Geospatial Mapping of Drinking Water Contamination and Health Implications in a Semi-Arid Tehsil of Pakistan

Iffat Batool[1], Hira Zafar[2], Awais Munir[3], Asma Majeed[4], Iftikhar Ahmed[5], Mudassar Irfan[6], Muhammad Abdullah Haroon[7], Waheed Ullah Khan[8] and Tahreem Zafar[9]

https://doi.org/10.62345/jads.2025.14.3.103

Abstract

The right to safe drinking water remains a key challenge in developing countries, despite international agreements on Sustainable Development Goal 6 (SDG 6). This research evaluated the quality of groundwater and the associated health impacts in Ahmedpur East, a semi-arid tehsil in the Bahawalpur District, Pakistan, using laboratory analyses, geospatial maps, and hospital health data. The 12 groundwater samples were tested in accordance with the APHA (2017) standards for pH, total dissolved solids (TDS), electrical conductivity (EC), calcium (Ca 2+), magnesium (Mg 2+), potassium (K 2+), and turbidity. Findings revealed that TDS exceeded 1,500 mg/L and EC exceeded 2,000 µS/cm at several locations, indicating high turbidity (>10 NTU) and microbial contamination in low-income areas. In contrast, high hardness was associated with a higher incidence of kidney stones. The conceptual framework combines the water health nexus model and the environmental determinism theory, in which the influence of physicochemical water degradation determines the direct effect on disease spatial patterns. The results are consistent with the theoretical premises of environmental exposure as a cause of disease prevalence in population health. GIS overlays revealed a high degree of spatial convergence between contamination hotspots and disease clusters, indicating that groundwater quality deterioration is a key determinant of local health outcomes. This paper highlights the importance of community-based water treatment, round-the-clock surveillance, and geospatial surveillance as indicators of achieving water security.

Keywords: Groundwater Quality, Water Quality Index, Geospatial Analysis, Public Health.

Introduction

Water is universally acknowledged as the most essential resource for sustaining life, underpinning health, food security, economic growth, and ecological balance. Despite covering

[1]*MS Scholar, Institute of Agro-Industry and Environment, The Islamia University of Bahawalpur, Pakistan. Email: karimhaider8654@gmail.com*
[2]*Student, Institute of Agro-Industry and Environment, The Islamia University of Bahawalpur, Pakistan. Email: hirazafar1526@gmail.com*
[3]*Lecturer, Institute of Agro-Industry and Environment, The Islamia University of Bahawalpur, Pakistan. Corresponding Author Email: awais.munir@iub.edu.pk*
[4]*Assistant Professor, Institute of Agro-Industry and Environment, The Islamia University of Bahawalpur, Pakistan. Email: asma.majeed@iub.edu.pk*
[5]*Assistant Professor, Department of Agricultural Engineering, Khawaja Fareed University of Engineering and Information Technology, Rahim Yar khan, Pakistan. Email: iftikharahmedifii@gmail.com*
[6]*Student, Department of Agricultural Engineering, Khawaja Fareed University of Engineering and Information Technology, Rahim Yar khan, Pakistan. Email: mudassararfan18@gmail.com*
[7]*Student, Department of Agricultural Engineering, Khwaja Fareed University of Engineering and Information Technology, Rahim Yar khan, Pakistan. Email: abdullah64050@gmail.com*
[8]*Assistant Professor, College of Earth and Environmental Sciences, University of the Punjab, Lahore, Pakistan. Email: waheed.cees@pu.edu.pk*
[9]*PhD Scholar, Institute of Agro-Industry and Environment, The Islamia University of Bahawalpur, Pakistan. Email: tahreem.zafar23@gmail.com*

Compliance with ethical standards: There are no conflicts of interest (financial or non-financial). This study did not receive any funding.

about 71% of Earth's surface, only 2.5% of the total water is freshwater, and less than 1% of this is readily available for direct human use in rivers, lakes, and shallow groundwater aquifers (Shiklomanov & Rodda, 2004). This limited freshwater resource has become increasingly threatened by rapid population growth, climate change, industrial expansion, and unsustainable agricultural practices (Taylor et al., 2020). The World Health Organisation (WHO, 2021) estimates that 2.2 billion people globally lack access to safely managed drinking water services, while 4.2 billion people lack access to safe sanitation facilities. The consequences of this water insecurity are stark: each year, an estimated 485,000 deaths occur from diarrheal diseases attributable to contaminated drinking water (WHO, 2019). Inadequate access to clean water also perpetuates cycles of poverty, malnutrition, and poor education outcomes, especially in low- and middle-income countries (UNICEF, 2020). Compounding the problem is the growing pollution of freshwater sources. Groundwater, once considered a pristine and safe source, is increasingly contaminated with nitrates, arsenic, fluoride, heavy metals, and pathogenic microorganisms. Industrial effluents, untreated sewage, pesticide leaching, and agricultural runoff have degraded aquifers worldwide, with particularly severe consequences in developing nations where water treatment infrastructure is inadequate (Mekonnen et al., 2016).

Thus, the challenge is not simply one of water scarcity but also of water quality. The dual crises of quantity and quality now define the global discourse on water security, calling for integrated, sustainable solutions. Recognising the gravity of the water crisis, the international community adopted *Sustainable Development Goal 6 (SDG 6): Clean Water and Sanitation* as part of the 2030 Agenda for Sustainable Development. SDG 6 aspires to "ensure availability and sustainable management of water and sanitation for all" by 2030. Its targets include achieving universal and equitable access to safe drinking water, improving water quality by reducing pollution, and implementing integrated water resources management (UN, 2015). While progress has been made, recent UN-Water reports indicate that the world is off track to achieve SDG 6. Sub-Saharan Africa and South Asia remain the most affected regions, with millions still dependent on untreated groundwater and surface water sources (UN-Water, 2023). Moreover, climate change, driven by altered precipitation patterns, glacial melt, and rising sea levels, further complicates water management, increasing the risks of both floods and droughts. The emphasis on SDG 6 underscores the interlinkages between water and other goals such as *SDG 3 (Good Health and Well-being), SDG 11 (Sustainable Cities and Communities),* and *SDG 13 (Climate Action).* Without ensuring safe water, progress on health, education, gender equality, and poverty eradication will remain elusive. Groundwater has historically been the backbone of human civilisations. Ancient societies such as those of the Indus Valley, Mesopotamia, and the Nile developed irrigation systems that relied on both surface and groundwater. The 20th century marked a dramatic increase in groundwater abstraction, termed the "silent revolution," driven by the Green Revolution, population growth, and urban expansion (Famiglietti, 2014).

Globally, groundwater now supplies about 43% of irrigated agriculture and 50% of drinking water needs (UNESCO, 2020). Its widespread use stems from its perceived reliability, natural filtration, and lower infrastructure requirements than those of surface reservoirs. However, this dependence has led to unsustainable extraction rates. Countries like India, Pakistan, the United States, and China are the largest abstractors, with Pakistan alone withdrawing 65 km³ annually, ranking fourth worldwide (Famiglietti, 2014; Munir et al., 2025). This over-reliance has consequences: falling water tables, saline intrusion, and aquifer contamination. Moreover, while once considered immune to pollution, aquifers are now increasingly compromised by agricultural chemicals, industrial waste, and poor sanitation. The historical reliance on groundwater, while beneficial for human development, has become a liability due to overexploitation and mismanagement. South Asia is among the most severe cases of groundwater stress. India and Pakistan together account for more than one-third of global groundwater withdrawals (Mekonnen et al., 2016). In Bangladesh and West Bengal, naturally occurring arsenic contamination affects an estimated 60 million people, with concentrations reaching up to 70 times the WHO limit (UNEP, 1999). Similarly, nitrate contamination from fertiliser use is widespread in Punjab (India and Pakistan), increasing risks of "blue baby syndrome" in infants and gastrointestinal illnesses in adults (Kumar et al., 2023).

In Pakistan, 70% of the population depends on groundwater. However, studies by the Pakistan Council of Research in Water Resources (PCRWR) indicate that two-thirds of water samples are unsafe for drinking (PCRWR, 2017). Arsenic, fluoride, salinity, and microbial contamination remain the key threats. Sub-Saharan Africa faces a dual burden of water scarcity and poor quality. Many countries rely on shallow wells and boreholes that are vulnerable to faecal contamination because of poor sanitation infrastructure. For example, in Nigeria, over 60% of rural households depend on shallow groundwater sources, often contaminated with pathogens that cause cholera and diarrhoea outbreaks (Oloruntoba et al., 2014). The absence of treatment facilities means communities consume contaminated water directly, contributing to high child mortality rates. Latin America, despite abundant water resources, faces localised groundwater contamination crises. In Mexico, overexploitation of aquifers around Mexico City has caused both falling water tables and fluoride contamination, leading to widespread dental and skeletal fluorosis (Rodríguez et al., 2015). Similarly, in Brazil's semi-arid regions, agricultural runoff and pesticide residues threaten groundwater quality. Countries like Peru and Bolivia struggle with arsenic contamination in high-altitude aquifers, as do countries in South Asia. These comparative cases underscore common global trends: dependence on groundwater for survival, increasing contamination, and inadequate management responses.

Pakistan is classified as a water-stressed country, with per capita availability declining from 5,600 m^3 in 1951 to less than 1,000 m^3 in 2022, a level below the threshold for absolute scarcity (Khan et al., 2023). Rapid urbanisation, industrialisation, and agricultural intensification have placed immense pressure on limited resources. Groundwater forms the backbone of domestic and agricultural supply, yet its quality is rapidly deteriorating due to Industrial effluents, heavy metals and chemical discharges in Punjab and Sindh. Agricultural runoff caused by fertilisers and pesticides contaminates shallow aquifers. Sanitation issues caused by leakage from sewage and poorly managed solid waste—natural contaminants by arsenic in southern Punjab, fluoride in Sindh, and salinity in Cholistan. Studies across Lahore, Faisalabad, and Karachi consistently reveal high levels of microbial contamination, rendering municipal water unsafe (Ihsanullah et al., 2009). In rural areas, poor sanitation further compounds risks, with diarrhoea, hepatitis, and typhoid as leading causes of morbidity and mortality (Murtaza et al., 2024).

Ahmedpur East, a tehsil in Bahawalpur District, southern Punjab, epitomises the challenges of groundwater dependence in Pakistan. With a population of over one million, the majority of households rely directly on groundwater from tube wells and hand pumps. The semi-arid climate, low rainfall, and proximity to the Cholistan desert exacerbate water stress, while the Sutlej River provides limited surface water. Preliminary surveys indicate that groundwater quality in Ahmedpur East is highly variable, with many areas exceeding WHO limits for TDS, EC, calcium, magnesium, and turbidity (Anwar et al., 2024). Elevated salinity compromises water palatability, while hardness-inducing ions increase the risk of kidney stones and cardiovascular disease. High turbidity levels, particularly in Islamic Colony and surrounding low-income neighbourhoods, suggest infiltration of microbial contaminants due to poor drainage and sanitation infrastructure (Hafeez et al., 2025). Public health data from the Tehsil Headquarters (THQ) Hospital corroborates these findings, showing high incidences of typhoid, hepatitis, diarrhoea, and kidney stones directly associated with contaminated drinking water. GIS-based spatial analysis reveals clear overlaps between contamination hotspots and disease clusters, reinforcing the direct link between groundwater quality and health outcomes in the region. While numerous studies have assessed groundwater contamination across Pakistan, Ahmedpur East has received limited scholarly attention despite its large population and acute vulnerability. By integrating physicochemical testing with geospatial disease mapping, this study provides a holistic understanding of the nexus between water quality and human health. Beyond offering baseline data for local authorities, the research aligns with broader national and international objectives under SDG 6, contributing to evidence-based policymaking for sustainable water management.

Materials and Methods

Study Area Description

Geographic Location

The study was conducted in Ahmedpur East, one of the largest tehsils in Bahawalpur District, located in the southern region of Punjab, Pakistan. Geographically, the tehsil lies between latitudes 29° 9′ N and longitudes 70° 16′ E, at an elevation of approximately 105 meters above sea level. The area is bounded to the northwest by the Sutlej River, while the southeastern portion merges with the Cholistan Desert, a hyper-arid ecosystem with extreme climatic variations. The proximity of Ahmedpur East to both fertile alluvial plains and desertic landscapes makes its groundwater highly variable in terms of quality.

Climate and Hydrology

The region falls within a semi-arid climatic regime, characterised by scorching summers with average maximum temperatures exceeding 45°C and relatively mild winters with average lows around 18°C. Annual precipitation is sparse (100–250 mm), concentrated during the monsoon months of July to September. This limited rainfall, coupled with high evapotranspiration rates, constrains surface water recharge, making groundwater the dominant source of domestic and agricultural supply.

Demographics and Socio-economic Profile

According to the 2017 Pakistan Census, Ahmedpur East had a population exceeding 1,078,000, distributed across urban neighbourhoods, peri-urban colonies, and rural villages. The majority of households rely on tube wells, hand pumps, or municipal pipelines that draw from shallow aquifers. Agriculture forms the backbone of the local economy, with wheat, cotton, and sugarcane as major crops. The socio-economic disparities are marked: while wealthier households may afford filtration or bottled water, the majority of residents, especially in low-income colonies, depend directly on untreated groundwater, exposing them to contamination risks.

Water Sources

Groundwater extraction occurs at varying depths. Shallow aquifers (30–60 ft) near irrigated canal zones tend to provide relatively better-quality water due to recharge from canal seepage. However, in southern areas adjoining the Cholistan desert, groundwater is often saline and brackish at depths of 300–800 ft. Overexploitation of tube wells, lack of centralised treatment facilities, and seepage from agricultural fields and sewage drains contribute to progressive degradation of water quality.

Sampling Protocols

Site Selection

A total of 12 sampling sites were strategically chosen across Ahmedpur East, covering densely populated residential areas, institutional campuses, and peri-urban settlements. Criteria for Selection included: Population density (high-density neighbourhoods are more prone to contamination). Proximity to agricultural land (potential influence of fertiliser/pesticide leaching). Socio-economic diversity (to capture disparities in water infrastructure). Reported health complaints (areas with anecdotal evidence of waterborne diseases). The sites included Sadiq Public School, Adalat, Islamic Colony, Satellite Town, and surrounding residential zones. GPS coordinates were recorded using Garmin portable GPS units to enable accurate geospatial mapping.

Sampling Procedure

Water samples were collected from household taps and hand pumps after flushing for 3–5 minutes to eliminate stagnant water. Pre-cleaned polypropylene bottles (500 mL) were used, rinsed thrice with the sample water before final Collection. Bottles were sealed, labelled (RC-68 to RC-79), stored in insulated coolers, and transported to the Public Health Engineering Department (PHED) Laboratory in Bahawalpur within 6 hours of Collection. Field data (temperature, odour, and turbidity by observation) were also recorded.

Quality Assurance

Standard protocols recommended by the American Public Health Association (APHA, 2017) were followed. Field blanks and duplicate samples were collected at 10% of sites to ensure data reliability.

Laboratory Analysis of Physicochemical Parameters

The samples were analysed at the PHED Laboratory for critical drinking water parameters. Each parameter was selected for its significance in determining potability, aesthetic acceptability, and health risks. Results were compared with the WHO Drinking Water Guidelines (2017).

pH (Hydrogen Ion Concentration)

The pH of water samples was measured using a calibrated digital pH meter equipped with a glass electrode. Before measurement, the instrument was standardised with buffer solutions of pH 4.0, 7.0, and 9.2 to ensure accuracy. pH is a fundamental parameter as it indicates the acidity or alkalinity of water, directly influencing the solubility of metals and the activity of microorganisms. According to WHO standards, acceptable drinking water should have a pH between 6.5 and 8.5. Values below 6.5 can increase corrosively and lead to leaching of toxic metals from distribution pipes, while values above 8.5 reduce disinfection efficiency, thereby compromising microbial safety.

Total Dissolved Solids (TDS)

TDS was determined gravimetrically using a digital TDS meter, which measures the total dissolved solids concentration, including calcium, magnesium, sodium, potassium, bicarbonates, chlorides, and sulfates. The WHO recommends a maximum permissible limit of 1,000 mg/L for TDS. Values exceeding 1,500 mg/L generally impart an unpleasant salty taste, cause gastrointestinal irritation, and reflect salinity intrusion into aquifers, a common issue in semi-arid zones such as southern Punjab.

Electrical Conductivity (EC)

EC was measured with a digital conductivity meter and expressed in microsiemens per centimetre (µS/cm). This parameter reflects the ionic strength of water and strongly correlates with TDS. As per WHO guidelines, drinking water should not exceed 1,500 µS/cm. Elevated EC values indicate high salinity, which limits the use of water for drinking and irrigation and, in severe cases, can contribute to dehydration and mineral imbalance in humans.

Turbidity

Turbidity was measured with a turbidity meter and reported in Nephelometric Turbidity Units (NTU). This test quantifies the presence of suspended particles, including clay, silt, organic matter, and microorganisms. WHO prescribes a maximum turbidity of ≤5 NTU in drinking water. Higher levels compromise aesthetic quality, interfere with disinfection, and provide a protective environment for pathogens such as *Escherichia coli*, *Vibrio cholerae*, and *Salmonella typhi*. In this way, elevated turbidity serves as a proxy for microbial risk, often correlating with outbreaks of diarrhoea, cholera, and typhoid.

Calcium (Ca^{2+}) and Magnesium (Mg^{2+})

Concentrations of calcium and magnesium were measured using the complex metric titration method with ethylenediaminetetraacetic acid (EDTA). For precision and validation, selected samples were further analysed using an Atomic Absorption Spectrophotometer (AAS). These two parameters are the principal contributors to water hardness. WHO standards specify maximum concentrations of 200 mg/L for calcium and 150 mg/L for magnesium. Excess hardness affects palatability, contributes to scaling in household and industrial pipelines, and is associated with adverse health outcomes, including kidney stones, cardiovascular stress, and digestive complications.

Potassium (K^+)

Potassium levels were analysed using flame photometry, a sensitive technique for detecting alkali metals in aqueous solutions. Potassium occurs naturally in trace amounts, but elevated levels usually indicate fertiliser runoff or leakage from sewage systems. WHO recommends concentrations below 12 mg/L for safe drinking water. Chronic exposure to higher levels can lead to hyperkalemia, posing significant health risks to individuals with renal impairments or those on potassium-restricted diets.

Heavy Metals (Lead and Others)

Although not the primary focus of the study, selected samples were analysed for heavy metals, with particular attention to lead (Pb), using AAS. Lead is considered one of the most toxic elements in drinking water, and the WHO has set its permissible limit at 0.01 mg/L. Even at trace levels, lead exposure has severe neurological, developmental, and behavioural effects, particularly in children, and increases the risk of cardiovascular diseases in adults.

Integration of Health Data

Data Source

Public health data were obtained from the Tehsil Headquarters (THQ) Hospital, Ahmedpur East, which serves as the primary referral centre for the region. Records from outpatient departments (OPD) covering 2022–2023 were screened.

Disease Categories

Waterborne diseases: Typhoid, diarrhoea, cholera, hepatitis A & E.
Water-related diseases: Kidney stones, skin diseases, gastrointestinal infections.
Other relevant conditions: food poisoning and parasitic infections.

Data Handling

Patient data were anonymised to protect confidentiality. Incidence rates were calculated as cases per 1000 population. Cross-tabulation was performed to associate disease prevalence with contaminated water zones.

GIS-Based Geospatial Analysis
Software and Data Input
Spatial mapping and analysis were performed using **ArcGIS v10.2**. Sampling site coordinates (GPS) and laboratory results were imported as point layers. Hospital disease data were geocoded based on patient residence.

Interpolation Methods
Inverse Distance Weighting (IDW)
Chosen for its simplicity and reliability in interpolating groundwater quality parameters. IDW assumes that points closer together are more similar than those farther apart, producing smooth gradient maps.

Kriging (comparative approach)
Although computationally intensive, kriging was tested to validate IDW results. Kriging incorporates spatial autocorrelation, yielding more statistically robust surfaces.

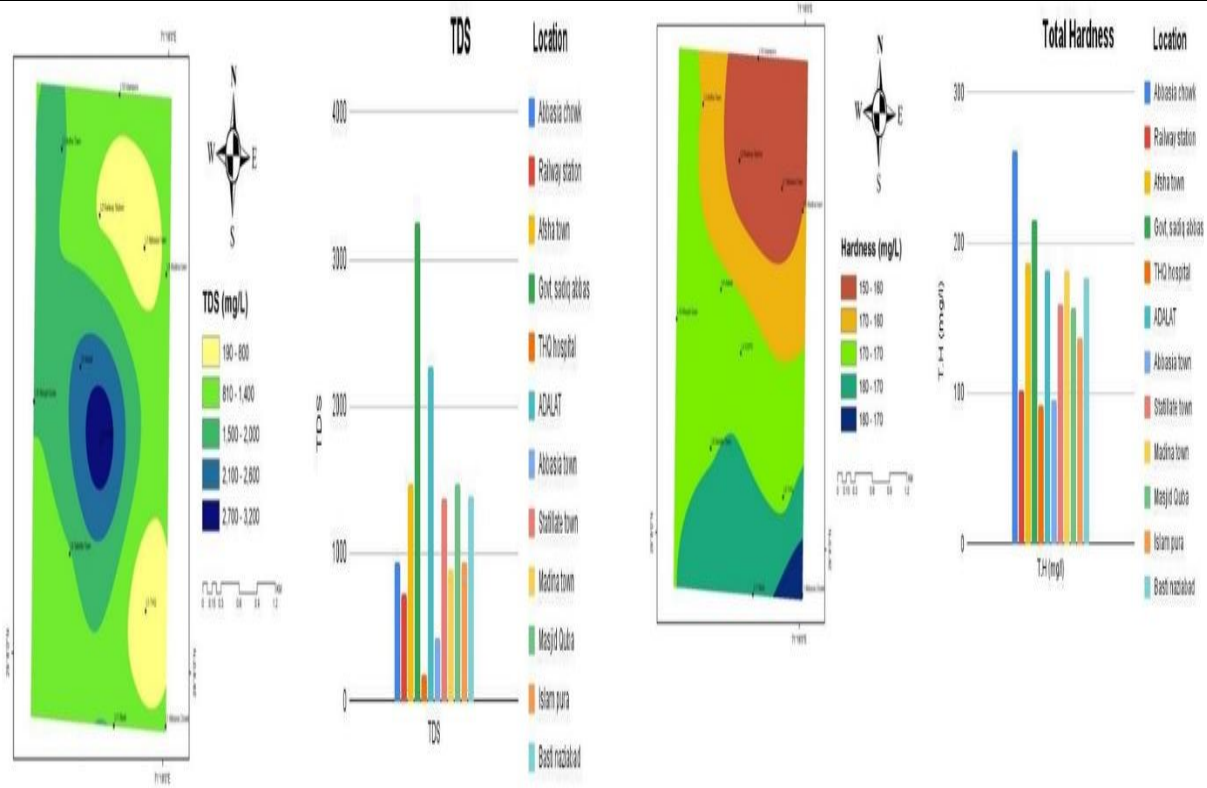
Spatial Analysis
Thematic maps were produced for each parameter (pH, TDS, EC, Ca, Mg, turbidity, and K). Overlay analysis was then applied to correlate contaminated zones with high disease incidence. This integration enabled the identification of disease hotspots associated with poor water quality.

Results and Discussion
Results
This chapter presents the laboratory findings and geospatial analysis of groundwater quality in Ahmedpur East. Results are organised parameter by parameter, with comparisons against WHO standards and interpretations of spatial patterns. Where relevant, results are further contextualised through correlations with hospital health records and comparisons with regional studies across Punjab. Groundwater quality in Ahmedpur East showed marked heterogeneity, with specific neighbourhoods presenting severely deteriorated conditions while others retained comparatively safe water. A total of twelve samples were collected from taps and hand pumps across institutional and residential locations, including Sadiq Public School, Adalat, Islamic Colony, Satellite Town, Masjid Quba, Afsha Town, THQ Hospital, Railway Station, Abbasia Town, Basti Naziabad, Madina Town, and Islampura. These locations were georeferenced and spatially analysed in ArcGIS to produce interpolated distribution maps for each parameter.

Total Dissolved Solids (TDS) and Total Hardness (TH)
TDS values varied widely across the study area, ranging from 190 mg/L near the Railway Station to 3,200 mg/L at Sadiq Public School and Adalat. The WHO recommends a limit of 1,000 mg/L for potable water, beyond which taste, palatability, and usability are compromised. The samples from Sadiq Public School and Adalat clearly fell into the "brackish" category, unsuitable for human consumption without treatment. Masjid Quba and Afsha Town reported intermediate values (1,500–2,600 mg/L), still well above safe thresholds. In contrast, the Railway Station and THQ Hospital zones yielded relatively fresher water (190–800 mg/L), suggesting aquifer recharge from canal seepage or localised groundwater heterogeneity. Spatial interpolation maps revealed a transparent north-to-south gradient of increasing TDS, with peripheral desertic areas most affected. Water hardness across Ahmedpur East fell within the "moderately hard" to "hard" category, with values ranging between 150 and 180 mg/L (as $CaCO_3$). Calcium concentrations were typically 67–88 mg/L in Abbasia Town, THQ Hospital, and Basti Naziabad. At the same time, magnesium levels varied significantly, from as low as

5 mg/L at the Railway Station to around 40 mg/L at Adalat and Basti Naziabad. Although hardness values were technically within WHO practical limits, they nonetheless contribute to scaling, taste issues, and, in chronic exposure cases, kidney stone formation.

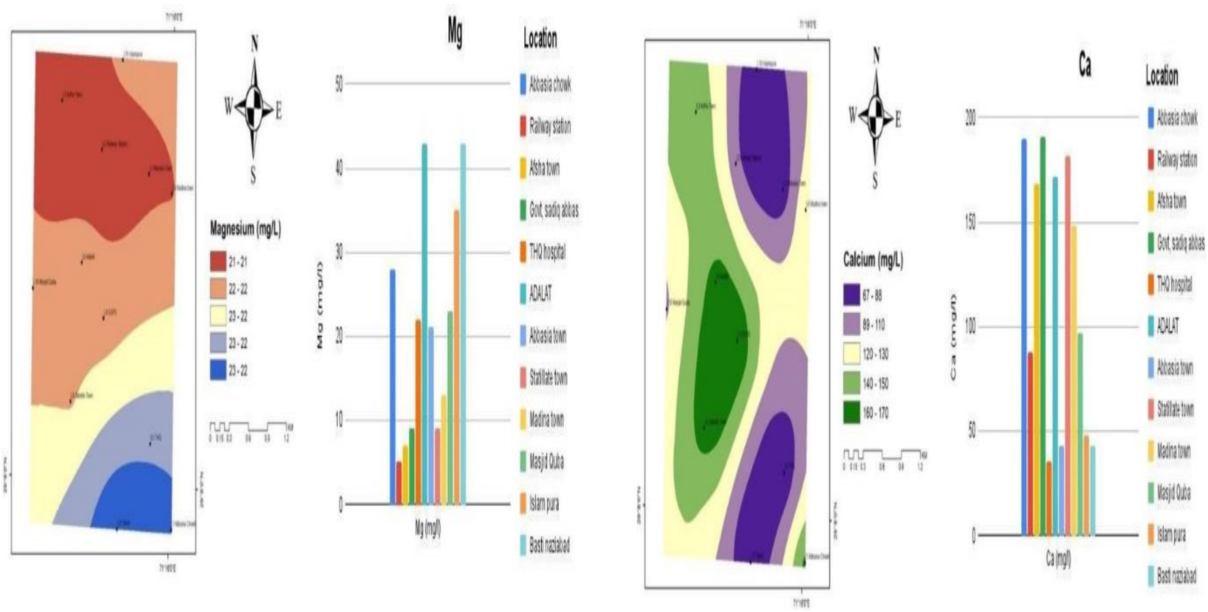
Figure 1: Spatial distribution of Total Dissolved Solids (TDS) and Total Hardness (TH) in Ahmedpur East



Calcium and Magnesium

Magnesium concentrations in the study area showed considerable variation across sampling sites. In Adalat and Basti Naziabad, the recorded value was 40 mg L^{-1}, while the Railway Station showed the lowest level with only 5 mg L^{-1} present in drinking water. Calcium levels also varied within the study area. The lowest concentrations were found in Abbasia Town, THQ Hospital, and Basti Naziabad, ranging between 67–88 mg L^{-1}. These values fall within the reported ranges for Ahmedpur East, highlighting spatial differences in the availability of these essential minerals across different neighborhoods. The spatial overlap between harder water zones and increased hospital reports of kidney stones underscores the public health implications of elevated Ca and Mg levels.

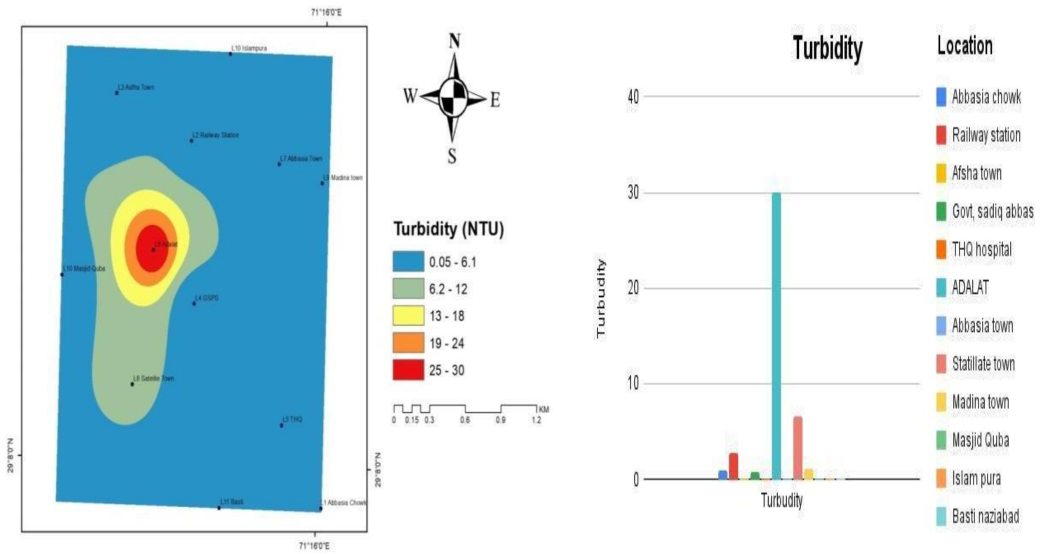
Figure 2: Spatial distribution of Magnesium (Mg) and Calcium (Ca) in Ahmedpur East



Turbidity

Turbidity levels in the study area ranged from as low as 0.05 NTU to as high as 30 NTU, far exceeding the WHO guideline of ≤5 NTU in multiple localities. Adalat showed extremely poor results, with turbidity values between 25 and 30 NTU, while Islamic Colony and other low-income neighborhoods exceeded 10 NTU. High turbidity is concerning because it reduces aesthetic quality, protects pathogens from disinfection, and increases the risk of waterborne diseases such as cholera, diarrhea, and typhoid. The turbidity spatial map confirmed that neighborhoods with poor drainage and sanitation infrastructure were hotspots of contamination, with particularly strong overlap with disease incidence data.

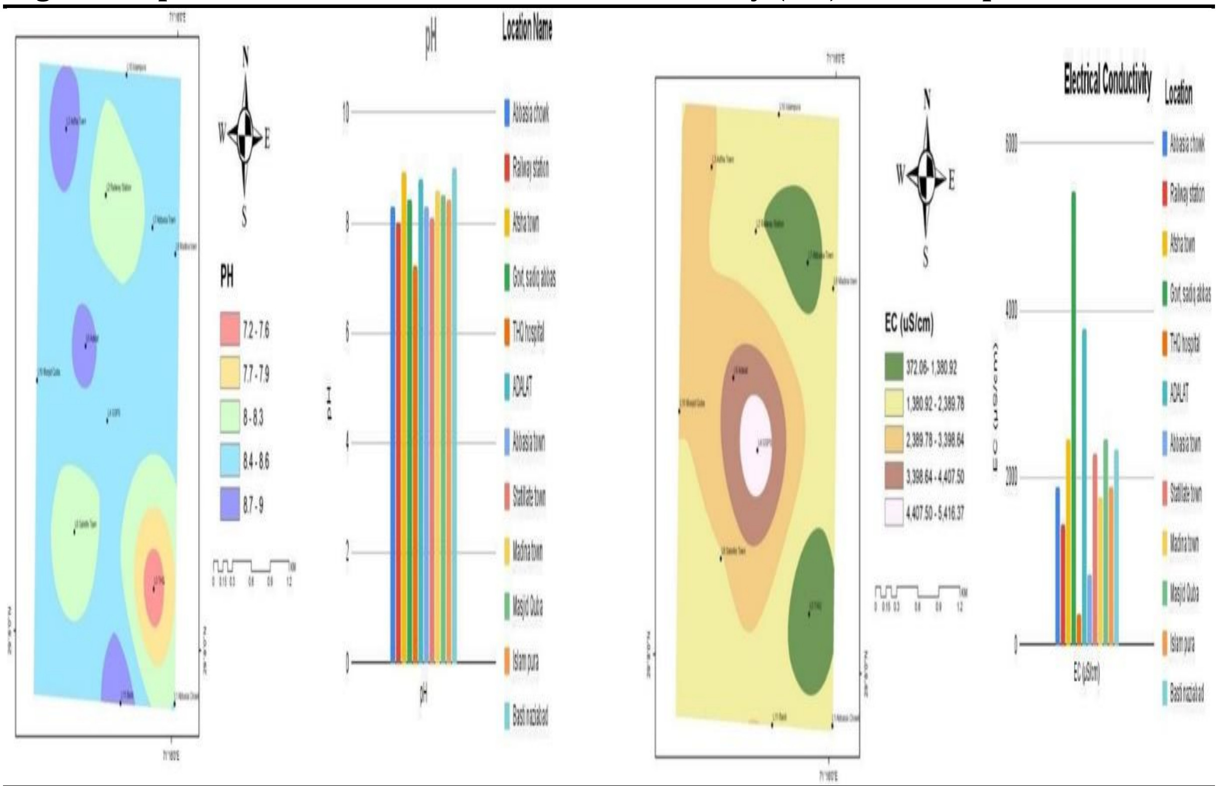
Figure 3: Spatial distribution of Turbidity (NTU) in Ahmedpur East



pH and Electrical Conductivity (EC)

The pH of groundwater in Ahmedpur East exhibited a distinct alkaline trend, ranging from near neutral (7.2–7.6) at the THQ Hospital to as high as 9.0 in Adalat, Afsha Town, and Basti Naziabad. Satellite Town and Railway Station samples ranged between 8.0 and 8.3, while many residential sites including Abbasia and Islampura reported values between 8.4 and 8.6. While alkaline water in this range does not pose immediate toxicity risks, high pH reduces the effectiveness of chlorine disinfection and contributes to scaling. The pH spatial map revealed that the most alkaline sites were also those with elevated TDS and EC, suggesting chemical interactions between mineral content and water buffering capacity. Patterns of EC closely mirrored those of TDS. At Sadiq Public School, EC ranged from 4,407 to 5,416 µS/cm, and in Adalat from 3,398 to 4,407 µS/cm, indicating a highly saline ionic load. In contrast, THQ Hospital and Abbasia reported values between 401 and 429 µS/cm, falling within acceptable limits. These results suggest that groundwater in southern and peripheral neighborhoods is subject to high mineralization, while central locations retain more usable water. High EC poses risks not only for drinking but also for agriculture, as it contributes to soil salinization and scaling in irrigation infrastructure.

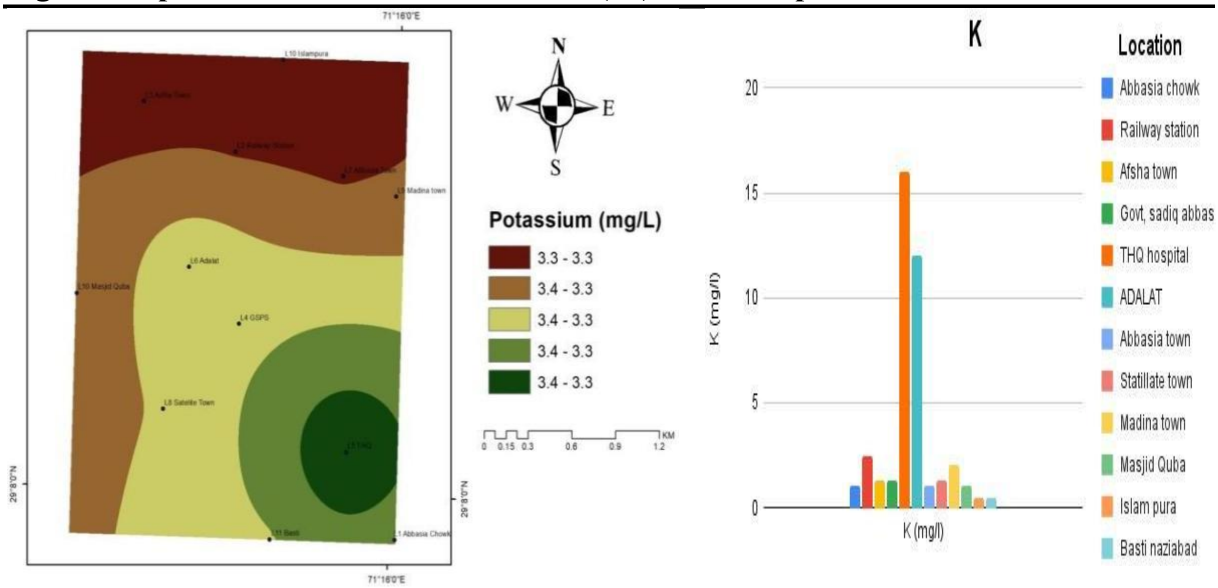
Figure 4: Spatial distribution of Electrical Conductivity (EC) in Ahmedpur East



Potassium and Heavy Metals

Potassium concentrations were reported as within WHO safe limits (<12 mg/L) across all sites, with no sample exceeding threshold levels. This suggests that fertilizer runoff or sewage leakage was not a major source of potassium contamination during the sampling period. Lead (Pb) was analyzed in selected samples using atomic absorption spectrophotometry; although no acute anomalies were reported in the thesis dataset, the limited scope of heavy metal testing warrants further investigation, particularly in areas vulnerable to industrial or agricultural inputs.

Figure 5: Spatial distribution of Potassium (K^+) in Ahmedpur East



Spatial Patterns from GIS Interpolation

Geospatial analysis using the IDW interpolation technique provided clear visualizations of contamination hotspots. A pronounced high-TDS and high-EC corridor was observed around Sadiq Public School and Adalat, with deterioration extending southward. Turbidity hotspots clustered in Islamic Colony and Adalat, aligning with poorly drained, low-income neighborhoods. Fresher, low-TDS pockets were identified around the Railway Station and THQ Hospital areas, reflecting aquifer recharge and better groundwater quality. pH gradients showed pervasive alkalinity, with the highest values in Adalat, Afsha, and Basti Naziabad. Kriging was tested for validation and yielded similar results, though IDW was adopted for primary presentation due to its suitability for the small-scale sampling design.

The hospital data collected from Tehsil Headquarters (THQ) Hospital Ahmedpur East indicated clear variations in the prevalence of waterborne and water-related diseases across neighborhoods. Typhoid was most frequently observed in Abbasia Chowk with 11.4% of cases, followed closely by Adalat with 10.1%, while other areas such as Islamic Colony, Afsha Town, and Islampura reported comparatively lower values ranging between 5.0% and 8.0%. Kidney stone cases showed a different distribution, with the highest occurrence recorded in Masjid Quba at 9.8% and in Abbasia Chowk at 9.7%, while remaining areas, including Satellite Town and Railway Station, presented reduced percentages fluctuating between 4.5% and 7.2%. Hepatitis A cases were notably concentrated in Satellite Town with 10.2% and Madina Town with 9.8%, whereas other neighborhoods, including Abbasia and Basti Naziabad, demonstrated values in the range of 5.0–8.0%. Food poisoning was reported at its maximum in Masjid Quba with 11.5%, followed by Afsha Town with 10.2%, while other locations such as Sadiq Public School and THQ Hospital showed reduced figures, falling between 4.0% and 7.0%. Collectively, Abbasia Chowk, Masjid Quba, Adalat, Satellite Town, and Madina Town emerged as the primary hotspots for disease prevalence, with all recording values above 9.0% in at least one disease category. In contrast, Railway Station, THQ Hospital, and Sadiq Public School consistently showed lower prevalence, with most values under 7.0%. These results indicate a wide spatial variation in disease occurrence, with the highest figures consistently above 10.0% in specific neighborhoods and the lowest generally between 4.0% and 6.0%. The overall range of disease prevalence across all sites extended from a minimum of 4.0% for food poisoning in certain low-incidence areas to a maximum of 11.5% for food poisoning in Masjid Quba.

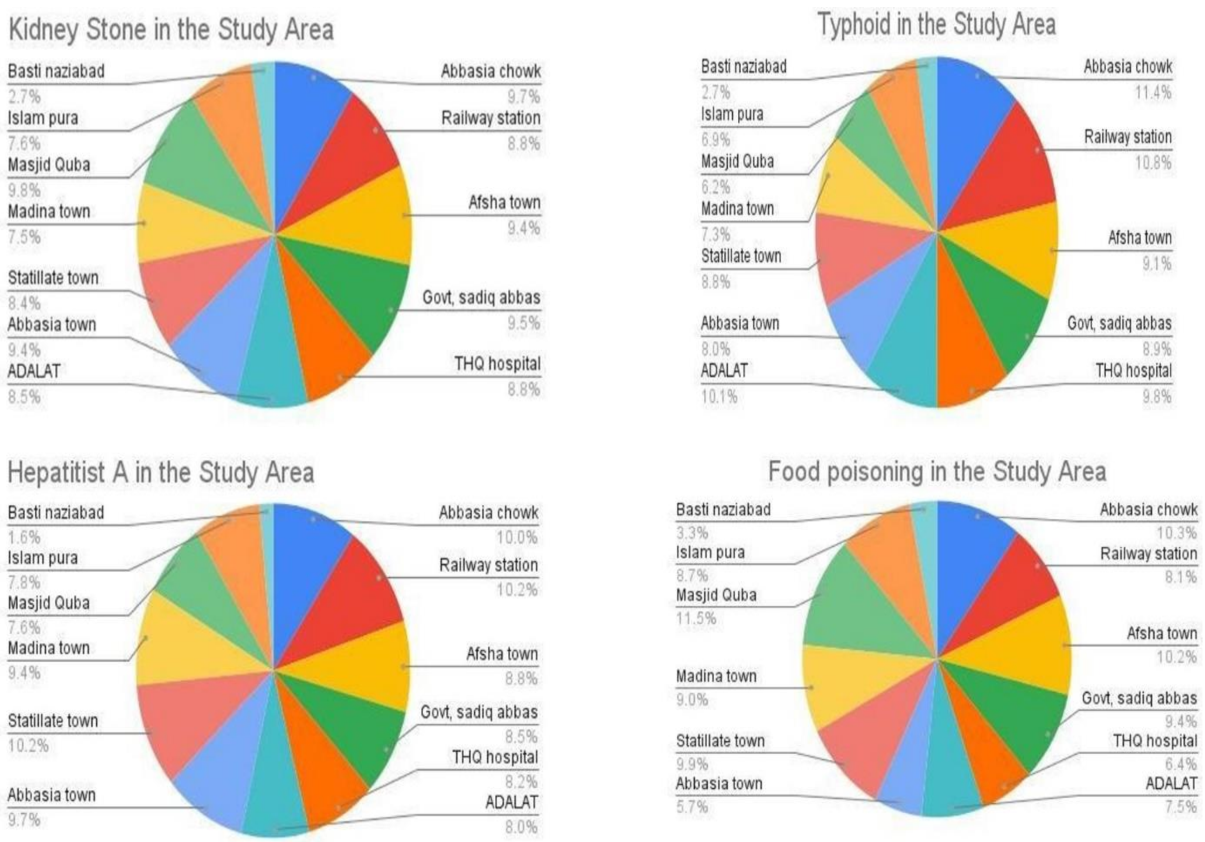
Health Data Correlation

Disease records obtained from THQ Hospital revealed strong spatial overlap with water-quality anomalies. Typhoid and diarrheal disease cases were concentrated in neighborhoods with high turbidity and poor sanitation, notably Islamic Colony and Adalat. Kidney stone prevalence was higher in areas with elevated Ca and Mg concentrations, while hepatitis cases were more widely distributed but showed increased counts in turbidity hotspots. This correlation underscores the link between deteriorating groundwater quality and public health burdens in Ahmedpur East. Although a formal statistical regression was not applied, the visual and spatial association was clear and compelling.

Seasonal Trends

The present dataset was limited to a single sampling campaign and therefore could not provide direct evidence of pre- versus post-monsoon variability. However, regional literature suggests that post-monsoon conditions typically increase turbidity and microbial risks due to surface runoff. In contrast, dry-season conditions increase salt vapour concentration, resulting in higher TDS and EC. For Ahmedpur East, it is reasonable to expect similar dynamics, but further seasonal sampling is required to validate these assumptions.

Figure 6: Data Collected from Tehsil Headquarters (THQ) Hospital,Ahmedpur East (2024)



Discussion

The results of this study provide compelling evidence that groundwater quality in Ahmedpur East has deteriorated to levels with significant public health implications. Elevated values of TDS, EC, hardness, turbidity, and alkaline pH were not only recorded in laboratory analyses but also spatially overlapped with disease patterns in the community. These findings are consistent with a growing body of national and international research highlighting the interconnectedness of groundwater contamination and human health risks. The high TDS values (>2,700 mg/L) observed in Adalat and Sadiq Public School reflect salinity intrusion into the local aquifer system. Such findings align with regional studies in Sindh and Punjab, where saline groundwater has been widely documented (Raza et al., 2020; Riaz et al., 2021). For instance, Riaz and colleagues (2021) reported that residents of Vehari District, Punjab, were exposed to elevated TDS and EC in drinking water, leading to health issues such as hypertension and renal stress. Similarly, in coastal Sindh, Rahman et al. (2019) found that consumption of saline water was directly associated with gastrointestinal discomfort and dehydration, particularly among vulnerable groups. Globally, groundwater salinity has been highlighted as a serious emerging challenge in semi-arid regions. Famiglietti (2014) emphasised that over-abstraction, coupled with poor recharge, has led to increasing salinisation in many parts of the developing world. Ahmedpur East mirrors these patterns: intensive irrigation practices and declining groundwater tables exacerbate salt accumulation, with significant consequences for both water quality and public health. Water hardness in Ahmedpur East ranged between 150 and 180 mg/L (as $CaCO_3$), classifying much of the supply as "moderately hard to hard." These values, though not exceeding WHO guidelines, are sufficient to influence long-term health outcomes. Khan et al. (2012) identified similar hardness ranges in Charsadda District, Khyber Pakhtunkhwa, where elevated calcium and magnesium levels were associated with an increased incidence of urolithiasis (kidney stones). Our hospital records show clustering of kidney stone cases in high-hardness areas is consistent with these findings. Other Pakistani studies also support this association. Malik et al. (2010) highlighted that chronic exposure to hard water in Punjab villages contributed to increased cases of renal calculi and cardiovascular complications. On a global scale, research from India and Sri Lanka similarly confirms a strong correlation between hardness and renal disorders (Subramani et al., 2012). These comparisons suggest that Ahmedpur East is part of a wider South Asian pattern where groundwater mineral content significantly affects population health.

The turbidity levels in Adalat (25–30 NTU) and Islamic Colony (>10 NTU) represent one of the most acute threats to water safety in Ahmedpur East. WHO (2017) emphasises that turbidity above 5 NTU enables microorganisms to survive disinfection, thereby facilitating outbreaks of waterborne diseases. This was evident in our data, where typhoid, diarrhoea, and hepatitis cases were concentrated in high-turbidity neighbourhoods. These findings align with previous research in Pakistan (Gang et al., 2024). Ihsanullah et al. (2009) reported high turbidity and coliform counts in Lahore's urban water supply, directly linked to diarrheal disease outbreaks. Similarly, Riaz et al. (2021) in Vehari found microbial contamination in over 60% of groundwater samples, highlighting the inadequacy of sanitation infrastructure. Comparable evidence from Bangladesh also indicates that turbidity is a major predictor of cholera outbreaks in rural communities (Nickson et al., 2005). Thus, Ahmedpur East fits within a broader regional narrative where poor sanitation and aquifer contamination create endemic microbial risks. Alkaline pH values (8.7–9.0) were observed in several neighbourhoods, particularly Adalat and Afsha Town. While alkaline water is not directly toxic, it reduces the efficiency of chlorine disinfection, thereby allowing pathogens to persist. This observation resonates with findings by Shakoor et al. (2015) in Lahore, who noted that highly alkaline water decreased the effectiveness of chlorination, contributing to continued microbial presence even after treatment. The higher prevalence of hepatitis and gastrointestinal illness in alkaline, turbid zones of Ahmedpur East is therefore consistent with the established literature. The spatial analysis conducted using IDW interpolation revealed clear contamination hotspots at Adalat and Sadiq Public School, with fresher water in the Railway Station and THQ Hospital areas. GIS-based mapping has increasingly been used in Pakistan to identify water quality risks. Shahid et al. (2015) employed GIS to map arsenic contamination in Lahore, demonstrating how spatial visualisation enhances understanding of exposure patterns. Our study extends GIS applications to salinity, hardness, turbidity, and pH, providing a more comprehensive groundwater risk profile.

Comparative studies in South Asia also demonstrate the value of GIS. Kumar et al. (2023) used spatial interpolation in India to map nitrate contamination and identify vulnerable populations. In Africa, Oloruntoba et al. (2014) applied GIS in Nigeria to correlate shallow sound contamination with diarrhoea outbreaks, yielding findings remarkably similar to those in the Ahmedpur East case. This alignment reinforces the robustness of geospatial methods in linking environmental parameters with public health outcomes. The patterns observed in Ahmedpur East are not isolated. Across Punjab, multiple districts face overlapping challenges. For instance, Vehari shows high microbial risks (Riaz et al., 2021), Lahore is plagued by arsenic and coliform contamination (Shahid et al., 2015), and Muzaffargarh has been identified as an arsenic hotspot (Nickson et al., 2005). Ahmedpur East's dominant issues, however, are salinity, hardness, and turbidity rather than arsenic. This highlights the heterogeneity of groundwater contamination across Punjab and the need for locally tailored interventions. Globally, parallels exist with Latin America and Sub-Saharan Africa. Rodríguez et al. (2015) documented contamination by fluoride and salinity in Mexico City aquifers, while Oloruntoba et al. (2014) highlighted turbidity-driven diarrheal outbreaks in Nigerian peri-urban communities. These studies underscore that although the contaminants differ, the outcomes of chronic health problems, reduced water usability, and socio-economic vulnerability are consistent worldwide. Taken together, the Ahmedpur East findings confirm that deteriorating groundwater quality is directly contributing to public health crises, echoing evidence from across South Asia and beyond. Elevated salinity and hardness are linked to chronic kidney and cardiovascular conditions, while turbidity and alkalinity amplify microbial risks, driving outbreaks of diarrheal diseases and hepatitis. The study not only reinforces prior research but also advances it by integrating laboratory data, GIS mapping, and hospital morbidity records into a single framework. This triangulated evidence clearly demonstrates that unsafe water is not merely an environmental issue but a pressing health emergency requiring urgent intervention.

The findings of this paper support the Water-Health Nexus Model, which holds that water quality is a defining factor in a population's well-being, especially when resources are limited (Waltner-Toews, 2001). High levels of total dissolved solids (TDS > 1,500 mg/L) and electrical conductivity (EC > 2,000 µS/cm) in Ahmedpur East indicated severe salinity intrusion, consistent with the theoretical hypothesis that environmental degradation is directly related to community well-being. The results confirm the Environmental Determinism Theory, initially formulated by Friedrich Ratzel and later developed by White (1974), which posits that conditions of the natural and anthropogenic physical environment influence patterns of human health, settlement, and behaviour. This deterministic relationship can also be depicted by the spatial clustering of kidney stone and cardiovascular disease cases in high-hardness areas, which demonstrates that exposure to mineralised water can physically and socially characterise community health patterns (Khan et al., 2012; Malik et al., 2010). In the same vein, the extreme turbidity in low-income communities like Adalat and Islamic Colony indicated the presence of microbes associated with waterborne illnesses, such as typhoid and diarrhoea. This result aligns with the Public Health Ecology Model, which views health as an ecological outcome arising from the complex interactions among environmental hazards, human vulnerability, and social infrastructure (Lalonde, 1974). The model also presupposes that environmental remediation and behavioural change should be the focus of interventions to decrease the disease burden. Even the overlap of polluted water areas with disease hotspots supports the Social Vulnerability Theory (Cutter et al., 2003), which argues that socio-economic disparities, poor governance, and insecure infrastructure compound the health consequences of environmental exposure. The conceptual and theoretical framework for spatial mapping, including GIS-based methods, contributes to understanding the spatial overlap between contamination and disease. This paper identifies the interplay between environmental and social determinants of health by integrating empirical evidence with geospatial visualisation, demonstrating that their juxtaposition creates unequal distributions of risk. Thus, the results of Ahmedpur East are not only local: they become part of the overall discussion of the environmental principles of health inequality and emphasise the need to reduce groundwater governance to sustainable levels, within the Sustainable Development Goals (SDG 6 and SDG 3) (UN, 2015; UN-Water, 2023).

Conclusion

This study assessed groundwater quality in Ahmedpur East and its health implications using physicochemical tests, GIS mapping, and hospital data. Results revealed alarming deviations from WHO standards, with high TDS and EC in Adalat and Sadiq Public School indicating saline intrusion. Hardness levels placed much of the supply in the "hard" category, correlating with kidney stone incidence. Turbidity exceeded safe limits in low-income neighbourhoods, suggesting microbial risks and explaining clusters of typhoid, diarrhoea, and hepatitis. Alkaline pH (8.5–9.0) further reduced disinfection efficiency. These findings demonstrate a clear link between groundwater contamination and public health burdens. Acute impacts include diarrhoea, typhoid, and hepatitis, while chronic risks include kidney stones, hypertension, and cardiovascular stress. Vulnerable communities are disproportionately affected due to reliance on untreated groundwater. Policy gaps persist, as Pakistan's National Water Policy (2018) lacks effective local implementation, monitoring, and regulation of groundwater abstraction. By integrating GIS spatial data with hospital morbidity records, this study highlights a replicable model for environmental–health research. Despite limitations such as small sample size and absence of microbial assays, the correlations are compelling. Ahmedpur East exemplifies the urgent need for integrated interventions that combine technical, institutional, and community-based solutions to safeguard public health and advance the SDGs.

Recommendations

This study recommends urgent action to safeguard drinking water in Ahmedpur East. Technically, routine monitoring, decentralised treatment units, pipeline rehabilitation, and GIS integration are needed. Social measures include awareness campaigns, gender-sensitive programs, and school-based safe water initiatives. Policy reforms should operationalise the National Water Policy (2018), enforce effluent standards, regulate groundwater abstraction, and strengthen health–environment integration. Sustainable management requires aquifer recharge, improved agricultural practices, and long-term research on groundwater dynamics. Achieving these goals demands political will, resource mobilisation, and community participation. With integrated efforts, Ahmedpur East can shift from reactive disease control to proactive water security and sustainable health outcomes.

References

- Adams, E. A., & Smiley, S. L. (2018). Urban–rural water access inequalities in Malawi: Implications for monitoring the Sustainable Development Goals. *Natural Resources Forum*, *42*(4), 217–226. https://doi.org/10.1111/1477-8947.12156
- Anwar, A., Munir, A., Fatima, N., Majeed, A., Rafiq, H. M., & Ahmed, I. (2024). Modelling of groundwater potential zones by using GIS and remote sensing techniques: A case study of Multan District. *iRASD Journal of Energy & Environment*, *5*(2), 111–130. https://doi.org/10.52131/jee.2024.0502.0048
- APHA. (2017). *Standard methods for the examination of water and wastewater* (23rd ed.). American Public Health Association.

- Cutter, S. L., Boruff, B. J., & Shirley, W. L. (2003). Social vulnerability to environmental hazards. *Social Science Quarterly, 84*(2), 242–261. https://doi.org/10.1111/1540-6237.8402002
- Famiglietti, J. S. (2014). The global groundwater crisis. *Nature Climate Change*, *4*(11), 945–948. https://doi.org/10.1038/nclimate2425
- Gang, M., Munir, A., Murtaza, G., Iqbal, R., Majeed, A., Shoaib, M., … Alkahtani, J. (2024). Agro-waste-based bio-nanocomposite for the mitigation of Pb (II) ions from water. *Polish Journal of Environmental Studies, 33*(5), 5635–5646. https://doi.org/10.15244/pjoes/183450
- Gleeson, T., Wada, Y., Bierkens, M. F., & van Beek, L. P. (2012). Water balance of global aquifers revealed by groundwater footprint. *Nature, 488*(7410), 197–200. https://doi.org/10.1038/nature11295
- Hafeez, A., Munir, A., Majeed, A., Ghufran, M. A., Ahmed, I., Nazli, F., … Munir, W. (2025). Geospatial analysis for flood hazard zonation in District Muzaffargarh (Pakistan). *Journal of Asian Development Studies, 14*(2), 1494–1509. https://doi.org/10.62345/jads.2025.14.2.115
- Ihsanullah, I., Rashid, A., & Malik, Z. (2009). Assessment of drinking water quality and its impact on residents of Lahore, Pakistan. *Pakistan Journal of Environmental Science, 36*(2), 41–50.
- Khan, F., & Qureshi, A. S. (2023). Pakistan's water scarcity: A looming crisis. *Water Policy, 25*(1), 22–34. https://doi.org/10.2166/wp.2023.180
- Khan, S., Shahnaz, M., Jehan, N., Rehman, S., Shah, M. T., & Din, I. (2012). Drinking water quality and human health risk in Charsadda District, Pakistan. *Journal of Cleaner Production, 60*, 93–101. https://doi.org/10.1016/j.jclepro.2012.02.016
- Kumar, M., Puri, A., & Singh, A. K. (2023). Groundwater nitrate contamination in South Asia: Sources, health risks, and management. *Environmental Reviews, 31*(1), 1–15. https://doi.org/10.1139/er-2022-0023
- Lalonde, M. (1974). *A new perspective on the health of Canadians: A working document.* Government of Canada.
- Malik, R. N., Hashmi, M. Z., & Huma, Y. (2010). Water quality and health risk in Pakistan: A critical review. *Environmental Monitoring and Assessment, 166*(1–4), 449–463. https://doi.org/10.1007/s10661-009-1019-9
- Mekonnen, M. M., Hoekstra, A. Y., & Savenije, H. H. (2016). Global anthropogenic phosphorus loads to freshwater and associated grey water footprints. *Water Resources Research, 52*(2), 574–589. https://doi.org/10.1002/2015WR016226
- Munir, A., Raza, S. N., Ahmed, I., Majeed, A., Nazeer, S., Ali, U., … Rafiq, H. M. (2025). Geospatial assessment of groundwater quality using water quality index (WQI) in Bahawalpur (Pakistan). *Journal of Asian Development Studies, 14*(3), 546–559. https://doi.org/10.62345/jads.2025.14.3.46
- Murtaza, G., Valipour, M., Usman, M., Ditta, A., Rizwan, M., Elshamly, A., … Munir, A. (2025). Ecological and health risk assessment of cadmium contamination in groundwater samples collected from the arid climatic region. *Polish Journal of Environmental Studies, 34*(3). https://doi.org/10.15244/pjoes/188185
- Nickson, R. T., McArthur, J. M., Burgess, W. G., Ahmed, K. M., Ravenscroft, P., & Rahman, M. (2005). Arsenic contamination of groundwater in Bangladesh and West Bengal, India. *Environmental Science & Technology, 39*(5), 1236–1245. https://doi.org/10.1021/es049532v

- Oloruntoba, E. O., Sridhar, M. K. C., & Omokhodion, F. O. (2014). Community water supply and diarrhoeal disease prevalence in Nigeria: A cross-sectional study. *Journal of Water and Health*, *12*(4), 864–873. https://doi.org/10.2166/wh.2014.057
- Pakistan Council of Research in Water Resources (PCRWR). (2017). *National water quality monitoring program (Annual report).* Islamabad: Ministry of Science and Technology.
- Rahman, M. A., Rahman, A. K. M., & Khan, A. H. (2019). Health implications of drinking saline water: A review of evidence from coastal Bangladesh. *Environmental Health Perspectives*, *127*(6), 065001. https://doi.org/10.1289/EHP4847
- Raza, A., Sadiq, R., & Khan, S. (2020). Salinity intrusion in groundwater: A critical challenge for Pakistan. *Water Resources Management*, *34*(9), 2993–3007. https://doi.org/10.1007/s11269-020-02568-1
- Riaz, R., Ahmad, S., & Aslam, A. (2021). Drinking water quality assessment and associated health risks in Vehari, Punjab. *Journal of Water and Health*, *19*(3), 371–383. https://doi.org/10.2166/wh.2021.128
- Rodríguez, R., Armienta, M. A., & Villanueva, M. (2015). Fluoride contamination of groundwater in Mexico City. *Environmental Geochemistry and Health*, *37*(4), 745–756. https://doi.org/10.1007/s10653-014-9682-1
- Shahid, M., Niazi, N. K., Dumat, C., Naidu, R., & Khalid, S. (2015). Arsenic in groundwater and its implications on water security in Pakistan. *Environmental Pollution*, *206*, 275–285. https://doi.org/10.1016/j.envpol.2015.07.005
- Shakoor, M. B., Niazi, N. K., & Bibi, I. (2015). Drinking water quality in Lahore: Chlorination challenges in alkaline waters. *Environmental Monitoring and Assessment*, *187*(1), 1–12. https://doi.org/10.1007/s10661-014-4211-7
- Shiklomanov, I. A., & Rodda, J. C. (2004). *World water resources at the beginning of the twenty-first century*. Cambridge University Press.
- Taylor, R. G., Scanlon, B., Döll, P., et al. (2020). Groundwater and climate change. *Nature Climate Change*, *10*(2), 93–102. https://doi.org/10.1038/s41558-019-0591-x
- United Nations (UN). (2015). *Transforming our world: The 2030 agenda for sustainable development.* United Nations General Assembly.
- UNESCO. (2020). *The United Nations World Water Development Report 2020: Water and climate change*. UNESCO Publishing.
- UNICEF. (2020). *Progress on household drinking water, sanitation and hygiene 2000–2020.* New York: UNICEF and WHO.
- UN-Water. (2023). *Summary progress update 2023: SDG 6 – Clean water and sanitation.* Geneva: United Nations.
- Waltner-Toews, D. (2001). *Ecosystem sustainability and health: A practical approach.* Cambridge University Press.
- White, G. F. (1974). *Natural hazards: Local, national, global.* Oxford University Press.
- World Health Organization (WHO). (2017). *Guidelines for drinking-water quality* (4th ed.). Geneva: WHO.
- World Health Organization (WHO). (2019). *Drinking water fact sheet.* Geneva: WHO.
- World Health Organization (WHO). (2021). *Progress on drinking water, sanitation and hygiene: 2000–2020.* Geneva: WHO.