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RESEARCH ARTICLE - EARTH SCIENCES

Use of Geographic Information System and Water Quality Index to Assess Groundwater Quality in Rawalpindi and Islamabad

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Abstract Water quality assessment has always been a dominant part of environmental quality management. The present study involved the suitability assessment and mapping of groundwater quality for agricultural activities and drinking purposes in Rawalpindi and Islamabad area. A total of 22 samples were collected from borewells and open wells, and these water samples were further analysed for physical and chemical characteristics on the basis of which different indices were developed. Water quality index was calculated for overall water quality quantification from the perspective of human consumption. The results showed that a greater proportion exhibited poor quality for drinking due to over-exploitation of groundwater resource, agricultural impact and direct release of contaminants. Further, evaluation of groundwater for its suitability for irrigation showed that majority of the groundwater was suitable for irrigation purposes.

Keywords Geographic information system · Groundwater · Islamabad · Rawalpindi · Water quality index · Water quality parameters

1 Introduction

Groundwater has attained global significance due to its multidimensional contributions such as support of habitat, maintenance of base flow to rivers quality and above all human consumption. When compared to surface water, it has been considered as a pure form of water, because of different natural purification mechanisms in soil column including ion exchange, filtration and aerobic decomposition. This is one of the reasons behind the over-extraction and consumption of this natural resource in semi-rural and rural areas all over the world [1].

Degradation of groundwater takes place mainly due to its quality parameter changes beyond the natural variations due to the introduction or removal of different substances [2]. Urban, modern agricultural and industrial activities and their increasing number of soluble chemical input are unfortunately posing a serious threat to this resource [3]. Nevertheless, fires, landslides and other surface processes that increase or decrease infiltration rate and exposure of downwards moving water to soil surfaces or blanket rock may also affect the shallow groundwater quality [4]. Therefore, the water quality is defined socially depending upon its intended or desired use. Different standards of water quality are set for different uses, and these standards are maintained through continuous monitoring of water quality, which is the most important step in the management of water resources, not only for the human existence but also for the integrity of whole ecosystems.

The contaminants transport from the point of discharge to groundwater system is function of pollutant type and characteristics of above aquifer soil–rock strata [5]. The degree of groundwater vulnerability is then evaluated accordingly. Naturally, this vulnerability is taken as the contaminants collection and transmittance ability of an aquifer from anthropogenic sources [6]. Unfortunately, multiple uncertainties are associated with vulnerability assessments of an aquifer such as estimates of hydraulic conductivity, unsatisfactory representation of major factors such as soil media [7], net recharge uncertainty, insufficient knowledge regarding chemical and physical properties of pollutants and their attenuation processes [8], which necessitates accurate field testing validation for all vulnerability estimates. Overall conditions of water quality (whether surface or groundwa-

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ter) are difficult to explain with a few parameters due to spatial variability of multiple contaminants. However, in geo-indicators context, five water quality indicators can be categorized: physical, biological, chemical, radioactive and aesthetic. Thus, there is a wide range of indicators that can be measured and others may be adopted in future.

Groundwater must be carefully managed to maintain its purity within standard limits as it is a fragile and important source of irrigation and drinking water. Till recently, laboratory investigations were used for the assessment of groundwater, but the introduction of geographic information system (GIS) has made integration of various databases very easy. GIS can be a powerful tool for developing solutions for water quality assessment, problems of water resources, determination of water availability and management of water resources on a regional or local scale. Assessment of quality of groundwater through spatial distribution mapping for various pollutants utilizing GIS technology, water quality index (WQI) studies and the resultant information on quality of water could be useful for policy makers to take remedial measures [9–12].

Water quality index developed for either drinking water or irrigation water expresses overall quality of water through a single number like a grade at a certain time and location based on different parameters of water quality [13]. Its main objective is to convert complex data of water quality into comprehendible and useable information. These indices are one of the most effective ways for water quality information provision to public, concerned authorities or policy makers for water quality management and considered as one of the simplest methods used for overall water quality assessment. A WQI is also defined as a rating reflecting the composite influence of different water quality parameters on the overall quality of water. The major advantage of this quality index is that it reduces the large amount of chemical, physical and biological parameters data to single number in a simple reproducible manner [14]. In fact, WQI has been used for the assessment of water quality of many water bodies around the world [14–17].

Mapping water quality indices within GIS framework will be a useful tool for water quality management. GIS and remote sensing have been used extensively by multiple researchers to assess the water quality all over the world, e.g. Aydi et al. [3] and Ketata-Rokbani et al. [18] in Tunisia, Shomar et al. [19] in Palestine, Gamvroula et al. [20] and Stamatis et al. [21] in Greece, Kumar et al. [22] in India, Baawain and Al-Futaisi [23] in Oman. The advancement of GIS and spatial analysis helps to integrate the laboratory analysis data with the geographic data and to model the spatial distributions of water quality parameters, most robustly and accurately. Hence, the present study was conducted having an objective of assessing suitability of groundwater quality for irrigation and drinking purposes by an integrated approach of traditional water quality analysis, GIS and WQI.

2 Materials and Methods

2.1 Study Area

The study area included Rawalpindi and Islamabad, commonly known as the twin cities of Pakistan (Fig. 1). Islamabad Federal Capital lies between 72°48′ and 73°22′ east longitudes and 33°28′ and 33°48′ north latitudes. Rawalpindi lies between 72°38′ and 73°37′ east longitudes and 33°04′ and 34°01′ north latitudes. On the north, it is covered by the Federal Capital, Islamabad [24].

Both the cities have a lot of variation in temperature, defined by distinct seasons, with a minimum and maximum temperature of −2 and 45 °C, respectively. The hottest of months is June, and the monsoon season occurs from July to beginning of September. Average annual precipitation is 95.2 mm with monthly averages of 267 and 309 mm in July and August, respectively, caused mainly by the Monsoon [24]. Seasonal conditions and rainfall of the twin cities are very much similar.

2.2 Data Collection and Analysis

Twenty-two sampling locations were identified from the study area for the purpose of mapping the groundwater quality (Fig. 1). Water samples were collected from open wells and borewells, which were extensively used for agriculture, drinking, and other domestic and industrial purposes. Water samples were collected in polypropylene containers, which were rinsed thoroughly several times with sample water prior to sample collection. All water samples were stored in an iced cooler during the field work. In laboratory, the samples were stored in a refrigerator with temperature maintained at 2 and 4 °C. During collection of samples and their handling, all possible precautions were taken to minimize contamination. These samples were collected during the months of September 2012–January 2013 and were analysed for various physiochemical per American Public Health Association (APHA) [25] standard methods. The parameters which were analysed included electrical conductivity (EC), hardness, pH, total dissolved solids (TDS), total alkalinity, Ca^{2+}, Fe, HCO_3^-, NO_3^-, Cl^-, K^+, Mg^{2+}, Na^+, SO_4^{2-}, Zn, As, Cu, Mn, Ni and Pb. The pH, EC and TDS were measured by Hanna Instrument (Model 8519 Italy) and Hach Conductivity/TDS meter model no. 44600-00, USA, respectively. Hardness was determined by EDTA titration method. K^+ and Na^+ were determined using flame photometer (PFP7 UK). Ca^{2+}, Mg^{2+}, Cl^- and HCO_3^- were analysed by titrimetric

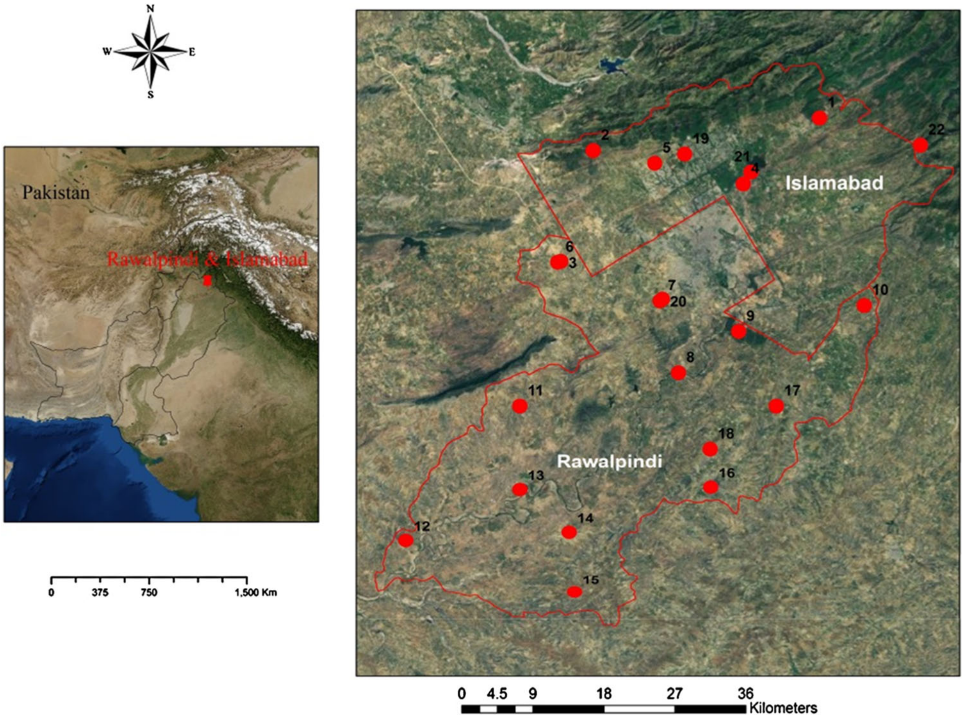

Fig. 1 Base map of the study area with sampling sites

method. SO_4 was determined by digital spectrophotometer model Sulfa Ver4 (Hach-8051). Iron was determined by Ferro Ver method (HACH cat. 21057-69). Rest of the elements were determined by AAS Vario 6, Analytik Jena AG. During water chemical analysis, a rigorous quality control programme was implemented which included duplicate water samples, standard solutions and reagent blanks. Analyses were repeated till 95 % accuracy and ±5 % precision were obtained.

2.3 GIS Analysis

A hand-held GPS device was used to obtain the latitude and longitude of the sampling sites. The different sampling locations were imported into GIS software through point layer. A unique code was assigned to each sample point and was stored in the point attribute table. The database file along with sample code for each sampling site contained separate columns for values of all chemical parameters. The geodatabase was used to generate the spatial distribution maps of selected water quality parameters as well as the WQI for drinking water; sodium adsorption ratio (SAR), sodium percentage (Na%), residual sodium carbonate (RSC), magnesium hazard (MH) and permeability index (PI) for irrigation water. Inverse distance weighted (IDW) raster interpolation technique of spatial analyst module in ArcGIS (version 10.0) software was used to delineate the locational distribution of various water pollutants.

2.4 Evaluation of Water Quality for Drinking Purpose

The WQI was calculated for the groundwater quality determination in the study area as it is useful tool for the assessment of overall water quality for drinking purposes. Different water parameters were selected, and WHO standards for drinking water were considered for those parameters. Then, these parameters were assigned weight (w_i) from 1 to 5; five representing the maximum weight depending upon the perceived impact of these pollutants on the human health. The next step was the computation of the relative weight [18] as given in Eq. (1).

$$W_i = w_i \Big/ \sum_{i=1}^{n} w_i \tag{1}$$

where w_i was each parameter's weight, W_i was the relative weight, and n was the number of parameters.

In next step, quality rating scale (q_i) of each parameter was calculated using Eq. (2).

$$q_i = C_i / S_i \times 100 \tag{2}$$

where q_i was the quality rating, C_i was the each parameter's concentration in water sample (mg/l), and S_i was the each parameter's WHO standard (mg/l).

Then, WQI was calculated by Eq. (3).

$$\mathrm{WQI} = \sum W_i \times q_i \tag{3}$$

2.5 Evaluation of Water Quality for Irrigation Purposes

The effect of mineral component of water on soil and plants decides the suitability of groundwater for irrigation purposes. The general criteria for assessing the quality of irrigation water are SAR, RSC, Na%, PI and MH. These parameters are important for determining the quality of groundwater for irrigation purposes.

Sodium adsorption ratio (SAR) according to Wilcox [26] is used to express reactions with soil and is a better measure of the sodium hazard. EC and SAR can reciprocally be used to assess quality of irrigation water. It was computed using the relationship given in Eq. (4). The concentrations were expressed in meq/l.

$$\mathrm{SAR} = \mathrm{Na}^{+} \times 100/\sqrt{\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+}/2} \tag{4}$$

RSC is an important parameter to assess the irrigation water suitability [27]. The formula used for calculation is Eq. (5), and concentrations were expressed in meq/l.

$$\mathrm{RSC} = \left[(\mathrm{HCO}_3 + \mathrm{CO}_3) - \left(\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+}\right)\right] \tag{5}$$

The third analysis was Na% computation. The measurement of Na in soil is considered imperative for groundwater solubility determination for irrigation purpose because it reduces the soil permeability after reacting and support little or no plant growth. Na% was calculated by the formula given in Eq. (6) with concentration in meq/l.

$$\mathrm{Na}\% = \left(\mathrm{Na}^{+}+\mathrm{K}^{+}\right) \times 100 \Big/ \left(\mathrm{Ca}^{2+}+\mathrm{Mg}^{2+}+\mathrm{Na}^{+}+\mathrm{K}^{+}\right) \tag{6}$$

Long-term use of irrigation water affects the permeability of soil influenced mainly by Mg^{2+}, Ca^{2+}, Na^{+} and HCO_3^- contents of the soil. PI is a significant parameter for the irrigation water suitability and affected soil permeability. Doneen [28] categorized irrigation water based on the PI using the formula given in Eq. (7) with concentrations expressed in meq/l.

$$\mathrm{PI} = \left(\mathrm{Na}^{+} + \sqrt{\mathrm{HCO}_3^{-}}\right) \times 100 \Big/ \left(\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+} + \mathrm{Na}^{+}\right) \tag{7}$$

Generally, Ca^{2+} and Mg^{2+} maintain equilibrium state in groundwater. Soil quality is affected by more Mg^{2+} present in water converting it to alkaline and decreases crop yield. MH value for irrigation water proposed by Szabolcs and Darab [29] is given by the formula in Eq. (8) where the concentrations were expressed in meq/l.

$$\mathrm{MH} = \mathrm{Mg}^{2+} \times 100/\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+} \tag{8}$$

Table 1 Statistical summary of physico-chemical parameters of groundwater samples

Parameters	Units	Min	Max	Mean	SD
pH		6.7	8.12	7.4	0.36
EC	µS/cm	337	2816	1413.45	720.18
HCO_3^-	mg/l	142	535	323.8	124.14
Na^+	mg/l	8	304	98.49	79.74
K^+	mg/l	1	13	4.62	3.63
TDS	mg/l	185	2232	1020.18	562.99
Ca^{2+}	mg/l	40	332	150.95	86.28
Mg^{2+}	mg/l	10	170	54.80	44.10
SO_4^{2-}	mg/l	8	714	141.11	158.89
Cl^-	mg/l	1	270	150.95	99.66
NO_3^-	mg/l	1.5	125	50.44	34.57
Hardness	mg/l	28	1228	456.77	339.59
Alkalinity	mg/l	6	222	71.73	80.30
Fe	mg/l	0.01	0.67	0.17	0.18
As	µg/l	0.04	3.91	0.83	0.86
Pb	mg/l	0.08	7.76	1.73	1.98
Cu	mg/l	0	0.15	0.03	0.05
Ni	mg/l	0	2.2	0.45	0.63
Mn	mg/l	0	0.6	0.10	0.17
Zn	mg/l	0	3.73	1.05	1.02

3 Results and Discussion

3.1 Spatial Analysis of Groundwater Quality

Understanding the quality of groundwater is essential as it is the main factor that determines its suitability for drinking use [30]. Statistical summary of selected chemical and physical parameters of water from the sampling sites is reported in Table 1.

Usually, one of the most important parameters of water quality is pH which has no direct impact on consumers. The required optimum pH is often varied between 7.0 and 8.5 [31]. The WHO maximum permissible limit for pH in drinking water is 8.5. The pH values of collected groundwater samples showed a variation from 6.7 to 8.12 with an average value of 7.14 (Table 1). This shows that the groundwater of the study area was mainly slightly acidic to alkaline. Spatial distributions of pH concentrations are shown in Fig. 2a. Low pH concentrations were more in Rawalpindi as compared to Islamabad. This might be due to lack of carbonate minerals from dolomite and limestone in the aquifers in Rawalpindi [32]. The presence of various dissolved salts is responsible for the electrical conductivity (EC) of water. It varied widely in the study area and ranged between 337 and 2816 µS/cm, with a mean of 1413.45 µS/cm. According to the maximum permissible limit of EC, i.e. 1500 µS/cm up

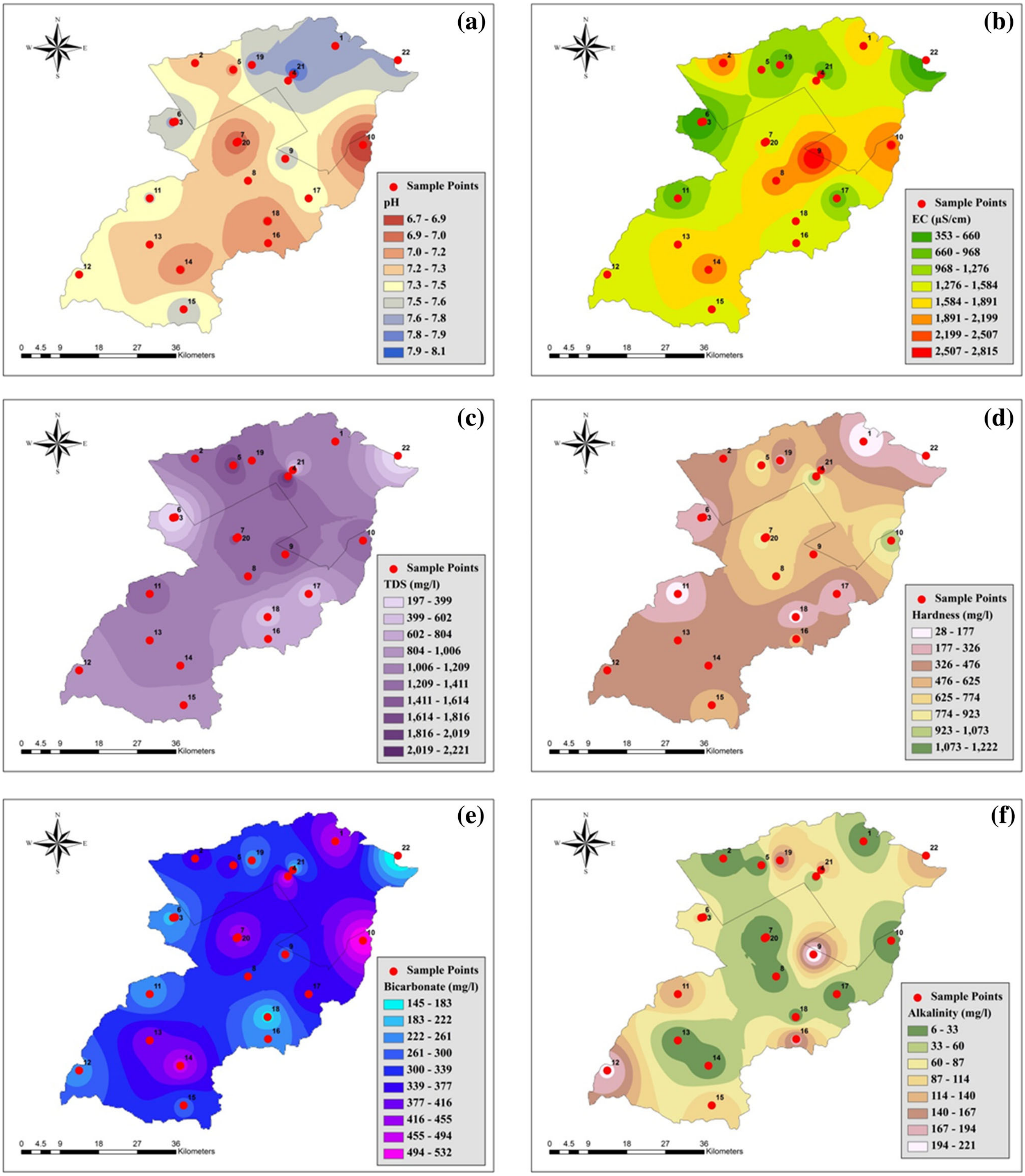

Fig. 2 Spatial distribution of **a** pH, **b** EC, **c** TDS, **d** hardness, **e** bicarbonate, **f** alkalinity

to 25 °C as prescribed by WHO [33,34], the interpretation of water quality with respect to EC indicated higher concentration of dissolved solids and more than 60 % of area lied in the range of good drinking water quality (Fig. 2b). The weight of residue left when a water sample has been evaporated to dryness represents the TDS in the water [35]. TDS accounts for the compounds of inorganic salts (primarily magnesium, calcium, sodium, potassium, chlorides, sulphates and bicarbonates) and small amount of dissolved organic matter. Therefore, depending upon the solubility of minerals, the concentration level of TDS in water varies considerably geologically [31]. In the study area, the TDS concentrations ranged from 185 to 2232 mg/l with an average of 1020.08 mg/l. Figure 2c shows that majority of the area showed TDS values >1000 mg/l making it unsuitable for drinking purposes [36]. Hardness in water is imparted by the cations present in water such as magnesium and calcium and anions such as chloride, sulphate, carbonate and bicarbonate [37]. Hardness in water >200 mg/l, which causes scale formation in distribution system and varied between 150 and 300 mg/l, may cause kidney and heart problems, and even >300 mg/l is considered as very hard water [38]. In this study, the hardness varied between 28 and 1228 mg/l with an average of 456.77 mg/l. The spatial distribution map shows that the majority of the groundwater lied in the range of very hard water (Fig. 2d). Figure 2e shows that majority of the groundwater samples had higher levels of bicarbonate than the WHO standard, i.e. 120 mg/l, making it one of the main alkalinity-imparting factors to the water [39]. Therefore, the water alkalinity of the region was also higher (Fig. 2f). The bicarbonate concentration varied between 142 and 535 mg/l with a mean of 323.8 mg/l, while the alkalinity varied between 6 and 222 mg/l with an average of 71.73 mg/l.

The major anions abundance in the study area was in the order of $SO_4^{2-} > HCO_3^- > Cl^- > NO_3^-$. The sulphate ion content in the area was higher. Its concentration varied between 8 and 714 mg/l with an average concentration of 141.11 mg/l (Table 1). The spatial distribution of sulphate ion concentration in groundwater of study area is shown in Fig. 3a. This map shows that 86.36 % of the collected groundwater samples were within the maximum allowable limit of 250 mg/l. The second most dominant anion was bicarbonate which has been discussed earlier. The third dominant anion was chloride. The concentration of chloride ion in groundwater of the study area varied between 1 and 270 mg/l with an average of 150.95 mg/l (Table 1). Chloride exceeded the maximum permissible limit of 250 mg/l in two locations only (Fig. 3b). Nitrate was the fourth dominant anion in the study area. These nitrates are the product of nitrogenous material conversion and aerobic stabilization of organic nitrogen. This whole phenomenon takes place in polluted water. Concentration of nitrate in groundwater samples varied between 1.5 and 125 mg/l with an average value of 50.44 mg/l (Table 1). Spatial distribution map shows that 63.64 % of the water samples in the study area were greater than the maximum permissible limit (Fig. 3c).

The predominant cation trend in study area was $Ca^{2+} > Na^+ > Mg^{2+} > K^+$. Calcium was the most dominant cation in study area. Its concentration varied between 40 and 332 mg/l with an average value of 150.95 mg/l (Table 1). In keeping with the WHO guideline, the maximum permissible limit is 75 mg/l, and in the study area, only 31.8 % of the groundwater samples were below the maximum permissible limit (Fig. 4a). Sodium was the second most dominant cation, and its concentration varied between 8 and 304 mg/l with an average value of 98.49 mg/l (Table 1). Na^+ distribution (Fig. 4c) was within the maximum permissible limits of 200 mg/l except for two samples. The magnesium ion concentration was low as compared to those of calcium and sodium, in the range of 10–170 mg/l with a mean value of 54.80 mg/l (Table 1). The 40.9 % of the samples had magnesium content above the maximum permissible limit (Fig. 4b). The high total concentrations of Ca^{2+} and Mg^{2+} are important factors which increase the hardness of water [40]. In the study area, the amount of potassium varied between 1 and 13 mg/l with an average value of 4.62 mg/l (Table 1), and it was found that all the samples were having potassium content within the permissible limit, except for one sample (Fig. 4d). Spatial distribution of zinc shows that the concentration of zinc was within the maximum permissible limits (Fig. 4e) with minimum and maximum of 0 and 3.73 mg/l, respectively. The mean of concentrations was 1.05 mg/l (Table 1). The concentration of iron in the area was mostly within the WHO standards except three samples (Fig. 4f). The concentration in the groundwater samples varied between 0.01 and 0.67 mg/l with an average concentration of 0.17 mg/l.

Figure 5a shows the spatial distribution of arsenic in the study area. Most of the groundwater samples showed lower arsenic concentration than the WHO standard of 0.05 mg/l. The concentration range was from 0.04 to 3.91 µg/l with mean value of 0.83 µg/l (Table 1). The concentration of copper varied between 0 and 0.15 mg/l with an average of 0.03 mg/l, and spatial distribution map shows that all samples were within the maximum permissible limits (Fig. 5b). The concentration range of manganese in the study area was from 0 to 0.60 mg/l with an average value of 0.10 mg/l with 27.27 % of groundwater samples above the maximum permissible limit (Fig. 5c). According to the provisional guideline values, the 45.5 % of the groundwater samples in the area of investigation contained nickel below the maximum permissible limit of 0.02 mg/l (Fig. 5d), varied between 0 and 2.2 mg/l, and mean concentration was 0.45 mg/l (Table 1). Spatial distribution map of lead shows all the groundwater samples containing concentrations greater than maximum permissible limit of 0.01 mg/l (Fig. 5e). The concentration of lead varied between 0.08 and 7.76 mg/l with an average of 1.73 mg/l. The major factor behind the higher metal concentration in groundwater of this specific area could be leaching from the soil as industrialization and urbanization have added different pollutants to the environment to a great extent. Major industries in areas with high-temperature processes such as metal industries, steel melting furnaces, re-rolling mills, oil mills, galvanizing and cement industries are responsible for the presence of heavy metals in water [41].

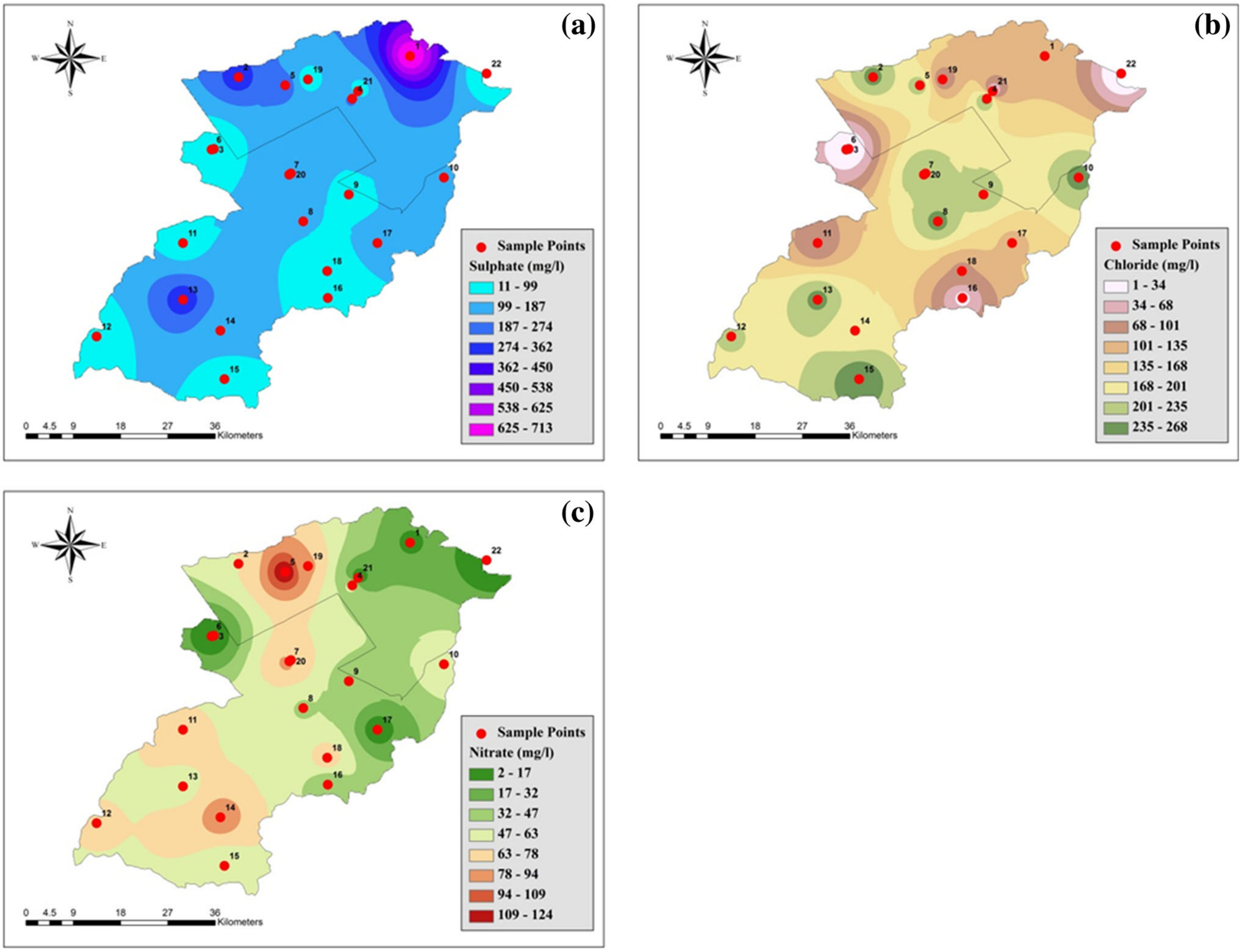

Fig. 3 Spatial distribution of **a** sulphate, **b** chloride, **c** nitrate

3.2 Water Quality Index (WQI)

Groundwater chemistry has been used as a tool to outlook water for irrigation and drinking purposes [42]. The WQI was selected to assess the water's suitability for drinking purposes. For computing WQI, different parameters were selected and weight was assigned to each parameter depending upon the perceived effect on human health [43,44]. Table 2 shows the assigned weight and relative weight of each parameter with WHO standards.

The maximum weight of 5 has been assigned to the parameters such as nitrate, arsenic and lead due to their major importance in assessment of water quality [45]. Other parameters were assigned weight between 1 and 5 depending on their importance in determination of water quality. The computed WQI for the groundwater samples values ranged from 21 to 201 (Table 3).

The interpolation map of the sample points for the area of investigation is shown in Fig. 6. 23 % of the groundwater samples represented "excellent water", 27 % represented "good water", 45 % indicated "poor water" and 1 % indicated "very poor water". The poor water quality was higher near the wastewater discharge points.

The water was classified into different categories on the basis of WQI according to the water grading standards (Table 4) also adopted by Ketata-Rokbani et al. [18] and Sahu and Sikdar [46]. According to these standards, the water near the wastewater discharge point was mostly poor while rest ranged from excellent to good water with excellent found in fewer points.

According to Haq and Cheema [47], the groundwater quality near the premises of Rawalpindi and Islamabad is also threatened due to industrial and municipal waste. The main reason for this contamination is recharge mechanism of Lai Nullah and Korang River that are carrying water of 0.545 million m^3/day. Another major cause of high concentration is the sewage system and garbage disposal. According to Willingness to Pay (WTP) survey under

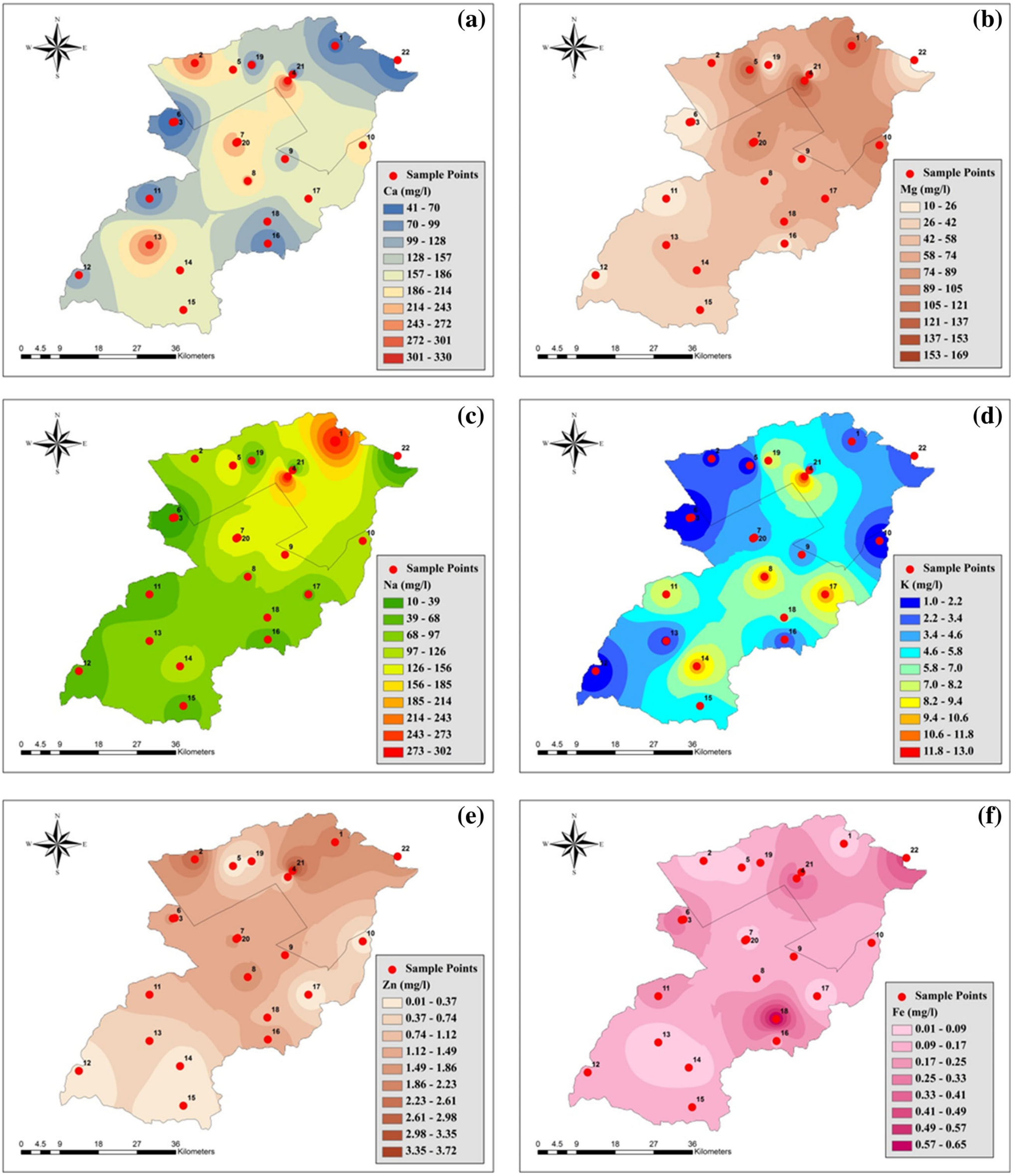

Fig. 4 Spatial distribution of **a** calcium, **b** magnesium, **c** sodium, **d** potassium, **e** zinc, **f** iron

Asian Development Bank (ADB) project, only 31 % of the total households have piped sewage and 66 % households drain their sewage to an open channel [48]. The situation is better for the urban area of Islamabad but not an ideal while the rural area has the same scenario. All this untreated sewage is discharged into Lai Nullah and its tributaries that join Soan River and other water channels in the study area. Khan and Ahmad [49] reported microbial

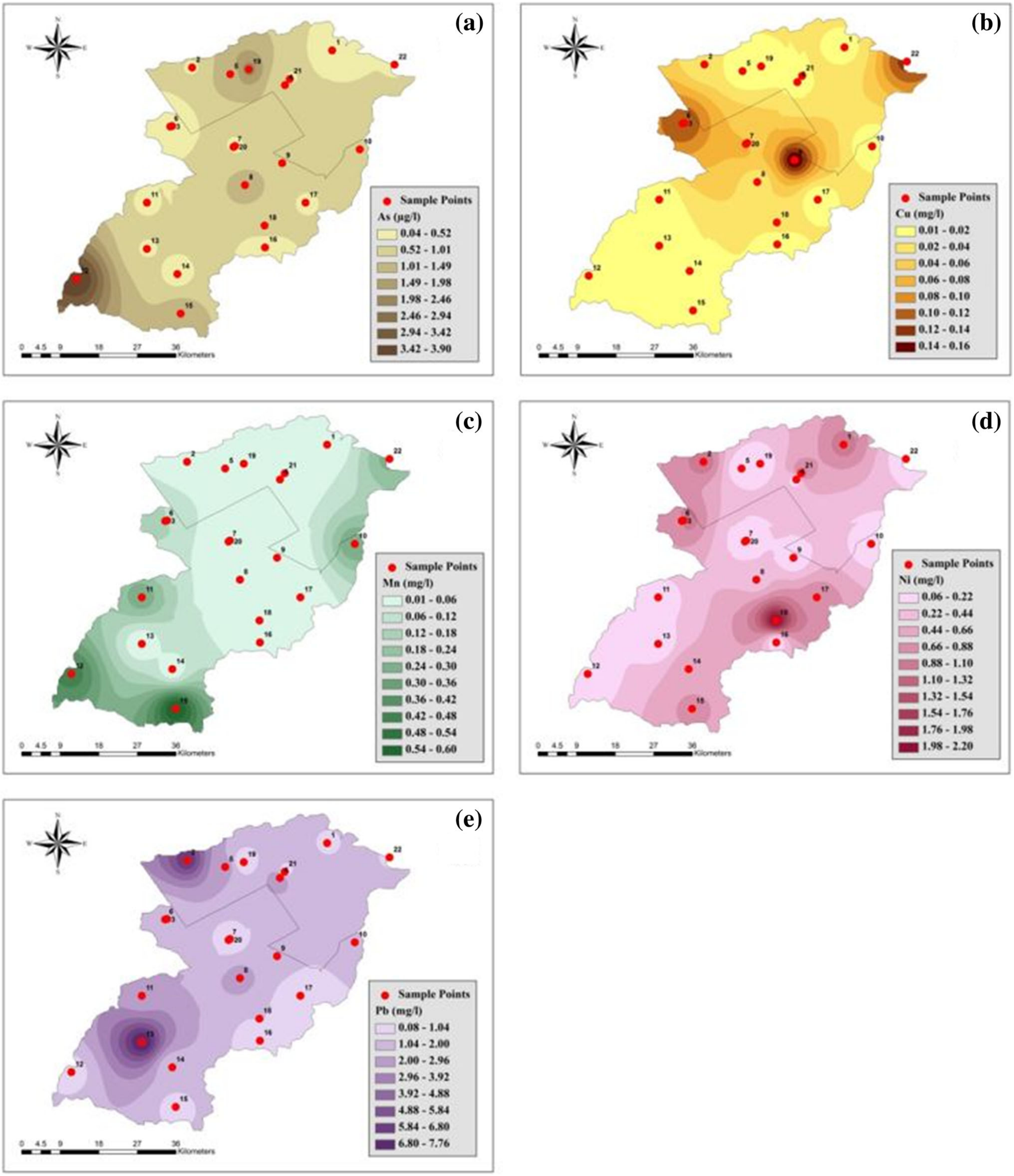

Fig. 5 Spatial distribution of **a** arsenic, **b** copper, **c** manganese, **d** nickel, **e** lead

contamination in all the groundwater samples taken from shallow aquifers due to sewage disposal through dug well system.

3.3 Water Quality for Irrigation Purposes

The suitability of groundwater for irrigation purposes depends on its mineral constituent [50]. According to

Table 2 Standard values given by WHO, calculated weight and relative weight of selected parameters of the Rawalpindi and Islamabad groundwater

Chemical parameters	WHO standard	Weight (w_i)	Relative weight (W_i)
TDS (mg/l)	1000	3	0.06
HCO_3^- (mg/l)[a]	120	2	0.04
Na^+ (mg/l)	200	3	0.06
K^+ (mg/l)	12	1	0.02
Ca^{2+} (mg/l)	75	2	0.04
Mg^+ (mg/l)	50	2	0.04
SO_4^{2-} (mg/l)	250	3	0.06
Cl^- (mg/l)	250	3	0.06
NO_3^- (mg/l)	45	5	0.10
Fe (mg/l)	0.3	4	0.08
Zn (mg/l)	3	3	0.06
As (µg/l)	50	5	0.10
Cu (mg/l)	1	4	0.08
Mn (mg/l)	0.5 (P)	3	0.06
Ni (mg/l)	0.02 (P)	4	0.08
Pb (mg/l)	0.01	5	0.10
		$\sum w_i = 52$	$\sum W_i = 1$

P provisional guideline values

[a] US Public Health Service values (WHO Standards are not available)

Table 3 Calculation of WQI for individual water samples

Sample number	WQI	Classification	Sample number	WQI	Classification
1	25.36	Excellent water	12	146.19	Poor water
2	21.92	Excellent water	13	87.95	Good water
3	136.51	Poor water	14	73.56	Good water
4	143.63	Poor water	15	142.8	Poor water
5	37.05	Excellent water	16	128.9	Poor water
6	201	Very poor water	17	75.4	Good water
7	167.4	Poor water	18	45.9	Excellent water
8	21.46	Excellent water	19	116.07	Poor water
9	170.08	Poor water	20	65.9	Good water
10	119.87	Poor water	21	86.95	Good water
11	96.85	Good water	22	123.45	Poor water

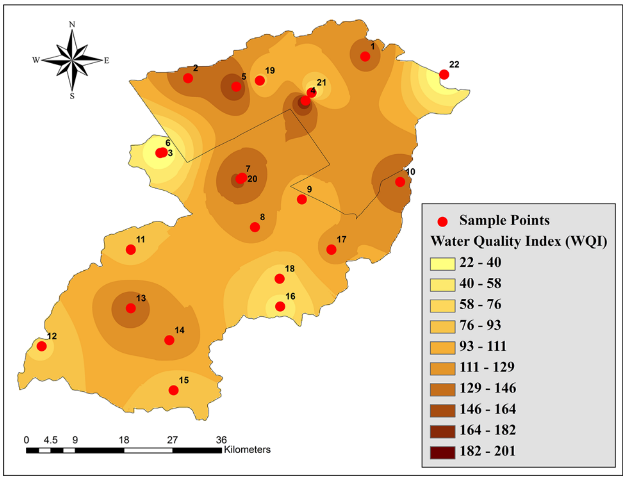

Fig. 6 Spatial distribution of water quality index

Sharaf [51] and Ben Brahim et al. [52], the evolution of groundwater chemistry might be dependent upon the chemical weathering of rocks, precipitation, evaporation and recycling of water in an irrigated area. As expressed by SAR, Na%, RSC, MH and PI, the relative proportion of sodium to other principal cations was adopted in this study for evaluating the water's suitability for irrigation purposes [38,53,54]. The criteria of water quality can be used by farmers as guidelines for selection of suitable management practices to control potential salinity hazard, if the available water quality would cause any problem to irrigation for maintaining existing soil productivity with the advantage of high crop yield under irrigation. Table 5 shows the calculated values of these techniques for each groundwater sample.

Table 4 WQI and water grading standards

WQI range	Type of water
<50	Excellent
50–100	Good water
100–200	Poor water
200–300	Very poor water
>300	Unfit for drinking

Table 5 Calculated groundwater quality parameters of Rawalpindi and Islamabad areas

Samples	SAR (meq/l)	RSC (meq/l)	Na% (meq/l)	PI (meq/l)	MH (meq/l)
1	4.89	−4.83	49.76	60.8	74.13
2	1.61	−11.78	21.61	32.2	22.37
3	0.84	0.18	21.63	57.8	29.46
4	3.41	−22	30.12	36.78	46.05
5	3.1	−14.77	25.83	34.48	51.62
6	0.36	−0.37	13.98	61.35	29.33
7	2.3	−16.46	25.53	33.34	40.34
8	1.49	−9.59	28.19	42.39	27.06
9	2.77	−6.97	36.64	48.16	38.67
10	1.7	−9.56	22.04	34.56	45.21
11	1.11	−1.48	27.79	53.24	22.63
12	1.26	−4.18	23.85	42.24	25.03
13	1.17	−10.53	16.79	29.73	21.74
14	2.17	−4.55	31.41	46.14	32.65
15	1.1	−5.85	20	35.82	25.47
16	1.14	−1.24	27	54.76	33.46
17	1.06	−8.21	17.79	30.94	35.57
18	1.69	−7.98	27.41	37.99	53.49
19	1.12	−1.66	27.68	52.37	17.45
20	1.74	−5.6	25.31	40.49	36.87
21	0.33	−0.96	12.44	51.8	28.99
22	0.28	−0.75	11.75	54.81	26.95

3.3.1 Sodium Adsorption Ratio (SAR)

Groundwater becomes unsuitable for irrigation purposes if SAR value rises above 9 (Table 6). In case of value >6, permeability problems will be caused by irrigation water by shrinking and swelling of clayey soils [55]. Greater risk of Na^+ occurs by higher SAR value in water, leading to the development of an alkaline soil [56], whereas a high salt concentration in water is responsible for formation of saline soil. In study area, SAR was ranging from 0.28 to 4.89 meq/l, indicating that 100 % of samples were suitable for irrigation purposes. Spatial distribution map of SAR is shown in Fig. 7a.

Table 6 Sodium hazard classes based on sodium adsorption ratio

SAR (meq/l)	Water quality
0–6	Good
6–9	Doubtful
>9	Unsuitable

3.3.2 Residual Sodium Carbonate (RSC)

The hazardous effect of carbonates and bicarbonates on the quality of agricultural water has been determined by RSC. Water is considered safe for irrigation if RSC value is <1.25 and unsuitable if its value rises above 2.5 [57]. Study area's groundwater was classified on the basis of RSC according to classification categories given in Table 7. The RSC in groundwater varied between −22 and 0.18 meq/l. Negative value of RSC indicated that Na^+ build-up was unlikely since sufficient Ca^{2+} and Mg^{2+} were in excess of what could be precipitated as CO_3^{2-}. However, with respect to RSC, all samples were within the safe quality categories for irrigation. This indicated the suitability of water for irrigation purpose. Spatial distribution map of RSC for the study area is shown in Fig. 7b.

3.3.3 Sodium Percentage (Na%)

The Na% in the study area varied between 11.75 and 49.76 meq/l. Spatial distribution map shows that 27 % of the groundwater samples represented "excellent water", 68 % represented "good water" and 5 % was within the permissible limit according to the categories of classification given in Table 8 (Fig. 7c). Generally, the agricultural yields are reported to be low in case of fields irrigated with water of unsuitable and doubtful classes. This is most probably due to osmotic effects in soil plant system caused by the presence of sodium salts. Hence, wet conditions restrict the circulation of water and air; in dry conditions, such soils become hard [55]. Subba Rao [42] has also reported the use of Na% to evaluate the quality of water for irrigation purposes.

3.3.4 Permeability Index (PI)

PI is classified under three classes. Class I and class II waters are classified as good and suitable for irrigation with maximum permeability of 75 % or more. Class III waters are unsuitable with maximum permeability of 25 % (Table 9). The analytical data are shown in spatial distribution map (Fig. 7d). The PI of the groundwater samples varied between 29.73 and 61.35 meq/l with an average value of 44.19 meq/l. It was observed that 100 % of the samples represented the "suitable water" based on the categorization scheme of PI, which is the class II of Doneen's chart [54].

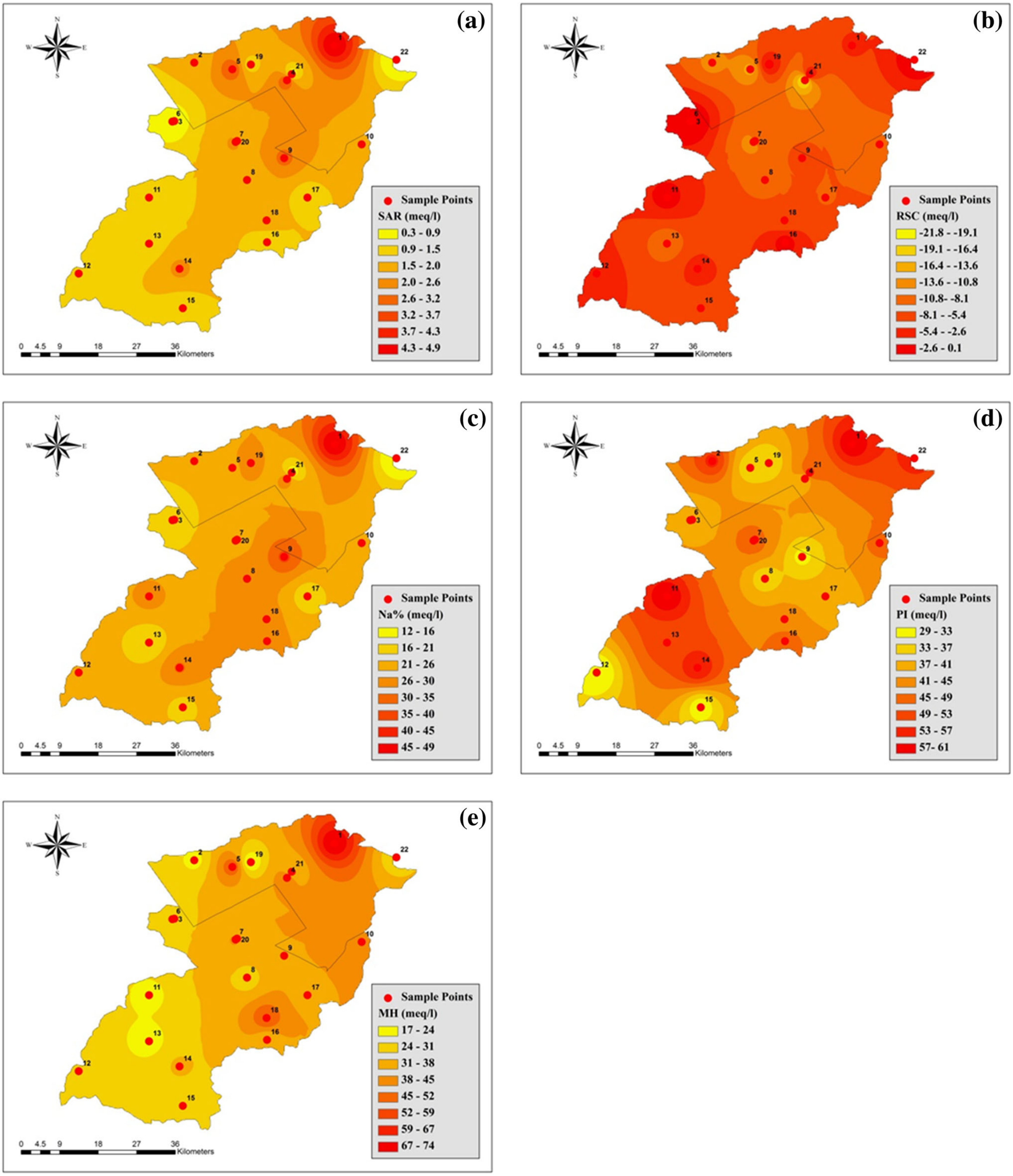

Fig. 7 Spatial distribution of **a** SAR, **b** RSC, **c** Na%, **d** PI, **e** MH

3.3.5 Magnesium Hazard

The deficiency of magnesium ions in plants causes yellowing between leaf veins in late season especially in older leaves, therefore considered essential for plant growth. The magnesium ratio values of the study area varied between 17.45 and 74.13 meq/l with an average value of 34.75 meq/l. Magnesium ratio is considered to be harmful and unsuitable for

Table 7 Water quality based on residual sodium carbonate

RSC (meq/l)	Water quality
<1.25	Good
1.25–2.5	Doubtful
>2.5	Unsuitable

Table 8 Sodium percentage water class

Na% (meq/l)	Water quality
<20	Excellent
20–40	Good
40–60	Permissible
60–80	Doubtful
>80	Unsuitable

Table 9 Water quality based on permeability index (PI)

PI (meq/l)	Water quality
>75 %	Good
25–75 %	Suitable
<25 %	Unsuitable

Table 10 Water quality based on magnesium hazard (MH)

MH (meq/l)	Water quality
<50	Suitable
>50	Unsuitable

irrigation use when exceeds more than 50 [29,58], and this would adversely affect the yield of crop, as soils become more alkaline. The spatial distribution map indicates that 86 % of the samples were not exceeding the magnesium ratio of 50, therefore suitable for irrigation (Fig. 7e). Only 14 % of the samples exceeded the magnesium ratio of 50 and were considered "unsuitable" (Table 10).

The study of the above techniques for the assessment of groundwater suitability for irrigation purposes confirmed the majority of the area having good or suitable water for irrigation. Several researchers have used the geochemical properties of water for the assessment of water quality for different purposes [59–65].

4 Conclusion

WQI is very efficient and useful in summarizing and reporting the monitoring data to the decision-makers to facilitate their understanding of groundwater quality status and to provide an opportunity for better use in future as well. The results and their analysis verified effectiveness of GIS as a tool for construction of various digital thematic layers and maps showing the spatial distribution of various parameters of water quality. The overall view of the WQI showed greater percentage of higher WQI value, indicating the deteriorated drinking water quality. However, SAR, RSC, Na%, PI and MH referred majority of the samples were suitable for irrigation purposes. In the study area, quality of drinking water is slowly reaching alarming stage. The continuous release of industrial effluents from different industries especially the ones with high-temperature processes is considered responsible for the accumulation of heavy metals in the aquifers. Therefore, proper planning is utmost requirement. Different treatment methods for heavy metals removal in effluents should be adopted prior to its release. This study can be taken as baseline information by the authorities for contaminants prevention and groundwater management in future.

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