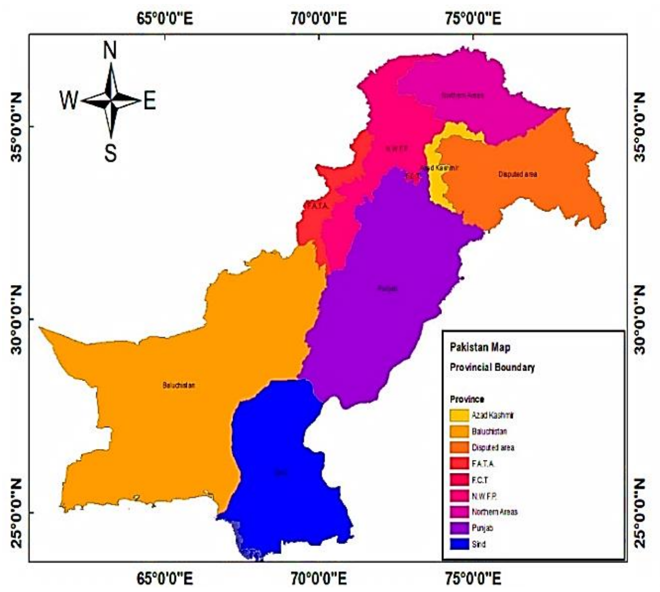
In a multitude of diverse regions across the globe, research endeavors have been carried out to assess and map the quality of groundwater and surface water using various water quality indices (WQI) and geospatial analyses. These studies aim to provide comprehensive insights into the state of water quality and its spatial distribution, with a primary focus on assessing the suitability of water for various purposes, particularly drinking. Akbar et al. (2020) examined the water quality in China's South Coastal Aquaculture region. Groundwater from four primary locations was analyzed to determine the WQI, and GIS techniques were used to assess geographical and temporal variations. Herojeet et al. (2016) assessed groundwater quality in Nalagarh Basin, Himachal Pradesh, India, employing quantitative approaches and multivariate analysis. The WQI revealed that a majority of groundwater samples in the region were of low quality. Gibrilla et al. (2011) utilized the WQI to analyze groundwater quality in Ghana, focusing on its suitability for drinking and cultivation. The study classified water quality into categories such as excellent, good, poor, and unsuitable for human consumption. Udeshani et al. (2020) investigated chronic kidney disease of unknown cause (CKDu) in Sri Lanka's arid areas and established a connection between drinking water quality and CKDu. Gaikwad et al. (2020) assessed water suitability for drinking in India's Kudal area, determining that the water quality was safe to drink. De Rosemond et al. (2009) compared different water quality evaluation techniques, finding that the Canadian Council of Ministers for the Environment (CCME) WQI offered an effective tool for assessing spatial and temporal changes in water quality. Prasad et al. (2019) evaluated groundwater quality in Mandal YSR district, India, using the WQI approach, revealing variations in water quality across different sampling sites. Yenugu et al. (2020) assessed water quality in towns near the Yerraguntla Mandal cement industry in South India, using 14 indicators to determine the WQI, indicating low water quality. Munagala et al. (2020) measured the WQI of groundwater near municipal trash dumpsites in Guntur, highlighting the need for planned landfill sites to minimize environmental impact. Mukate et al. (2019) introduced the Water Quality Index Integrated (WQII) and assessed groundwater quality, classifying it into five quality categories. Al-Omran et al. (2015) collected water samples from different areas in Riyadh, Saudi Arabia, and determined the WQI to assess the suitability of water for drinking. Nong et al. (2020) aimed to evaluate water quality near China's South to North Water Diversion Project using a wide range of parameters. Rana et al. (2018) studied groundwater and leachate near non-engineered landfill sites in Northern India, using WQI and other indices to assess water quality. State (2016) conducted groundwater quality mapping in the Awka City of Nigeria, identifying water quality issues related to rapid urbanization. Li et al. (2019) assessed drinking water quality index monitoring data and developed a WQI map to evaluate water quality across the study area. Nas and Berktay (2010) conducted a study on groundwater mapping in Konya, Turkey, revealing varying water quality across the region. Solangi et al. (2018) used geospatial and statistical techniques to assess drinking water quality in the Indus delta, Pakistan, categorizing water quality into different classes. Ahmed et al. (2020) assessed groundwater quality in elementary schools in Sindh, Pakistan, using GIS-based WQI to evaluate and map water quality. Khatiwada et al. (2002) conducted a study on drinking water quality mapping in the Kathmandu Valley of Nepal. Shabbir and Ahmad (2015) utilized GIS to analyze groundwater quality in Islamabad and Rawalpindi, assessing the suitability of groundwater for drinking. In Goa, India, Singh et al. (2014) evaluated surface water quality, mapping the Water Quality Index and assessing water quality seasonally. To address water quality issues in Bahawalpur, Punjab, research gaps and hypotheses could be formulated to better understand the extent of water quality concerns in the region and the potential effectiveness of GIS-based WQI approaches in addressing these issues.

3. MATERIALS AND METHODOLOGY

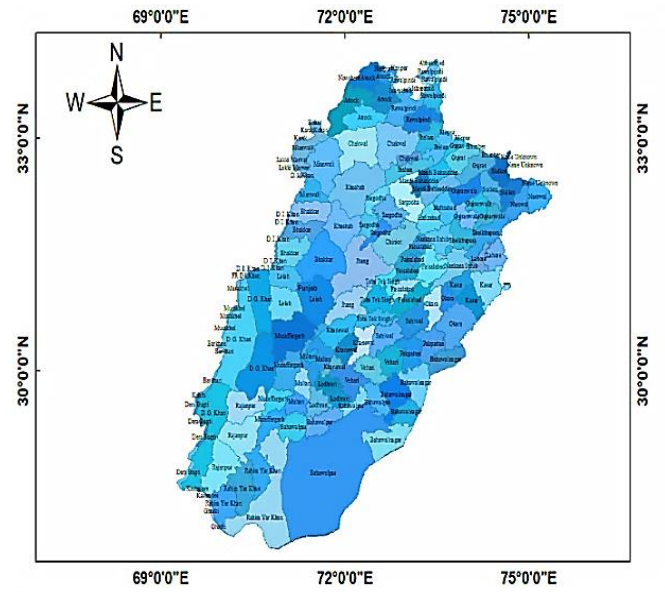
3.1 Study Area

Bahawalpur is a city located in the Punjab province of Pakistan. It has a rich history dating back to the 18th century when it was founded by Nawab Mohammad Bahawal Khan II. Bahawalpur was initially a princely state, and it became a part of Pakistan in 1955. The city of Bahawalpur has a number of historical landmarks that are worth visiting, including the Noor Mahal, Darbar Mahal, and Sadiq Garh Palace. These palaces were built by the Nawabs of Bahawalpur and are known for their stunning architecture and intricate designs. In terms of industries, Bahawalpur is primarily an agricultural city, with crops like cotton, wheat, and sugarcane being the main sources of income for the local population. There are also a number of small-scale industries in the city, including textiles, leather goods, and pottery. As for rivers, the Sutlej River runs near the city of Bahawalpur, providing water for irrigation and other purposes. The city is also located near the Cholistan Desert, which is home to a number of seasonal rivers and streams that flow during the monsoon season. These rivers are an important source of water for the local population and wildlife.

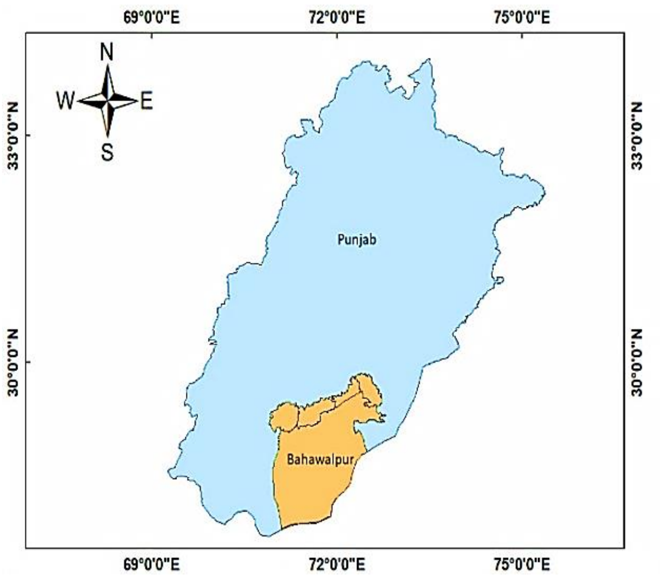
The study area includes the residential and agricultural areas of Bahawalpur City that are served by the Bahawalpur Canal, also known as the Abbasia Canal. Specifically, the study focuses on Goth Lashkar, Basti Miani, Basti Salhan, Riaz Colony, University Chowk, Satellite Town, Chack 10/BC, Model Town, and Islamic Colony. These are residential areas and located between the Sutlej River and the Abbasia Canal. The canal originates from the Sutlej River and passes through various cities and towns before emptying into the Arabian Sea. It is important that the Sutlej River is a major water source for the region, and it is possible that contamination from industrial, agricultural or domestic activities upstream may be contributing to the contamination of groundwater in Bahawalpur's residential areas. The river is associated with the agricultural areas in the city. The infiltration and the leaching to salts and fertilizers also contaminating the groundwater and make water polluted. The study area includes all the residential and agricultural areas and the depth of the groundwater varies throughout the area.



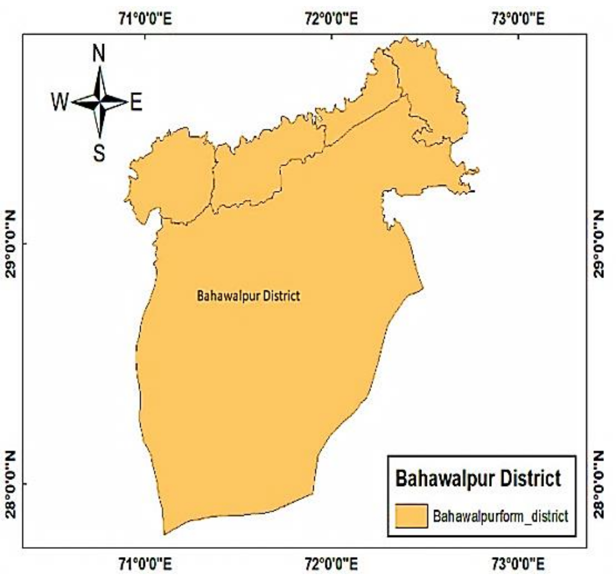
(a) Location of Province in Pakistan



(b) Location of Punjab with District



(c) Location of Bahawalpur District In Punjab



(d) Bahawalpur District

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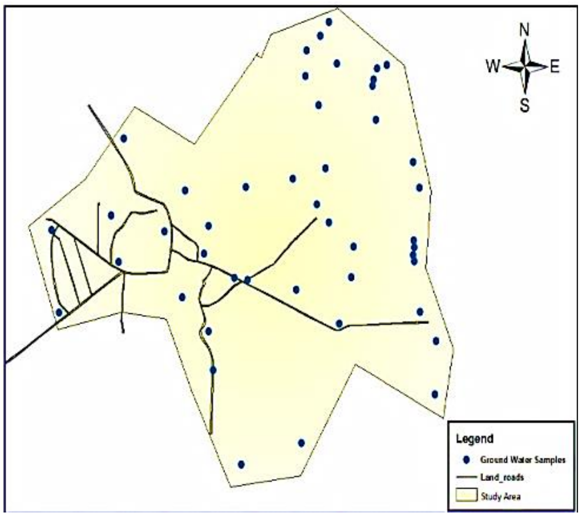

(e) Study Area Map with Groundwater Sample

Figure 1: Study Area Map

3.2 Groundwater sampling

Groundwater samples were taken at 45 distinct locations throughout the research study area. At each sampling location, GPS coordinates were recorded. Groundwater samples were taken from 3 different sources on the bases of depth:

Hand Pump (65-90ft)

Motors (110-130ft)

Tube Wells (260-300ft)

Each sample shall be 500 ml in volume. PVC bottles and a GPS meter were utilized to collect water samples. Each sample was labelled with a sample code.

Figure 2: Collected Groundwater Samples

3.2.1 Procedure

For the physical and chemical analysis of groundwater samples I labelled the PVC bottles with the sample code, date, time, Study area name, and GPS coordinates before sampling. A groundwater sample was taken in a PVC container from a certain spot. To get fresh groundwater, the tap was opened for 3 minutes before taking a sample in a PVC container. The sample was taken directly from the pump. I turned on the GPS meter after taking the groundwater sample and waited until at least three satellites were detected. Make a note of the GPS coordinates and write them down on the PVC bottle with a permanent marker.

3.2.2 Water Quality Index (WQI)

Environment Canada (2007) one of the most efficient methods for communicating information about the condition of any water body is the water quality index. The Water Quality Index (WQI) is a mathematical equation that is used to convert a vast amount of water quality data into a single value. It is simple and straightforward for decision-makers to understand the quality and potential applications of any water body. By combining complicated data and providing a score that represents water quality state, it aids in the understanding of water quality concerns. The following four procedures will be taken to create the Water Quality Index (WQI):

Step 1

The F1(Scope) indicates the proportion of variables that have failed to meet their objectives at least once during the specified time period, compared to the total number of variables that were measured. This metric is used to identify and measure the performance of variables and their ability to achieve their intended goals. By calculating the F1 score for Scope, we can determine the extent to which the measured variables have successfully met their targets and identify areas where improvements may be necessary to ensure that objectives are consistently achieved.

$$F1 = \frac{Number\ of\ Failed\ Variables}{Total\ Number\ Of\ Variables}\ X\ 100 \tag{1}$$

Step 2

The F2 (Frequency) measures the percentage of individual tests that fail to meet their objectives, also known as "Failed Tests."

$$F2 = \frac{Number\ of\ Failed\ Tests}{Total\ Number\ of\ Tests}\ X\ 100 \tag{2}$$

Step 3

The F3 (Amplitude) measures the amount by which failed tests values do not meet their objectives. It is calculated in three steps. F3 is calculated in three steps:

First, the number of times by which an individual concentration is greater than (or less than, when the objective is minimum) the objective is termed an 'excursion’. When the test value must not exceed the objective:

$$\text{excursion} = \frac{\text{Failed Test Value}}{\text{Objective}} - 1 \tag{3a}$$

For the case in which the test value must not fall below the objective:

$$\text{excursion} = \frac{\text{Objective}}{\text{ObjectFailed Test Valueive}} - 1 \tag{3b}$$

The collective amount by which individual tests are out of compliance is calculated by summing the excursions of individual tests from their objectives and dividing by the total number of tests. This variable is referred to as the normalized sum of excursions (nse):

$$\text{nse} = \frac{\sum_{i=1}^{n} \text{excursion}}{\text{number of Tests}} \tag{4}$$

F3 is then calculated by an asymptotic function that scales the nse from objectives to yield a range between 0 and 100.

$$\mathrm{F3} = \frac{\mathrm{nse}}{0.01\ \mathrm{nse}+0.01} \qquad (5)$$

Step 4

Calculate CCME Water Quality Index as:

$$\mathrm{CCME\ WQI} = 100 - \frac{\sqrt{(\mathrm{F1}^2+\mathrm{F2}^2+\mathrm{F3}^2)}}{1.732} \qquad (6)$$

3.3 Groundwater Analysis

Following parameters will be tested in groundwater samples to calculate water quality index (WQI). After determination of WQI it is easy to evaluate quality of water for drinking purpose.

Table 1: List of Parameters for groundwater

Serial No.	Analysis
1	pH
2	Turbidity
3	TDS
4	Calcium
5	Magnesium
6	Hardness
7	Alkalinity
8	Chloride
9	Iron
10	Conductivity

3.4 Analysis and Procedure

Using a laboratory manual, the following analyses were carried out on groundwater samples

3.4.1 pH

A digital pH meter was used to determine the pH of the samples. First of all, electrode is soaked in a known-pH buffer solution. Using the calibrating knob standardized the meter. After cleaning the electrodes, re-dipped them in the pH 7 buffer solution. Readings was noted. If the number is 7, the instrument has been calibrated. If this is not the case, adjusted the value until the dial reading reaches 7. The electrode was dipped in the solution after being rinsed with distilled water and pH was noted.

Figure 3: MT-103 Digital pH Meter

3.4.2 Turbidity

It measures clarity of water which is an important optimal characteristic of water. Turbidity meter was used to determined turbidity of water. Meter is shown in figure below. To perform test first instrument was powered on. Sample compartment lid was opened. The cover was closed when a test tube filled with distilled water was placed into the sample chamber. When you press SET 0, the readout will indicate '0'. Opened lid again and remove tube and again placed tube filled with water sample and pressed read. Then noted the reading shown on meter for each sample.

Figure 3: TES-1386 Turbidity Meter

3.4.3 Total Dissolved Solids

The oven dried technique was used to evaluate the dissolved solids of samples. Evaporating dishes were rinsed and put in a muffle furnace at 550°C for 30 minutes to conduct the experiment. Dishes were then allowed to cool to ambient temperature, and the empty weight of each dish was recorded as W1. Poured 50 mL of the well-mixed sample into the dish and allowed it to evaporate for an hour in an oven set at 103-105°C. The dish was then allowed to cool for a few minutes in the air before being placed in a desiccator to continue chilling in a dry atmosphere. After the dish has completely cooled, weigh it again and label it W2.To determine total dissolved solids filter paper is used. 500 ml. of sample is filtered using filter paper in evaporating dish that had been previously prepared and weighed. Then placed in oven at 103-105 "C for an hour. Allowed dish to cool at room temperature then weighed it again named as W4 (Woldeab et al., 2018). TDS is calculated as,

$$TDS = \frac{W4-W3}{V}\mathrm{X106} \qquad (7)$$

3.4.4 Calcium

A ten-milliliter sample of water was diluted with ten milliliters of distilled water. A pink hue was achieved by mixing 0.4 ml NaOH solution with 0.04 g Murexide indicator. After that, 0.01 M EDTA was used to titrate the solution. From pink, the endpoint was purple.

$$\mathrm{mg/L\ of\ Ca} = \frac{(D-E)\ X\ 400.8}{ml\ of\ Sample} \qquad (8)$$

Where,

D was ml titrant

E was mg CaCO3 equivalent to 1 ml.

3.4.5 Magnesium

Magnesium was estimated using calculation method that is,

mg/L Mg =

Total Hardness as CaCO3-2.5 (Calcium in mg/L.) x 0.243 (9)

3.4.5 Total Hardness

To acquire accurate hardness readings, the water sample is diluted. As a result, the 10 ml. sample was diluted in 20 mL distilled water. 1 ml. buffer inhibitor solution was added, along with 1-2 drops of Eriochrome black T indicator. When the color of the sample changes from red to violet blue, the endpoint has been reached.

The Total Hardness is calculated as,

$$\mathrm{Total\ Hardness\ as\ mg\ CaCO3} = \frac{(A-B)X\ C\ X\ 1000}{ml\ of\ Sample} \qquad (10)$$

Where,

A was ml of EDTA for titration of sample

B was ml of EDTA for titration of blank

C was calculated from standardization of EDTA titrant

C=ml of standard calcium solution/ml of EDTA titrant

3.4.6 Chlorides

A 10 ml sample of water was taken and 3 drops of potassium chromate indicator were added. Standard 0.02 M silver nitrate solution was used as titrant and end point was pinky yellow color. At the point burette reading was notes and chlorides are estimated as,

$$\text{Mg/L. CI} = \text{burette reading} * 35.45 \qquad (11)$$

3.4.7 Iron

Using the selection approach Iron HR method was selected. Poured 10 mL of untreated sample into the cuvette and then put the cap back on. Closed the lid and placed the cuvette in the holder. Hold down the Zero key. The display read "-0.0-," indicating that meter has been zeroed and ready for use. Removed the cuvette and placed one package of H193721-0 Iron High Range Reagent in its place. Replaced the cap and shanked vigorously until all of the powder had dissolved. The lid was shut and the cuvette was placed in the instrument again. Pressed timer and countdown show on the display, or alternatively wait three minutes before measuring and then press Read. When the timer finishes, the meter takes the reading. In milligrams per liter of iron the result was shown (Fe).

3.4.8 Electrical Conductivity

An EC meter was used to determine the electrical conductivity of the samples. Meter was first calibrated using standard buffer solution. Probe

was dipped in a sample and reading was noted when timer on the meter stop.

3.6 GIS Analysis

The sampling locations' latitude and longitude were determined using a hand-held GPS unit. Through a point layer, the various sampling locations were loaded into GIS software. The single code that was recorded in the point attribute database was supplied to each sample point. Separate columns of all parameters values and sample codes for each sample site were included in the database file. Using the geodatabase, selected water quality indicator geographical maps were generated and WQI for potable water were created. The ArcGIS (version 10.4) software spatial analysis component was used to determine the locational distribution of different water pollutants using the raster interpolation technique of reverse weighted distance (IDW).

3.7 Interpolation

When gathering information about an event and recording its geographical coordinates, it can be challenging to obtain data points everywhere we need them. This is where interpolation comes in. Interpolation is a mathematical technique used to estimate values "in between" the existing data points, allowing us to create a continuous surface. With field data being expensive to obtain, interpolation has become a popular approach in various fields.

The primary purpose of interpolation is to predict unknown values for various spatially-based phenomena, such as elevation, rainfall, temperature, noise level, and chemical dispersion, for any geographic point data. It can be performed using either raster or vector models, with the IDW approach being the most well-known interpolation method. Through interpolation, we can create a raster or vector surface that can help us better understand and analyses the spatial characteristics of a phenomenon.

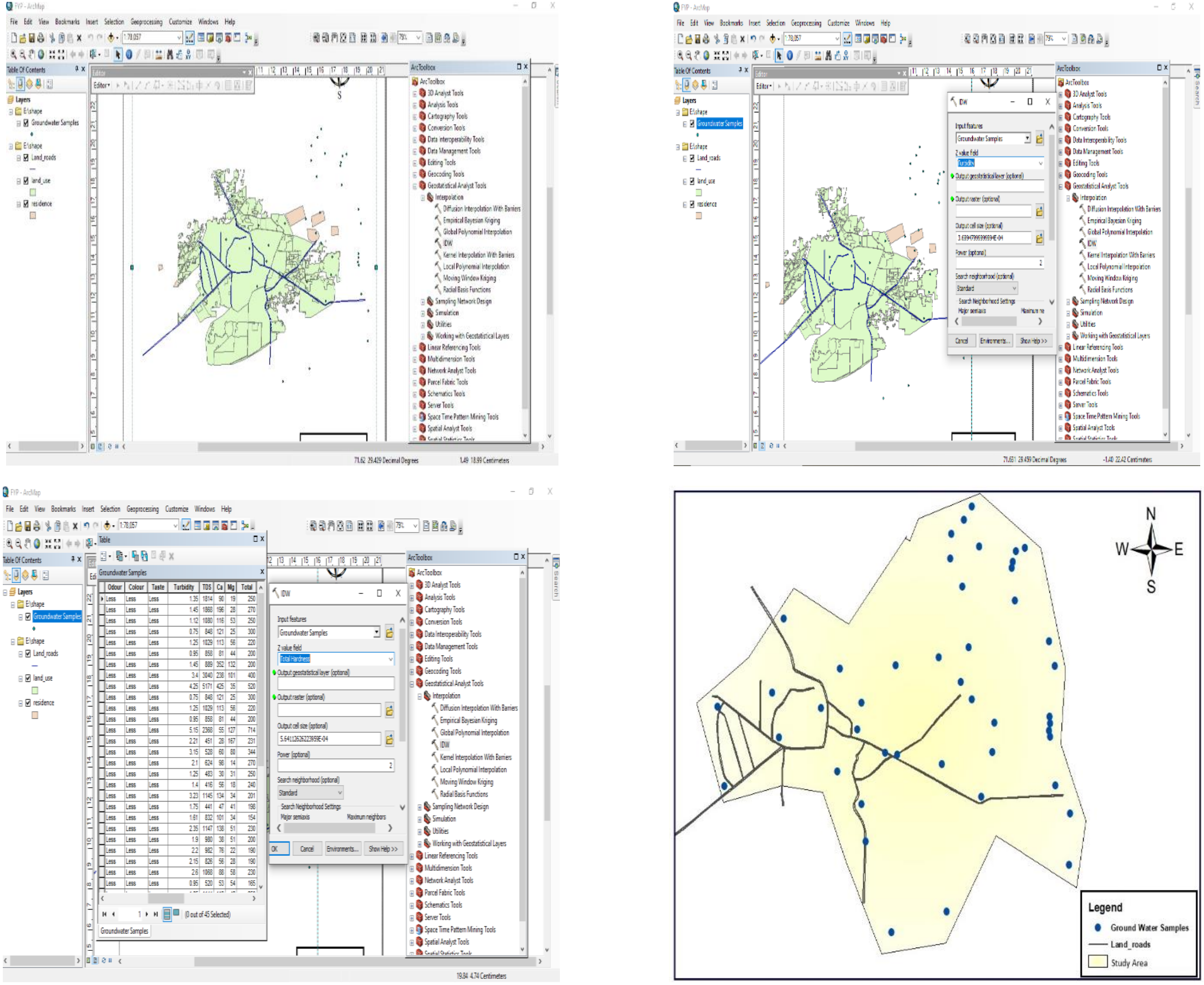

Figure 5: GIS Worksheet with procedures

4. RESULTS AND DISCUSSIONS

Groundwater samples were collected from different points in the study area using plastic bottles that were cleaned thoroughly prior to sample collection. The samples were then taken to the Public Health Engineering Department in Bahawalpur for analysis. A total of 45 samples were tested to determine the water quality of the site area. The results of the analysis were obtained following the methodology described in Chapter 3. These results are presented and explained as follows:

4.1 Geospatial Mapping through Interpolation Technique

4.1.1 pH

The groundwater samples were analyzed for pH levels using a digital pH meter. The average pH score obtained was 8.033, with a range of values from 7.06 to 8.62. These values were then compared with WHO standard values for drinking water provided in the appendix and the pH of most drinking-water lies within the range 6.5–8.5. The overall average value is within the permissible limit.

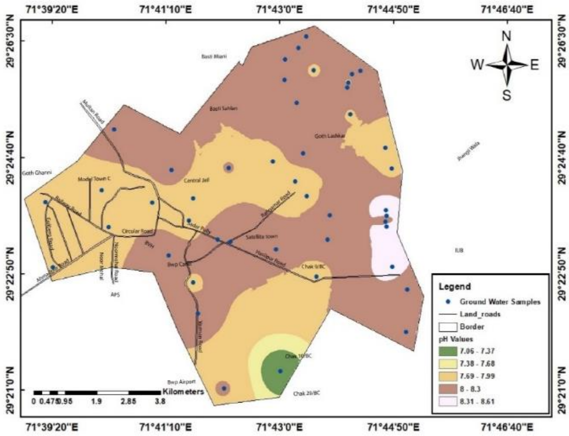

Figure 6: GIS map of pH in study area

To identify any locally distributed water pollutants in the study area, the Space Analyst module of ArcGIS version 10.7.1 was used. This module employs the reverse distance weighted (IDW) raster interpolation method. The pH concentration was mapped using this approach, which showed that the pH levels in groundwater samples were high in the Musa Colony area which is near to the main Hasilpur road and corresponds to the rural area, with values of 8.55 and 8.62, respectively and the pH levels in all other areas were within the permissible limits.

4.1.2 Turbidity

A turbidity investigation was conducted using a turbidity meter to measure the level of turbidity in groundwater. The turbidity values ranged from 0.44 NTU to 5.15 NTU, with an average value of 1.79 NTU. These results were then compared to the standard characteristics for drinking water as outlined by WHO which can be found in the appendix and the Turbidity values should be less than 5NTU. The overall average value is within the permissible limit.

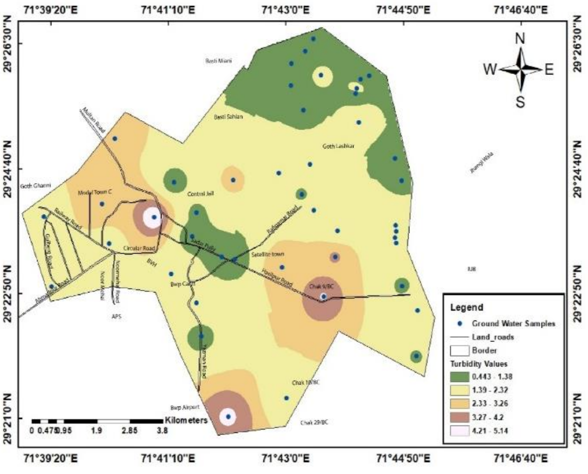

Figure 6: GIS map of Turbidity in study area

Once all GIS data was interpolated, the geospatial analysis maps was created to display the concentrations of turbidity values, which were classified into various equal intervals. The results of the GIS analysis show that the turbidity level in groundwater samples was very low and within the permissible limit in all the study area while its values just exceed the limit to 5.15NTU in Makhdumpura Old City Bahawalpur.

4.1.3 TDS

A study on Total Dissolved Solids (TDS) was conducted using dry oven techniques. The results of the groundwater TDS analysis showed a range of values from 276 mg/L to 5171 mg/L with an average value of 1031.86 mg/L. These values were compared to the drinking water standards set which are listed in the appendix and the TDS values should be less than 1000mg/L or 1000ppm. The overall average value is beyond the permissible limit.

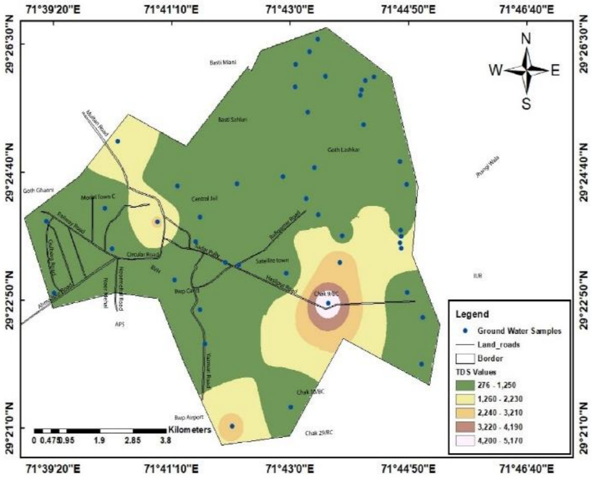

Figure 7: GIS map of TDS in study area

The geospatial analysis created using IDW showed distinct regions with varying TDS concentrations, which were categorized using different legends. The results of the GIS analysis show that the TDS level in groundwater samples was higher in the majority of the areas and 16 samples have values greater than 1000ppm while Islamic Colony and Chack 9 Mohajir Colony and its surrounding areas have the unacceptable TDS value and the cannot be used for drinking in any aspect.

4.1.4 Calcium

The calcium analysis of groundwater was conducted using the titration technique, and the obtained results showed that the calcium levels ranged from 28 mg/L to 425 mg/L, with an average of 106.288 mg/L. To determine the suitability of the water for drinking purposes, the obtained values were compared to the standard values set by the WHO and the value should be less than 75mg/L. The overall average value is beyond the permissible limit. Additionally, the WHO standard values are provided in the appendix for reference.

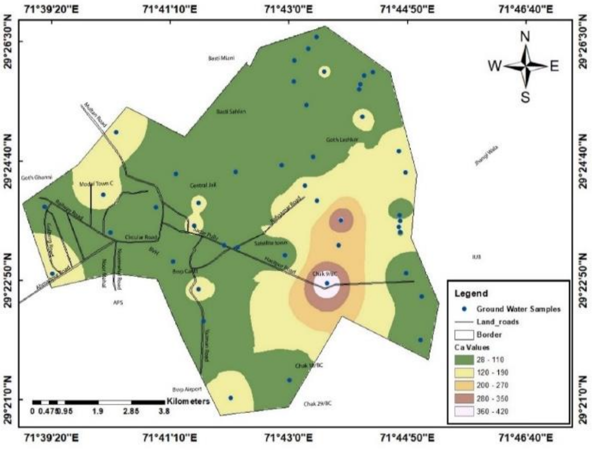

Figure 8: GIS map of Calcium in study area

The calcium value concentrations were mapped using a GIS system, with different legends representing the varying levels of calcium in the different regions. The GIS analysis revealed that the majority of the area had high levels of calcium in the groundwater samples and 28 samples have calcium value greater than the permissible limit while in chack no 9/BC, Musa Colony and the areas corresponding to the main Hasilpur road have its highest values. Overall the study area have greater variation of calcium values the areas includes the Makhdumpura Old City Bahawalpur linked areas to the canal have values of calcium in the permissible limit.

4.1.5 Magnesium

A study was conducted to assess the levels of magnesium in groundwater. The results showed that the magnesium concentrations ranged from 5 mg/L to 167 mg/L, with an average of 41.35 mg/L. To evaluate the quality of the groundwater, the obtained values were compared to the drinking water standard values set by WHO and the value of magnesium should be 30mg/L, which can be found in the appendix that accompanies the study. The overall average value is beyond the permissible limit.

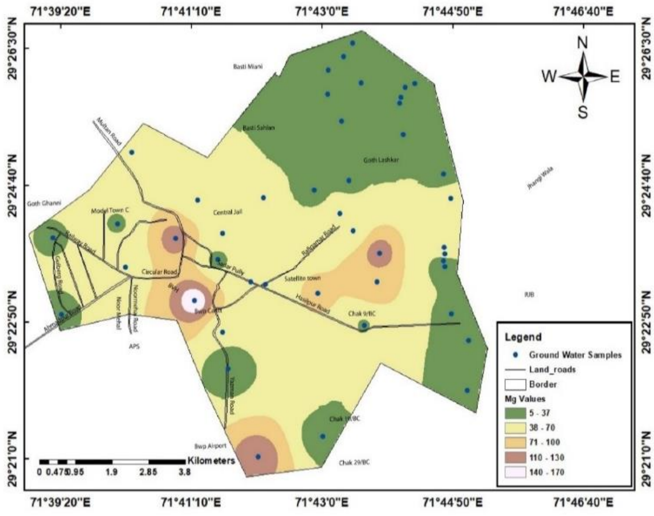

Figure 9: GIS map of Magnesium in study area

The distribution of magnesium concentrations in the groundwater samples was represented on a GIS map, with different colors used to differentiate between regions with varying concentrations. The map also includes a legend that helps to distinguish between the different concentration levels. The analysis revealed that the 25 of the sampled areas had high magnesium concentrations, which includes Bahawalpur Cantt region and nearby Islamic Colony areas, Makhdumpura Old City Bahawalpur and chack no 9/BC and its corresponding Badar Sher areas. The chack no 9/BC and its corresponding areas have too much highest of the magnesium values.

4.1.6 Total Hardness

The total hardness of water was determined in the study using the titration method. The results showed that the total hardness ranged from 100 mg/L to 1200 mg/L, with an average value of 401.11 mg/L. To evaluate the quality of the groundwater, the obtained values were compared to the drinking water standard values set by WHO and the value should be less than 500mg/L, which can be found in the appendix that accompanies the study. The overall average value is within the permissible limit. This research is important because high levels of total hardness in drinking water can have negative health and economic impacts, such as skin irritation, soap scum build-up, and decreased effectiveness of cleaning products.Several factors can contribute to the total hardness of water, including the geology of the surrounding area, human activities such as industrial and agricultural runoff, and the water treatment process. The results of the study can be used to identify areas where water treatment or source control measures may be necessary to reduce total hardness and improve water quality.

GIS analysis was conducted to visually represent the distribution of total hardness in the study area. An interpolated map was created to show the levels of total hardness at different locations, and the results were displayed using a legend. The results show the level of hardness is varying throughout the study area and have its highest concentrations in 14 samples areas and have its highest concentration in Chack no 9/BC and the Islamic colony areas. The overall study areas have greater extent of variation of Total hardness values.

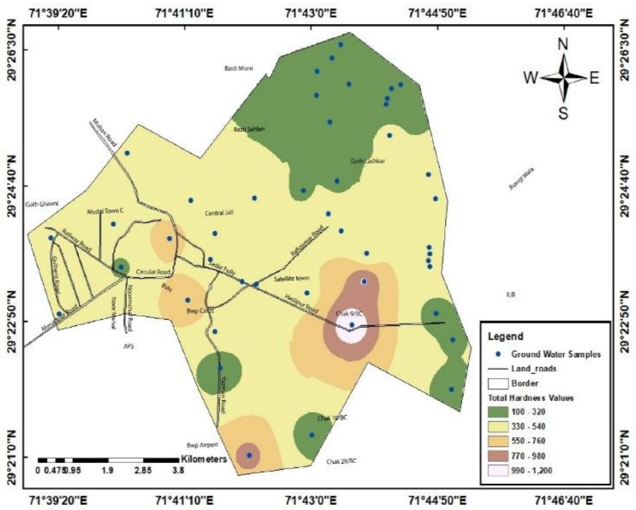

Figure 10: GIS map of Total Hardness in study area

4.1.7 Total Alkalinity

The total alkalinity of water was determined in the study using the titration method. The results showed that the total alkalinity ranged from 90 mg/L to 714 mg/L, with an average value of 233.93 mg/L. To evaluate the quality of the groundwater, the obtained values were compared to the drinking water standard values set by WHO and the value should be 500mg/L, which can be found in the appendix that accompanies the study. The overall average value is within the permissible limit.

Total alkalinity is an important water quality parameter as it can affect the pH level of water and its ability to neutralize acidic substances. Several factors can contribute to the total alkalinity of water, including the presence of bicarbonate, carbonate, and hydroxide ions. High levels of alkalinity can cause scaling and corrosion in pipes and equipment, leading to costly repairs and replacements.

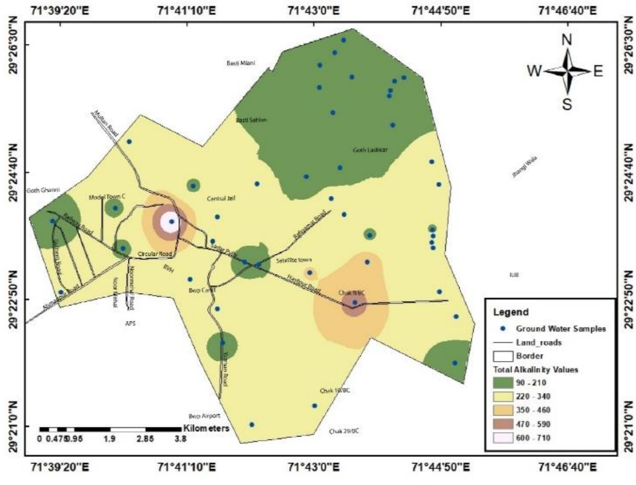

Figure 11: GIS map of Total Alkalinity in study area

The GIS analysis was also conducted to visually represent the distribution of total alkalinity in the study area. An interpolated map was created to show the levels of total alkalinity at different locations, and the results were displayed using a legend. The values shows that the concentration of Alkalinity is within the limits throughout the study area while 2 samples have value greater than the permissible limit which includes Model Town and Chack No 9. The all other study areas have values within the limits.

1.2 Environmental Policy

4.1.8 Chlorides

The levels of chlorides in groundwater were studied using titration technique, and the research findings indicated that the chloride concentration ranged from 35 mg/L to 450 mg/L, with a mean value of 138.13 mg/L. This research is important as it helps to establish safe levels of chloride in drinking water. According to the World Health Organization (WHO), public drinking water should not contain more than 250 mg/L of chloride.

There are several potential sources of surface water chlorides, such as rocks containing chlorides, agricultural run-offs, industry wastewater, oil well wastewater, and effluent wastewater from wastewater treatment plants. These sources can contribute to the overall chloride concentration in the water and may require monitoring to ensure safe levels are maintained.

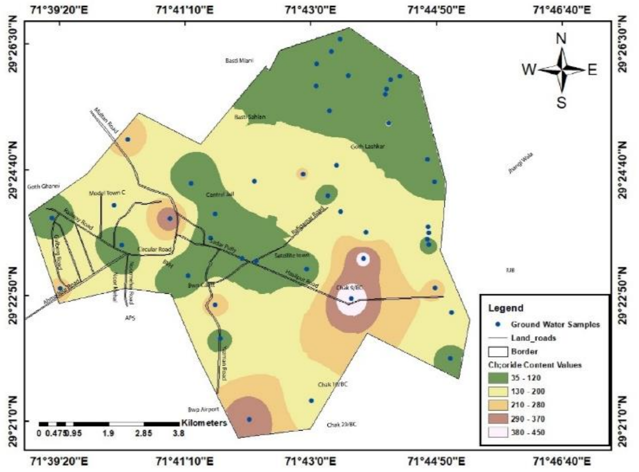

Figure 12: GIS map of Chloride Contents in study area

After conducting GIS analysis, it was observed that the majority of the study area had low levels of chlorides in the groundwater samples. The results were visually represented through an interpolated map that showed separate positions with the concentrations of chlorides values, which were marked by various legends. This information can be useful in identifying areas where groundwater may be at risk of contamination by chloride, which could lead to health issues if consumed by humans or animals.4 study areas which includes Chack No 9 BC, old city Bahawalpur, Badar sher and Airport nearby areas have higher chlorides contents values while all other areas have its value within the permissible limit.

1.2 Environmental Policy

4.1.9 Iron

The study conducted an analysis of Iron (Fe) concentration in groundwater samples. The samples were found to have concentrations ranging from 0 to 0.6 mg/L, with a mean of 0.0622 mg/L. The obtained values were then compared to standard values for drinking water by WHO and the value should be 0.1mg/L. which can be found in the appendix that accompanies the study. The overall average value is within the permissible limit.

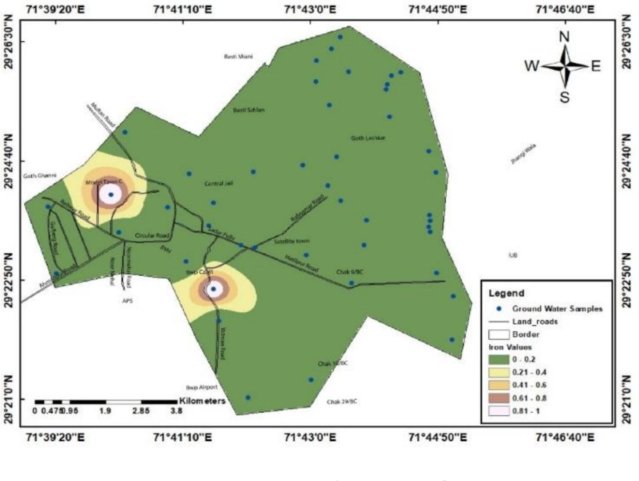

Figure 13: GIS map of Iron in study area

The concentration of Iron (Fe) in different locations was mapped on a GIS map with various legends. The study found that the concentration of Iron (Fe) was zero in most of the groundwater samples obtained from the study area while 6 samples have Iron values which is beyond the permissible limit. However, certain areas such as Bahawalpur Cantt, Model Town C, Central Jail, and Goth Lashkar had a presence of Iron (Fe) with varying concentrations. Overall, the study provides valuable information on the quality of groundwater in the study area and highlights areas that may require further attention to ensure safe water usage.

4.1.10 EC

The electrical conductivity (EC) analysis of the groundwater was conducted using a digital EC meter, which revealed EC values ranging from 432 to 8080, with a mean of 1661.77. The obtained values were then compared to standard values for drinking water by WHO and the value should be 197.14 µs/cm, which can be found in the appendix that accompanies the study.

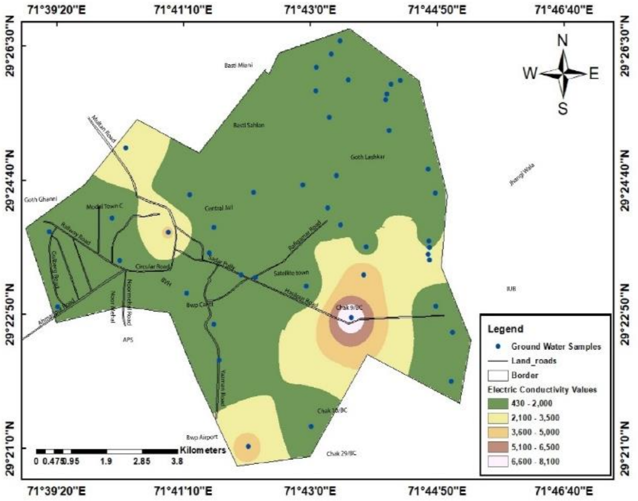

Figure 14: GIS map of Electrical Conductivity in study area

The Interpolation IDW technique in GIS was utilized to create a map that depicted distinct legends for several locations with varying EC concentrations. The GIS analysis revealed that all the study area had higher EC levels in groundwater samples, with significant variation across the region.

4.2 Water Quality Index

Water quality is a crucial aspect for human health, and it is affected by various variables and their boundary values. Water samples that exceed these boundary values can have adverse effects on human health. Evaluating water quality by tabulating and comprehending these features is a significant challenge for authorities and administrators in this area. The Water Quality Index (WQI) is a single figure that can be computed and used to describe overall groundwater quality. It offers a quick approach to determining water quality by examining a single aggregate number and its related scale. WQI collects a large number of water quality characteristics and presents them in understandable terms, such as "Excellent," "Good," "Fair," "Marginal," and "Poor."

The first research on evaluating water quality by pollution level was conducted in Germany in 1848. It took over a decade to develop the WQI, and Horton created a WQI in 1965 based on eight water quality criteria. The Oregon Department of Environmental Quality (ODEQ) established the first Oregon Water Quality Index (OWQI) in the 1970s based on the translation of groundwater quality parameters into normalized values by sub-indices and combining these sub-indices to create a single integer for the expression of water quality. The Canadian Water Quality Index CCME WQI was created in the 1990s and calculated using the frequency of variable sampling, the frequency of failed variables, and the divergence from the standards' goal.

In this research, a GIS-based Water Quality Index (WQI) was used to determine groundwater quality in the research region. It is a helpful technique for assessing overall water quality for drinking purposes. GIS is an effective tool in which results at specific locations can be interpolated over the entire study area using interpolation and statistical tools. In this study, 10 water quality parameters at 45 locations were calculated, and a GIS layer of each parameter was prepared using the IDW interpolation technique. Different water parameters were chosen, and WHO drinking water regulations were taken into account for those parameters. The water quality index is calculated from the Canadian Water Quality Index Technique where the Scope, frequency and Amplitude is calculated by using the WHO Standard values which is attached in the appendix. The

Water Quality Index value of each parameter is calculated and the overall value is computed by taking the summation and average of all the values.

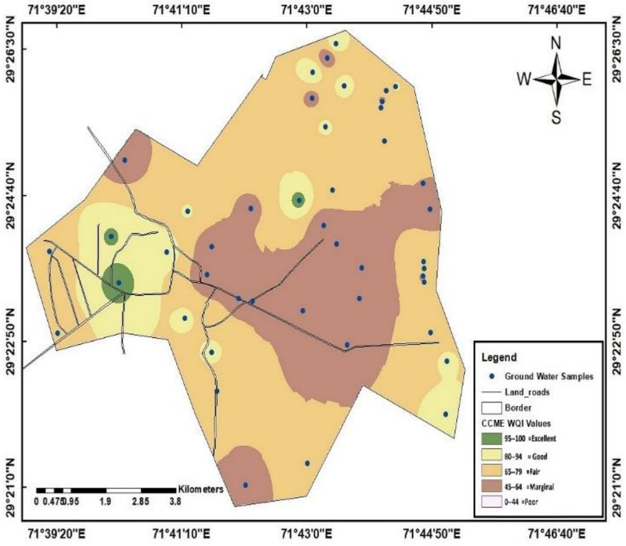

Figure 15: GIS map of WQI in study area

The water was categorized into several groups based on WQI values. Null of the groundwater samples represented "excellent water", 18% represented "good water", 45 % indicated "Fair water", 22% indicated "Marginal water" and 15% water was Poor for drinking purposes. The poor water quality was higher in Model Town and its corresponding areas and near Rafiqamar road Al-Raheem Town.

4.3 Discussion

The water quality index suggests that overall water quality of Bahawalpur City is 65%. Total 45 samples were collected out of which 11 were from Tube well, 21 from motor pump and 13 from hand pump. The Tube well depth ranges from (260-300ft) and overall water quality of tube well varies from fair to good. The locations of the samples were from the agricultural land that shows the water quality is suitable for drinking and agricultural purposes in that areas at that depth. The motor pump samples ranges from (110-130ft) and overall water quality of motor pump varies poor to fair where most of the samples are in poor and fair situation. The areas including Chack no 9 Mohajir colony, Badar sher, Model Town B, Makhdumpura old city Bahawalpur, Riaz colony have poor water quality at a depth of 110-120ft. The hand pump samples ranges from (65-90ft) and overall water quality of hand pump varies from poor to fair. The areas including civil hospital, one unit, yazman road and Islamic colony where depth from 80-90ft have fair water quality while all other areas have poor water quality. Overall the minimum depth should be 130ft and more so that the quality of the groundwater can be enhanced.

5. CONCLUSION & RECOMMENDATIONS

Water is an essential resource for human beings, but unfortunately, it is often contaminated and unfit for drinking. In certain areas like Islamic Colony, Model Town, heavy metals such as iron have been detected in groundwater testing samples. As people use this contaminated groundwater for drinking, it can have a severe impact on human health. Although the pH and turbidity of groundwater samples meet the acceptable threshold, other parameters like TDS, TA, TH, Ca, Mg, Cl, and EC did not meet the permissible limit. Only a few rural areas, such as Basti Salhan and Goth Lashkar, showed normal and permissible water quality parameters. However, throughout the study area, the EC value exceeded the permissible limit, indicating contamination and hazardous groundwater quality. The overall water quality in the city is only 65%, indicating that contamination is widespread and the areas includes Model Town, Islamic Colony, Chack no 9/BC and corresponds areas and few areas from rural have poor water quality. This contaminated water also has an adverse effect on soil salinity and the overall quality of water. It is clear that groundwater quality is not safeguarded for drinking, and urgent action is needed to address this critical issue.

5.1 Conclusion

Overall, the water quality in Bahawalpur City, as summarized in the Water Quality Index (WQI), is considered fair but not suitable for drinking in most areas. The areas includes Badar Sher, Chack No 9 Muhajir Colony, Mukhdumpura Old city Bahawalpur, Karbala Road Model town B, Ialamic Colony and Al Hafeez Town Yazmzn Road have poor water quality. The change in soil strata and properties, coupled with the city's location near the River Sutlej, which has been dry for a long time, leads to the over-extraction of groundwater and the seepage of total dissolved solids, resulting in water pollution. The city's proximity to desert areas also impacts water quality, making it unfit for drinking. The electrical conductivity (EC) of groundwater varies from 276 mg/L to 5171 mg/L, with higher levels observed throughout the city due to the presence of dissolved salts from both natural sources and human activities, such as irrigation with saline water and improper disposal of industrial effluent. The over-extraction of groundwater can also lead to an accumulation of salts in the soil and groundwater. The presence of natural geological formations like limestone and dolomite leads to higher levels of calcium, magnesium, total hardness, and total alkalinity in groundwater, with values ranging from 28 mg/L to 425 mg/L, 5 mg/L to 167 mg/L, 100 mg/L to 1200 mg/L, and 90 mg/L to 714 mg/L, respectively The increased levels of total dissolved solids (TDS) in groundwater, ranging from 276 mg/L to 5171 mg/L, are attributed to the use of fertilizers and pesticides in agricultural land and poor waste management practices. Chloride concentrations in groundwater range from 35 mg/L to 450 mg/L, with higher levels found in rural areas due to salt deposits or rock formations. The pH level of groundwater in Bahawalpur City ranges from 7.06 to 8.62, indicating that the water is basic or alkaline in nature. The turbidity levels of groundwater vary from 0.44 NTU to 5.15 NTU, with only a few samples exhibiting slight turbidity due to the presence of suspended particles like silt, clay, and organic matter.

5.2 Recommendations

After completing analysis on the study area following recommendations are made, Wastewater must be discharged in the water body after proper treatment. The impact of sugar and oil industries on the quality of water in the city's groundwater, canals and river must be observed and proper steps should be taken to prevent groundwater to pollute. For the prevention of wastewater seepage in soil and groundwater the drainage system must be lined properly. The effectiveness of water treatment plants in the city must be ensured. Water filtration plants must be installed in each area to overcome the availability of good quality of water in the city and their cleaning must be done after regular intervals. Strategies for improving water quality must be studied and implemented. Due to the high-water consumption, the relevant authorities should consider recycling and wastewater reuse. Because, if we continue to use solely groundwater, our water would quickly decline. Regular testing of water quality of specific areas after certain time period is important to identify contamination sources and take necessary measures to address them. Local authorities must conduct frequent water quality tests in residential areas and provide reports to residents. Proper waste disposal is critical to prevent water source contamination, and residents should be encouraged to dispose of waste properly, with adequate facilities provided. Community awareness is important and educating residents about clean water's importance and their role in maintaining water quality is necessary. This can be done through community meetings, public service announcements, and other outreach programs. Regular cleaning of water storage tanks is also essential to prevent the growth of harmful organisms like bacteria. Therefore, local authorities must ensure that water storage tanks are cleaned regularly. Industrial pollution can have a significant impact on water quality, so monitoring and controlling it in the area is also necessary to prevent contamination of the water supply.

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