



Groundwater quality assessment and its vulnerability to pollution: a study of district Nowshera, Khyber Pakhtunkhwa, Pakistan

Muhammad Jamal Nasir · Muhammad Tufail ·
Tehreem Ayaz · Sardar Khan · Amir Zeb Khan ·
Ming Lei

Received: 15 October 2021 / Accepted: 12 August 2022 / Published online: 19 August 2022
© The Author(s), under exclusive licence to Springer Nature Switzerland AG 2022

Abstract Groundwater is the drinking water source for the majority of rural settlements of district Nowshera, Khyber Pakhtunkhwa, Pakistan. The study aimed to analyze the groundwater quality and its vulnerability to pollution and to develop its spatial distribution mapping. For this purpose, forty-eight groundwater samples were collected from dug wells, tube wells, and hand pumps of sixteen villages and analyzed for physicochemical parameters. The XY coordinates of the sample's sources were marked by Magellan Triton 1500 handheld global positioning system (GPS). The results were compared with WHO and Pak-EPA guidelines. The results of the majority

of selected parameters were found within the WHO and Pak-EPA guidelines; however, in certain areas the concentration of total dissolved solids (TDS), chlorides (Cl^-), and alkalinity were higher than the guideline limits. Based on cumulative water quality the excellent water quality prevails over an area of 376 km² (21% of district area), good water quality 726 km² (42%), poor 424 km² (24%), very poor 116 km² (6%), and unfit for drinking 84 km² (4%). The water of the Nizampur and Rashaki areas were categorized unfit for drinking. The groundwater quality of nearly one-half of the district varies from poor to very poor, and the soil type and vadose zone sediment/material was found the key reason for groundwater contamination. Based on the infiltration capacity of vadose zone material, the study area was divided into four water pollution vulnerable zones. The low vulnerable zone covers an area of 104 km², moderate 862 km², high 667 km², and very high 93 km². The most important factor which determines the vulnerability of the groundwater to contamination is the vadose zone material/sediment which in turn determines the soil infiltration capacity. The generated groundwater susceptibility and water quality maps provide critical information for identifying optimal locations for supply wells.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s10661-022-10399-9>.

M. J. Nasir · M. Tufail
Department of Geography, University of Peshawar,
Peshawar 25120, Pakistan

T. Ayaz (✉) · M. Lei
College of Resources and Environment, Hunan
Agricultural University, Changsha 410128,
People's Republic of China
e-mail: tehreemayaz17301@yahoo.com

S. Khan
Department of Environmental Sciences, University
of Peshawar, Peshawar 25120, Pakistan

A. Z. Khan
PaK-Austria Fachhochschule: Institute of Applied Sciences
and Technology, Mang, Haripur 22620, Pakistan

Keywords Groundwater quality · Vadose zone ·
Spatial distribution · Geo-processing · Inverse
distance weighting · Water pollution

Introduction

Groundwater extracted from shallow aquifers is the primary source of drinking water for over two billion global inhabitants (Alley et al., 2002; Olorode et al., 2018). Groundwater accounts for 33% of total global water withdrawals. Ensuring safe supply of groundwater for drinking is one of the most important drivers of sustainable development. Groundwater quality to a larger extent depends on the quality of recharged water. Any change in origin and composition of recharged water, caused by various hydrological and anthropogenic factors, can cause change in the groundwater quality (Vasanthavigar et al., 2010). Various anthropogenic activities, i.e., rapid urbanization, industrialization, inconsiderate use of insecticides and chemical fertilizers, are continuously contaminating the groundwater resources, which is a serious threat to human health (Adelodun et al., 2020; Li, 2020). According to World Health Organization (WHO) estimates, 0.82 million people died in 2016 due to waterborne diseases (Pruss-Ustun et al., 2016). Therefore, it is not only important to control pollution but also to periodically evaluate the groundwater quality (Lukubye & Andama, 2017; Patil et al., 2012).

Although more than 80% inhabitants of Khyber Pakhtunkhwa have access to safe drinking water, in some areas of well-developed districts, i.e., Charsadda, Mardan Peshawar, and Nowshera, almost 6,000,000 people are still drinking polluted water (Yousaf et al., 2013). The majority population in the province rely on groundwater resources which are highly susceptible to pollution from municipal waste and infiltration of contaminated recharged water (Khan et al., 2013). The groundwater quality deterioration has been reported by various researchers from other parts of Pakistan (Ahmad et al., 2020; Aleem et al., 2018; Khalil et al., 2018; Nasir et al., 2017; Shahid et al., 2017). The provision of safe drinking water is a global challenge and is a highly debatable topic because it is increasingly contaminated by rapid urbanization and industrialization (Ayuba et al., 2017; Edokpayi et al., 2018; Fantong et al., 2009; Khatri & Tyagi, 2015; Murtaza et al., 2020).

The major anthropogenic sources of groundwater contamination are municipal waste, and agricultural and industrial runoff (Mushtaq et al., 2020; Zhang et al., 2020). The low and middle-income countries in Asia and Africa experienced rapid urbanization

and fast industrialization, which led to environmental degradation. Most of the streams and rivers in urban agglomerations are the dumping grounds for domestic waste and industrial wastewater (Agarwal et al., 2015; Ferronato & Torretta, 2019; Burri et al., 2019). The situation is further deteriorated by over exploitation of groundwater resources due to overpopulation, which causes increased water scarcity (Boretti & Rosa, 2019; Lambooy, 2011).

During the last couple of decades, various researchers studied numerous aspects of water quality assessment using a variety of geospatial techniques including artificial neural network (Nguyen et al., 2020), multivariate statistical analysis (Elumalai et al., 2020), analytical hierarchy process (AHP) (Saranya & Saravanan, 2020), frequency ratio model (Arshad et al., 2020) and Shannon's entropy method (Gao et al., 2020), spatial interpolation (Anand et al., 2021; Bhunia et al., 2018; Kalawapudi et al., 2020; Somvanshi et al., 2012; Srivastava et al., 2019; Yang et al., 2020). The integration of physicochemical data of water quality variables with GIS is significant for geo-visualization, spatial and temporal inconsistency of water quality (Hasan & Rai, 2020).

Water-borne infections account for around 80% of all human diseases (Daud et al., 2017). When groundwater becomes contaminated, it is difficult to restore to an acceptable quality. However, the contamination can be precluded by preventing the contaminants from entering the system. As a result, it is critical to periodically check the quality of groundwater and devise methods and means to safeguard it against contamination. The current study is an attempt to analyze the groundwater of district Nowshera for selected physicochemical water quality parameters, i.e., pH, electrical conductivity (EC), total dissolved solids (TDS), alkalinity, chlorides (Cl^-), sulphate (SO_4), and nitrates (NO_3).

District Nowshera is located between $33^\circ 04' 00''$ to $34^\circ 10' 00''$ N latitude and $71^\circ 44' 50''$ to $72^\circ 15' 05''$ E longitude. District Swabi bordered it from the north and district Charsadda from the northwest. To the east of district Nowshera is located district Attock of Punjab province, in the south district Kohat and in the west district Peshawar.

Figure 1 depicts the location of district Nowshera. The total geographical area of the district is 1748 km^2 out of which the agriculture area accounts for 52,540 ha. The population of

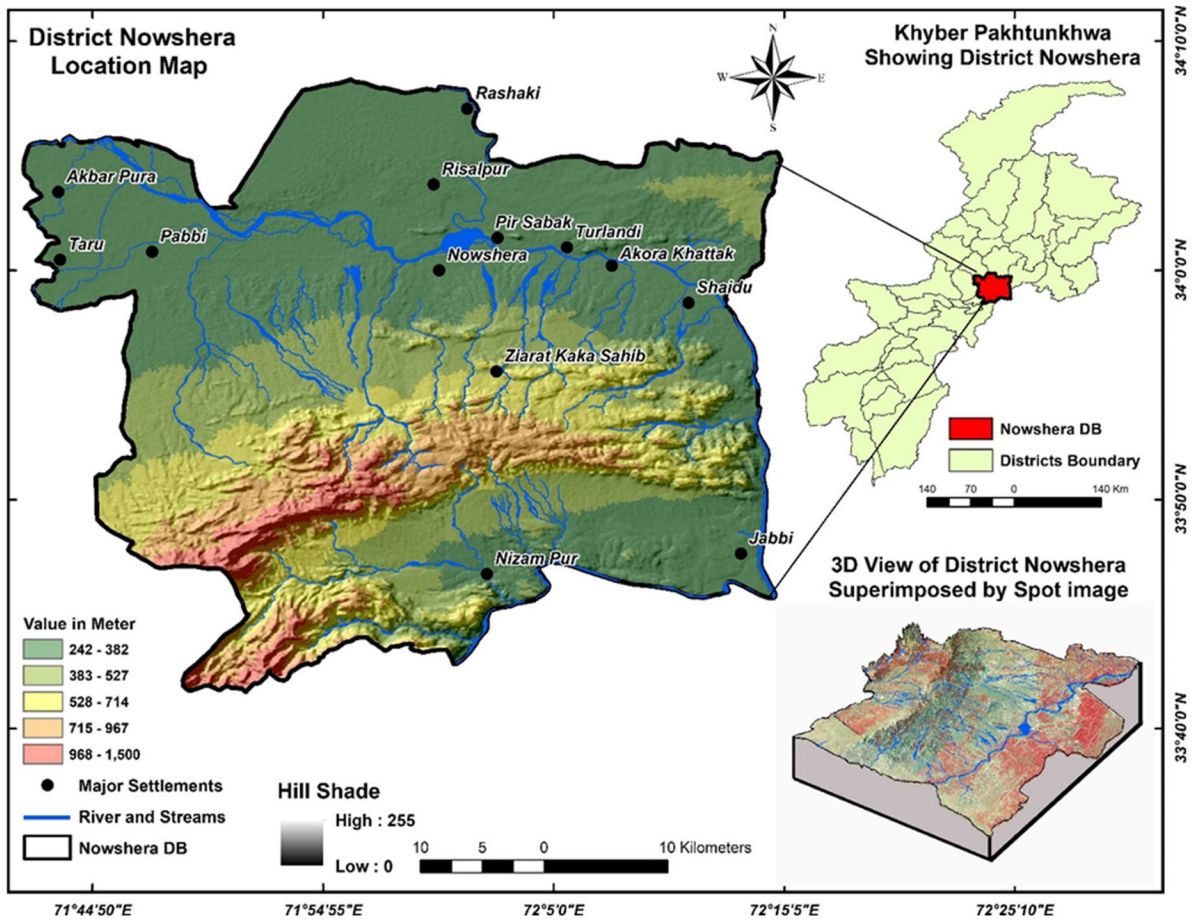


Fig. 1 Location of Nowshera District, district boundary was acquired from the District census report, while DEM was derived from the USGS Earth Explorer website and was analyzed for 3D in ArcScean 10.5

the district was 874,374 persons in 1998, which increased to 1,518,549 persons in 2017; the intercensus increase in population is 73.67%. The population density has increased from 500 persons/km² in 1998 to 869 persons/km² in 2017. The district is divided into three tehsils, i.e., Jehangira, Nowshera and Pabbi. The drainage is dominated by seasonal torrents flowing from Attock Cherat range (south to north) toward River Kabul which flows from west to east and is the main perennial stream of the district. Groundwater extracted from shallow aquifers is the main source of water for the inhabitants of the district, besides some villages located in the vicinity of Attock-Cherat range; the spring water is also utilized for drinking. The study region is part of the Peshawar Valley, an intermountain valley developed about three million years ago (Burbank &

Raynolds, 1988), and covers an area of 8000 km². The valley is made up of extensive layers of sediments that were accumulated during the Pleistocene period. The literature suggested that these deposits are around 150 m thick. The sediments were mostly gravel, pebbles, and sand, with horizontally bedded clay and other fine material (Cornwell, 1998). Sediment geomorphology and lithology are important in the evolution of aquifer systems, hydraulic conductivity, and water movement (Bowling et al., 2005).

The study region has a hot continental climate that is chilly in winters and sweltering in summers. There are two rainy seasons: the monsoon rainy season, which lasts from July to August, and the winter-spring rainy season, which lasts from January to March. The study area region receives 50.8 mm and 18.2 mm of rainfall in July and August, respectively.

The villages and settlements were scattered across the territory, mainly along waterways and roads. The rock outcrop regions are located in the district of Nowshera's south, east, and west, while the barren ground is dispersed randomly across the district, controlling the process of infiltration and percolation.

Material and methods

Sampling

The groundwater samples were collected from three different groundwater sources, i.e., tube wells, hand pumps, and dug wells. As more than 56% of the total area is rock outcrops and barren land, majority of the human settlements are dispersed with no water

supply schemes. According to the 2017 census, there are 24 union councils (UC) and 129 villages in the district Nowshera. Out of these 24 UC, 16 have tube wells, hand pumps, and dug wells either managed by the government or NGOs, so the samples were collected from 16 UC, three from each UC. A total of 48 groundwater samples were collected for analysis. The XY coordinates of the sampled location were recorded with the help of the Magellan Triton 1500 handheld global positioning system (GPS). Figure 2 depicts the location of sampled villages. The samples were collected in pre-cleaned 450-ml capacity polypropylene bottles with the utmost care following the methodology proposed by Alfaifi et al. (2020). In case of tube wells, the tube well was pumped for 5 to 10 min before sampling. Proper care was ensured during the groundwater sample collection.

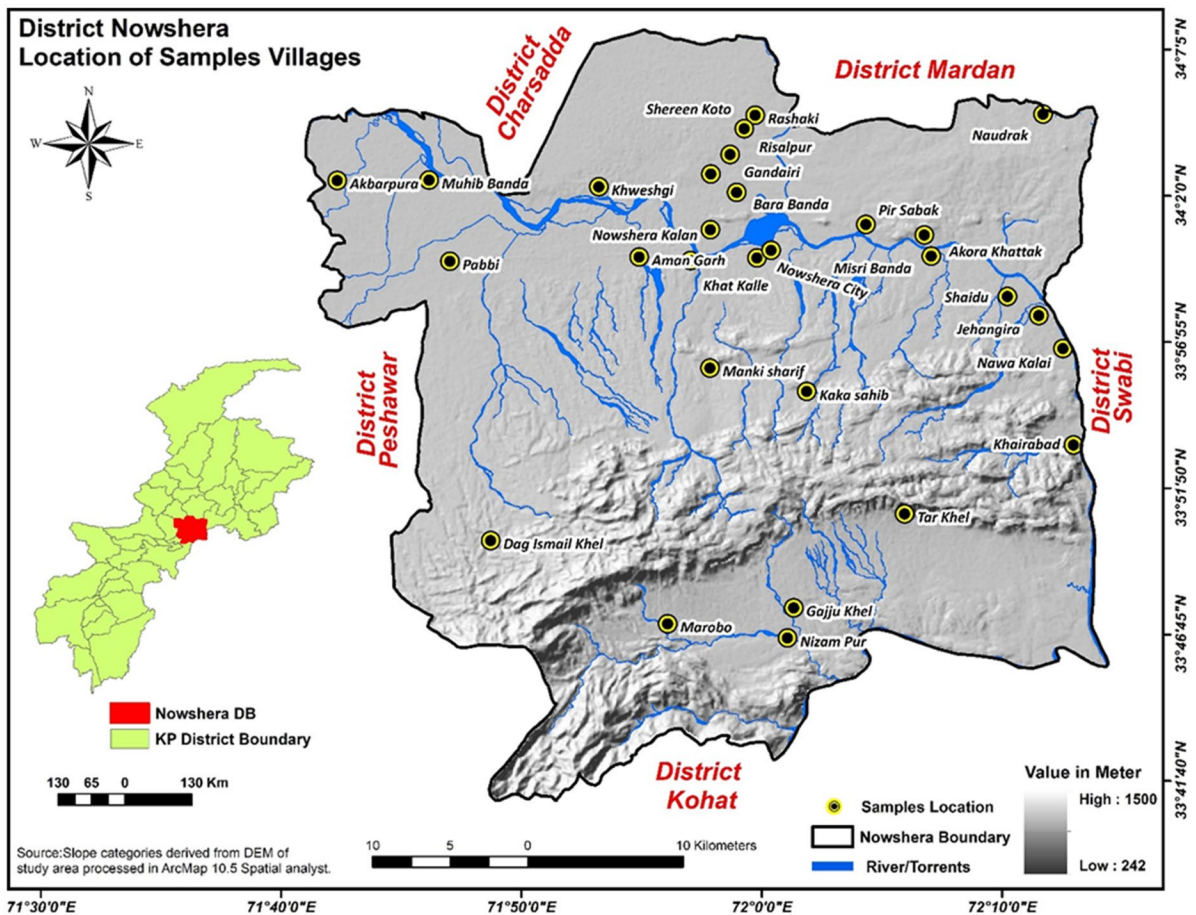


Fig. 2 The study area (District Nowshera) and locations of sampled villages

Analytical procedure

The taste and odor of the collected samples were determined on site by smelling and tasting water; however, no odor or taste was noticed in any sample. For measuring the pH and EC, Hanna pH Meter HI99192 and Jenway England EC meter were used, respectively. For the measurement of TDS, the gravimetric method was employed. To determine the concentration of SO_4 , the standard procedure of Eaton et al. (2005) was followed. For the concentration analysis of Cl, NO_3 , and alkalinity, the American Public Health Associates (APHA, AWWA, 1998) standard methodology was adopted.

For geo-visualization and spatial distribution of the selected water quality parameters, ArcGIS 10.5.2 Spatial Analyst was used. The XY coordinates were recorded with the help of GPS and imported to the ArcGIS environment and then subsequently interpolated for the creation of a continuous surface using Inverse Distance Weighting (IDW) method. The IDW approach is a deterministic spatial interpolation method, which is the simplest and most widely used by researchers for groundwater level and quality data (Yang et al., 2020; Nistor et al., 2020; Arkoç, 2022). The fundamental assumption of the method is that the components of every given set of points are associated with each other, but their resemblance is inversely related to the distance between the two sites. The methodology suggested by Ahmad et al. (2020) was employed to estimate the concentrations of all selected parameters across the district. The created continuous surface generated by interpolating the parameter point data was subsequently classified into five classes, i.e., excellent, good, poor, very poor, and not fit for drinking.

Results and discussion

pH

pH is the measurement of electrically charged particles in a substance, and it is the indication of how acidic or basic (alkaline) the substance is. The pH of water is utilized to assess its interaction with different rocks and material and usually ranges from 0 to 14. The pH of water can change the concentration of other water quality parameters. Besides, the pH

concentration can change the characteristics of water, i.e., solubility of metal and existence of microorganisms (Ho et al., 2003). The WHO guideline limit of pH for safe drinking water is 6.5 to 8.5; however, a little variation in its concentration has no distinct impact on human health, but its higher concentration has an unpleasant smell and can cause gastrointestinal tract irritation (GIT).

The concentration of pH in all the collected groundwater samples varies from 7.2 to 8.3, with an average pH of 7.71. The minimum pH concentration (7.2) was observed in the dug well water sample of Akbarpura and hand pump water samples of Akbarpura and Khat Kalle. The maximum pH concentration (8.3) was observed in the tube well water samples of Kaka sahib. The study revealed that the concentration of pH in almost all the collected groundwater samples was within the guideline limits (6.5–8.5). The results of pH are shown in Fig. 3, while the pH distribution of water samples collected from hand pumps, tube wells, and dug wells is shown in Figs. 4A, 5A, and 6A, respectively. Detail is given in the Table S1 of supplementary information (SI). The highest pH value of hand pump water samples was recorded for Shaidu (8.1), tube well for Kaka Sahib (8.3), and dug well for Misri Banda, Nowshera city, and Shaidu (7.9), while the lowest pH value of hand pump water samples was recorded for Khatkille and Akbarpura (7.2), tube wells for Noeshera Kalan and Pabbi (7.6), and dug wells for Akbarpura (7.2).

Electrical conductivity (EC)

Electrical conductivity of water refers to the capacity of water to pass electric current. It can affect the concentration of dissolved substances like Cl, NO_3 , SO_4 , PO_3 . The low EC of water is the result of contamination by various organic compounds, i.e., oil, sugar, etc. The difference in EC in the groundwater samples of various areas is indicative of the fact of contamination in water (Vadde et al., 2018). The minimum EC value (1.18 $\mu\text{S}/\text{cm}$) was observed in the groundwater samples of hand pumps of Akbarpura village, while the maximum value (643 $\mu\text{S}/\text{cm}$) was recorded in the hand pump water samples of village Khweshgi. However, the EC value of all the 48 samples was within the Pakistan-Environmental protection Agency (Pak-EPA, 2008) permissible limit (1500 $\mu\text{S}/\text{cm}$). According to Neal et al. (2005) the higher EC is mainly because of various natural processes occurring in the groundwater

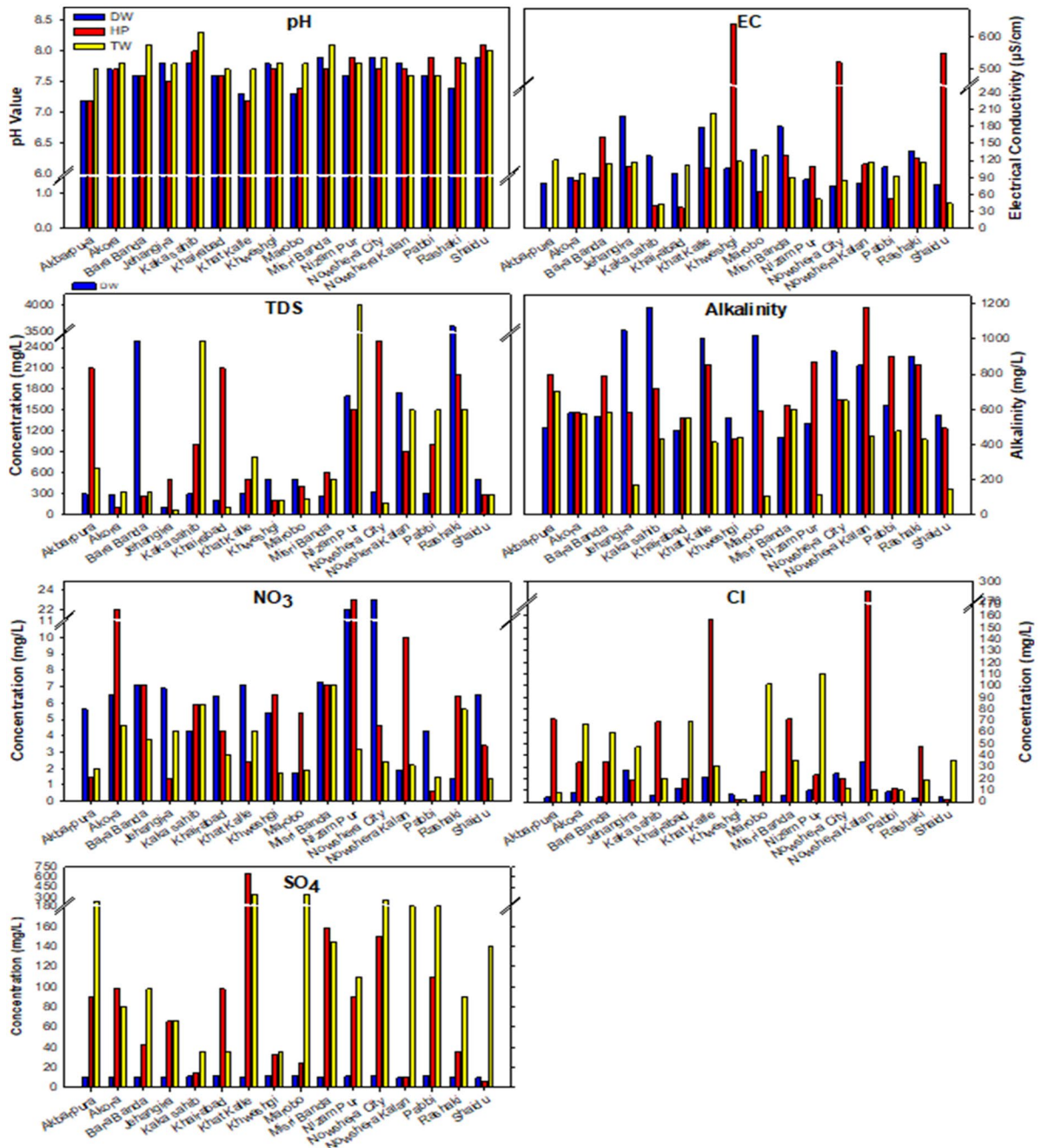


Fig. 3 Concentration of various parameters in water samples of dug wells (DW), hand pumps (HP), and tube wells (TW) collected from district Nowshera

aquifers. Figure 3 depicts the EC values of various groundwater samples, while the spatial distribution for the water samples of hand pumps, dug wells, and tube wells is shown in Figs. 4B, 5B, and 6B, respectively. Detailed data is given in SI (Table S1).

Though the EC of all the water samples were below the guideline value, still there is a clear variation in the EC values of various samples. The highest EC values were reported from the sample of hand pump for Khweshgi (643 $\mu\text{S}/\text{cm}$), tube

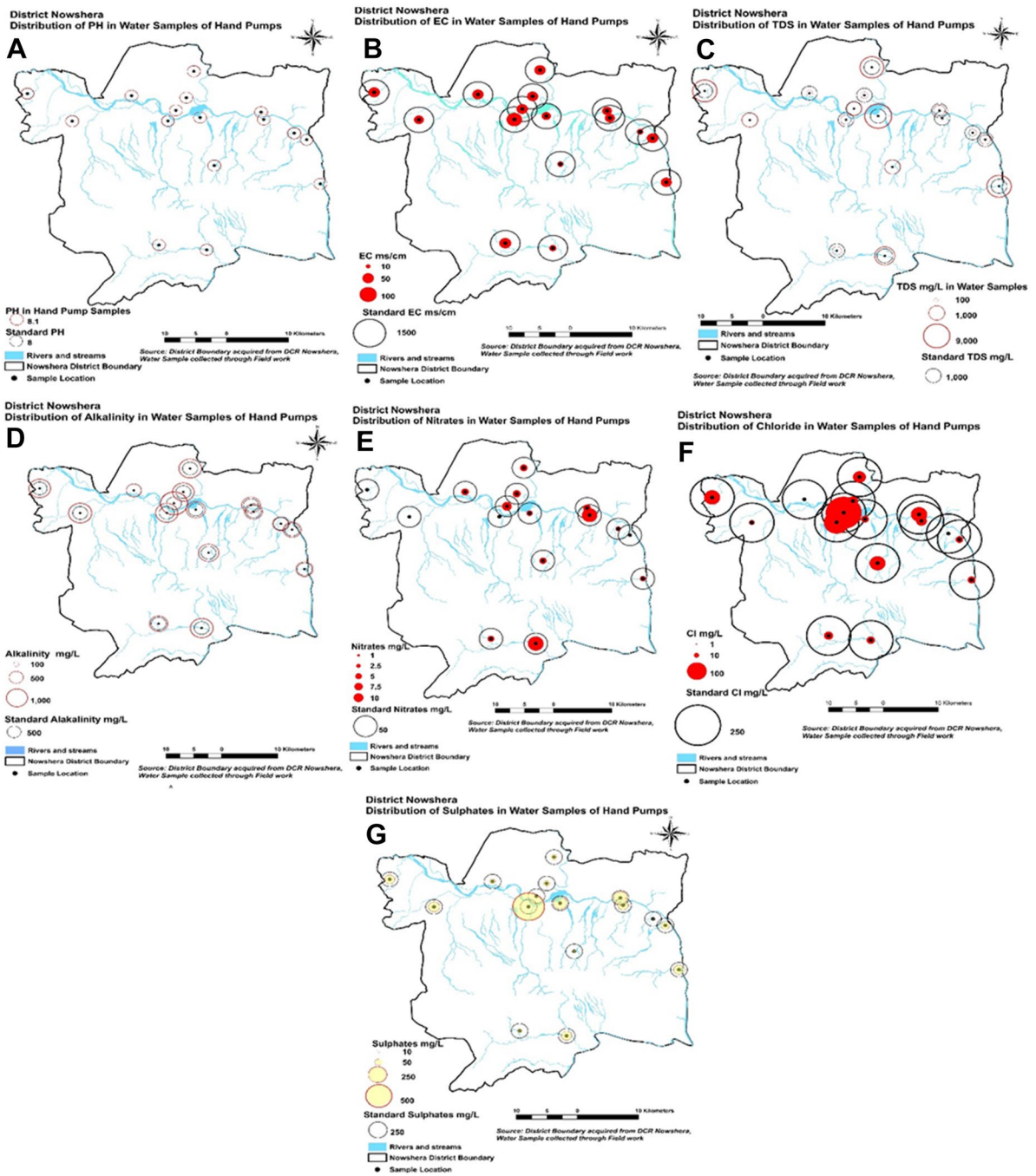


Fig. 4 Concentration of various parameters in water samples of hand pumps collected from district Nowshera, **A** pH, **B** EC, **C** TDS, **D** alkalinity, **E** NO₃, **F** Cl, **G** SO₄

well for Khat Kalle (202 μS/cm), and dug well for Jehangira (198 μS/cm), while the lowest were reported from the water samples of hand pump for

Akbarpura (1.18 μS/cm), tube well for Kaka Sahib (43μS/cm), and dug well for Nowshera City (74.5 μS/cm).

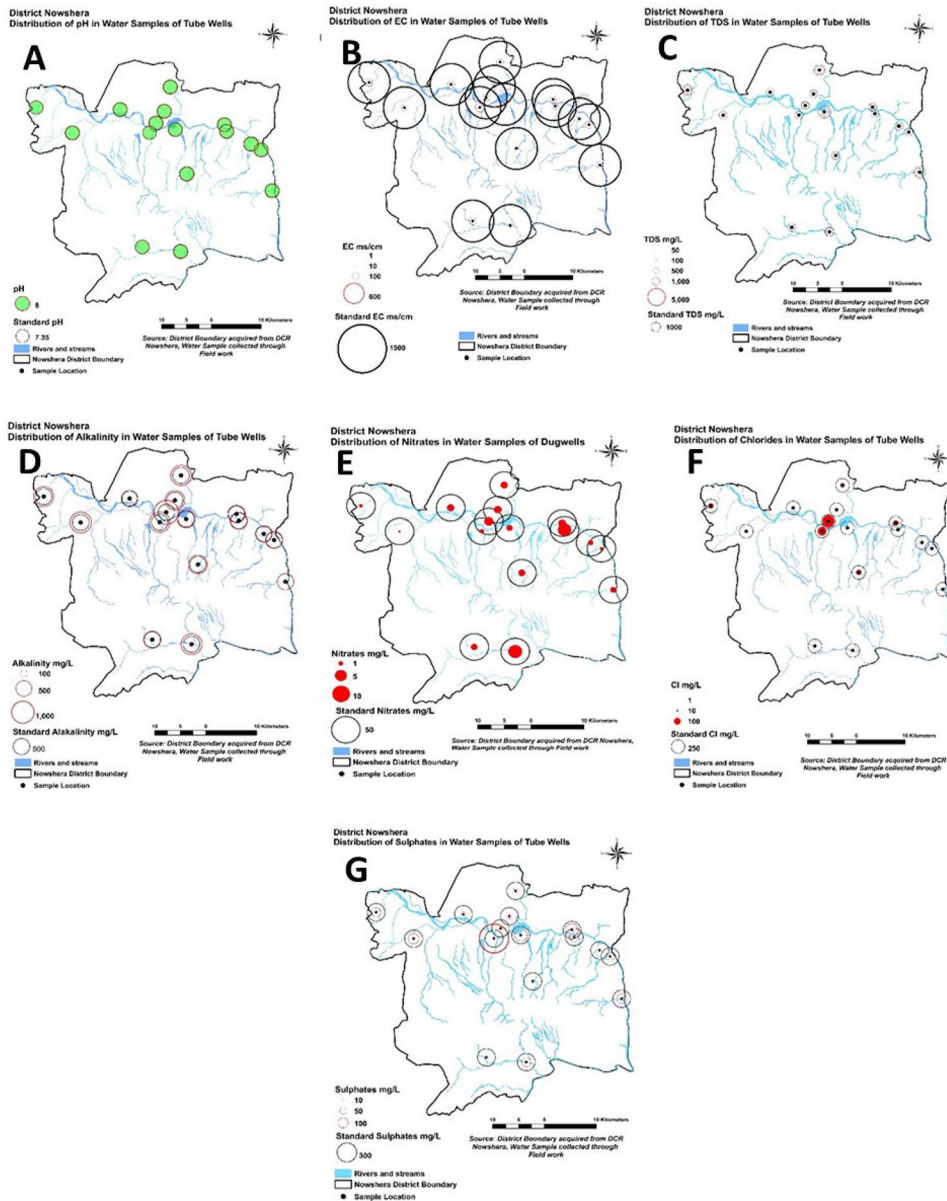


Fig. 5 Concentration of various parameters in water samples of tube wells collected from district Nowshera, **A** pH, **B** EC, **C** TDS, **D** alkalinity, **E** NO_3 , **F** Cl, **G** SO_4

Total dissolved solids

TDS is the measure of the collective proportion of all the contaminants present in the water sample. TDS are the mineral salts (HCO_3^- , Cl, Ca^{2+} , Mg, K, Na, and SO_3 etc.) and various organic matters larger than 2 microns. The TDS in the collected groundwater samples varies spatially mainly due to variation in the lithological and topographical conditions. The

health effects of total dissolved solid are not well documented; however, the water with higher concentration of TDS is not permitted (Islam et al., 2017). The allowable limit recognized by WHO is 1000 mg/l.

The minimum TDS value of 50 mg/l was reported in the groundwater sample from tube well in village Jehangira, while the highest value was recorded in the water samples of tube well from Nizampur area (4000 mg/l), which exceeds the WHO permissible

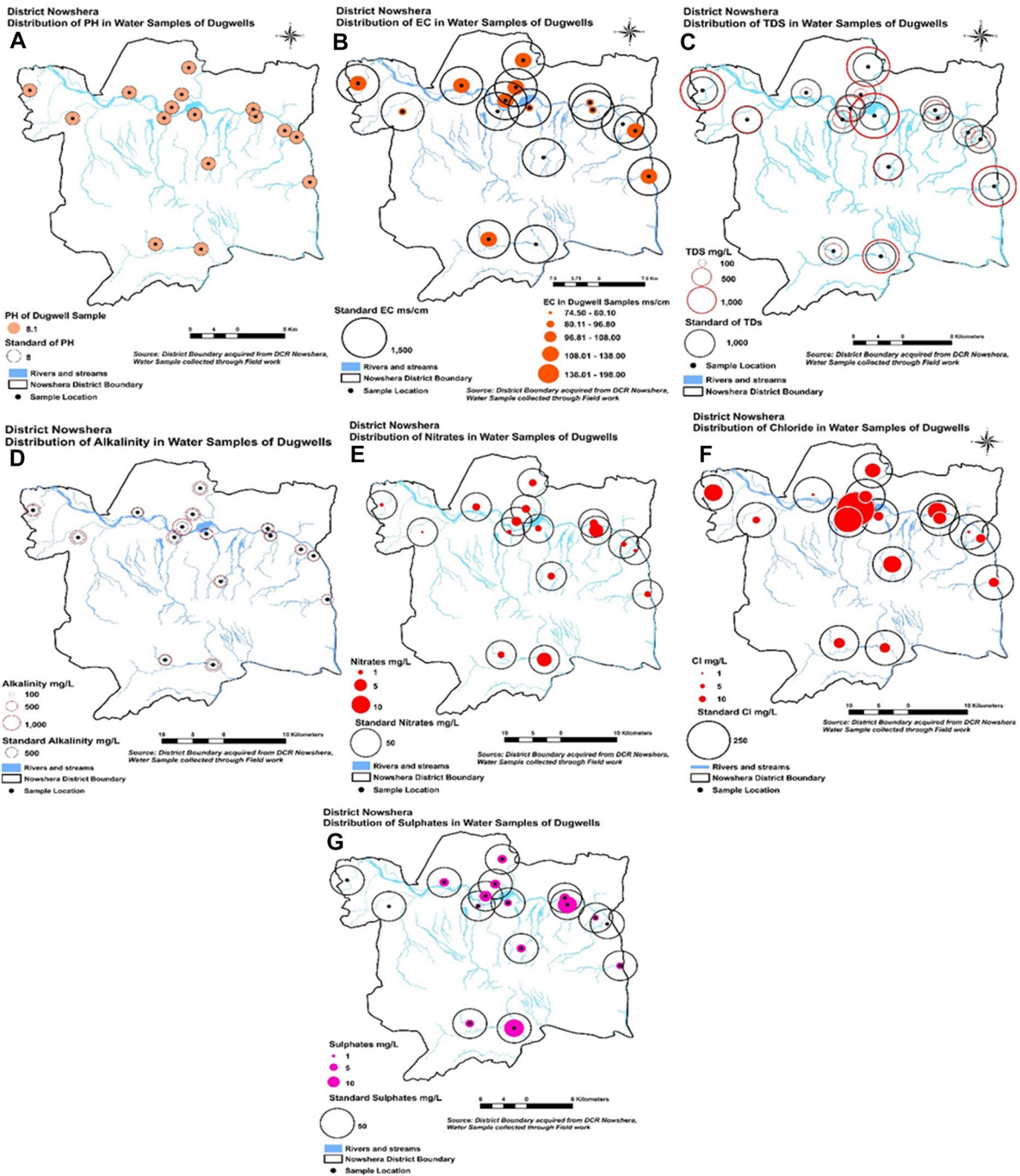


Fig. 6 Concentration of various parameters in water samples of dug wells collected from district Nowshera, **A** pH, **B** EC, **C** TDS, **D** alkalinity, **E** NO₃, **F** Cl, **G** SO₄

limit (< 1000). The results of the analysis are depicted in Fig. 3, and its spatial variability is shown in Figs. 4C, 5C, and 6C. Detail is given in SI (Table S1). The highest TDS values in the water samples of hand

pump were found for Nowshera City (2500 mg/l), tube well also for Nizampur (4000 mg/l), and dug well for Rashaki (3600 mg/l), while the lowest TDS values were recorded in the water samples of hand pump for

Akora Khattak (100 mg/l), and tube well (50 mg/l) and dug well (100 mg/l) for Jehangira. According to WHO, the TDS value of less than 300 mg/l is regarded as excellent water for drinking, value between 301 and 600 mg/l is considered as good, 601 and 900 mg/l referred as fair, 901 and 1200 mg/l poor, and more than 1200 mg/l is regarded unacceptable for drinking (WHO, 1996).

Alkalinity

Alkalinity refers to the capability of water to neutralize acids and bases and hence preserve a fair pH level; in other words, it is the ability of water to resist acidification. The higher alkalinity in groundwater is affected by the concentration of CO_2 and HCO_3^- . The WHO acceptable limit for alkalinity in water is from 200 to 600 mg/l. However, according to US-EPA, the alkalinity in water may not exceed 500 mg/l. The alkalinity concentration in the groundwater samples collected from the study area varied from 106 to 1180 mg/l.

The lowest alkalinity (106 mg/l) was recorded in the water samples of tube well of village Marobo, while the highest alkalinity (1180 mg/l) in the water samples collected from hand pump of Nowshera Kalan and dug wells of Kaka Sahib. Besides, the study found that the majority of groundwater samples collected from villages has exceeded the permissible limit for alkalinity set by US EPA (1985). Analyzed results are shown in Fig. 3, whereas spatial distribution is given in Figs. 4D, 5D, and 6D. Detail is given in SI (Table S1).

Nitrate (NO_3)

Nitrates are naturally occurring in water; however, the higher concentration of NO_3 in water is the indicator of contamination from anthropogenic sources. The main sources of NO_3 in groundwater and surface water are chemical fertilizers, animal and human waste, industrial runoff, and disintegration of various organic compounds. The allowable limits for NO_3 in drinking water as set by WHO and Pak-EPA are 50 mg/l. The higher concentration of NO_3 vitiates the water quality by facilitating the algal growth; besides, it can also affect the health of pregnant women (Bruning-Fann & Kaneene, 1993).

The analysis of the results revealed that NO_3 concentration in collected samples varied from 0.6 to

23 mg/l. The lowest concentration (0.6 mg/l) was reported from the hand pump source of village Pabbi, while the maximum concentration (23 mg/l) was recorded in the water samples collected from the hand pumps of Nizampur and dug wells of Nowshera City and village. The average NO_3 concentration for the study area was recorded 5.9 mg/l. The results are shown in Fig. 3, while distribution is shown in Figs. 4E, 5E, and 6E. Detailed data is given in SI (Table S1). Although the concentration of NO_3 in the groundwater samples was within the WHO permissible limits, the highest concentration was noted in the groundwater samples of hand pump collected from village Nizampur (23 mg/l), tube well for Misri Banda (7.1 mg/l), and dug well in village Nowshera City (23 mg/l), while the lowest NO_3 concentration values were recorded in the water samples of hand pump for village Pabbi (0.6 mg/l), tube well for Shaidu (1.4 mg/l), and dug well for Rashaki (1.4 mg/l).

Chloride (Cl^-)

Almost all water contains Cl^- ; however, its concentration varies spatially due to variation in the mineral composition of the soil/land. The smaller concentration of Cl^- is not significant; however, the higher concentration can cause problems. The Cl concentration in uncontaminated water is usually below 10 mg/l. It is naturally occurring in rock salt, and its presence gives a saline test to food and water, and oxidizes metals (Kataria et al., 2011). There is no guideline established for Cl concentration in water, as it has no harmful effect on human health. However, it can corrode the metallic items and can harm plants (Saxena & Sonwani, 2019).

Results showed the lowest Cl concentration (2 mg/l) for the hand pump source of Khweshgi and Shaidu and tube well source of Khweshgi, while the highest value (286 mg/l) was recorded in the water samples collected from hand pumps in village Nowshera Kalan. The study results revealed that the concentration of Cl in almost all the water samples except the water samples collected from village Nowshera Kalan was within the permissible limit (250 mg/l), established by Pak-EPA (2008). The analysis is shown in Fig. 3, and distribution is shown in Figs. 4F, 5F, and 6F. Detail is given in SI (Table S1).

Sulphate (SO₄)

The atmospheric sulphur contains sulphur dioxide (SO₂), sulphate ion, and sulphide. Sulphides, especially H₂S (hydrogen sulphides), are soluble in water; besides, it leaches down from soil and rocks. There is no acceptable guideline for SO₄; however, the desirable concentration of SO₄ in drinking water is lower than 250 mg/l. According to Abubakar and Adekola (2012), the higher concentration of SO₄ gives a bitter taste and rotten egg-like smell to water. As for its effects on human health, it can cause dehydration, diarrhea, and laxative action if consumed in higher concentration (WHO, 1996). The analysis revealed that SO₄ concentration in collected groundwater samples varied from 6 to 650 mg/l. The highest concentration of SO₄ was reported in water samples collected from the hand pump of village Khat kille, and the lowest concentration was found in the hand pump samples of village Shaidu. The higher SO₄ than the allowable limit was reported for the water samples collected from village Khat kille. Sulphate concentration is shown in Fig. 3, and spatial distribution is shown in Figs. 4G, 5G, and 6G. Detail is given in SI (Table S1).

Several studies on portable water quality assessment were conducted in different areas of Khyber Pakhtunkhwa. Jehan et al. (2019) assessed the hydro-chemical properties of drinking water in the Bajaur district (Former Bajaur agency). The analysis revealed that all the selected parameters, i.e., pH, TDS, total suspended solid (TSS), dissolved oxygen, alkalinity, and phosphate, were within the permissible limits, except for SO₄⁻² and NO₃. Their study attributed the higher concentration of SO₄⁻² and NO₃ to the excessive use of agrochemicals. A similar study conducted by Ullah et al. (2014) in district Dir Lower of Khyber Pakhtunkhwa also found that alkalinity, TDS, pH, SO₄, Cl, and NO₃ were within the permissible limits set by WHO. A study carried out by Gul et al. (2016) in district Nowshera analyzed the portable drinking water for odor, color, EC, pH, TDS, hardness, SO₄, Cl, NO₃, and sodium. The study concluded that flood water inundated wells and water tanks with silt and garbage, causing massive environmental damage, altering groundwater quality, and posing a risk of water-borne illnesses in the area. A similar study by Yousaf et al. (2013) on the impact of the 2010 flood on the portable water of district

Nowshera revealed that most of the parameters, i.e., total solids (TS), TDS, hardness, alkalinity, SO₄, Cl, and NO₃, were much higher than the WHO standards, which were attributed to the impacts of 2010 flood.

The infiltration capacity of vadose zone versus water quality map

The XY coordinates of all the water sample areas were imported to ArcGIS environment, and the concentration value of all the selected water quality parameters was entered in the attribute table attached to the XY point layer. The following steps were involved in the analysis:

1. The concentration value of each parameter is then summed to get a consolidated value for each sample point.
2. Simultaneously, the permissible limit of all the studied water quality parameters was also summed up.
3. The consolidated parameter value of each sample was subtracted from its consolidated permissible limit value (1–2).
4. The value obtained (3) were subsequently interpolated to get a continuous surface, where each pixel got a consolidated concentration value of the water quality parameters. The layer was consequently reclassified into five water quality zones, i.e., (1) excellent, (2) good, (3) poor, (4) very poor, and (5) unfit for drinking using the equal interval classification method in ArcMap 10.8. The results of the analysis were the water quality maps for all three water sources, which illustrated the groundwater quality of the study area based on combined concentration of selected water quality parameters.

Table 1 shows the area and percentage under various water quality zones of district Nowshera. Similarly, Fig. S2 of SI shows the chart representation of percent area under various water quality zones of District Nowshera. Figure 7A–C illustrates the water quality maps of the three sources, i.e., hand pump, tube well, and dug well, respectively, while Fig. 7D shows the cumulative water quality map. Analysis of Table 1 and Fig. 7D suggested that in almost 33% of the area of the district Nowshera the concentration of selected parameters was within the allowable limits

Table 1 Area and percentage under various water quality zones of District Nowshera

Water quality	Area km ²	Percentage
Excellent	386.49	22.11
Good	726.13	41.54
Poor	424.18	24.27
Very poor	126.47	7.23
Unfit for drinking	84.79	4.85
	1748.06	100.00

and the water quality based on selected parameters varied from good to excellent. However, in the majority of the area (56.72% of the total area), the water quality is poor, while in the remaining area of the district the water quality varied from poor to unfit for drinking. The groundwater quality of 02.96% of the total district area is classified as unfit for drinking.

The increase in population, rapid urbanization, and industrialization generated a large volume of effluent which infiltrated in permeable areas into shallow groundwater aquifers causing groundwater

contamination (Rad & Fazlali, 2020). Studies suggested that a contaminant that has been released into the environment may leach down and contaminate the groundwater. Therefore, the transmission of contaminants is relatively easier in the porous and permeable soil and vadose zone material. The vadose zone, also referred to as un-saturated zone, is the area between top of the groundwater aquifer and top of the earth’s surface. It extends from the top of the water table to the earth’s surface. Therefore, it plays a significant part in the movement of contaminants from the earth’s surface to groundwater aquifer (Nahin et al., 2020).

The information about the composition of vadose zones and other drastic parameters, i.e., recharge rate, soil type, topography, and depth of groundwater aquifer, were available with the Public Health Department as borehole data and were subsequently acquired from the Public Health Department district Nowshera. The analysis of collected information revealed that the composition of the vadose zone varies from place to place. The vadose zone material/sediment in various areas of district Nowshera

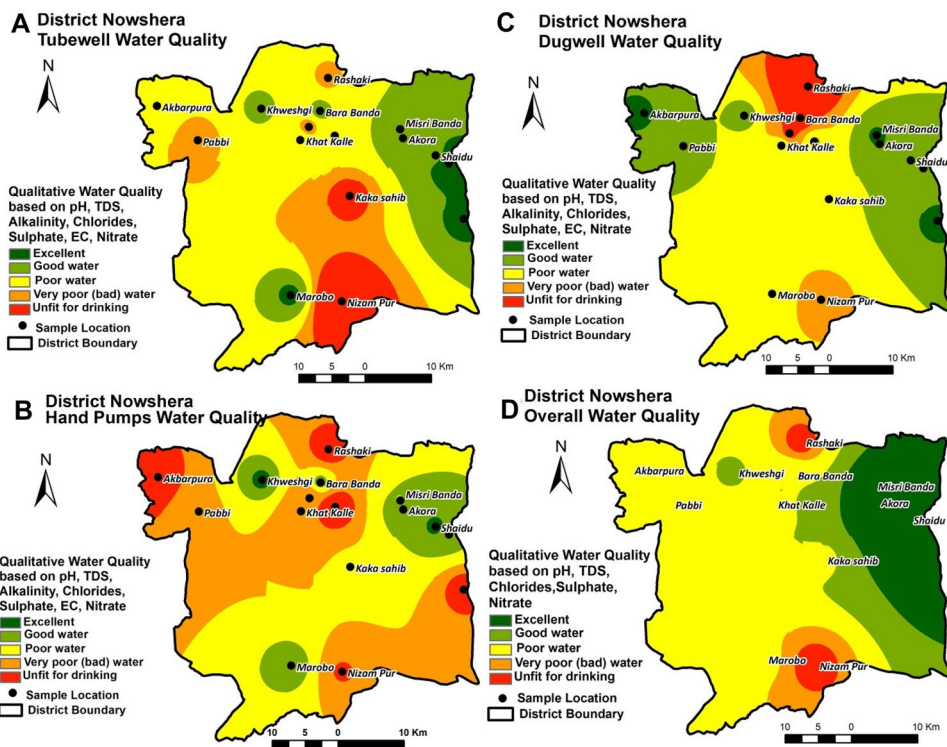


Fig. 7 Water quality maps of district Nowshera, **A** hand pumps, **B** tube well, **C** dug well, **D** cumulative water quality map

varies from clay, silt, sand to gravels and boulders. The borehole data was assigned with various scores based on the amount of sand silt and clay which determine the infiltration characteristics of the sediment. For instance, clayey and silty sediment/material was given a score of 1, clayey, silty, and sandy material a score of 2, clay, silt, and sand mixed with pebble and gravels was given a score of 3, sandy and gravelly material a score of 4, and predominant gravelish soil was given a score of 5 (Muhammad & Khalid, 2017). The scoring was assigned based on the infiltration characteristics of material which may affect the groundwater aquifer susceptibility to pollutants. The analysis of vadose zone material revealed that almost 40% of the vadose zone material was clay, sand mixed with gravels, while 20% was clay mixed with gravels.

The vadose zone data along with other parameters including recharge rate, soil type, topography, depth of groundwater aquifer was processed in the ArcGIS 10.5 Spatial Analyst environment, and a continuous layer was created and consequently reclassified in 5 infiltration zones, i.e., (1) very low infiltration, (2) low infiltration, (3) moderate infiltration, (4) high infiltration, and (5) very high infiltration. Both the water quality zone layer and infiltration capacity layers were processed through overlay analysis, and the infiltration capacity layer was overlaid by ground water quality layer. The analysis revealed that very poor quality and unfit drinking groundwater zones were overlaid by very high infiltration zones. Figure 8A illustrates the commutative groundwater quality map and Fig. 8B the infiltration capacity layer. Table 2 shows the water pollution vulnerable areas of district Nowshera and

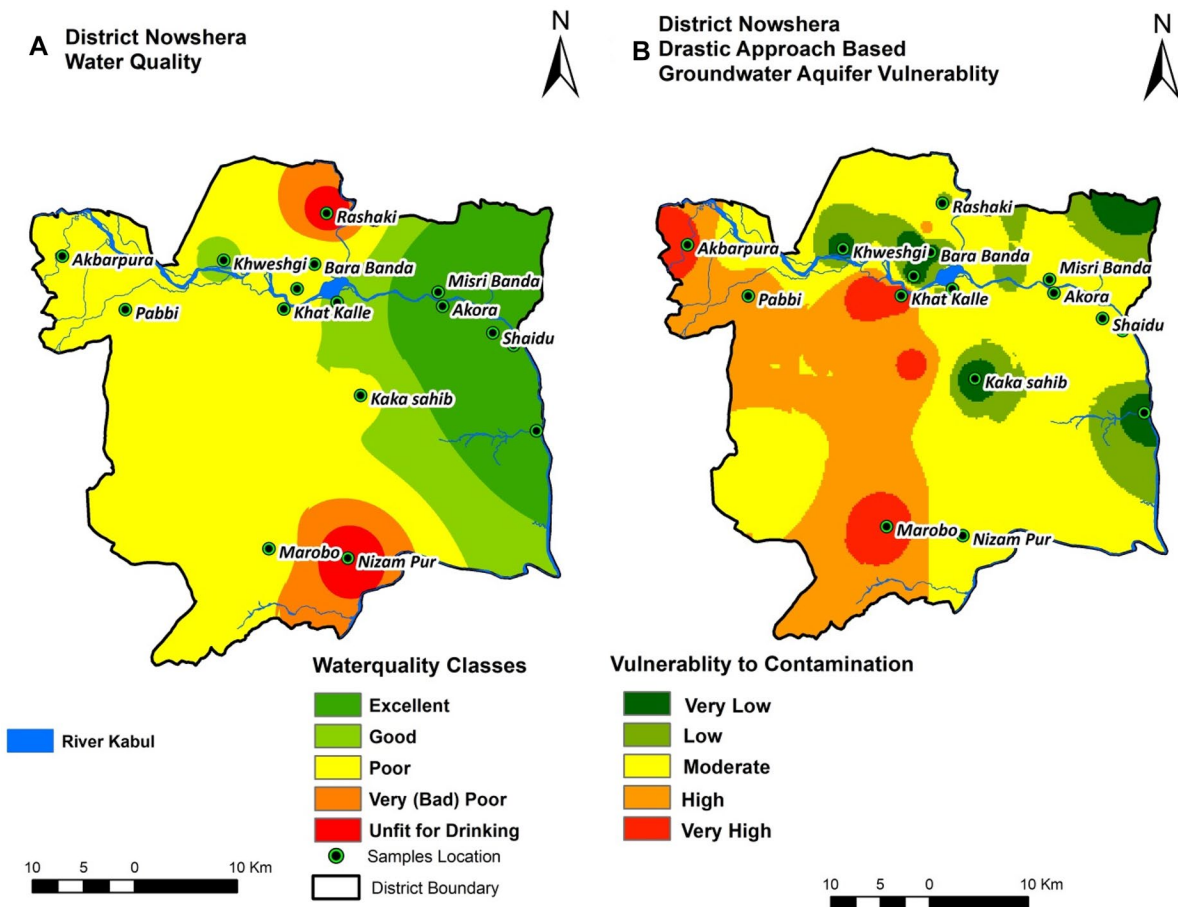


Fig. 8 Water quality map of district Nowshera superimposed by vadose zone map, illustrating the infiltration effects on groundwater contamination

Table 2 Vulnerable areas to water pollution of District Nowshera

S. no	Status	Settlements	Area km ²	%age of total area
1	Low	Kaka Sahib, Khairabad, Nowshera Kalan, Nandrak, Bara Banda, Khweshge, and Ganderi Bala	114.06	6.52
2	Moderate	Jhangira, Shaidu, Misri Banda, Gajju Khel, Tarkhel, Nawa Kalle, Misalabad, Muhib Banda, Pir Sabak, and Dag Ismail Khel	872.72	49.93
3	High	Nowshera, Nowshera Cantt, Risalpur, Shereen Koto, Pabbi, and Akora Khattak	667.6	38.19
4	Very high	Rashaki, Akbarpura, Nizampur, Khat Kalle, Marobo, Manki Sharif, and Aman Garh,	93.68	5.36

areas under various zones based on vadose zone material analysis in the ArcGIS Spatial analyst. Besides, the water quality is also affected by July 2010 flood in river Kabul. The areas inundated by floodwater in July 2010 (Fig. 8A) still have poor to very poor water quality (Yousaf et al., 2013). According to research conducted by Ahmad et al. (2021), in district Peshawar, there has been a drop in groundwater quality from 2012 to 2019, with the groundwater quality deterioration being more pronounced in densely populated regions. Nitrate concentrations were found to be high in the area of farms due to the excessive use of nitrogenous fertilizers and pesticides. The study shows that anthropogenic activities were the primary cause of spatio-temporal variability in groundwater quality in the studied region.

Conclusion

It is concluded that the concentration of selected parameters in the collected groundwater samples of the majority of district area (56.72% of the total district area) was slightly above the permissible limits set by WHO and Pak-EPA. In these areas of district Nowshera, the concentration of the total dissolved solid, alkalinity, Cl, and SO₄ were higher than their permissible limits. The groundwater quality assessment revealed that the groundwater quality of study area is acceptable with some exemptions. Based on cumulative water quality, the excellent water quality prevailed over an area of 331.72 km² (18.97% of district area), the good water quality covered an area of 244.28 km² (13.97% of the district area), poor 991.87 km² (56.72% of the district area), very poor quality 128.99 km² (7.38%), and unfit for drinking 51.71 km² (2.96% of the district area). The water of the Nizampur, Sajjo Khel, Kamar Sar,

and Miskinabad areas were categorized as unfit for drinking. Based on the drastic approach-based infiltration capacity of the study area suggested that the low vulnerable zone covered an area of 69.92 km², the low vulnerable area of 199.83 km², moderate 901.45 km², high 348.72 km², and very highly vulnerable zone covered an area of 93.97 km². The study concluded that the groundwater quality of about 33% is good to excellent, while for the rest of 64% is poor to very poor; however, in only about 2.96% of the district area the groundwater quality is unsafe. Similarly, almost 33% of the study area is moderately to highly vulnerable to groundwater pollution. The most important factor which determines the vulnerability of the groundwater to contamination is the vadose zone material/sediment which in turn determines its infiltration capacity. The vadose zone material in most such groundwater quality zones is a mixture and sandy gravels, where the transmission of contaminants was relatively easier due to porous and permeable soil and vadose zone material. The toxic material from various sources, i.e., industrial and municipal effluent, waste disposal/landfill sites, agriculture runoff, easily infiltrates down to groundwater shallow aquifers. Besides, the water quality of the study area also deteriorated by July 2010 flood in river Kabul.

Groundwater aquifer contamination susceptibility maps are meant to serve as a diagnostic tool for determining wherein comprehensive hydro-geochemical assessment has been most needed and where urgent safety precautions are likely to be required to deal with a possible groundwater pollution problem. The research might assist the district health authorities in better understanding groundwater quality trends, formulating location-specific policies, and developing future health-related regulations.

Limitations

Hardly any of the groundwater aquifer pollution susceptibility assessment methodologies are free of errors and sufficiently resilient to manage the changing hydro-geological and hydrological circumstances. In addition to the insufficient information and imperfect measurement methods, errors in qualitative approaches arise from subjective assigning of variable scores and rankings, as well as inaccuracies in interpolation methods used for mapping. Numerical methods are also prone to mistakes because of various assumptions made to simplify ecological processes. Therefore, all vulnerability studies are inherently uncertain. The classification of vadose zones is difficult, time-consuming, and difficult, particularly at regional level, and small-scale variations in vadose-zone may be overlooked in the present study.

Author contribution MJN: conceptualization, writing original draft, supervision, methodology, software. **MT:** data collection, analysis, software, data curation. **TA:** visualization, software, writing, reviewing, editing, and formatting. **SK:** reviewing and editing. **AZK:** reviewing and editing. **ML:** reviewing and editing.

Availability of data and materials All data generated or analyzed during this study are included in this published article (and its supplementary information files). The datasets generated and/or analyzed during the current study are available in the WHO repository (<https://www.safewater.org/factsheets-1/2017/1/23/tds-and-ph>) while Pakistan EPA standards are derived from the Government of Pakistan, Pakistan Environmental Protection Agency (Ministry of Environment), National Standards for Drinking Water Quality (NSDWQ). <https://waterinfo.net.pk/sites/default/files/knowledge/NSDWQ%20Drinking%20Water%20%202007.pdf>

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

References

Abubakar, B., & Adekola, O. (2012). Assessment of borehole water quality in Yola-Jimeta Metropolis, Nigeria. *International Journal of Water Resources and Environmental Engineering*, 4(9), 287–293. <https://doi.org/10.5897/ijwree12.012>

- Adelodun, B., Ajibade, F. O., Ighalo, J. O., Odey, G., Ibrahim, R. G., Kareem, K. Y., & Choi, K. S. (2020). Assessment of socioeconomic inequality based on virus-contaminated water usage in developing countries: A review. *Environmental Research*. <https://doi.org/10.1016/j.envres.2020.110309>
- Agarwal, A., Prajapati, R., Singh, O. P., Raza, S. K., & Thakur, L. K. (2015). Pesticide residue in water—A challenging task in India. *Environmental Monitoring and Assessment*, 187(2), 1–21. <https://doi.org/10.1007/s10661-015-4287-y>
- Ahmad, M., Jamal, A., Tang, X. W., Al-Sughaiyer, M. A., Al-Ahmadi, H. M., & Ahmad, F. (2020). Assessing potable water quality and identifying areas of waterborne diarrheal and fluorosis health risks using spatial interpolation in Peshawar, Pakistan. *Water*, 12(8), 2163. <https://doi.org/10.3390/w12082163>
- Ahmad, W., Iqbal, J., Nasir, M. J., Ahmad, B., Khan, M. T., Khan, S. N., & Adnan, S. (2021). Impact of land use/land cover changes on water quality and human health in district Peshawar Pakistan. *Scientific Reports*, 11(1), 1–14.
- Aleem, M., Shun, C. J., Li, C., Aslam, A. M., Yang, W., Nawaz, M. I., & Buttar, N. A. (2018). Evaluation of groundwater quality in the vicinity of Khurrianwala industrial zone, Pakistan. *Water*, 10(10), 1321. <https://doi.org/10.3390/w10101321>
- Alfaifi, H. J., Kahal, A. Y., Abdelrahman, K., Zaidi, F. K., Albassam, A., & Lashin, A. (2020). Assessment of groundwater quality in Southern Saudi Arabia: Case study of Najran area. *Arabian Journal of Geosciences*, 13(3), 1–15. <https://doi.org/10.1007/s12517-020-5109-2>
- Alley, W. M., Healy, R. W., LaBaugh, J. W., & Reilly, T. E. (2002). Flow and storage in groundwater systems. *Science*, 296(5575), 1985–1990. <https://doi.org/10.1126/science.1067123>
- Anand, A., Singh, P., Srivastava, P. K., & Gupta, M. (2021). GIS-based analysis for soil moisture estimation via kriging with external drift. In *Agricultural water management* (pp. 391–408). Academic Press. <https://doi.org/10.1016/B978-0-12-812362-1.00019-9>
- APHA, AWWA. (1998). *Standard methods for the examination of water, and wastewater* (20th ed.). American Public Health Association.
- Arkoç, O. (2022). Modeling of spatiotemporal variations of groundwater levels using different interpolation methods with the aid of GIS, case study from Ergene Basin, Turkey. *Modeling Earth Systems and Environment*, 8(1), 967–976. <https://doi.org/10.1007/s40808-021-01083-x>
- Arshad, A., Zhang, Z., Zhang, W., & Dilawar, A. (2020). Mapping favorable groundwater potential recharge zones using a GIS-based analytical hierarchical process and probability frequency ratio model: A case study from an agro-urban region of Pakistan. *Geoscience Frontiers*, 11(5), 1805–1819. <https://doi.org/10.1016/j.gsf.2019.12.013>
- Ayuba, R., Tijani, M. N., & Omonona, O. V. (2017). Hydro-chemical characteristics and quality assessment of groundwater from shallow wells in Gboloko area, central Nigeria. *Global Journal of Geological Sciences*, 15, 65–76. <https://doi.org/10.4314/gjgs.v15i1.6>
- Bhunja, G. S., Shit, P. K., & Maiti, R. (2018). Comparison of GIS-based interpolation methods for spatial distribution of soil organic carbon (SOC). *Journal of the Saudi Society*

- of *Agricultural Sciences*, 17(2), 114–126. <https://doi.org/10.1016/j.jssas.2016.02.001>
- Boretti, A., & Rosa, L. (2019). Reassessing the projections of the world water development report. *NPJ Clean Water*, 2(1), 1–6. <https://doi.org/10.1038/s41545-019-0039-9>
- Bowling, J. C., Rodriguez, A. B., Harry, D. L., & Zheng, C. (2005). Delineating alluvial aquifer heterogeneity using resistivity and GPR data. *Groundwater*, 43(6), 890–903. <https://doi.org/10.1111/j.1745-6584.2005.00103.x>
- Bruning-Fann, C. S., & Kaneene, J. B. (1993). The effects of nitrate, nitrite and N-nitroso compounds on human health: A review. *Veterinary and Human Toxicology*, 35(6), 521–538.
- Burbank, D. W., & Reynolds, R. G. H. (1988). Stratigraphic keys to the timing of thrusting in terrestrial foreland basins: Applications to the northwestern Himalaya. In: Kleinspehn, K.L., Paola, C. (eds) *New perspectives in basin analysis*. *Frontiers in Sedimentary Geology*. Springer, New York, NY. https://doi.org/10.1007/978-1-4612-3788-4_17
- Burri, N. M., Weatherl, R., Moeck, C., & Schirmer, M. (2019). A review of threats to groundwater quality in the anthropocene. *Science of the Total Environment*, 684, 136–154. <https://doi.org/10.1016/j.scitotenv.2019.05.236>
- Cornwell, K. (1998). Quaternary break-out flood sediments in the Peshawar basin of northern Pakistan. *Geomorphology*, 25(3–4), 225–248. [https://doi.org/10.1016/S0169-555X\(98\)00061-0](https://doi.org/10.1016/S0169-555X(98)00061-0)
- Daud, M. K., Nafees, M., Ali, S., Rizwan, M., Bajwa, R. A., Shakoor, M. B., Arshad, M. U., Chatha, S., Deeba, F., Murad, W., Malook, I., & Zhu, S. J. (2017). Drinking water quality status and contamination in Pakistan. *BioMed Research International*. <https://doi.org/10.1155/2017/7908183>
- Eaton, A. D., Clesceri, L. S., Rice, E. W., Greenberg, A. E., & Franson, M. A. H. (2005). Standard methods for the examination of water and wastewater. *American Public Health Association*, 1015.
- Edokpayi, J. N., Enitan, A. M., Mutileni, N., & Odiyo, J. O. (2018). Evaluation of water quality and human risk assessment due to heavy metals in groundwater around Muledane area of Vhembe District, Limpopo Province, South Africa. *Chemistry Central Journal*, 12(1), 1–16. <https://doi.org/10.1186/s13065-017-0369-y>
- Elumalai, V., Nethononda, V. G., Manivannan, V., Rajmohan, N., Li, P., & Elango, L. (2020). Groundwater quality assessment and application of multivariate statistical analysis in Luvuvhu catchment, Limpopo, South Africa. *Journal of African Earth Sciences*, 171, 103967. <https://doi.org/10.1016/j.jafrearsci.2020.103967>
- Fantong, W. Y., Satake, H., Ayonghe, S. N., Aka, F. T., & Asai, K. (2009). Hydrogeochemical controls and usability of groundwater in the semi-arid Mayo Tsanaga River Basin: Far north province, Cameroon. *Environmental Geology*, 58(6), 1281–1293. <https://doi.org/10.1007/s00254-008-1629-x>
- Ferronato, N., & Torretta, V. (2019). Waste mismanagement in developing countries: A review of global issues. *International Journal of Environmental Research and Public Health*, 16(6), 1060. <https://doi.org/10.3390/ijerph16061060>
- Gao, Y., Qian, H., Ren, W., Wang, H., Liu, F., & Yang, F. (2020). Hydrogeochemical characterization and quality assessment of groundwater based on integrated-weight water quality index in a concentrated urban area. *Journal of Cleaner Production*, 260, 121006. <https://doi.org/10.1016/j.jclepro.2020.121006>
- Gul, I., Rehman, I., Hashim, N., & Ahmad, I. (2016). Groundwater contamination in district Nowshera Khyber Pakhtunkhwa. In the wake of super-flood 2010. *Science Technology and Development*, 35(3), 131–140. <https://doi.org/10.3923/std.2016.131.140>
- Hasan, M. S. U., & Rai, A. K. (2020). Groundwater quality assessment in the Lower Ganga Basin using entropy information theory and GIS. *Journal of Cleaner Production*, 274, 123077. <https://doi.org/10.1016/j.jclepro.2020.123077>
- Ho, K. C., Chow, Y. L., & Yau, J. T. S. (2003). Chemical and microbiological qualities of The East River (Dongjiang) water, with particular reference to drinking water supply in Hong Kong. *Chemosphere*, 52(9), 1441–1450. [https://doi.org/10.1016/S0045-6535\(03\)00481-8](https://doi.org/10.1016/S0045-6535(03)00481-8)
- Islam, R., Faysal, S. M., Amin, R., Juliana, F. M., Islam, M. J., Alam, M. J., & Asaduzzaman, M. (2017). Assessment of pH and total dissolved substances (TDS) in the commercially available bottled drinking water. *Iosr Journal of Nursing and Health Science Ver. IX*, 6(5), 35–40. <https://doi.org/10.9790/1959-0605093540>
- Jehan, S., Khan, S., Khattak, S. A., Muhammad, S., Rashid, A., & Muhammad, N. (2019). Hydrochemical properties of drinking water and their sources apportionment of pollution in Bajaur agency, Pakistan. *Measurement*, 139, 249–257. <https://doi.org/10.1016/j.measurement.2019.02.090>
- Kalawapudi, K., Dube, O., & Sharma, R. (2020). Use of neural networks and spatial interpolation to predict groundwater quality. *Environment, Development and Sustainability*, 22(4), 2801–2816. <https://doi.org/10.1007/s10668-019-00319-2>
- Kataria, H. C., Gupta, M., Kumar, M., Kushwaha, S., Kashyap, S., Trivedi, S., & Bandewar, N. K. (2011). Study of physico-chemical parameters of drinking water of Bhopal city with reference to health impacts. *Current World Environment*, 6(1), 95–99. <https://doi.org/10.12944/CWE.6.1.13>
- Khalil, I. A., Troeger, C., Blacker, B. F., Rao, P. C., Brown, A., Atherly, D. E., & Reiner, R. C., Jr. (2018). Morbidity and mortality due to shigella and enterotoxigenic Escherichia coli diarrhoea: The Global Burden of Disease Study 1990–2016. *The Lancet Infectious Diseases*, 18(11), 1229–1240. [https://doi.org/10.1016/S1473-3099\(18\)30475-4](https://doi.org/10.1016/S1473-3099(18)30475-4)
- Khan, S., Shahnaz, M., Jehan, N., Rehman, S., Shah, M. T., & Din, I. (2013). 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>
- Khatrri, N., & Tyagi, S. (2015). Influences of natural and anthropogenic factors on surface and groundwater quality in rural and urban areas. *Frontiers in Life Science*, 8(1), 23–39. <https://doi.org/10.1080/21553769.2014.933716>
- Lambooy, T. (2011). Corporate social responsibility: Sustainable water use. *Journal of Cleaner Production*, 19(8), 852–866. <https://doi.org/10.1016/j.jclepro.2010.09.009>
- Li, P. (2020). To make the water safer. *Exposure and Health*, 12, 337–342. <https://doi.org/10.1007/s12403-020-00370-9>
- Lukubye, B., & Andama, M. (2017). Physico-chemical quality of selected drinking water sources in Mbarara

- Municipality, Uganda. *Journal of Water Resource and Protection*, 9(7), 707–722. <https://doi.org/10.4236/jwarp.2017.97047>
- Muhammad, S., & Khalid, P. (2017). Hydrogeophysical investigations for assessing the groundwater potential in part of the Peshawar basin, Pakistan. *Environmental Earth Sciences*, 76(14), 1–12. <https://doi.org/10.1007/s12665-017-6833-0>
- Murtaza, K. O., Romhoo, S. A., Rashid, I., & Shah, W. (2020). Geospatial assessment of groundwater quality in Udhampur District, Jammu and Kashmir, India. *Proceedings of the National Academy of Sciences, India Section a: Physical Sciences*, 90(5), 883–897. <https://doi.org/10.1007/s40010-019-00630-7>
- Mushtaq, N., Singh, D. V., Bhat, R. A., Dervash, M. A., & bin Hameed, O. (2020). Freshwater contamination: Sources and hazards to aquatic biota. In *Fresh water pollution dynamics and remediation* (pp. 27–50). Springer, Singapore. https://doi.org/10.1007/978-981-13-8277-2_3
- Nahin, K. T. K., Basak, R., & Alam, R. (2020). Groundwater vulnerability assessment with DRASTIC index method in the salinity-affected southwest coastal region of Bangladesh: A case study in Bagerhat Sadar, Fakirhat and Rampal. *Earth Systems and Environment*, 4(1), 183–195. <https://doi.org/10.1007/s41748-019-00144-7>
- Nasir, M. S., Nasir, A., Rashid, H., & Shah, S. H. H. (2017). Spatial variability and long-term analysis of groundwater quality of Faisalabad industrial zone. *Applied Water Science*, 7(6), 3197–3205. <https://doi.org/10.1007/s13201-016-0467-3>
- Neal, C., House, W. A., Jarvie, H. P., Neal, M., Hill, L., & Wickham, H. (2005). Phosphorus concentrations in the river Dun, the Kennet and Avon canal and the river Kennet, southern England. *Science of the Total Environment*, 344(1–3), 107–128. <https://doi.org/10.1016/j.scitotenv.2005.02.009>
- Nguyen, P. T., Ha, D. H., Jaafari, A., Nguyen, H. D., Van Phong, T., Al-Ansari, N., & Pham, B. T. (2020). Groundwater potential mapping combining artificial neural network and real AdaBoost ensemble technique: The DakNong province case-study, Vietnam. *International Journal of Environmental Research and Public Health*, 17(7), 2473. <https://doi.org/10.3390/ijerph17072473>
- Nistor, M. M., Rahardjo, H., Satyanaga, A., Hao, K. Z., Xiaosheng, Q., & Sham, A. W. L. (2020). Investigation of groundwater table distribution using borehole piezometer data interpolation: Case study of Singapore. *Engineering Geology*, 271, 105590. <https://doi.org/10.1016/j.enggeo.2020.105590>
- Olorode, O. D., Adeneye, S. O., Morakinyo, A. D., Oyenyin, O. A., Akpochafor, M. O., & Omojola, A. D. (2018). Physio-chemical investigation and analyses of contaminants in groundwater flow. Case study—Papalanto, Ifo local government area, South-Western Nigeria, Ogun State. *The European Research Journal*, 5(3), 440–448. <https://doi.org/10.18621/eurj.382807>
- Pak-EPA. (2008). Pakistan Environmental Protection Agency. National Environmental Quality Standards, Ministry of Environment, Pakistan. Retrieved at 10.05.10. Retrieved from <http://www.pakepa.org/neqs.html>
- Patil, P. N., Sawant, D. V., & Deshmukh, R. N. (2012). Physico-chemical parameters for testing of water—A review. *International Journal of Environmental Sciences*, 3(3), 1194.
- Pruss-Ustun, A., Wolf, J., Corvalán, C., Bos, R., & Neira, M. (2016). *Preventing disease through healthy environments: A global assessment of the burden of disease from environmental risks*. World Health Organization.
- Rad, P. R., & Fazlali, A. (2020). Optimization of permeable reactive barrier dimensions and location in groundwater remediation contaminated by landfill pollution. *Journal of Water Process Engineering*, 35, 101196. <https://doi.org/10.1016/j.jwpe.2020.101196>
- Saranya, T., & Saravanan, S. (2020). Groundwater potential zone mapping using analytical hierarchy process (AHP) and GIS for Kancheepuram District, Tamilnadu, India. *Modeling Earth Systems and Environment*. <https://doi.org/10.1007/s40808-020-00744-7>
- Saxena, P., & Sonwani, S. (2019). Primary criteria air pollutants: environmental health effects. In *Criteria air pollutants and their impact on environmental health* (pp. 49–82). Springer, Singapore. https://doi.org/10.1007/978-981-13-9992-3_3
- Shahid, S. U., Iqbal, J., & Khan, S. J. (2017). A comprehensive assessment of spatial interpolation methods for the groundwater quality evaluation of Lahore, Punjab, Pakistan. *NUST Journal of Engineering Sciences*, 10(1), 1–13. <https://doi.org/10.24949/njes.v10i1.239>
- Somvanshi, S., Kunwar, P., Singh, N. B., Shukla, S. P., & Pathak, V. (2012). Integrated remote sensing and GIS approach for water quality analysis of Gomti river, Uttar Pradesh. *International Journal of Environmental Sciences*, 3(1), 62. <https://doi.org/10.6088/ijes.2012030131008>
- Srivastava, P. K., Pandey, P. C., Petropoulos, G. P., Kourgiyalas, N. N., Pandey, V., & Singh, U. (2019). GIS and remote sensing aided information for soil moisture estimation: A comparative study of interpolation techniques. *Resources*, 8(2), 70. <https://doi.org/10.3390/resources8020070>
- Ullah, S., Javed, M. W., Shafique, M., & Khan, S. F. (2014). An integrated approach for quality assessment of drinking water using GIS: A case study of Lower Dir. *Journal of Himalayan Earth Science*, 47(2).
- US EPA. (1985). United State Environmental Protection Agency. DRASTIC: A standard system for evaluation groundwater potential using hydrogeological settings Ada, Oklahoma.
- Vadde, K. K., Wang, J., Cao, L., Yuan, T., McCarthy, A. J., & Sekar, R. (2018). Assessment of water quality and identification of pollution risk locations in Tiaoxi River (Taihu Watershed), China. *Water*, 10(2), 183. <https://doi.org/10.3390/w10020183>
- Vasanthavigar, M., Srinivasamoorthy, K., Vijayaragavan, K., Ganhi, R. R., Chidambaram, S., Anandhan, P., & Vasudevan, S. (2010). Application of water quality index for groundwater quality assessment: Thirumanimuttar sub-basin, Tamilnadu, India. *Environmental Monitoring and Assessment*, 171(1), 595–609. <https://doi.org/10.1007/s10661-009-1302-1>
- WHO. (1996). *Guidelines for drinking water quality* (2nd ed.). World Health Organization.
- Yang, W., Zhao, Y., Wang, D., Wu, H., Lin, A., & He, L. (2020). Using principal components analysis and IDW interpolation to determine spatial and temporal changes of surface water quality of Xin’anjiang river in Huangshan, China. *International Journal of Environmental Research and Public Health*, 17(8), 2942. <https://doi.org/10.3390/ijerph17082942>

- Yousaf, S., Zada, A., & Owais, M. (2013). Physico-chemical characteristics of potable water of different sources in District Nowshera: A case study after flood–2010. *Journal of Himalayan Earth Sciences*, *46*(1), 83–87.
- Zhang, H., Li, H., Yu, H., & Cheng, S. (2020). Water quality assessment and pollution source apportionment using multi-statistic and APCS-MLR modeling techniques in Min River Basin, China. *Environmental Science and Pollution Research*, *27*(33), 41987–42000. <https://doi.org/10.1007/s11356-020-10219-y>

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.