Spatio - Temporal Variability Assessment of Groundwater Quality of Peshawar District, Pakistan

By

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DEDICATION

Dedicated to my parents, husband and kids

for their unwavering support, care, motivation and cooperation throughout my academic journey. Words can hardly describe my thanks and appreciation to you.

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Tayyaba Sana

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LIST OF ABBREVIATIONS

Abbreviation	Explanation
LULC	Landuse/ Landcover
WHO	World Health Organization
NSDWQ	National Standard Drinking Water Quality
pH	Power of hydrogen
EC	Electrical Conductivity
UN	United Nations
IDW	Inverse Distance Weighted
USGS	United States Geological Survey
GWPZ	Ground water Potential Zone
E coli	Escherichia coli
GIS	Geographical Information System

ABSTRACT

Groundwater is extensively been used for drinking purposes. However, due to anthropogenic activities, the groundwater quality is deteriorating. To cater the health of a city, the groundwater quality needs to be monitored on a regular basis. The study aims to explore the spatio-temporal variation of various groundwater quality parameters and evaluate the outcome of landuse/ landcover on water quality parameters and water table depth for the years 2012 &2023 of the Peshawar district, Pakistan. Water samples (105) for the year 2012 and 133 for the year 2023 were randomly collected from the entire district to assess physical, chemical, and biological parameters. The water quality was assessed for seven parameters (pH, EC, turbidity, chloride, calcium, nitrate & e-coli), and compared the results with the permissible limits of Pak NSDWQ and WHO. For the LULC dynamics, how they affect the quality of groundwater and water table depth, Landsat images were classified for the years (2012 and 2023) and land cover maps were generated. Waterborne disease data was collected for 2022 to study the adverse consequences of groundwater quality on human health. The presence of e-coli in 57% of samples poses a significant risk to public health. The comparison of the results revealed that the water quality and water table depth in Peshawar is decreasing over the years. This decrease was more visible in areas where urbanization was high, thus showing the negative impacts of the LULC changes on the groundwater quality and water levels. The patient's disease data revealed that more than one lac diarrhea, cholera, typhoid fever & Acute hepatitis (A & E) patients were reported to health units, and most of them were from those areas where water quality has decreased and e-coli is positive. To sum up, the point sources of anthropogenic activities (domestic sewage, industrial wastes & agricultural activities) remain the main driver of water pollution in the region. This study could help district health decision-makers to apprehend the trends of groundwater quality, make proper site-specific actions, and formulate future health strategies.

Chapter 1

INTRODUCTION

1.1. General Background

Water makes up around 71% of the Earth's surface, can be found in various forms including oceans, rivers, lakes, glaciers, and subterranean aquifers. Its universal solvent property enables it to dissolve a wide array of substances, facilitating crucial chemical reactions within living organisms and allowing for the transportation of nutrients and minerals. Moreover, water plays a pivotal role in human activities including agriculture, industry, and domestic use. It serves as a vital resource for irrigation; ensuring crops receive the necessary hydration for growth. In industrial settings, water is indispensable for various processes like cooking, cleaning, and manufacturing. At the household level, utilized for drinking, cooking, bathing, and sanitation. Water is essentially a necessary element for life on earth, impacting every aspect of our surrounding. However, factors such as rapid population growth, urbanization, and unequal distribution of water resources, industries, and climate change contribute to water scarcity.

1.2. Groundwater

Groundwater, a vital source of drinking water for millions globally, is often cleaner and requires less treatment than surface water sources. Unlike what is commonly believed, aquifers hold the majority of the fresh water on Earth below, which makes them essential during dry spells (Morris et al.,2003). Formed through the percolation and infiltration of rainwater or snowmelt, groundwater resides in the saturated zone beneath the Earth's surface within soils and geological formations. Given that, more than 30% of the people on planet directly depends on groundwater aquifers for drinking, as it is an essential source. Groundwater, defined as geological structures consisting of wholly saturated voids, plays a significant role in global water resources (Winkler et al., 2010).

Out of the total global water resources, only three percent is freshwater, with the majority being saline and unsuitable for drinking. Of this freshwater, 30.1% found in groundwater, while 68.7% is held in ice and glaciers, rendering them crucial sources of freshwater (Mishra.,2023). Groundwater potential refers to the available groundwater in specific areas, determined by hydrogeological and hydrologic factors. Stored in aquifers, groundwater provides a reliable and relatively constant water source, even during droughts or periods of low surface water availability. Accessible through wells, groundwater serves a range of functions, encompassing drinking water supply, irrigation for agriculture, support for industrial practices, and sustenance of ecosystems (Morris et al., 2003).

Aquifers, consisting of underground layers of permeable rock, sediment, or soil, serve as natural storage reservoirs for groundwater, replenish by precipitation and surface water infiltration. The significance of aquifers as a water supply source is particularly evident in arid and semi-arid regions, where surface water sources like lakes and rivers may be scarce or seasonal. In such areas, communities and agriculture heavily rely on groundwater from aquifers to meet their water needs. However, it is imperative to manage and use groundwater resources sustainably. Over-extraction can lead to aquifer depletion, resulting in land subsidence, saltwater intrusion in coastal areas, and a long-term reduction in water availability. Therefore, implementing proper groundwater management strategies, including monitoring, regulation, and the promotion of water conservation practices, is crucial for ensuring the long-term sustainability of aquifer resources.

Although there has always been an abundance of freshwater available on Earth, its availability is not always consistent, and its quality may not always meet usage requirements. Groundwater availability is influenced by topography, geological structures, geology, geomorphology, slope, drainage patterns and climate.

1.3. Factors Affecting Groundwater

Various factors influence the rate and extent of groundwater table, including rainwater as the primary source of recharge on the land surface. Additionally, geological, topographic and human elements play significant roles, all of which as discussed below.

1.3.1. Precipitation Pattern

Seasonal variations in groundwater levels influence by distinct wet and dry seasons. High rainfall leads to increased groundwater recharge and rising water levels. Conversely, in dry seasons, recharge diminishes, potentially causing a decline in groundwater levels. The interplay between evaporation and precipitation significantly influences these fluctuations. Regions characterized by high precipitation and low evaporation tend to maintain higher water levels.

1.3.2. Human Activities

Population growth, urbanization, deforestation, and the drying of wetlands are human-induced factors that contribute to fluctuations in groundwater levels. These activities enhance runoff, reducing recharge. Additionally, overuse of groundwater for purposes such as irrigation, industry, or domestic consumption can lead to groundwater depletion.

1.3.3. Land Use Practices

Land use practices, such as urbanization and deforestation, can alter the natural hydrological cycle and affect groundwater. Paved surfaces in urban areas can increase surface runoff, reducing groundwater recharge. Deforestation can lead to soil erosion and decreased infiltration, affecting groundwater levels.

1.4. Groundwater Pollution

Groundwater pollution is the result of the contamination of groundwater by various substances, rendering it unsuitable for human consumption and detrimental to the environment. This contamination can stem from either natural processes or human activities. When harmful substances infiltrate the soil and mix with groundwater, it leads to contamination. Additionally, during percolation and infiltration, rainwater or surface water can pass through polluted soil, becoming contaminated and carrying pollutants from the surface into the groundwater. Similarly, when liquid pollutants from rocks or surface soil enter the groundwater, it further degrades the quality of this vital resource. Anthropogenic activities, including the improper disposal of municipal and industrial pollutants, as well as the unregulated use of crop pesticides, play a significant role in exacerbating water quality issues (Fida., 2023).

1.5. Sources of Groundwater Pollution

The sources of groundwater pollution encompass both natural and human activities, including agriculture, industrial processes, residential and commercial operations. The primary culprits in aquifer pollution are the release or leakage from industrial waste sites, petroleum storage tanks, septic systems, and certain subterranean structures, like wells or contaminated recharge water below the water table.

1.6. Groundwater Quality

The chemical, physical, and biological characteristics of water determine its acceptability for various purposes like drinking, irrigation, industrial activities, and maintenance of aquatic life. Which is known as water quality. Factors such as geological conditions, human activities, and natural processes contribute to the variability in groundwater quality. Parameters like pH, total dissolved solids (TDS), nitrate levels, heavy metals, chloride, bacteria, pathogens, pesticides, herbicides, and volatile organic compounds commonly used to evaluate groundwater quality. Polluted portable water is a major cause of waterborne diseases affecting human populations. Assessing various water quality parameters is crucial for enhancing quality of life and preventing illnesses, however, guidelines established for comparing physicochemical parameters. Therefore, providing safe water supplies to the population consider a primary responsibility of governments in less developed countries, in contrast, many individuals in developed nations have access to safe potable water. Similar to many other developing nations, Pakistan grapples with severe water scarcity and pollution. The country has nearly depleted its available water resources and classified as water-stressed, with a projected water scarcity in the near future. Pakistan experiences a lower precipitation rate compared to the evaporation rate, leading to a continual decline in water levels in its rivers, lakes, and groundwater reserves. Prolonged droughts and the absence of new water reservoir construction further exacerbate this issue (Noureen, 2022).Given Pakistan's status as a developing country, the government must engage in effective planning regarding water availability, quality, and combating waterborne diseases. A concerning statistic reveals that 89% of groundwater across the country falls below recommended safe limits for human consumption (Rasheed, 2021). In regions like Peshawar, Mardan and Charsadda districts of Khyber Pakhtunkhwa, approximately 6 million residents lack access to clean potable water. The rest of population relies on dug wells and tube wells, which are more vulnerable to pollution from various sources like sewerage lines, toilets, and seepage of contaminated water (Imran., et al 2018).

1.7. Health Issues

Contaminated water can harbor various pathogens, including bacteria, viruses, and parasites. Which can cause waterborne diseases such as Cholera (A bacterial infection that causes severe diarrhea and dehydration), Typhoid fever (A bacterial infection that causes high fever, abdominal pain, and gastrointestinal issues) and Hepatitis A (A viral infection that affects the liver and causes symptoms such as jaundice, fatigue, and nausea) (Pal, 2018). Consumption of contaminated water can lead to gastrointestinal problems such as diarrhea, vomiting, stomach cramps, and nausea. Chemical Contaminants such as heavy metals (e.g lead, arsenic), pesticides, and industrial pollutants, can contaminate water sources and pose health risks. Long-term exposure to these contaminants can lead to various health problems, including neurological disorders, developmental issues, and cancer. It is important to note that the specific health effects can vary depending on the type and concentration of contaminants, individual susceptibility, and duration of exposure. Access to safe and clean drinking water, along with proper water treatment and monitoring, is crucial in preventing water-related health issues.

1.8. Use of GIS in Groundwater Assessment

GIS is widely used for assembling, evaluating and management of spatial data. It develops fresh information from pre-existing data. The geo-processing tasks assemble spatial information, which applies a systematic function to produce results in the form of tables and interactive maps. The analyst tool in ArcGIS frequently used to delineate the GWPZ, vulnerability assessment of GWPZ and to assess the quality of water (Halder, 2022).

The investigations of Groundwater by field surveys are time-consuming, very costly, which require skilled people (Sahour, 2020). In contrast, space technology has emerged with its advantage in the availability of spectral, temporal and spatial data, which covers a large area in a short period as a valued tool for the monitoring, management, and assessment of groundwater resources.

It is significant to map the parameters of groundwater in Peshawar city since this assists in the detection of zones that may be at risk of future environmental health concerns. Regular groundwater contamination monitoring is important to ensuring the consistent use of safe water sources (Carrard, 2019). IDW maps are used to see geographical patterns and trends in data, making it simple to spot locations with high or low values (Zuo et al, 2016).

1.9. Groundwater Management and Planning

The importance of water quality cannot be overstated. Poor water quality can lead to a range of negative impacts, including the spread of waterborne diseases, harm to aquatic ecosystems, and contamination of food and drinking water sources. Therefore, it is crucial to implement effective water quality management strategies, including pollution prevention, water treatment, and conservation measures. The monitoring and modeling of Groundwater provide information regarding the quality and quantity at a given time. An appropriate planned monitoring system gives a guideline to manage the Groundwater system (Orellana, 2012).

As per the water strategy profile of Pakistan (2002), a notable surge in population growth has witnessed in recent years. In 2002, the population was three times greater than it was in 1960. Projections suggest that the demand for domestic water will reach 12.1 Million Acre Feet (MAF), expected to increase upto 4.0 Billion Cubic Meters (BCM) by 2025, encompassing both rural and urban sectors. Given the current state of overexploitation of water resources, there is an urgent need for comprehensive planning and effective management to meet the existing demand.

1.10. Literature Review

Groundwater is indeed a crucial natural resource for providing reliable and cost-effective drinking water supply, both in rural and urban areas. It plays a significant role in supporting human well-being and the functioning of aquatic and terrestrial ecosystems. One of the key advantages of groundwater is its widespread availability. It serves as a vital source of freshwater in various regions worldwide, especially in areas where surface water may be limited or unreliable. In fact, groundwater currently contributes approximately 34% of the total annual water supply globally (Chen, 2016). Its widespread availability, natural filtration, and resistance to short-term variations make it an important source of freshwater globally. However, proper management and conservation practices are crucial to ensure the long-term sustainability of groundwater resources.

The literature on water quality and its impact on human health is extensive and covers various aspects of water contamination and its consequences. Researchers have investigated the presence of contaminants in water sources, such as heavy metals, pesticides, nitrates, and pathogens, and their potential health effects on human populations. Studies have shown that exposure to contaminated water can lead to various health problems, including gastrointestinal illnesses, reproductive issues, neurological disorders, and even cancer. For example, a study by (Falk, 2022) estimated that unsafe water, sanitation, and hygiene practices are responsible for around 485,000 diarrheal deaths each year.

Furthermore, researchers have explored the impact of land use and land cover on water quality. Land use activities, such as agriculture, urbanization, and industrialization, can contribute to water pollution through the discharge of pollutants into water bodies. Studies have found that agricultural runoff, for instance, can introduce excessive nutrients, pesticides, and sediment into water sources, leading to eutrophication and degradation of water quality. However, the impact of land use and land cover change on water quality can also affect the water table depth. Changes in land cover, such as deforestation or urban development, can alter the hydrological cycle, leading to changes in groundwater recharge rates and water table levels. Several studies have investigated the relationship between land use/land cover change and water table depth, highlighting the importance of sustainable land management practices to maintain groundwater resources.

Many scholars have conducted research on water quality and land use issues in various regions of the world, including Pakistan. Here are a few more studies conducted by scholars who have contributed to the understanding of these issues in Pakistan.

Study conducted by (Broers, 2004) on regional monitoring of temporal changes in groundwater quality. The aim of the study was to enhance the detection and comprehension of changes in groundwater quality over time. The study employed various techniques, including time series analysis, concentration-depth profiles, age dating, and concentration-depth prognoses based on historical solute inputs. To detect trends in groundwater quality, the study utilized a combination of trend analysis on time series data at specific depths and time-averaged concentration-depth profiles. This approach allowed for the identification of changes in groundwater quality over time. By integrating information from different sources and utilizing various analytical methods, the study aimed to improve the understanding of how groundwater quality evolves over time and the factors that contribute to these changes. This type of research is crucial for effective groundwater management and the development of strategies to mitigate potential risks associated with changing groundwater quality.

A Significant Contribution was made by (Sun, 2009) who made Comparison of interpolation methods for depth to groundwater and its temporal and spatial variations in the Minqin oasis of northwest China. The first objective was to select an optimal interpolation method in this region from among kriging methods (including ordinary kriging (OK), simple kriging (Haseena et al.), and universal kriging (UK)), the inverse distance weighting (IDW) method, and the radial basis function (RBF) method. By comparing the interpolation accuracy of depth to groundwater for each method and analyzed the errors. Secondly, the best interpolation method used to analyze temporal and spatial variations of depth to groundwater. Finally, analyzed the trend in depth to groundwater over the past 22 years using the Kendall method and developed an autoregressive prediction equation for depth to groundwater.

Groundwater quality using GIS in Konya City, located in the central part of Turkey assessed by (Nas et al., 2010); the objectives were to provide an overview of present groundwater quality Determine spatial distribution of groundwater quality parameters such as pH, electrical conductivity, chloride, sulfate, hardness, and nitrate concentrations. Map groundwater quality in the Konya City area by using GIS and geo-statistics techniques. An interpolation technique, ordinary kriging, used to obtain the spatial distribution of groundwater quality parameters. Final map shows the southwest of the city has optimum groundwater quality, however, the groundwater quality decreases south to north of the city.

A contribution made by (Subramani,2012), on the Study of groundwater quality with GIS application for Coonoor taluk in Nilgiri district. Groundwater threats due to anthropogenic activities in India, leading to deterioration in groundwater quality. The possibility of groundwater contamination is due to the mixing up of toxic chemicals, fertilizers, waste disposed sites and industrial sites. The study's first objective was to analyze the ground water quality parameters using GIS. Second was to interpret groundwater quality parameters using GIS. Third was to develop an integrated groundwater quality map of Coonoor Taluk using GIS. The results show that the groundwater quality in Coonoor Taluk reduced due to pollution. The GIS bare zoning of groundwater quality map used as a guideline for predicting the groundwater quality to new areas. The study provided an approach for solving the water quality problem in Coonoor Taluk.

Research work done by (InamUllah, 2014), on assessment of drinking water quality in Peshawar, Pakistan. The present study considered water quality assessment of 32 locations inside Peshawar. Groundwater samples were collected from tube wells and household ends and subjected to physical, chemical and bacteriological analysis as well as presence of heavy metals, to check their suitability for drinking. Results revealed that physical and chemical characteristics of 96.87% of samples were within the permissible limits. However, 84.35% of the samples collected from household ends contaminated with coliform bacteria, not considered safe for human consumption. 31.2% of the samples collected directly from tube wells also showed suspicious results. Faulty distribution and storage infrastructure and their lack of maintenance concluded main reasons behind drinking water contamination in Peshawar.

Jehan et al., (2019) in Bajaur agency did excellent work on drinking water and its health impact on the Bajaur agency. The analysis process carried out for parameters like TDS, PH, Conductivity, Dissolved Oxygen, Hardness, Alkalinity, Phosphate, and nitrate. All the parameters fall under the acceptable limits of WHO and USEPA, apart from the DO and suspended solids, which were greater.

Adnan., (2019) introduced a simple approach for Groundwater Quality Analysis, Classification, and Mapping in Peshawar, Pakistan. More than 100 groundwater samples collected and analyzed for physio-chemical parameters in a laboratory.

Hierarchal clustering analysis (HCA) and classification and regression tree (CART) analysis were sequentially applied to produce potential clusters/groups (groundwater quality classes), extract the threshold values of the clusters, classify and map the groundwater quality data into meaningful classes, and identify the most critical parameters in the classification. This study presents a simple tool for the type of groundwater quality based on several aesthetic constituents and can assist decision-makers to develop and support policies and/or regulations to manage groundwater resources.

A relevant study conducted in Khyber Pakhtunkhwa Province by (Awan et al., 2022). The study involves the chemical and bacteriological analysis of water from different sources i.e., bore, wells, bottle, and tap, from Peshawar, Mardan, Swat and Kohat districts of Khyber Pakhtunkhwa (KP) province, Pakistan. Fiftey(50) water samples (10 samples from each source) from each district, were collected and analyzed for sulphate, nitrates, nitrites, chlorides, total soluble solids and coliforms (E. coli). Results indicated that majority of the water sources had unacceptable E. coli count i.e.> 34 CFU/100mL. E. coli positive samples were high in Mardan District, followed by Kohat, Swat and Peshawar district. Among all districts, the water quality found comparatively more deteriorated in Kohat and Mardan districts than Peshawar and Swat districts.

Gossweiler et al., (2019) analysis Spatial and Temporal Variations in Water Quality and Land Use in a Semi-Arid Catchment in Bolivia. This study investigated patterns of river water quality in a peri-urban/rural catchment in Bolivia, in relation to land use during a 26-year period. Satellite images used to determine changes in land use. To assess water quality, data in the dry season from former studies (1991–2014), complemented with newly collected data (2017), were analyzed using the National Sanitation Foundation-Water Quality Index method and the Implicit Pollution Index method. The study found that forest, urban, and peri-urban areas experienced the highest rates of relative increase in land use area. On the other hand, water infiltration zones, bare soil, shrub land, and grassland areas showed relative decreases. Over time, there was a clear deterioration in water quality, with the worst quality observed at the catchment outlet compared to the headwaters. Statistical analyses indicated a significant correlation between declining water quality and the expansion of urban areas.

Sohail et al., (2019) conducted study on impacts of urbanization and land cover dynamics on underground water in Islamabad, Pakistan using GIS and Remote Sensing Techniques. The objective of the study was to evaluate the water quality index and examine the significant changes in land cover types, vegetation cover, rate of urbanization, and their potential impact on groundwater resources in Islamabad, the capital city. To assess the extent and nature of changes in the study area, Landsat TM, ETM, and OLI images from 1993, 1997, 2002, 2007, 2013, and 2017 selected for comparison. The analysis revealed notable transformations, including a decrease in vegetation, barren land, and water areas. In contrast, built-up areas expanded from 51.10 km2 to 105.77 km2. Furthermore, the study identified 16 sites in Islamabad where the water quality index categorized as unsuitable (with a value of < 300 WQI) for drinking water due to significant human activities influencing the water quality.

Ahmad et al., (2021) conducted a study to assess the temporal changes in groundwater quality from 2012 to 2019 in relation to land-use/land-cover and its impact on the residents of Peshawar, Pakistan. 105 and 112 groundwater samples collected from tube wells in 2012 and 2019, respectively. These samples analyzed for seven standard water quality parameters, including pH, electric conductivity (EC), turbidity, chloride, calcium, magnesium, and nitrate. Additionally, patient data for waterborne diseases collected for the years 2012 and 2019 to examine the relationship between groundwater quality and human health. Landsat satellite images from 2012 and 2019 classified to observe the dynamics of land-use/land-cover in relation to groundwater quality. The findings revealed a decrease in groundwater quality in 2019 compared to 2012, with more pronounced effects observed in densely populated areas.

A study by (Yar et al.,2022) who investigated rapid land use and land cover changes in Peshawar City from 1991 to 2014, employing GIS and remote sensing technologies. Utilized Landsat TM imagery to analyze alterations in both urban and peri-urban areas, focusing on their effects on groundwater. Additionally, temporal and spatial water table data for 1991 and 2014 obtained from WSSP

Peshawar. The study applies a Cellular Automata-Markov model to project future changes in built-up areas up to 2044 based on past trends (1991-2014), examining their impact on agricultural land encroachment and groundwater levels. The findings suggest that the most significant groundwater depletion will occur in the southern parts of the city. Central areas experienced a sharper decline in groundwater levels compared to the outskirts.

Ullah et al., (2013) evaluated the current water quality of the River Kabul near Peshawar, Pakistan. In 2009, samples were collected from seven sites both upstream and downstream of the River Kabul. Additionally, samples collected from the Budni Drain, which carries wastewater from Peshawar Industrial Estate and domestic sewers, to assess their contribution to river pollution. The study encompassed the analysis of physicochemical and microbiological parameters of the samples, along with an investigation into potential sources of contamination. The findings revealed an escalating pollution gradient from the upstream (city entrance) to the downstream (city exit) areas, attributed to the discharge of domestic wastewater agricultural activities, and direct dumping of solid waste into the river.

1.11. Justification of Research

Being the industrial, agricultural, and trade hub of Khyber Pakhtunkhwa, Peshawar has experienced a substantial population growth, leading to an increased demand for safe drinking water. This study is an attempt to evaluate the quality of drinking water in District Peshawar. The research will analyze the water quality parameters from field visits and laboratory tests using geo-spatial/geo-statistical tools and techniques. Results from this study will be useful for decision makers and urban planners for planning/managing safe drinking water schemes in future.

1.12. Study Objectives

The major objectives adopted for the study are:

- To evaluate the temporal (2012 & 2023) variability in groundwater quality by evaluating its physio-chemical (potentially toxic elements) and biological (Escherichia coli) parameters and its impact on human health.

- To monitor land use/ land cover influence on groundwater quality and water table depth.

1.13. Scope of Study

Drinking water contamination is one of the core issues in many developing countries and of the challenges confronting scientists and planners. Water pollution is a physical process that occurs in various water resources such as lakes, groundwater, and rivers due to anthropogenic activities. In Pakistan, water quality in most of the cities is decreasing quickly.

Peshawar is currently confronting with a dual water predicament, which requires immediate attention and action. The first challenge is the scarcity of water resources, leading to water shortages and inadequate supply for the growing population. This scarcity exacerbated by factors such as climate change, population growth, and inefficient water management practices. The second challenge is the deteriorating quality of available water sources. Groundwater contamination, mainly due to industrial and agricultural activities, has resulted in the presence of harmful pollutants and toxins. This poses a significant risk to public health, as contaminated water can lead to waterborne diseases and other health issues. To comprehensively understanding the water quality situation in Peshawar, conducting spatial-temporal analyses encompassing physical, chemical, and biological assessments of groundwater would be the most effective strategy to address the degradation of drinking water quality in the area.

Chapter 2

MATERIALS AND METHODS

2.1. Study Area

The research focused on District Peshawar, the capital of the Khyber Pakhtunkhwa province in Pakistan. This selection driven by the remarkable population surge observed over a span of three decades, primarily attributed to the resettlement of internally displaced people (IDP) and a substantial influx of Afghan refugees since 1979.The situation has resulted in multifaceted pressures on natural resources. Peshawar is strategically located, bordered by Mohmand Agency to the Northwest, District Nowshera to the East, District Charsadda to the North, and Khyber Agency to the West and South. To the West lies the Afghan border, approximately 40 kilometers away. Positioned at the gateway of the renowned Khyber Pass, Peshawar is located between 33° 44' and 34° 15' North latitudes, and 71° 22' and 71° 42' East longitudes.

This district covers a total area of 12162 square km, which is divided into 92 Union Councils and 346 village/ neighborhood councils. This geographical context is particularly relevant in light of the substantial impact on groundwater quality, a matter of significant concern for public health. The Kabul River enters the district at Warsak and follows an eastern course along the northern boundary. From the southwest, the Bara River enters District Peshawar and flows in a northeastern direction through the district, eventually joining the Kabul River in Nowshera District. The region experiences higher rainfall in the winter season, ranging from 20 to 77mm, as compared to the summer. The Valley of Peshawar characterized by consolidated deposits of silt, sands, and recent geological gravel. This geographical information system is pertinent to understand the environmental health implications, particularly concerning water quality in the area as shown in Figure 2.1.

2.2. Administrative Divisions of Peshawar District

According to (Adnan et al., 2014), the Peshawar District encompasses a total area of 1257 km2, constituting just 1.69% of the entire province. Administratively, the district divided into four towns: town 1, town 2, town 3, and town 4. Figure 2.2 illustrates that town 4 is the largest, covering approximately 45% of the land area. Town 2 encompasses 35% of the area, followed by town 3 at 16%, and town 1, which includes the cantonment areas, occupying a mere 2% of the district's total area. The district comprises 92 union councils, 48 union councils designated as rural areas, while the remainder classified as urban areas as depicted in Figure 2.2.

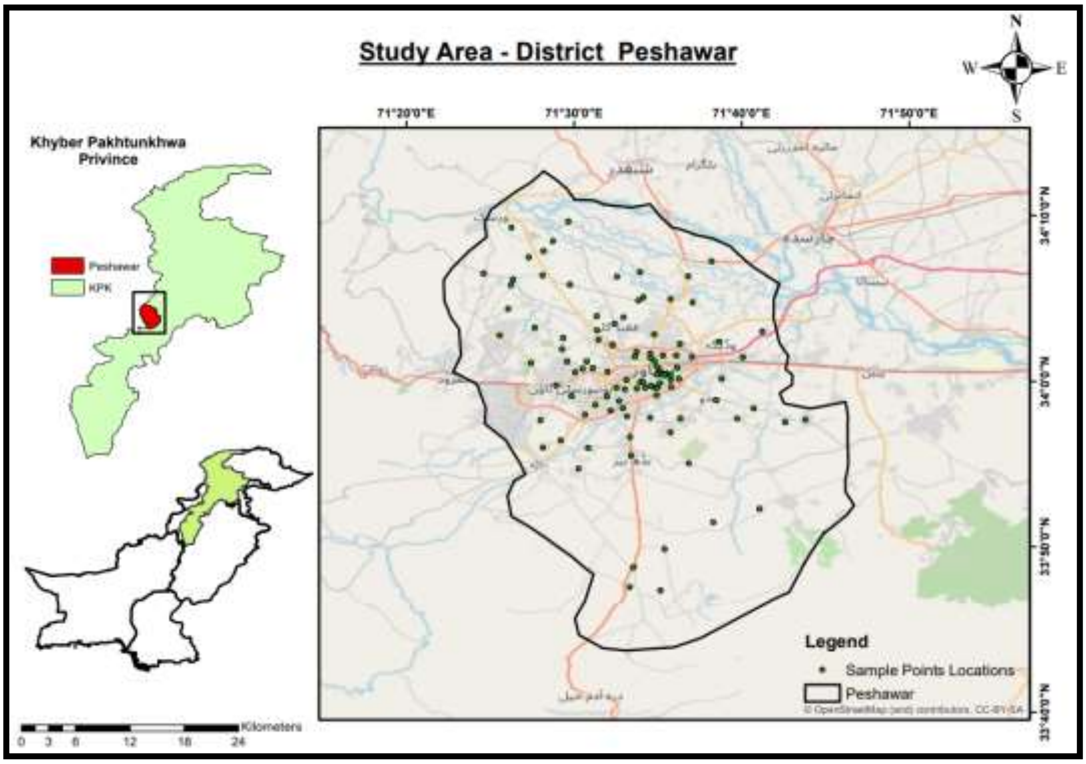

Figure 2.1. Study area Peshawar district.

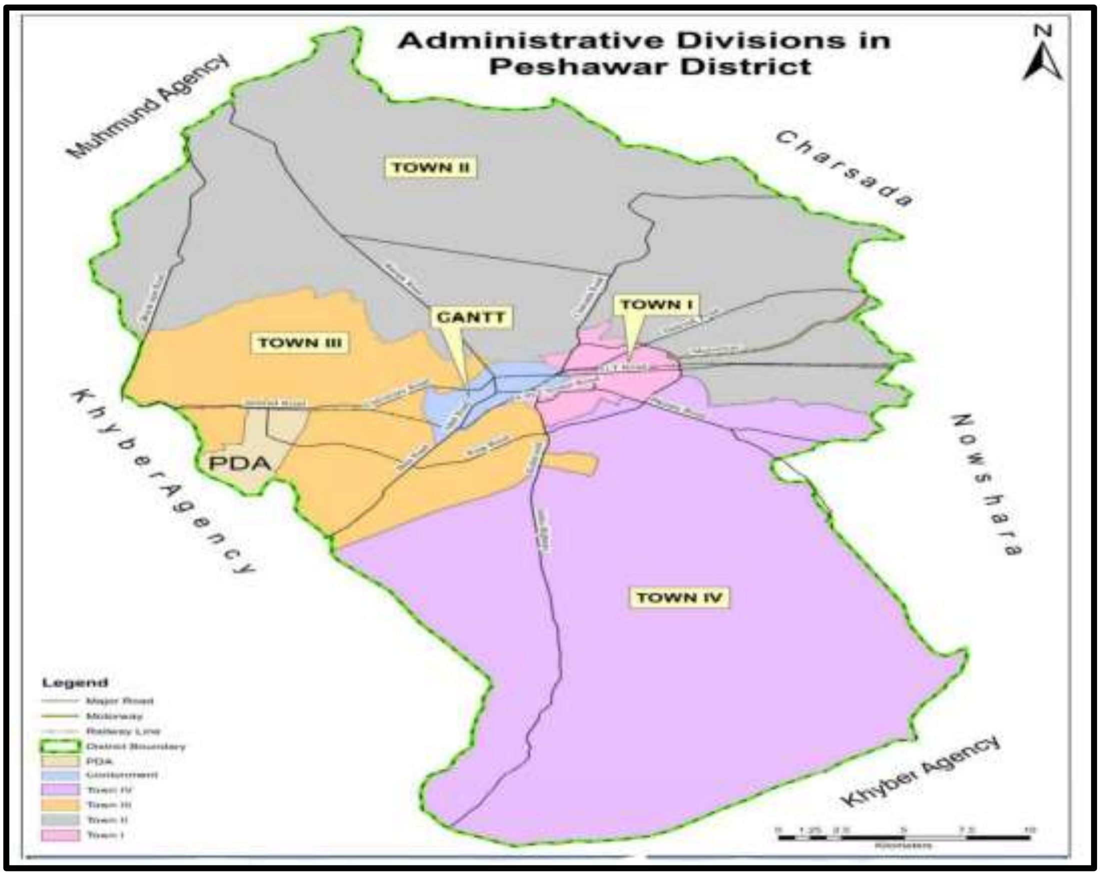

Figure 2.2. Administrative Divisions of Study Area.

2.3. Demography

2.3.1. Population

The population of Peshawar is proliferating, and according to the census carried out in 2017, the population of the city is 4.27 million (PBS, 2017). The population trend in the Peshawar District in various decades shown in Table 2.1. From 1972 to 1981, the growth rate in the population was 3.64%; from 1981 to 1998, the growth rate increased to 3.7%, while from 1998 to 2017, it further increased to 4% and more than doubled, shown in Figure 2.3.

Table 2.1. Population growth trend in decades.

District	**Population Census** 9/16/1972	**Population Census** 3/1/1981	**Population Census** 3/1/1998	**Population Census** 3/15/2017
Peshawar	807,012	1,113,303	2,026,851	4,269,079

Source: Pakistan Bureau of Statistics 2018**.**

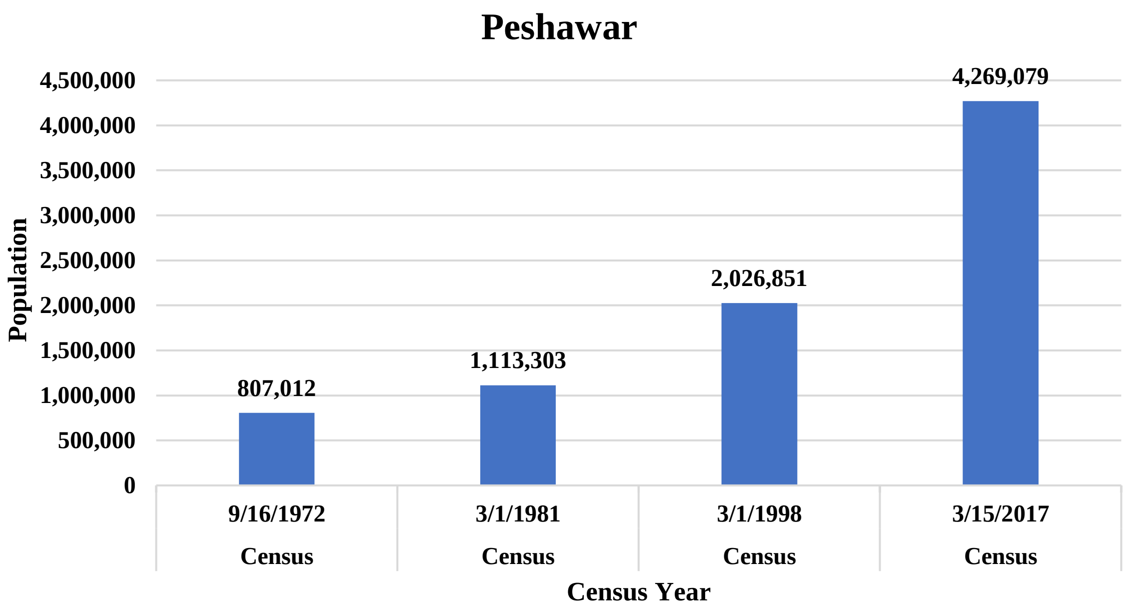

Figure 2.3. Population trend in Peshawar district since 1972.

2.3.2. Land Use Distribution

For every society to prosper and advance globally, land usage must be properly managed (UPU, 2017). The Peshawar District's land resources are under tremendous strain due to growing urbanization and human needs. Given the region's ongoing reliance on agriculture, the growth of industrial and urban regions may have an impact on both agricultural land and the socioeconomic structure of the area. The current administration has created a carefully thought-out land use plan that takes into account both population demands and the potential of natural resources.

Peshawar District's current land use pattern is described in the most recent land use report (UPU, 2017), which is divided into three primary zones. The district's overall zoning depicted in Figure 2.4, which includes an urban zone, a southern zone, and an agricultural zone in the north.

2.3.3. Topography

The topography of Peshawar District characterized by mountainous terrain along its western and southwestern perimeters. The central and eastern portions, in contrast, are predominantly flat. As depicted in Figure 2.4, a gentle slope extends from the south towards the west, followed by a similar slope from the north towards the east. The Bara River, along with all streams originating in the southern and western regions, flows towards the northeast and eventually empties into the Kabul River, located at the eastern fringes of Peshawar District. In the central flat area, surface elevations range from 288 to 344m, with the highest points reaching 454m to 682m, as illustrated on the topographical map as shown in Figure 2.5.

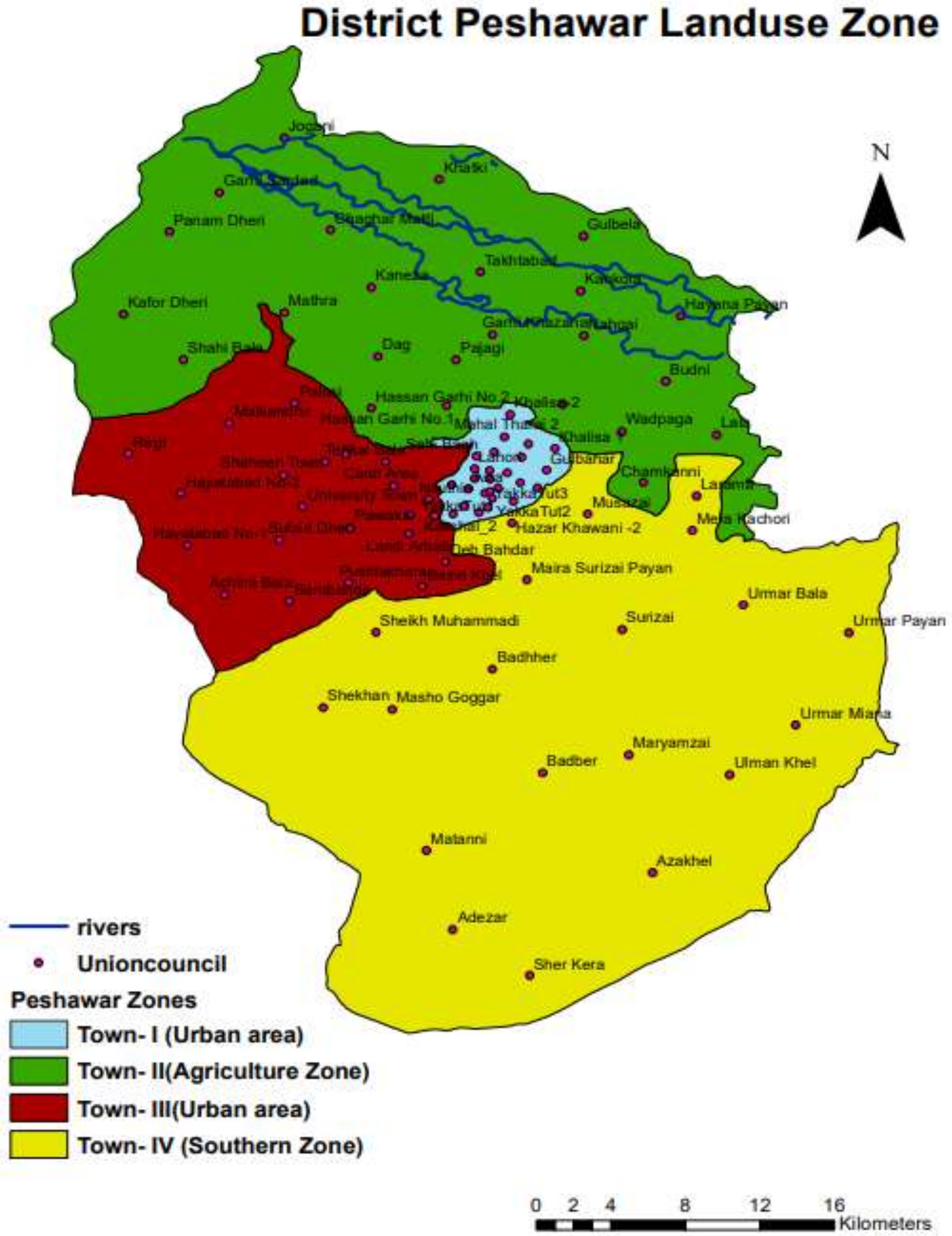

Figure 1.4. Peshawar land use zones.

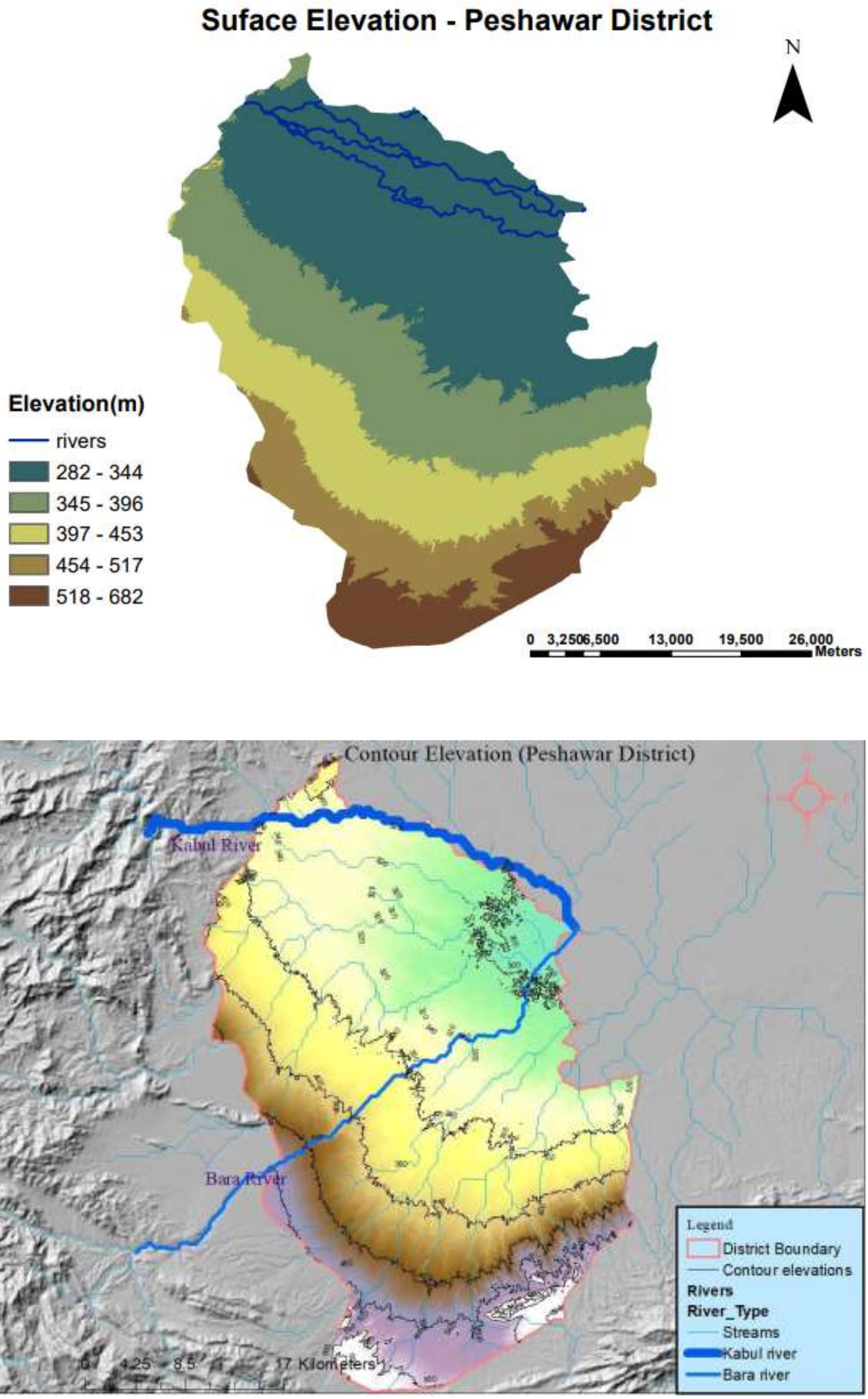

Figure 2.5. Peshawar ground surface elevation.

2.4. Methodology

The study pursued its objectives through two primary steps. The initial phase encompassed an assessment of the temporal variability in groundwater quality for selected parameters, focusing on the years 2012 and 2023. The subsequent phase involved evaluating the impact of land use and land cover on water quality and water table depth depicted in Figure 2.6. The objectives accomplished by collecting water samples from all potential groundwater sources within the study area, along with recording GPS waypoints and groundwater levels. Subsequently, these samples underwent comprehensive laboratory analysis for various water quality parameters (physical, chemical & biological). Landsat-7/8 satellite imagery with a 30m resolution used for land use/ land cover and water table depth analysis. To gain a comprehensive understanding of the water quality scenario in Peshawar, the spatial-temporal analysis of groundwater encompassing physical, chemical, and biological aspects emerged as the most effective approach in addressing the degradation of ground water quality in the region.

2.5. Water Quality Field Survey and Laboratory Analysis

2.5.1 Data Collection

Prior to commencing the water quality analysis, a comprehensive sampling protocol devised to ensure a systematic approach to data collection in the field. This guide included crucial details such as date, time, location, and the number of designated sampling points. For the collection of water samples, half-liter polyethylene bottles with screw caps employed to prevent any potential leakage during transportation. The selection of polyethylene containers was deliberate, as they do not exhibit issues related to metal adsorption commonly associated with glass containers. Furthermore, they are less susceptible to breakage during transportation compared to glass bottles.

A total of 105 groundwater samples from the year 2012 were sourced from existing literature, while 133 groundwater samples for 2023 were specifically collected from tube wells. Great care taken throughout the sampling process. All plastic bottles used for sampling underwent thorough cleaning and subsequently inverted for an extended period to ensure complete drying.

Prior to collecting a sample from a source, the water allowed to flow freely for a sufficient duration, after which the sample collected, and the bottle promptly sealed by securely placing the lid over it. Ensuring tight closure of the bottles was paramount to prevent any form of leakage or external contamination.

2.5.2 Analytical Procedure

The physical properties (pH, TDS, Turbidity, and Electric Conductivity), chemical properties (Chloride, Calcium, Magnesium, Nitrate), and biological property (E-coli) of the water samples were analyzed at the Institute of Geology, University Of Punjab, Lahore. Standard analytical methods outlined in the 23rd Edition of the Standard Methods of American Public Health Association employed as shown in Table 2.3. The standards set forth by the World Health Organization (WHO) and National Standards for Drinking Water (NSDWQ) presented in Table 2.2.

2.5.3. Biological / E-Coli Tests (MPN Method)

Thirty-five (35) groundwater samples randomly selected to monitor presence of E-coli in Peshawar, which is a strong indicator of sewage or animal waste contamination. The samples then taken to Institute of geology, university of Punjab within 24 hours after collection. The Most Probable Number (MPN) method used to estimate the concentration of E. coli, which is a statistical technique.

In the MPN method for E. coli, the samples diluted and inoculated into multiple tubes containing a growth medium specific for E. coli. The tubes then observed for growth after incubation at 37°C for 24 hours. The number of positive tubes used to estimate the concentration of E. coli in the original sample. Used a standard chart to correlate the number of positive tubes with the most probable number (MPN) of organisms present. Identified the pattern of positive reactions observed in the tubes and determine the corresponding MPN value based on the chart.

Table 2.2. Permissible limits set by US-EPA, PAK-EPA and WHO.

Parameter	WHO limit(mg/l)	NSDWQ (mg/l)
pH	6.5-8.5	6.5 to 8.5
Electrical Conductivity	<1000	<1000
Chloride (Khan et al.)	250	250
Calcium	100-300	100-300
Nitrate	50	<50
Magnesium	Less than calcium	Less than calcium
Turbidity	5 NTU	5 NTU
E coli	No presence	No presence

Table 2.3. Water quality parameters and methods of analysis (APHA, 23rd edition),

Parameters	Analysis Method
pH	pH Meter
Electrical Conductivity (µS/cm)	E.C meter, (Brand: Hanna)
Turbidity (NTU)	Method of 2130. B using Turbidity Meter
Calcium (mg/L)	EDTA Titration, Standard Method 3500- Ca. B
Magnesium (mg/L)	EDTA Titration, Standard Method 3500-Mg. B(2012)
Nitrate as Nitrogen (mg/L)	Standard method 4500- NO3 B. using Spectrophotometer
Chloride (mg/L)	Standard Method- 4500 Cl- B
Heavy Metals	Atomic Absorption Spectroscopy
E-Coli(MPN/100ml)	Most Probable Number (MPN) method

2.6. Health Data

The poor management of water quality resulting from rapid population growth is leading to an increase in health issues caused by various factors such as bacteria, pathogens, organic substances and minerals present in drinking water. In developing countries, the contamination of drinking water with microbes is responsible for a significant proportion of health problems, with approximately five million children's deaths attributed to this issue (Chowdhary et al., 2020). Pakistan, in particular, faces a significant challenge, with estimates suggesting that 30% of all diseases and 40% of all deaths in the country due to unsafe drinking water (Ahmad et al., 2021). Similar studies conducted in China, India, Bangladesh and Pakistan have reported high concentrations of contaminated parameters that directly affect human health. Improper sewage disposal, heavy rainfall, floods, and increasing populations identified as major sources of water contamination (Haseena et al., 2017).

For the analysis of the water-related disease in the district, common waterborne diseases data (cholera, typhoid fever, hepatitis A&E, and diarrheal diseases) collected from Health Department of Khyber Pakhtunkhwa, Pakistan for year 2022.

2.7. Impact of Land Use/ Land Cover

Several researchers explained that there is a good relationship between land use and land cover (LULC) and surface water quality (Chen et al., 2016). Land Use and Land Cover (LULC) changes can significantly affect the physical, chemical, and biological processes within a watershed, leading to potential degradation of surface water quality. Landsat data is a versatile tool widely employed in various applications such as agriculture, forestry, urban planning, environmental monitoring, and natural resource management. It offers valuable insights into land surface dynamics, vegetation changes, water resource monitoring, disaster impact assessment, and urban growth analysis.

For this study, LULC changes quantified between 2012 and 2023 using remotely sensed data from LANDSAT 7/ 8 with a 30-meter spatial resolution. The images, acquired on 15 April 2012 and 10 April 2023 respectively, underwent rigorous pre-processing including geometric and radiometric corrections using ArcGIS 10.8.2. Both images spatially referenced in the Universal Transverse Mercator (UTM) projection system (zone 42 north) with the World Geodetic System (WGS) 1984 as a datum. Subsequently, individually processed for land use classification through supervised maximum likelihood classification (MLC) using training sample polygons.

Based on field observations, four primary land use classes identified (Chowdhary et al., 2020), (1) Agriculture, (2) Range land, (3) Built-up areas, and (4) Water bodies. Zonal statistical tools applied to LULC and water quality parameters to assess the impact of LULC on water quality. Zonal statistics involves the calculation of values for each zone based on values from another dataset, achieved by converting the centroids of union councils into point features. Using these point features, water quality values derived for land cover. Values for each land cover tabulated using the "zonal statistics as table" tool in ArcGIS 10.8.2.

2.8. Water Table Data

To evaluate the impact of Land Use Land Cover (LULC) on groundwater levels, wells data collected from WSSP Peshawar for the years 2012 and 2023 respectively. This data collection necessitated by the increasing scarcity of water resources due to factors such as urbanization, climate change, expanding industrial and agricultural activities, and domestic demand. The collected well data was processed using ArcGIS 10.8.2 software. The Inverse Distance Weighting (IDW) interpolation technique employed to generate raster data, enabling the changes in water levels over the years. For further evaluation, zonal statistical tools employed to monitor the influence of LULC on water table depth. This analysis involved comparison of LULC data with the corresponding water level data. By examining the statistical relationship between these variables, the impact of different land uses on water table depth evaluated. Which provided insight into how changes in land use, driven by factors such as urbanization and agricultural expansion, can affect groundwater levels.

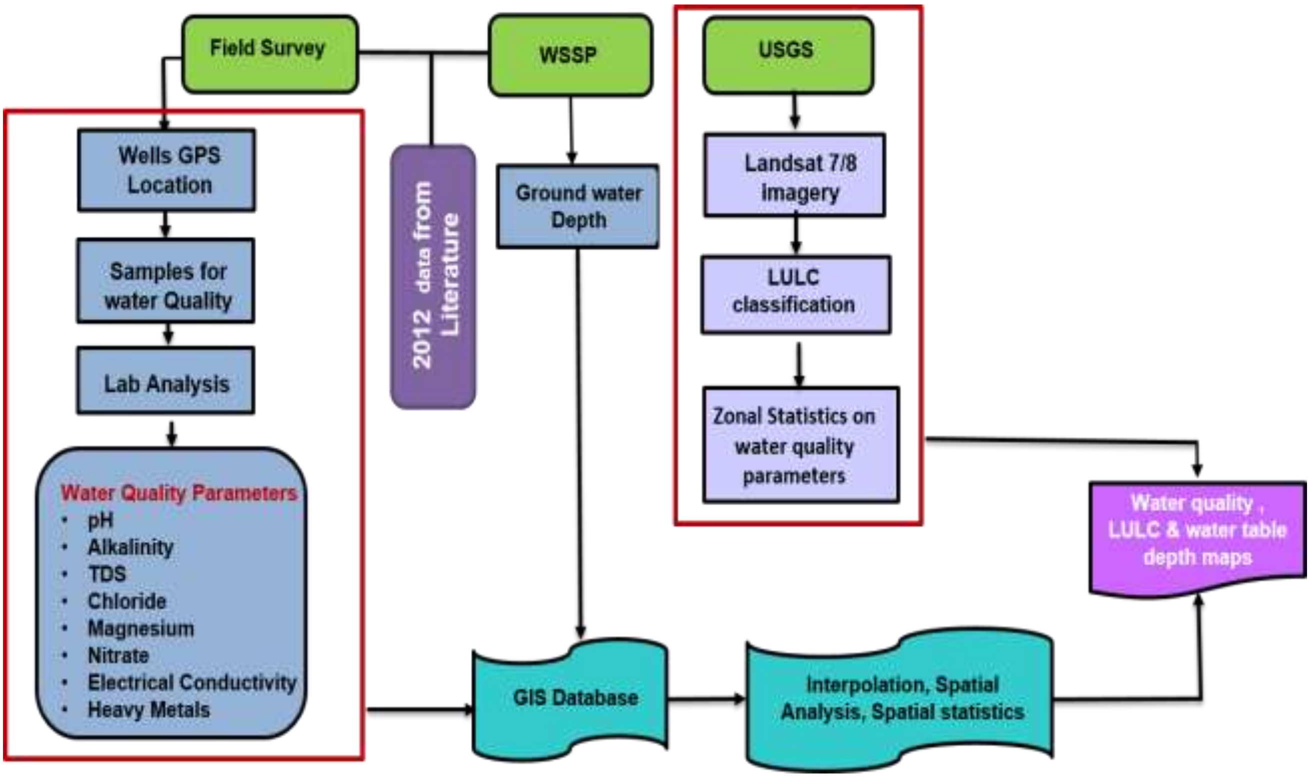

Figure 2.6. Methodology / procedure for groundwater quality.

Chapter 3

RESULTS AND DISCUSSIONS

The findings of groundwater contamination including physiochemical and biological parameters presented and elaborated in this chapter. National and international standard values of different parameters and statistical analysis tabulated and each parameter along with its role in the overall contamination canvas discussed. To assess ground water quality of the Peshawar, 105 water samples collected from the literature for year 2012 and 133 water samples collected randomly from the entire district in 2023. With the help of GPS, location of the source recorded. Different physio-chemical & biological parameters analyzed, discussed in the following paragraphs. Land use/ land cover impact on water quality and water table depth analyzed. Results and distribution of parameters shown with the help of different thematic maps. Descriptive statics depicted in Table 3.1 showed range of parameters with standard deviation for year 2012 and 2023.

3.1 Correlation Analysis

Correlation analysis is a statistical approach for determining how strongly two variables are linked. Correlation is said to be positive when an increase in one parameter causes an increase in another parameter, and it is harmful when an increase in one parameter causes a decrease in another parameter, which means the equilibrium of the water chemistry remains unaffected. The correlation coefficient (r) has a value between +1 and -1. Tables 3.3 and 3.4 show a significant correlation among physiochemical parameters for 2012 and 2023. A positive correlation found among electrical conductivity, calcium, magnesium, chloride, and TDS. A slightly different trend found in non- correlated parameter nitrate & turbidity.

Table 3.1. Descriptive Statistics

2012				2023		
Parameter	**Range**	**Average**	**STD**	**Range**	**Average**	**STD**
pH	7.10-8.08	7.77	0.1	6.8 - 8.6	7.59	0.463
EC (µS/cm)	389-1691	824.51	180.54	300-1671	821.01	231.63
Turbidity (NTU)	0.16-7.09	0.62	0.33	0.05 - 17.12	1.08	2.2
Magnesium (mg/l)	65-429.24	178.5	52.7	9.45-379.35	89.20	94.69
Calcium (mg/l)	60 -367.73	186.42	30.33	65.93 -659	313.65	123.66
Nitrate (mg/l)	0.09-41.72	19.07	7.67	0.67-163.88	35.43	34.93
Chloride (mg/l)	13-94.79	31.1	9.84	9.98-88.75	35.44	16.72

Table 3.2. Permissible Limits WHO / Pak- NSDWQ

Parameter	**2012 value**	**2023 value**	**WHO limit**	**NSDWQ**
pH	7.10-8.08	6.8 - 8.6	6.5-8.5	6.5 to 8.5
E.C(µS/cm)	389-1691	300-1671	300	300
Turbidity(NTU)	0.16-7.09	0.05 - 17.12	<1000	<1000
Calcium(mg/l)	60 -367.73	65.93 -659	100-300	100-300
Nitrate(mg/l)	0.032-41.72	0.67-88.64	50	<50
Chloride (mg/l)	13 -94.79	9.98-88.75	250	250
TDS	216-795	250-1236	<500	<500

Table 3.3. Parameter correlation 2012

	PH	EC	TDS	Calcium	Magnesium	Turbidity	Chloride	Nitrate
PH	1							
EC	0.23	1						
TDS	0.09	0.51	1					
Calcium	0.32	0.42	0.15	1				
Magnesium	0.20	0.84	0.46	0.24	1			
Turbidity	0.08	0.09	0.03	0.01	0.15	1		
Chloride	0.14	0.79	0.45	0.49	0.71	0.01	1	
Nitrate	0.08	-0.11	-0.13	0.15	-0.12	0.04	0.12	1

Table 3.4. Parameter Correlation 2023

2023 Parameters Correlation								
	PH	EC	TDS	Calcium	Magnesium	Turbidity	Chloride	Nitrate
PH	1							
EC	-0.38	1						
TDS	0.10	0.12	1					
Calcium	-0.44	0.61	0.10	1				
Magnesium	0.49	0.45	0.47	0.3	1			
Turbidity	0.1	0.17	0.13	0.034	0.05	1		
Chloride	-0.09	0.20	0.48	0.33	0.08	0.21	1	
Nitrate	0.16	-0.16	-0.31	0.02	-0.28	0.06	0.16	1

3.2 IDW Maps for Physio Chemical Analysis

3.2.1 pH

Only among all physiochemical parameters, the only pH consider as a basic indicator for water quality assessment, which has no direct effect on human health, as it brings a change in parameters like pathogens survival and the solubility of metals (Khan et al., 2013). In some cases, it can cause gastrointestinal irritation though intermittent pH change would not have definite impacts on individuals.

The minimum and maximum value of pH of 2012 found to be 7.1 (Union council Shaheen Muslim town) and 8.08 (Union council Mera Kachori), for 2023 the minimum 6.8 found for union council (Shaheen Muslim town, Din Bahar, Cantt Area) and maximum value 8.6 in Union Council (Sarband). Spatial interpolation map of pH for year 2012 shows that approximately in all union councils pH values lies between 7.5-8 except in Mera Kachon but in 2023 pH value of these areas increased to 8-8.5 as shown in Figure 3.1.

In these two periods (2012-23), the highest concentration of the pH found in the built-up areas. Which could probably due to the construction and the wastewater discharge from the domestic areas. In the agriculture area (Kafoor dheri, Malakanddir), the reason of the highest pH concentration could be the use of pesticides and fertilization application in the area. The pH values of all the samples were within the limit of WHO guidelines of water quality except for Sarband.

3.2.2 Electrical Conductivity

EC is the measurement of solution/water to conduct electricity due to the presence of dissolved inorganic material in ionized form and higher amounts of inorganic ionized material lead to higher conductivity (Syrmos et al., 2023). Conductivity is useful for the assessment of the water quality of a particular area. Conductivity is acting as a baseline for the measurement of EC for a specific area, and once its developed, use for comparison with regular conductivity evaluation. The conductivity of water does not have direct health consequences; however, high conductivity indicates the addition of some pollutants to it.

The analysis results indicate that the minimum and maximum value of EC recorded in 2012 was 389 µS/cm and 1695µS/cm and in 2023, the minimum & maximum EC was 300 µS/cm and 1671 µS/cm, respectively. EC of water samples (17%) at some localities noted above the permissible value, which is 1000 µS/cm as per WHO standards as shown in Figure 3.2. The high value of EC in water may be due to the natural processes that occur in the aquifer. The high value of EC at some areas such as Jogani, Mera Kocho, pagagi & musazai may be due to the agricultural activity in these areas and leaching of minerals due to natural processes that occur around the aquifer.

3.2.3 Chloride

According to the laboratory analysis, chloride's minimum and maximum value in 2012 were 13.30mg/l and 94.79mg/l, while in 2023, the minimum and maximum value was 10.03-88.64mg/l. Chloride values in both years are within permissible limits of less than 250mg/l, as shown in Figure 3.3.

Chloride found in surface and groundwater is due to natural and anthropogenic sources such as sewage, industrial effluents, septic tanks and inorganic fertilizers leaching and runoff. It may also increase in the drinking water due to the water treatment process, as chlorine and chloride are used. No health concern at the level of drinking water noticed. However, the increased chloride level can cause corrosion in the distribution system and lead to an increased concentration of metal in the drinking water, giving an unacceptable taste to the water at a level above 250 mg/L WHO (2011). High chloride values in water can harm plants during transpiration due to increased chloride (salinity) at the root zone. As a result, the difference creates an osmotic pressure of water present within plant cells and outside the plant, making it difficult to take up water.

3.2.4 Calcium Hardness

Based on the drinking water quality standards, the maximum desirable calcium level in drinking water is 100 mg/l. The maximum and minimum calcium concentrations in 2012 and 2023 were 60.05-367.73 mg/l and 65.93 -659.5 mg/l as shown in Figure 3.4.

Calcium in high concentration causes hardness in water and generally enters the groundwater while water percolates via calcium and magnesium minerals. The familiar sources of calcium and magnesium are carbonate rocks. Although these ions do not pose any health threats, in some cases, cardiovascular diseases noticed. Besides health issues, calcium and magnesium also cause scale production in water distribution systems and supply pipelines.

3.2.5 Turbidity

Turbidity is the muddy appearance of water due to fine suspended particles in water. It is due to various suspended materials such as silt, clay, organic matter, or microscopic organisms in the water. A high turbidity concentration will affect light penetration and ecological productivity. The increase in sedimentation and siltation can harm the cultivated areas. Excessive rate of turbidity in the drinking water is unpleasant and may cause health issues in humans. Excessive turbidity helps in the growth of pathogens in the water, which causes intestinal disease in the human body. In the study area, the minimum and maximum turbidity in 2012 was 0.16 NTU and 7.09 NTU, while in 2023, the minimum and maximum turbidity were 0.05 NTU and 17.12 NTU- in most areas beyond WHO and NSDWQ standards as depicted in Figure 3.5. The turbidity of the Peshawar district increased in a decade, which is the symbol of another hazard. The leading cause of this is excessive excavation, construction activities, and land disturbance, leading to sediment runoff and turbidity in nearby groundwater and poor wastewater management system.

3.2.6 Nitrate

Per the WHO and NSDWQ guidelines, potable water nitrate should not exceed 50 mg/L. Nitrate mainly occurs in groundwater but is available in small amounts in surface water. Sources of Nitrate in water include agricultural activities, such as using fertilizers and manure, urban runoff, sewage discharge, and industrial processes. These sources can contribute to the contamination of groundwater and surface water bodies. Excessive nitrate levels in drinking water can pose health risks, especially for infants and pregnant women. When nitrate ingested, it convert into nitrite ($NO2^-$) in the body, interfering with the oxygen-carrying capacity of red blood cells, leading to methemoglobinemia or "blue baby syndrome." This condition can cause oxygen deprivation in infants, resulting in serious health consequences.

The minimum value of Nitrate found in 2012 was 0.035 mg/L, and the maximum value was 41.62 mg/L, while in 2023, the minimum value of Nitrate was 0.67, and the maximum was 88.64. The values of Nitrate in 2012 were within the limit of the WHO standard, but in 2023, 20% of samples were beyond this limit, Figure 3.6. These areas have unsustainable agriculture activities; thus, the increase of Nitrate in 11 years is at its peak. Excessive levels of Nitrate in water can negatively affect human health and the environment.

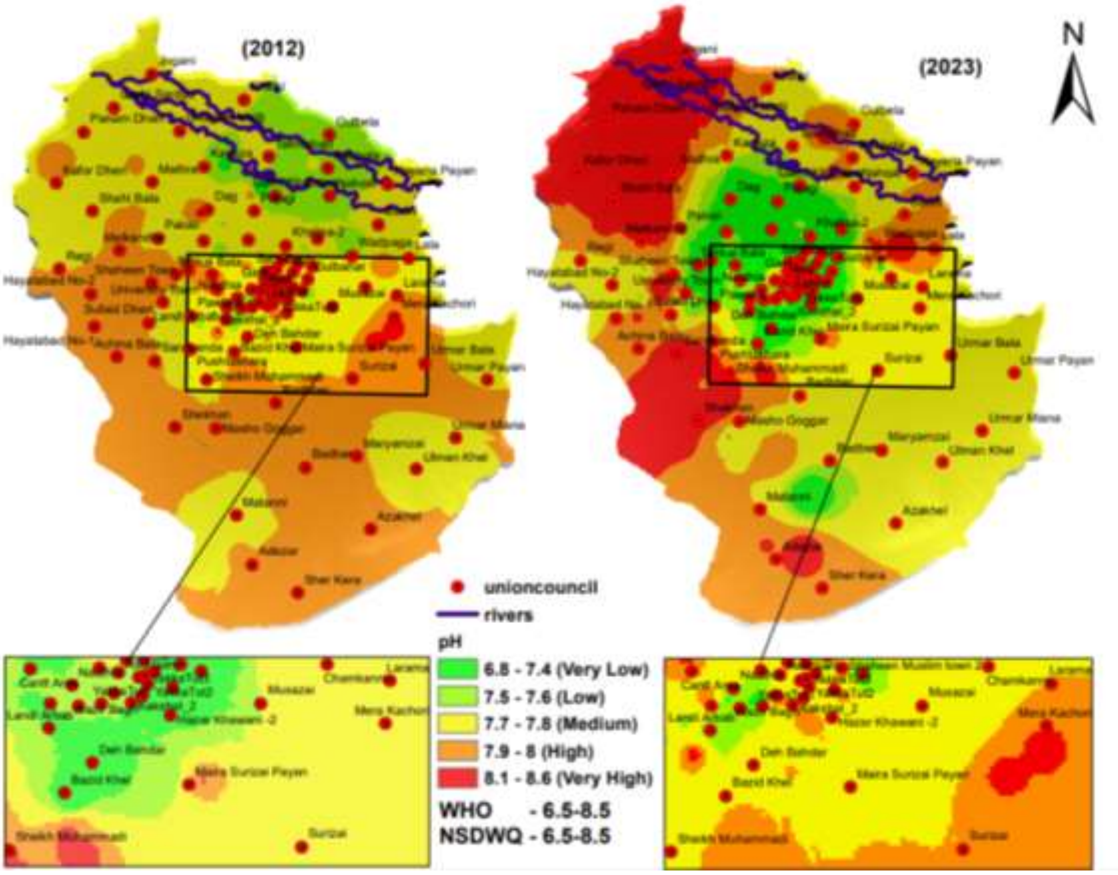

Figure 3.1. PH of the groundwater of two years (2012 & 2023).

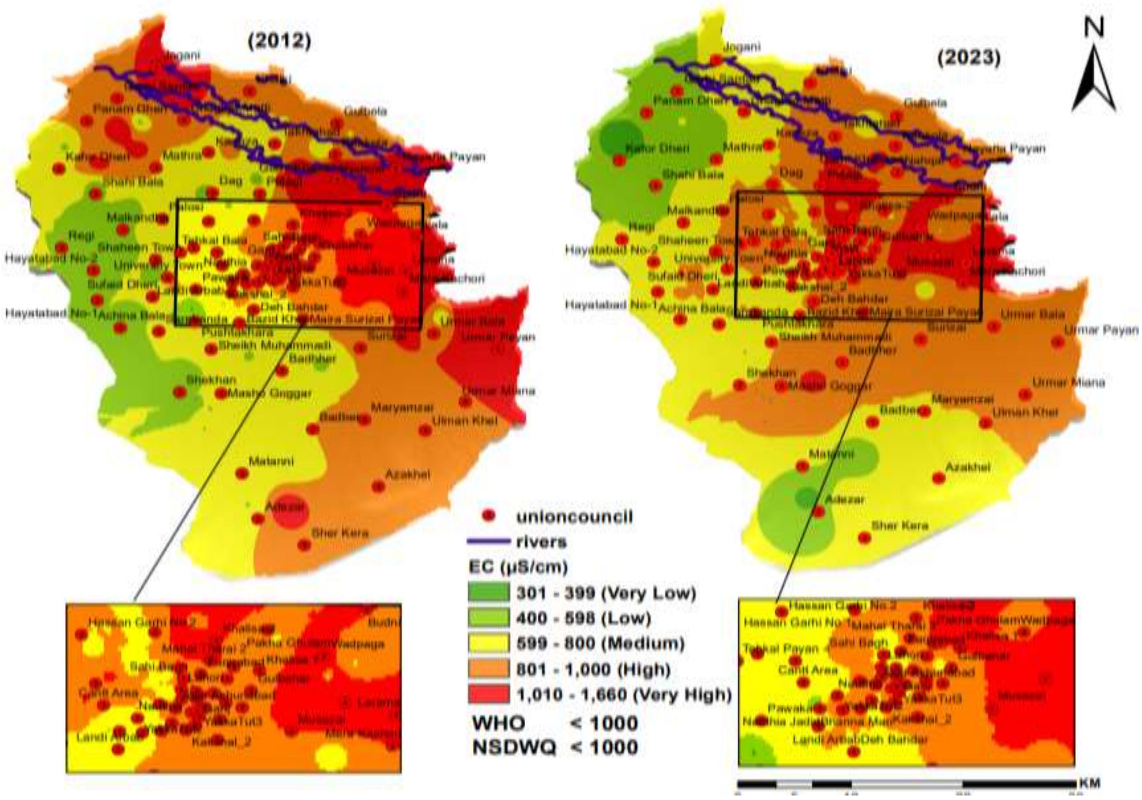

Figure 3.2. EC of the groundwater of two years (2012 & 2023).

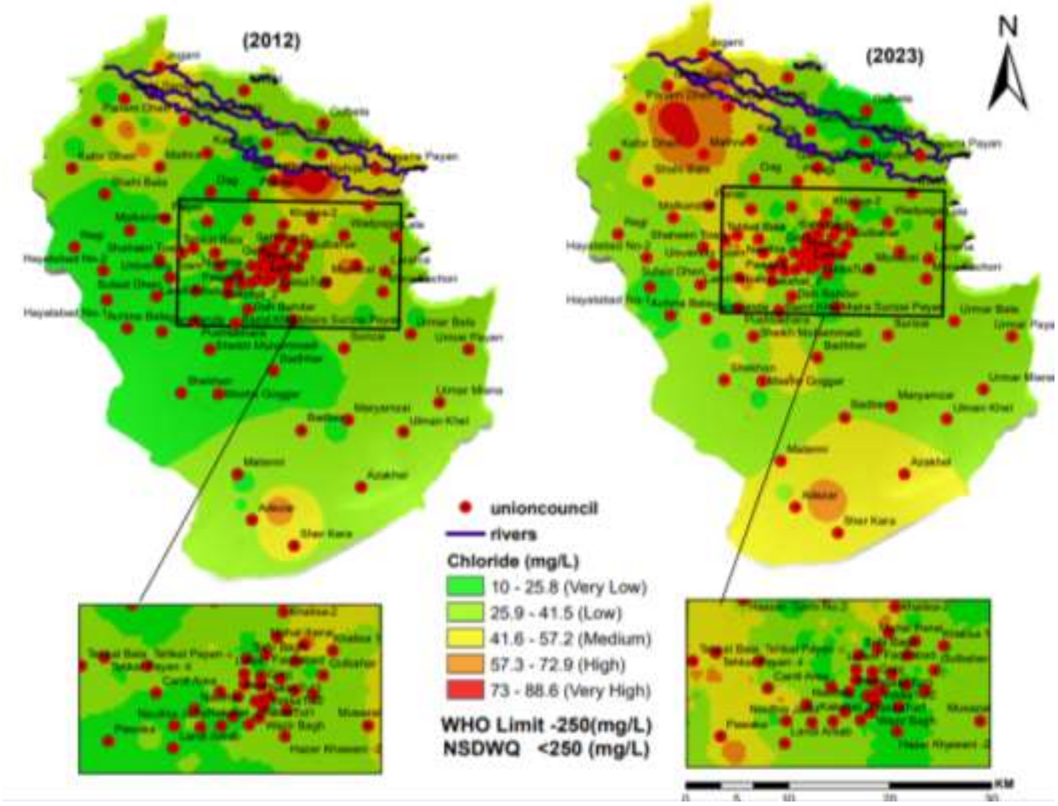

Figure 3.3. Chloride of the groundwater of two years (2012 & 2023).

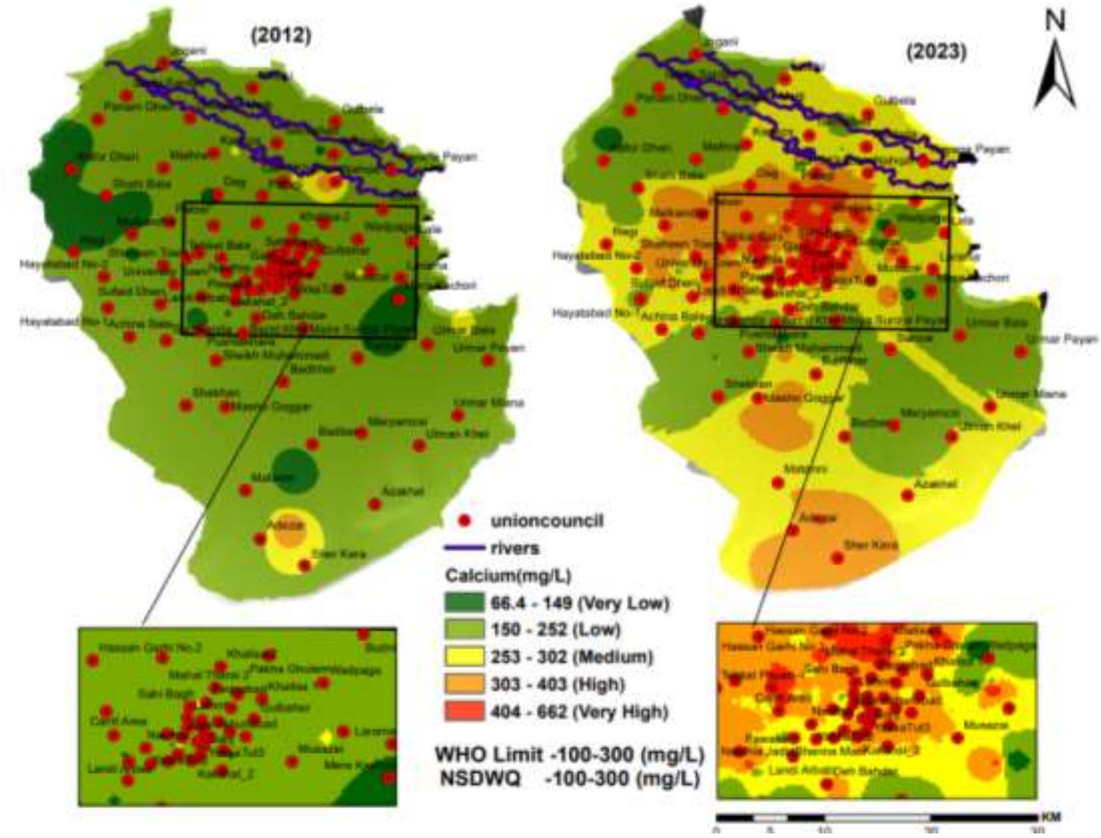

Figure 3.4. Calcium of the groundwater of two years (2012 & 2023).

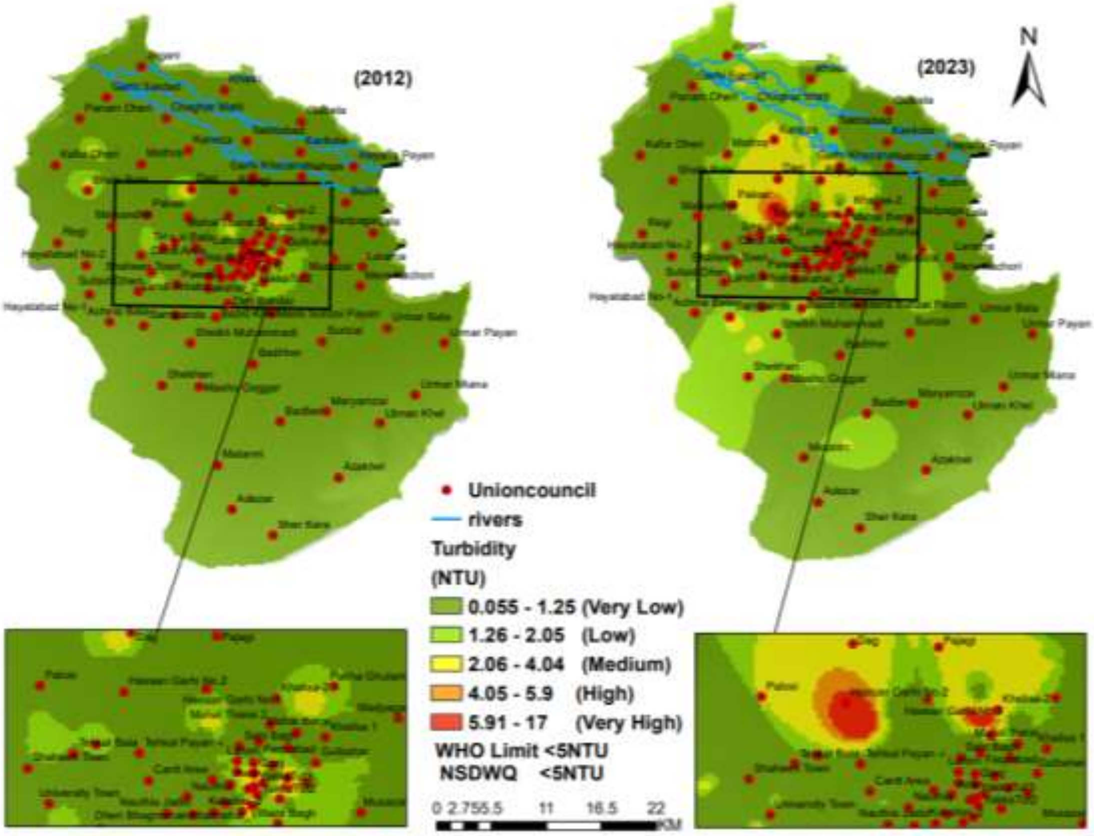

Figure 3.5. Turbidity of the groundwater of two years (2012 & 2023).

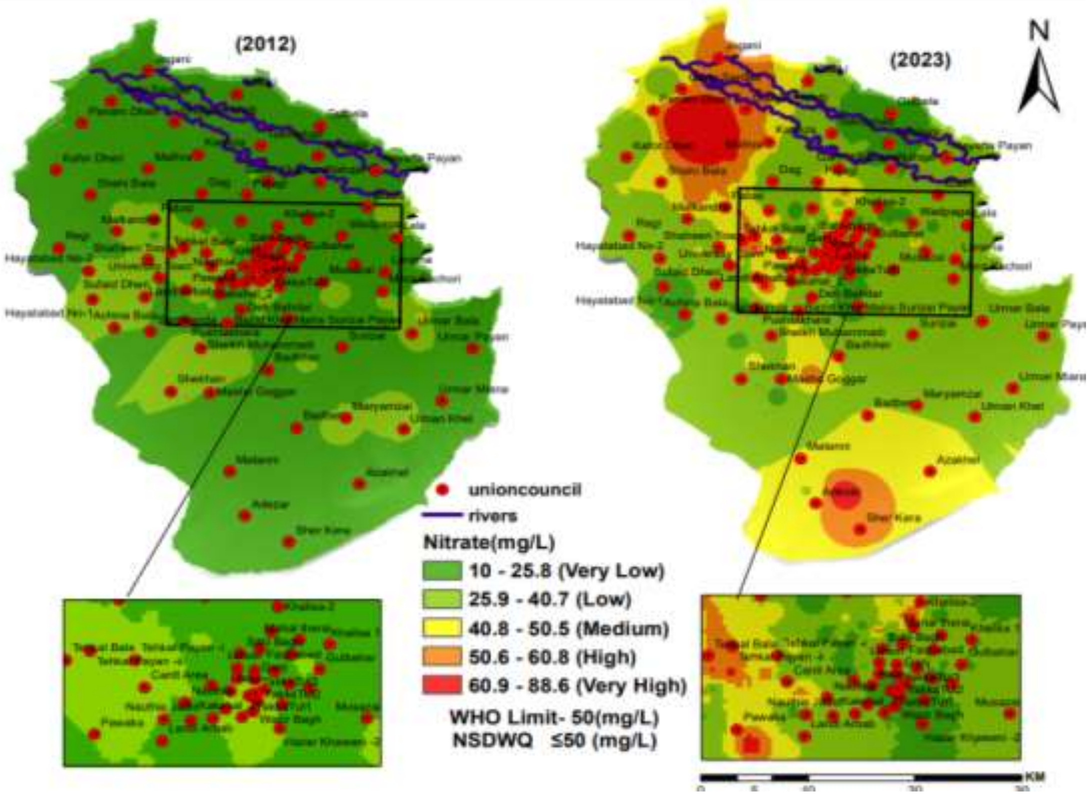

Figure 3.6. Nitrate of the groundwater of two years (2012 & 2023).

3.2.7 Microbiological Analysis

Microbial analysis of the water samples performed by determination of most probable number (MPN) of E-coli (Escherichia Coli) in 100ml of water sample. E. coli are bacteria mostly found in human and warm-blooded animal feces. It enters into the drinking water system via damage and cracked sewage supply pipelines, which pass through or are in direct contact with the bathrooms and kitchen drains, due to insufficient sanitation and unhygienic practices and cause many serious diseases such as hepatitis A, salmonella, and serious stomach problems. The existence of *E. coli* in food or water normally signals recent fecal contamination or poor hygienic conditions in food processing facilities (Odonkor et al., 2013).

The microbiological analysis of 35 random water samples revealed the presence of E coli in 57.15% of samples. Hotspot analysis of samples shown in Figure 4.6. Table 4.4 shows the percentage of E coli contamination for all 35 samples, the contaminated samples categorized according to the risk grade as per WHO standards .The data describes that there is very high risk in 22.85% ground water samples, which is indication of fecal contamination into water. Results shows that e-coli ranging from 1 to 1600. Maximum values are in Tehkal bala, chamkni, Sheikh Junaind abad, Warsak road, Sheikh Muhammadi, Cantt area & Sarband as shown in Figure 3.7.

Table 3.5. Total E-Coli.

Total E-coli MPN/100	**Risk Grade WHO=0**	**Source(n=35) (%)**	**WHO Limit**
0	A (no risk)	42.85	Presence of number of bacteria
1-10	B (Low Risk)	25.7	
11-100	C (High Risk)	8.6	
101- >1000	D (Very High Risk)	22.85	

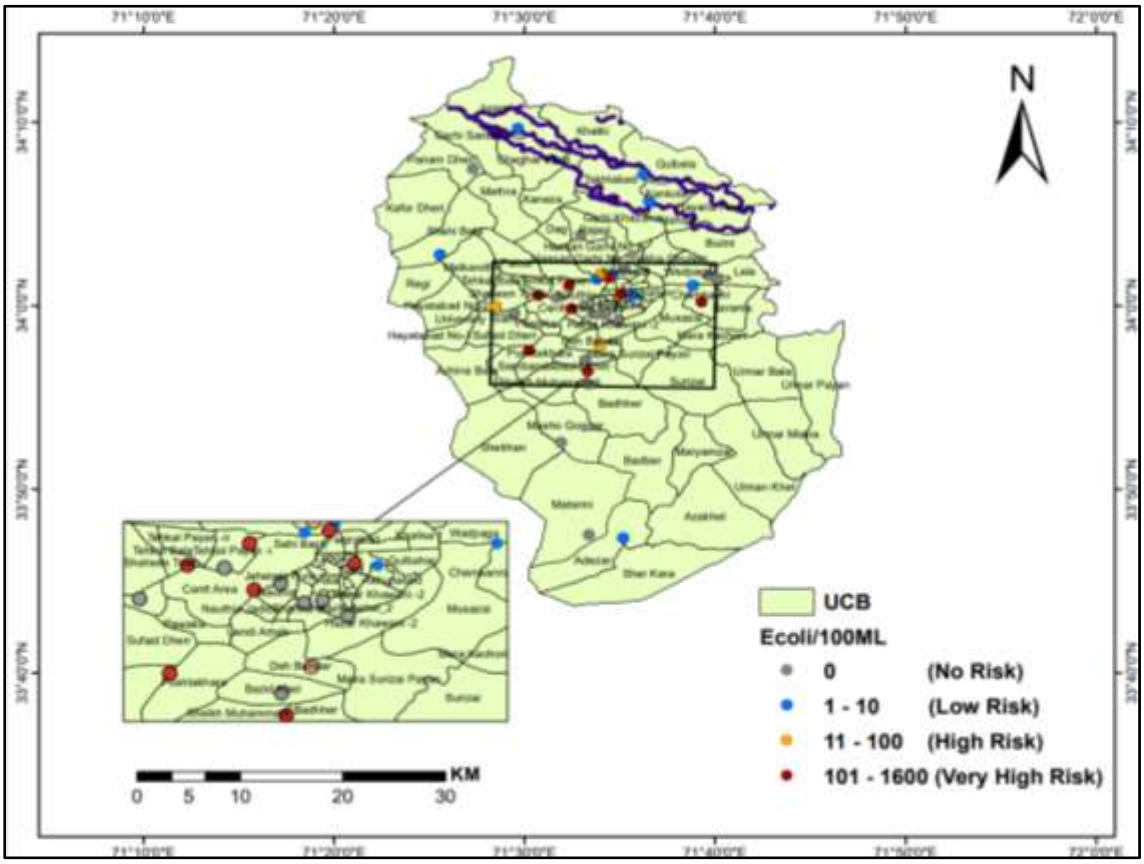

Figure 3.7. Hotspot analysis for E-Coli.

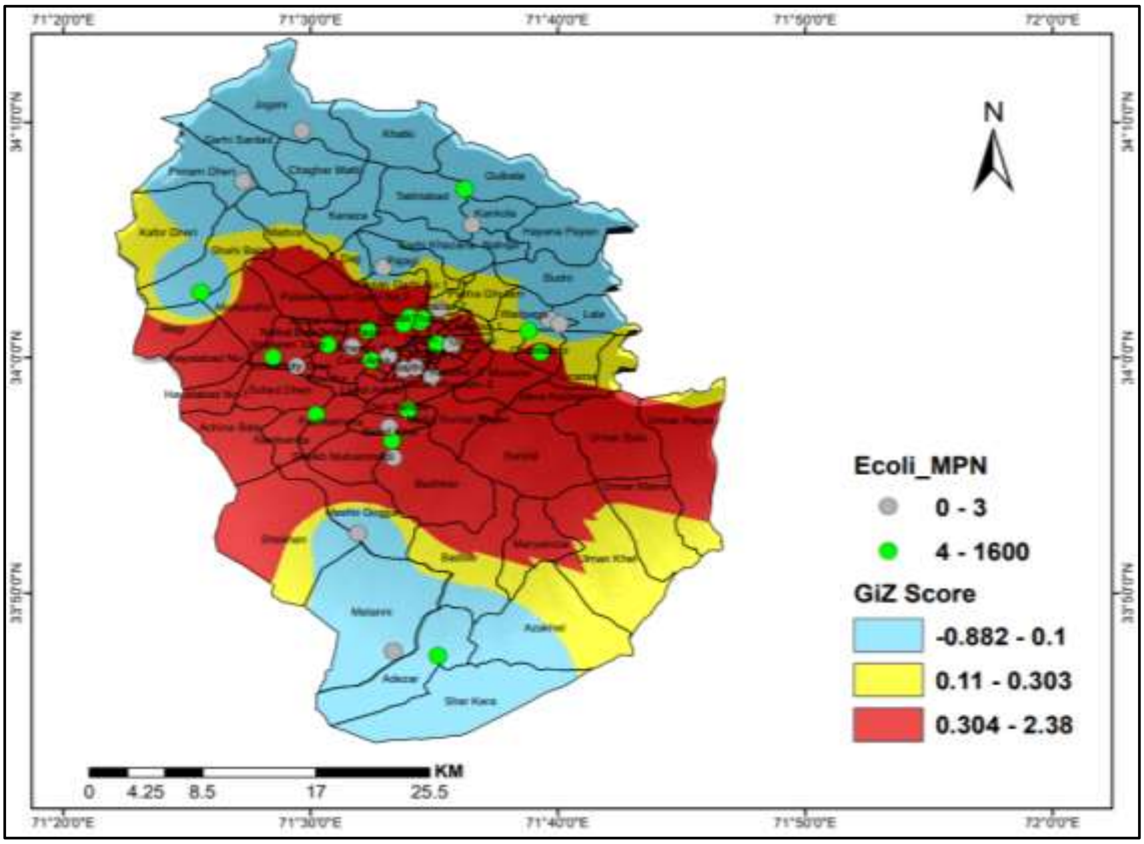

Figure 3.8. IDW map of E coli based on hot spot analysis.

3.3. Health Data Analysis

Water borne disease data of 2022 collected from Peshawar Health Department including basic heath units (BHU) and rural health units (RHU) shown in figure 4.8. Acute diarrhea (non-cholera), Acute Viral Hepatitis A, Bloody Diarrhea, typhoid fever & cholera patient's data collected, graphically represented in Figure 3.10. IDW map of each disease prepared after hot spot analysis based on GiZScore shown in Figure 3.11. This analysis identified statistically significant spatial clusters of high values (hot spots-red colour) and low values (cold spots-blue colour). By relating disease data with e-coli results, it has shown that mostly patients are from those areas where water contaminated with bacteria. This is indication of infiltration of contaminated water and sewage through cross connection and leakage points into source. In addition, affected areas are highly populated and dense.

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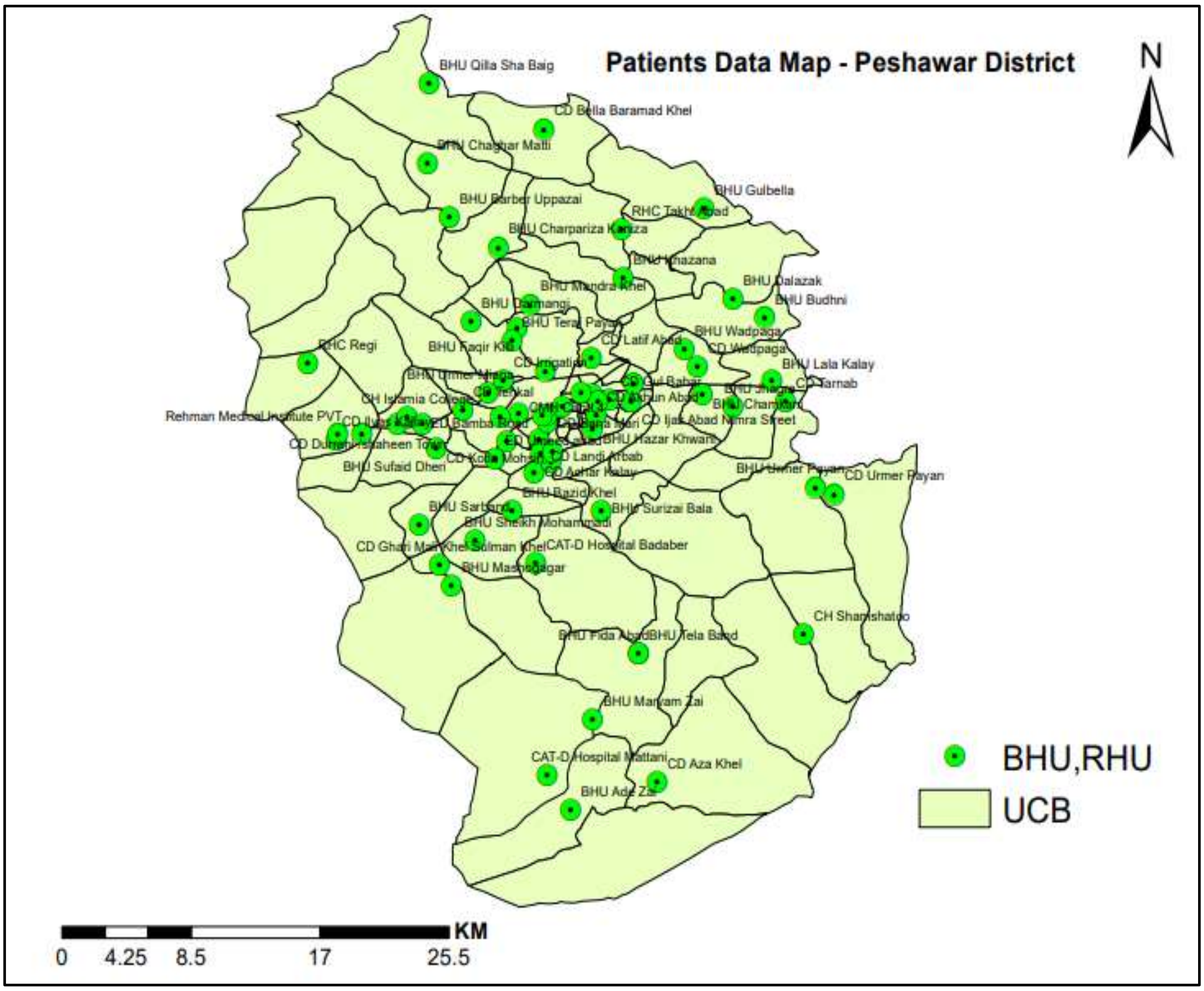

Figure 3.9. Patient data mapping showing locations of BHU & RHU.

Table 3.6. Patient's data waterborne diseases.

Acute Diarrhea (Non-Cholera)	Acute Viral Hepatitis (A & E)	Typhoid Fever	Bloody Diarrhea	Cholera
83314	830	4256	10210	4065
Total Patients: 102675				

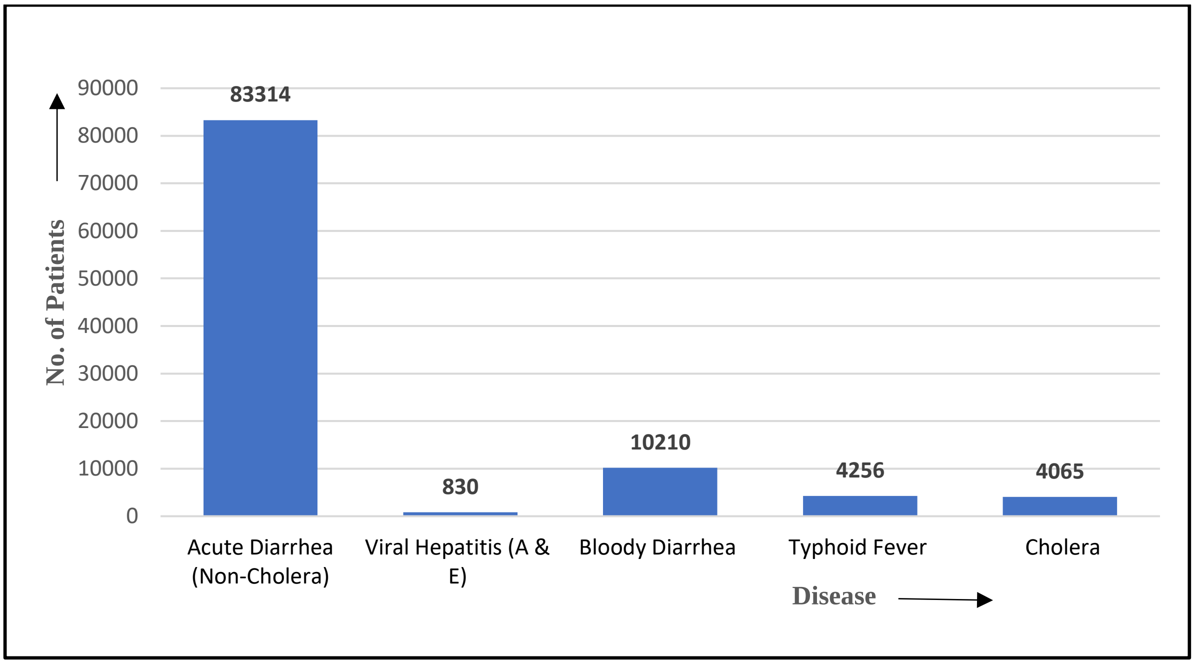

Figure 3.10. Water borne diseases (Year 2022) (Source PHE).

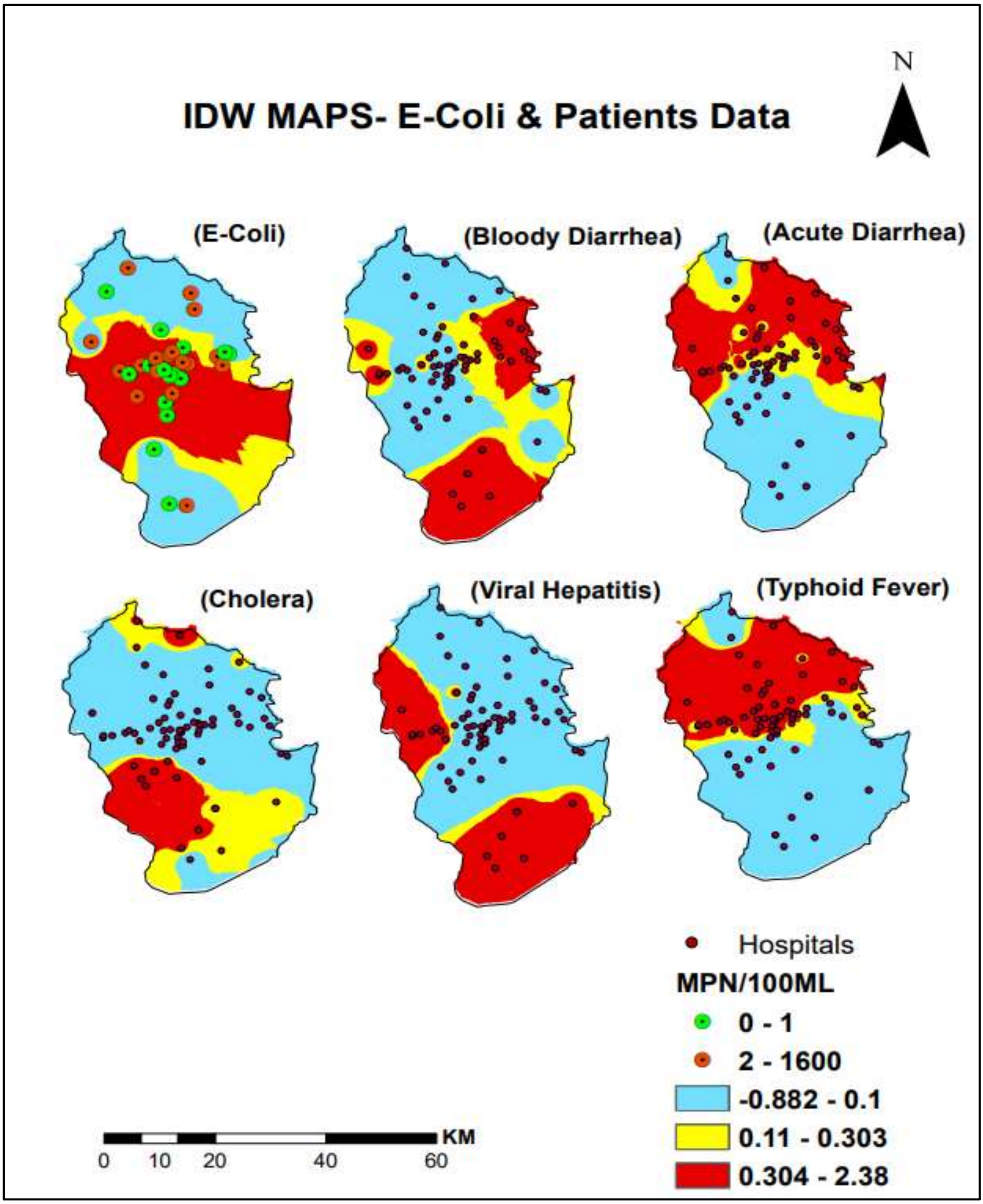

Figure 3.11. IDW maps gastrointestinal diseases

3.4. Landuse / Landcover Impacts on Water Quality & Water Table Depth

To study land use/ landcover impact on groundwater quality and water table depletion in 2012 and 2023, supervised classification (MLC) was performed on Landsat-7/8 imagery. Several studies have shown that the Maximum Likelihood Classified technique is the most frequent, thriving and broadly adopted classification algorithm (Ahmed et al., 2015; Bhalli et al., 2012; Jamal et al., 2012; Manandhar et al., 2009; Prakasam, 2010; Rawat et al., 2013; Yuan et al., 2005). Four land use/ land cover classes were selected based on visual interpretation, physiographical information of the research area, and using open source Google Earth Figure 3.11. The analysis revealed that in 2012, built-uses covered over 27% of the city's land, over 38% of agricultural land, rangeland 35% of the city, and merely 1% of water bodies. Compared to 2023, the area covered by built-up area has enhanced to more than 17%, agricultural land has jumped to over 42%, and rangeland has decreased to about 21%.In contrast, the change in the area under water bodies was insignificant as shown in Table 3.7 and Figure 3.13.

The data showed two dissimilar trends in four major land use categories. Areas under rangeland have recorded a sharp decline, while on the other side, built-up areas and agricultural land have registered a noticeable increase as shown in Figure 3.12. This rapid population growth is attributed to advancement in industrial sectors, enhanced transportation facilities, increasing demand for building new houses and improving economic conditions. The expansion of built areas, such as urban areas and infrastructure development, has increased impervious surfaces and reduced natural infiltration, resulting in higher runoff and decreased water quality. Similarly, the expansion of agricultural land contributes to water pollution through the excessive use of fertilizers and pesticides.

3.4.1 Land Use/ Land Cover Impact on Water Quality

The specific land categories in an area have activities and characteristics that can affect water quality. Table 3.8 shows the impact of land use/ land cover on water quality. For instance, in extensive agriculture, large farms are cultivated with relatively lower inputs of pesticides and fertilizers, resulting in a lesser impact on groundwater quality. On the other hand, intensive agriculture involves small farms that utilize high levels of fertilizers and pesticides, leading to a more significant impact on groundwater quality. Additionally, groundwater quality in built-up land areas can vary significantly depending on the disposal of polluted water from anthropogenic activities and contaminated sites. The disposal of such water can have adverse effects on groundwater quality. The zonal statistic tool employed to assess the association between different land classes and changes in mean concentration for various water quality parameters. This tool helps estimate the influence of land use/land cover conditions on groundwater quality in the region.

3.4.2 Temporal Change on Water Table Depth

Temporal change in groundwater levels assessed based on the source data collected from different parts of Peshawar for 2012 and 2023, shown in Figure 3.14. The results plotted on the map showed a decreasing trend in water levels over the years. The highest recession or lowering of the water table occurred in Sheikh Muhammadi, Achini Bala, Adezai, Sherkara, Maryamzai, Malakandhir, Palosai, Kaushal-1, Hazar Khwani, university town, cantonment area. Water table deplition depicted in Figure 3.15 showed rapid growth in built environment, increased population and over extraction of groundwater resulted in lowering down of groundwater table about 6 to 7 meter. The lowering of the water table can have significant implications for local ecosystems, agricultural practices, and access to water resources. It may lead to reduced availability of water for wells and can potentially lead to land subsidence or other environmental hazards.

3.4.3 LULC Impact on Water Table Depth

Land use/ land cover influence on water table depth shown in Table 3.9. Water table depletion is notable in built up areas and rangeland where mean values changed from (25.79 to 32.88) meter and (22.29 to 33.18) meter, respectively. Due to rapid increase in population, the demand for water increased, resulted greater extraction of groundwater resources. This over extraction affected decline in the water table, as more water pumped out than replenished through natural processes like rainfall and infiltration. Urbanization, impervious surface and agricultural practices lead to significant decrease in water levels.

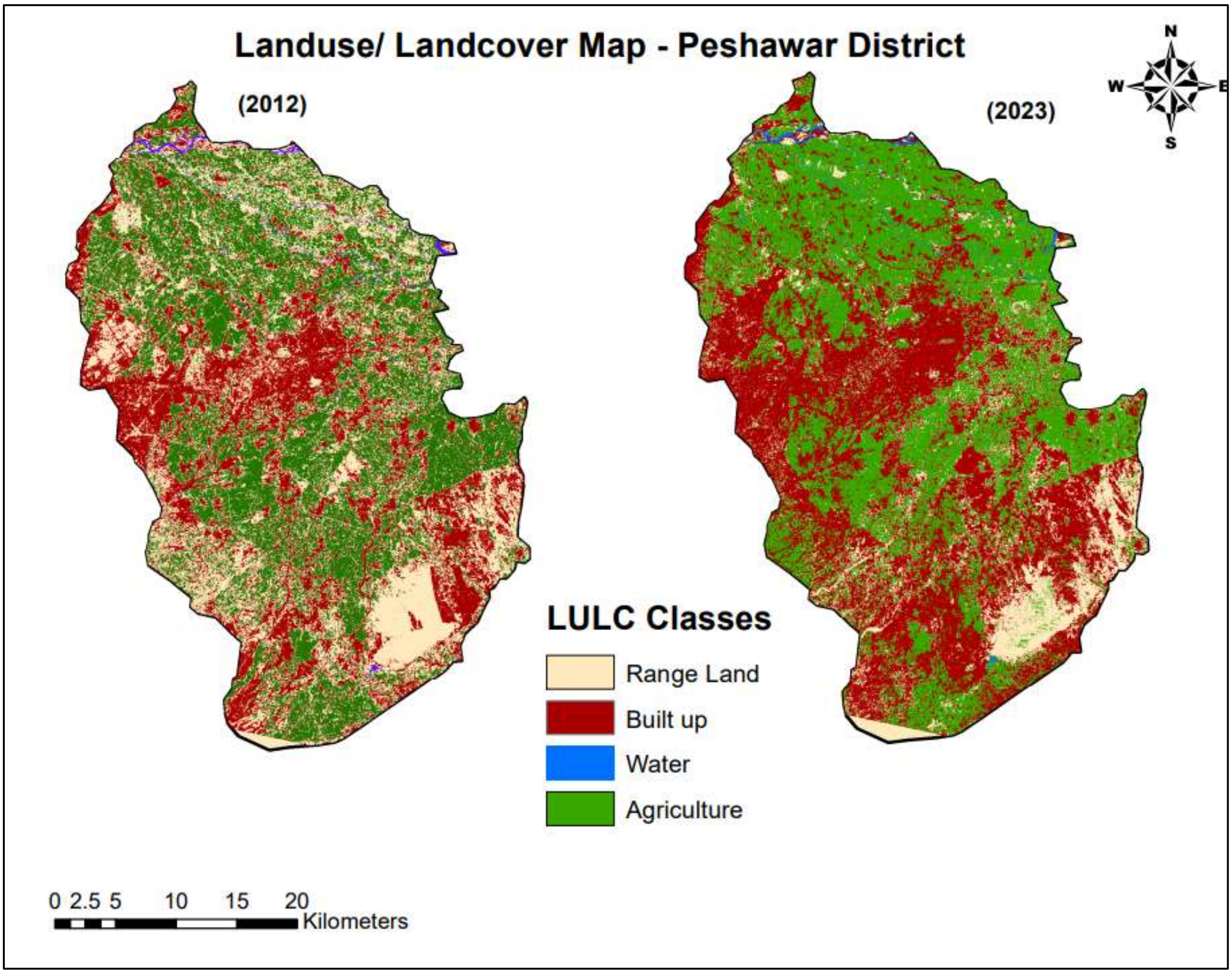

Figure 3.12. LULC map showing changes occurred 2012 vs 2023

Table 3.7. Landuse / landcover changes 2012 vs 2023.

LULC	**2012**		**2023**		**LULC Changes**
	Area sq Km	**Percentage**	**Area sq Km**	**Percentage**	
Agriculture	481.24	38	528.24	42	4%
Built - up	336.88	27	551.07	44	17%
Range Land	438.72	35	174.66	14	-21%
Water	8.04	1	7.55	1	-

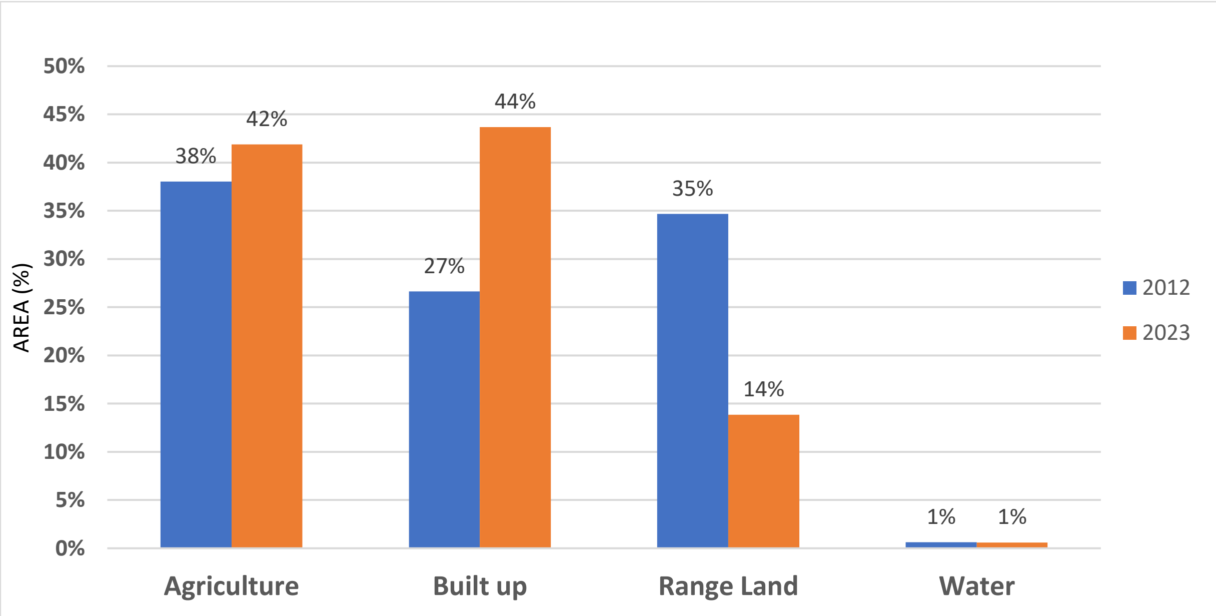

Figure 3.13. Landuse/ landover change (2012-2023).

Table 3.8. Effects of landuse / landcover on water quality parameters.

Agriculture								
	2012				2023			
Parameters	**Min**	**Max**	**Mean**	**STD**	**Min**	**Max**	**Mean**	**STD**
pH	7.10	8.06	7.77	0.11	6.926	8.556	7.809	0.234
Conductivity	473.83	1633.30	832.98	198.71	300.78	1557.86	795.32	167.76
Turbidity	0.19	3.00	0.64	0.31	0.132	15.65	1.36	1.26
Calcium	60.05	341.06	186.75	30.69	69.68	607.20	284.69	54.73
Chloride	13.34	90.87	31.06	10.77	10.04	88.30	38.23	12.04
Magnesium	65.55	415.63	179.75	55.88	14.36	379.29	150.96	67.20
Nitrate	0.09	41.08	18.50	7.86	10.04	88.30	38.23	12.04
Rangeland								
pH	7.17	8.07	7.78	0.09	6.864	8.422	7.78	0.183
Conductivity	389.82	1664.89	841.66	157.62	310.58	1658.42	791.42	150.12
Turbidity	0.19	3.30	0.55	0.27	0.054	13.00	12.94	1.12
Calcium	62.10	367.73	187.01	32.30	109.70	623.78	291.25	40.30
Chloride	13.30	92.98	32.48	8.87	13.22	86.24	37.92	8.52
Magnesium	85.42	428.48	181.22	49.01	17.57	366.78	153.29	53.01
Nitrate	0.16	41.46	18.28	7.51	1.22	86.24	37.92	8.52
Water								
pH	7.59	7.77	7.68	0.05	7.083	8.224	7.862	0.220
Conductivity	825.87	1277.23	979.70	120.00	370.43	1180.03	763.26	173.99
Turbidity	0.46	1.04	0.71	0.13	0.458	7.71	2.69	2.09
Calcium	171.02	217.11	193.29	11.58	157.55	580.68	276.78	58.77
Chloride	27.16	46.95	38.93	5.27	12.66	65.73	41.75	12.14
Magnesium	189.42	316.23	233.85	36.99	31.63	371.98	195.64	78.48
Nitrate	5.14	19.86	9.83	3.64	12.66	65.73	41.75	12.14
Built-up								
pH	7.16	8.08	7.78	0.10	6.823	8.595	7.761	0.260
Conductivity	394.33	1691.69	744.67	171.23	300.70	1451.54	769.50	158.63
Turbidity	0.16	7.09	0.77	0.46	0.089	16.99	1.25	1.62
Calcium	75.67	354.55	181.46	25.45	69.24	654.09	293.82	53.25
Chloride	13.71	94.79	26.83	9.13	10.86	88.65	37.46	9.56
Magnesium	82.15	429.24	165.00	52.43	11.35	378.90	127.35	64.59
Nitrate	0.27	41.72	22.65	6.74	1.85	88.65	37.46	9.56

Table 3.9. Landuse / landcover impact on water table depth.

LULC	2012				2023			
	Min	**Max**	**Mean**	**Std**	**Min**	**Max**	**Mean**	**Std**
Agriculture	6.88	245.07	64.74	55.59	6.29	263.46	72.89	58.20
Rangeland	6.87	244.18	73.14	54.69	8.15	246.03	108.89	51.77
Built-up	7.05	246.89	84.64	51.90	6.41	279.63	107.89	55.71
Water	7.88	200.49	24.90	35.38	7.78	211.39	29.29	29.91

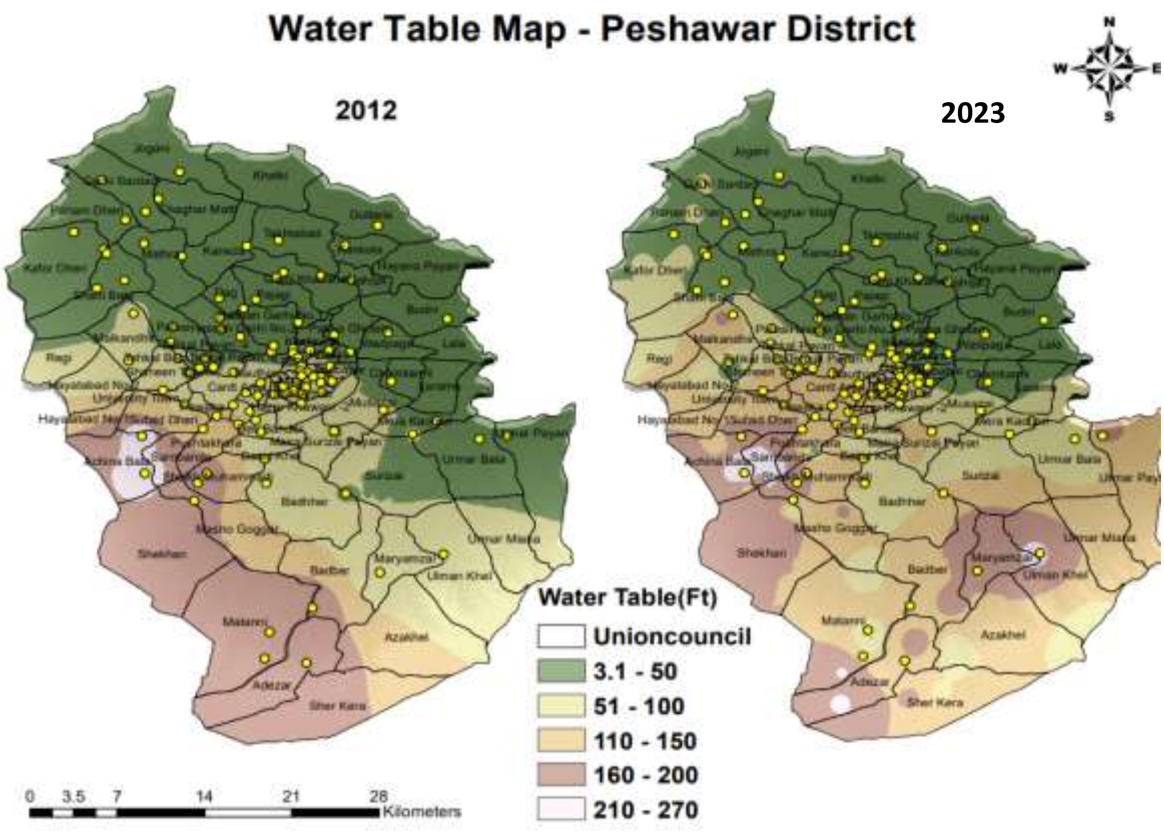

Figure 3.14. Water table changes 2012 vs 2023.

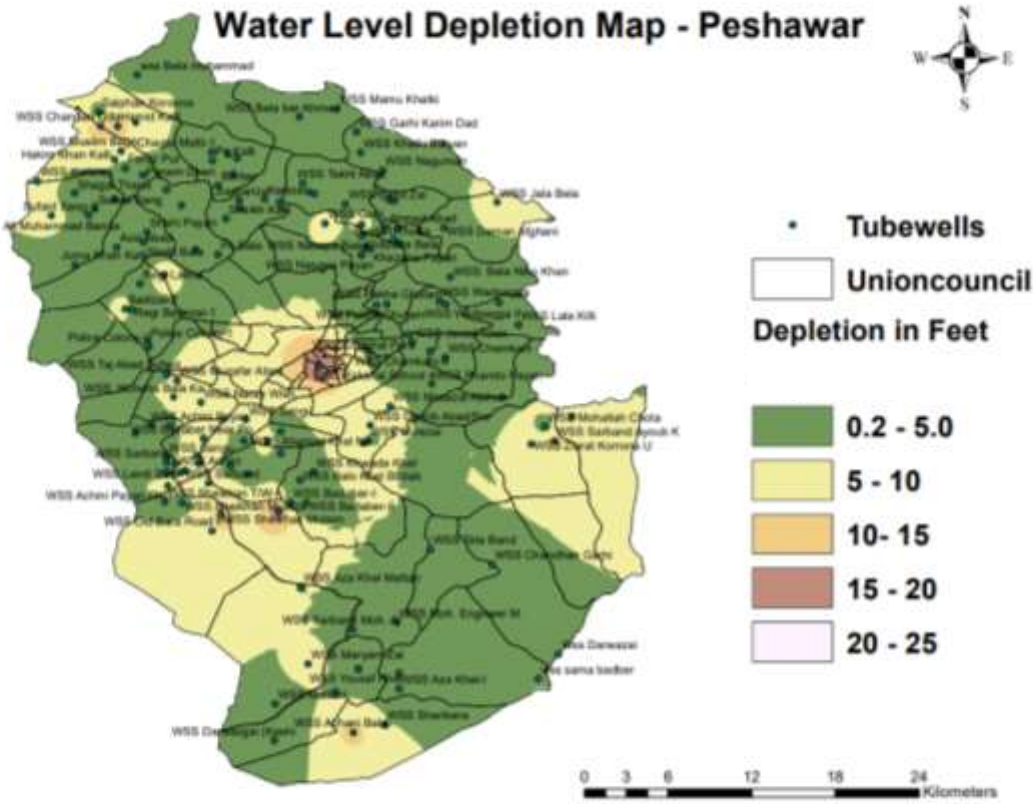

Figure 3.15. Water table depletion 2012 to 2023 (Source: WSSP Peshawar).

Chapter 4

CONCLUSIONS & RECOMMENDATIONS

4.1. Conclusions

The water quality of the Peshawar District assessed in two stages. The first step involved the collection of water samples from the study area through field surveys. For this purpose, 105 in 2012 and 133 in 2023, water samples from tube wells were collected along with GPS waypoints marking the location of the water source.

The second step was the laboratory analysis for physical, chemical, and biological parameters (pH, Electric Conductivity, Chloride, Calcium, Nitrate, turbidity, and E. coli). The analysis carried out in the Institute of Geology Punjab University Lahore laboratory.

The laboratory analysis results were imported into ArcGIS, and the Inverse Distance Weighting Chang (2012) technique was used for interpolation as shown in Figure 4.1 to Figure 4.5. Laboratory analysis showed that maximum values in 2012 for pH, EC, Turbidity, Cl (chlorides), Calcium Hardness & Nitrate (NO3) concentrations, 8.08 with an average 7.7, 1691 (µS/cm) with average 824.51 (µS/cm), 7.09 NTU with average 0.62 NTU, 94.79mg/l with average value 31.1mg/l, 367.73mg/l with average 186.42, and 41.72mg/l with average 19.07mg/l respectively. Maximum parameter concentration values in 2023 for pH, EC, Turbidity, Cl (chlorides), Calcium Hardness and nitrate (NO3) were found to be 8.6 with an average of 7.59, 1671(µS/cm) with average 821(µS/cm), 17.12 NTU with average 1.08NTU, 88.75mg/l with average 35.44, 659mg/l with average 313mg/l, 163.88mg/l with average 35.43mg/l, respectively. Results revealed an increasing trend in parameter concentration compared to 2012 results, and all parameters concentrated in the central city. Spatio-temporal interpolation of pH as depicted in Figure 3.1 displays an increasing trend in the Southeastern region of the study area in Union councils from Mera Kachori to Sher Kera, in the northwest from Jogani to Malakandair and south-west Achni Bala to Shekhan. EC values were high in the central city, which may be due to sewage leakage, and the increasing trend observed from northeast to south-west Khzana, Dag, palosai, mashoghagar and Shekhan, which may be due to agricultural runoff. Turbidity and Chloride values increased in the north of the study area Jogani, Mathra, Palosai, Panam Dheri, Takht Bala due to floods and industrial discharge into Kabul River and in south Shekhan, sarband and Mattani due to urban runoff and agricultural activity. Calcium directly related to hardness. However, an increasing trend observed in the central city due to old plumbing systems having calcium deposits and old pipes made of materials like galvanized iron or copper that can lead to higher calcium levels in the water. Increasing trends in the north and south of the study area due to a geological composition like chalk and limestone formations contribute to high calcium levels in the water.

The spatial analysis of nitrate concentration in 2012 as shown in Figure 3.6, indicates that nitrate values were within the guideline value set by the World Health Organization (WHO) despite agricultural activities. However, in subsequent years, concertation levels increased in south zone of study area and in the city's center. Highly populated areas like Hayatabad, Malakandair, Landi Arbab and Tehkal Bala showed increasing trend. This urbanization has led to sewage water leaching into the ground and mixing with water supplies. Rapid urbanization and increased agricultural activities in the North-East and South-West peripheral areas like Jogani, Panam Dheri, Mathra, Mattani, Mashogagar, Azakhail, Sherkara, showed higher nitrate values. This suggests that the urbanization process and its associated activities contribute to the higher nitrate levels in these areas.

Microbiological analysis of groundwater samples revealed the presence of e-coli in 57% of samples. Out of 35 samples, 20 samples (57%) contaminated with positive e-coli, which exceeds the WHO and NSDWQ (0 MPN/ 100 ml) as shown in Table 3.5. Most affected areas were in the central cities having the maximum number of E. coli, like University Town, Shaheen Town, Mehl Tarai, Wadpaga, Chamkani, Mera Surazai Payan, Regi and Bazid Khail. This might be due to contaminated water and sewage infiltration into groundwater through cross-connection and leakage points. Water-borne diseases like acute diarrhea, cholera, typhoid fever, and hepatitis (A&E) are the most recent emerging and re-emerging infectious diseases, which have recently proven to be the most significant health threat worldwide. Waterborne disease data 2022 from the Peshawar health department showed 102675 people suffered from the waterborne disease over the year Table 3.6 showed 83314 diarrhea, 4065 cholera, 4256 typhoid fever and 830 viral hepatitis (A&E) patients visited basic health units (BHU) and rural health units (RHU) in the previous year . IDW of hotspot analysis as Figure 3.11 showed most patients were from those areas where pathogenic microorganisms and chemicals were present in water sources.

4.1.1. Land use / Land cover Changes

The Maximum likelihood classification (supervised) performed for two years, 2012 and 2023, and the analysis of supervised images provided information about land use/land cover of the study area as shown in Figure 3.12. The analysis of year 2012 classified image revealed, agriculture land covered 481.24 sq km (38%), water bodies covered 8.04 sq km (1%), range land covered 438.72 sq km (35%) and built-up covered 336.88 sq km (27%) of total area The analysis of the 2023 classified image showed 528.24 sq km (42%) agricultural cover, 7.55 sq km (1%) water bodies, 174.66 sq km (14%) rangeland cover and 55.07 sq km (44%) built area cover. The analysis showed a decrease in rangeland and increased agriculture and built-up land as depicted in Table 3.7.

4.1.2. Land use/ Landover Impact on Groundwater Quality

Groundwater quality parameters showed an increasing trend for 2023 in all land-use types (agriculture, rangeland, water, built-up) compared to 2012 as depicted in Table 3.8. In agricultural areas, concentration of nitrate, calcium and magnesium switches (19.54 mg/L with a Standard deviation of 68.81 mg/L). This means that the concentration of these parameters was significantly increased in the year 2023 compared to 2012. The high nitrate, magnesium, and calcium concentrations could be the frequent use of pesticides and fertilizers at the farm level. In rangeland, the concentration of nitrate and calcium increases by 19.04 (mg/L) and 104.24 (mg/L), respectively, due to the high infiltration of chemicals by nearby industries, weathering of rocks over time and biological processes that release nutrients into the soil. In built-up land cover, water is contaminated and polluted by the mixing of waste or drainage water from the household, enlarging calcium and magnesium concentration by 112.36 (mg/L) and 38 (mg/L), respectively, which is alarming for residents. Calcium's high level in built-up areas may be due to the decomposing of chemicals in construction materials, weathering of buildings with the passage of time and effluent from wastewater treatment plants that often use lime or other materials containing calcium and magnesium to treat and stabilize the wastewater. If these chemicals discharge into soils, they can increase calcium and magnesium levels.

4.1.3. Land use/ Land Cover Impact on Water Table Depth

The study examined the linkage of LULC change on underground water over the years in Peshawar district. Main source of water supply in study area are wells and tube wells to meet domestic, agricultural and industrial demands. By analyzing the overall data it became evident that northern zone of study area having Kabul river and irrigation canals due to which these areas experienced less water table depletion due to continuously recharge. The maximum water table depletion observed in central part, the population hub, followed by southern part by 6 to 7 meters. Effect of water table depletion in southwestern part of the district is due to absence of water bodies essential to recharge aquafer. Which is main reason of high water table in southern zone 48 to 82 meters.

In addition, Table 3.9 showed land use/ land cover alterations and groundwater table experienced extraordinary changes in the study area. The improved irrigation facilities, rapid urbanization and enhanced industrial uses are the significant reasons behind this fluctuation in groundwater level. Depletion in water level is more prominent in built-up and range land where the water table is depleted an average of 6 to 7 meters, respectively.

4.2. Recommendations

Results showed that water quality of district Peshawar has degraded over the last decade. To improve water quality, Poly Vinyl Chloride pipes should replace old and rusted pipes due to their highly resistant to corrosion and bio-film contamination, which can be a breeding ground for bacteria and viruses. Implement a regular monitoring and testing program to assess groundwater quality. Drinking water quality tests and continuous assessments should be conducted regularly to check groundwater quality. Water quality for heavy metals should be assessed in future. Improving water quality is a multifaceted and long-term process that requires various stakeholders' collective effort and commitment. Regular monitoring, public awareness, and effective governance are critical to successful water improvement strategies. In continuation to this following recommended:

a. Population should spread evenly by providing basic facilities in other areas.
b. Used water/ sewerage water should not be disposed off untreated.
c. Small irrigation channels from existing water bodies to be made for irrigation where water table is depleting at a faster rate.
d. Preferably, drip irrigation system to be used and flood irrigation to be avoided to conserve water resources.
e. Recharge wells to be constructed along with rainwater storage tanks to improve water table.
f. General public should be educated about the serious issue of water scarcity and encouraged to use Water conservation faucets.

g. To ensure general public health safety, food graded pipes should be used in water supply system to avoid rust and other contaminations.
h. Drinking water filtration plants to be constructed all over the district to supply quality of drinking water.
i. Regular monitoring and checking of water quality in existing water supply system.
j. Efficient water supply system for every household to curb installation of private tube wells in houses for domestic use.
k. Continuous monitoring of patients who suffered from water borne diseases and identify source of contamination and mark contaminated points in those area. Provide alternate source of drinking water other than contaminated one.

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