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Spatial variability of groundwater quality of Sabour block, Bhagalpur district (Bihar, India)

D. K. Verma[1] · Gouri Sankar Bhunia[2] · Pravat Kumar Shit[3] · S. Kumar[1] · Jajati Mandal[1] · Rajeev Padbhushan[1]

Abstract This paper examines the quality of groundwater of Sabour block, Bhagalpur district of Bihar state, which lies on the southern region of Indo-Gangetic plains in India. Fifty-nine samples from different sources of water in the block have been collected to determine its suitability for drinking and irrigational purposes. From the samples electrical conductivity (EC), pH and concentrations of Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sodium (Na^+), Potassium (K^+), carbonate ion (CO_3^{2-}), Bicarbonate ion (HCO_3^-), Chloride ion (Cl^-), and Fluoride (F^-) were determined. Surface maps of all the groundwater quality parameters have been prepared using radial basis function (RBF) method. RBF model was used to interpolate data points in a group of multi-dimensional space. Root Mean Square Error (RMSE) is employed to scrutinize the best fit of the model to compare the obtained value. The mean value of pH, EC, Ca^{2+}, Mg^{2+}, Na^+, K^+, HCO_3^-, Cl^-, and F^- are found to be 7.26, 0.69, 38.98, 34.20, 16.92, 1.19, 0.02, and 0.28, respectively. Distribution of calcium concentration is increasing to the eastern part and K^+ concentrations raise to the downstream area in the south-western part. Low pH concentrations (less than 6.71) occur in eastern part of the block. Spatial variations of hardness in Sabour block portraying maximum concentration in the western part and maximum SAR (more than 4.23) were recorded in the southern part. These results are not exceeding for drinking and irrigation uses recommended by World Health Organization. Therefore, the majority of groundwater samples are found to be safe for drinking and irrigation management practices.

Keywords Groundwater quality · Spatial distribution · GIS · RBF model

Introduction

Groundwater quality is influenced by both the natural and anthropogenic activities (Kouras et al. 2007). Groundwater has been the bastion for congregation of the domestic need of >80 % of rural and 50 % of urban inhabitants, executing the irrigation requirements of approximately 50 % of irrigated farming (Uberoi 2010; Nair et al. 2007). It has been found that 70–80 % of agricultural production of India derives from groundwater irrigation. Observing of ground water quality is an attempt to attain information on chemical properties throughout representative sampling in various hydro-geological units. In recent times, intensive agricultural activities and pollution of surface due to population growth have tremendously affected groundwater quality. In Bihar, drinking water quality primarily depends upon the ground water. The recent report from Bihar government stated that the drinking water sources in rural areas are not safe in most of the area and the health of the

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rural population is at risk (Singh et al. 2014a). Out of the 38 districts, 13 districts located along the river Ganges are partially affected by arsenic contamination (As >50 ppb) whereas the drinking water sources of 6373 habitations of 22 districts are affected with excess Fluoride (>1.5 ppm) and presence of excess iron in groundwater is in majority of the districts arsenic contamination is a major problem in and around the river Ganges in Bihar (http://phed.bih.nic.in/Water-Quality.htm). Recent report stated that the groundwater As contagion has extended to 16 districts, intimidating more than 10 million people in Bihar (Ghosh et al. 2009; Saha 2009; SOES 2012). Water and sanitation-related infections and diseases of the alimentary tract constitute 60–80 % of the illness in rural areas (Mishra 2009). Bhagalpur is directly affected by arsenic contamination in ground water. The report of Central Ground Water Board, *CGWB* (2009), in Bhagalpur area irrigated by varying sources comprise only 35.01 % of the total cropped area, out of which only 9.48 % is dish up by surface water and the remaining 25.53 % is provided by ground water. Assessment of groundwater quality for drinking and irrigation is important for present and future water management. Consequently, the characterizations of irrigation water quality play an imperative role in improving its management strategies for profitable farming. The improper management of water systems may cause serious problems in availability and quality of water in near future (Kendaragama 2000; FAO 2003). Therefore, it is essential to study the quality of groundwater.

Measuring the chemical composition of groundwater determines its suitability for the source of water for human and animal consumption, irrigation, and for industrial and other purposes (Babiker et al. 2007). Hence, scrutinizing the quality of water is significant as clean water is obligatory for human well-being and the veracity of aquatic ecosystems. GIS based mapping of groundwater quality is an significant component of a groundwater planning strategy, provides potential contaminated zone and indicates suitability of water for drinking, irrigation (Adhikary and Biswas 2011; Al Hallaq and Elaish 2012; Adhikary et al. 2012) and other purposes.

The present investigation was undertaken to study the physico-chemical characteristics of groundwater of Sabour block, Bhagalpur district (Bihar, India) between 2012 and 2013. Consequently, the geochemical observation of groundwater permits us to attain imperative information on chemical weathering of rocks. Sabour block in Bhagalpur district is situated on the bank of Ganga River, even though most of the people fulfill their need for water from groundwater. The characteristics such as electrical conductivity (EC), pH, calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+), carbonate (CO_3^{2-}), bicarbonate (HCO_3^{2-}), chloride (Cl^-), fluoride (F^-), Hardness, sodium adsorption ratio (SAR) and residual sodium carbonate (RSC) were studied. The spatial variation of irrigation and drinking water quality was mapped using GIS, utilizing the data generated from chemical analysis of water samples collected from the area under study.

Materials and methods

Study area

The study area is situated between and 25°07′10″ and 25°18′15″N latitude and 86°59′24″ and 87°10′25″E longitude and 37.19 m mean sea level and covers almost 114.95 km² (Fig. 1). The climate is subtropical with an average annual rainfall and evaporation value of about 1300 and 2100 mm, respectively (average of 30 years). Southwest monsoon (July–September) contributes 80 % of total rainfall. Generally the eastern and northeastern parts of the district receive higher amount of rainfall. The monthly mean temperature ranges from 20 to 45 °C, while the annual mean temperature is 31 °C. The study area consists mainly of alluvial soil formation. Soils are coarse loamy, mixed, hyperthermic, and Typic Haplustepts. The surface soils comprise mostly of ferruginous lime quartzite, granites, and schistose rock minerals (Verma et al. 2015). The land use has changed significantly over the years due to urbanization. Out of the total area, nearly 80 % is cultivated, and the rest is occupied by habitats, roads, ponds, forests, and so on. This area was well covered earlier with dense vegetation. Pearl millet is the main rainy season crop along with guar, chickpea, and green gram. These are followed by wheat and mustard in winter.

Sampling and analysis

Total of 59 ground water samples were collected from the dug wells (open well), hand pumps, submersible pump and deep tube well in the region during the post monsoon period between November 2012 and January 2013. The spatial locations of surveyed points (59) were recorded through Global Positioning System (GARMIN International Inc., Kansas, USA). The groundwater samples were collected in 1 L narrow mouth pre-washed polyethylene bottles. Electrical conductivity (EC) and pH values were measured in the field using a portable conductivity and pH meter. In the laboratory, the water samples were filtered through 0.45 μm Millipore membrane filters to separate suspended particles. Acid titrations were used to determine the concentration of bicarbonate; carbonate (CO_3^{2-}) and Mohr's titration method were used to determine the concentration of chloride in groundwater. Concentrations of major anions (F^-) were determined by UV
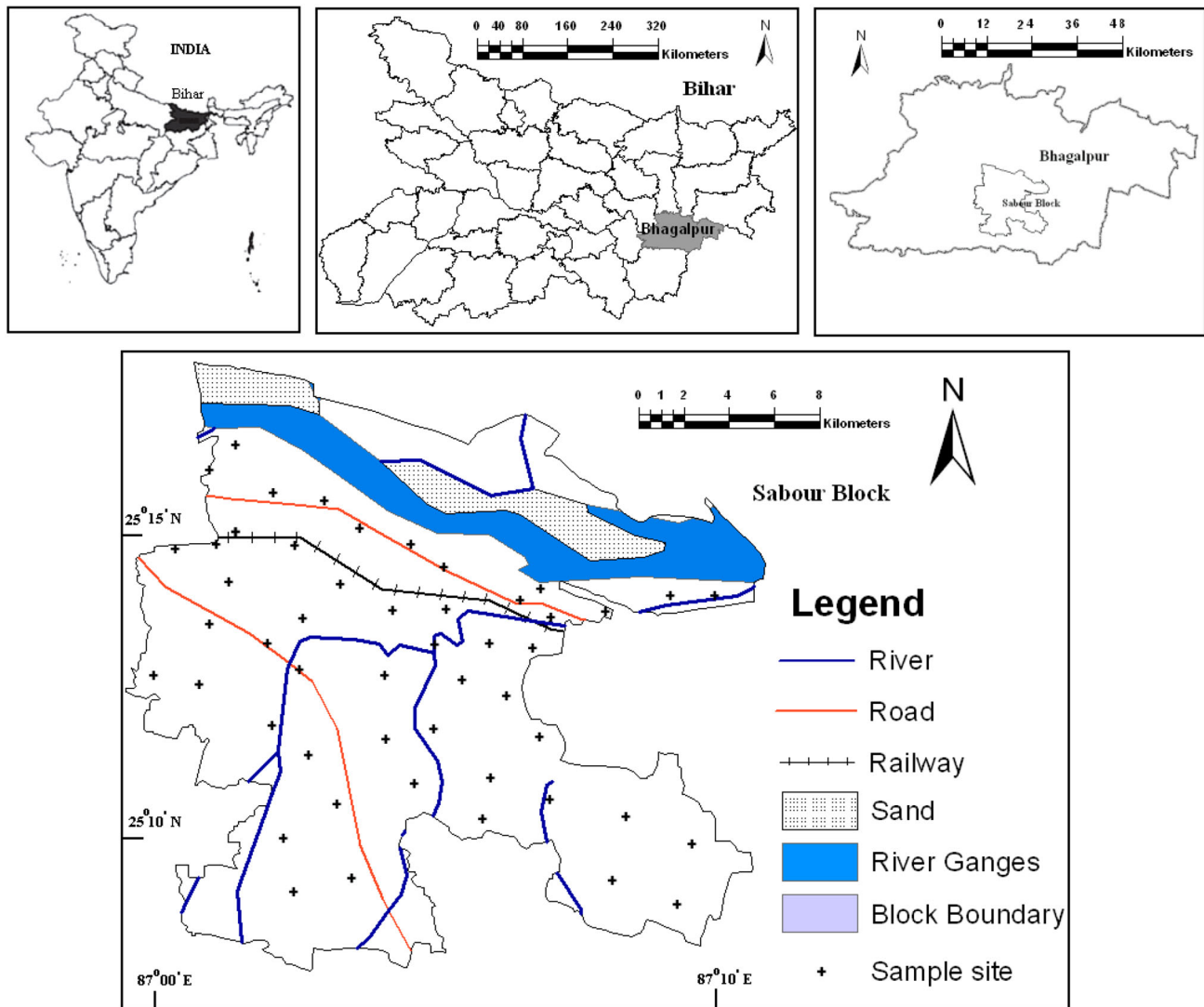
Fig. 1 Location of map to the sampling site area of Sabour Block, Bhagalpur District, Bihar

spectrophotometer. Concentration of major cations (Ca^{2+}, Mg^{2+}, Na^+, and K^+) were determined by flame Photometry and flame atomic absorption spectrophotometer (AAS).The initial physio-chemical characteristics of groundwater samples and quality of drinking and irrigation water were determined using the standard analytical methods (Table 1).

Spatial variability of groundwater quality

To understand the spatial variation of groundwater quality analyses were performed employing ArcGIS software v.9.0 (ESRI, Atlanta, USA). Survey of India (SOI) topographical sheet with a scale of 1:50,000 covering the entire study block was scanned. Topographical sheets were geo-referenced with Universal Transverse (UTM) projection System and World Geodetic System (WGS) 84 datum based on

first order polynomial transformation. The sample locations were digitized as points and database were generated in association with physico-chemical properties derived from the survey points.

The deterministic interpolation methods (i.e. *IDW* inverse distance weighting, *LPI* local polynomial interpolation, *RBF* radial basis function) create continuous surfaces from measured points by taking advantage of mathematical formulae that determine either the extent of similarity or the degree of smoothing of the surface. Surface maps of all the groundwater quality parameters were prepared using Radial Basic Function (RBF) method. RBF model was used to interpolate data points in a group of multi-dimensional space (Pal et al. 2014). In the RBF interpolation technique a completely regularized spline kernel function is used to control the smoothness of the surface for the higher parameter value. The groundwater

Table 1 Methods of estimation of different hydrochemical parameters of groundwater

Parameters	Methods
Electrical conductivity (EC)	Conductivity Bridge method (Richards 1954)
pH	Digital pH meter
Calcium (Ca^{2+})	EDTA titration method (Richards 1954)
Magnesium (Mg^{2+})	EDTA titration method (Richards 1954)
Sodium (Na^+)	Flame Photometric method (Osbom and Johns 1951)
Bicarbonate (HCO_3^-)	Acid titration method (Hesse 1971)
Carbonate (CO_3^{2-})	Acid titration method (Hesse 1971)
Chloride (Cl^-)	Mohr's titration method (Hesse 1971)
Fluoride (F^-)	Alzarin S visual method (Crosby et al. 1968)
Potassium (K^+)	Flame Photometric method (Osborn and Johns 1951)
Hardness (As calcium carbonate concentration)	EDTA titration method (Richards 1954)
Sodium adsorption ratio (SAR)	$SAR = \dfrac{Na^+}{\sqrt{\frac{Ca^{++}+Mg^{++}}{2}}}$

quality data has been checked by a histogram tool and normal Quantile–quantile (QQ) plots to see if it shows a normal distribution pattern. Root Mean Square Error (RMSE) is employed to scrutinize the best fit of the model by evaluating its value, and the smallest value of RMSE determines the most suitable model to the data. Accurate predictions have a value close to zero. For each water quality parameter, prediction performances were assessed by cross-validation.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left[Z(x_i) - Z \times (x_i)\right]^2} \qquad (1)$$

In this research, the procedure for the application of methodology in the framework of GIS software for spatial analysis of groundwater chemistry is illustrated in Fig. 2, and the following steps (Mehrjardi et al. 2008) were followed: (1) Exploratory spatial data analysis (ESDA) was performed using ArcGIS v9.0 software for the groundwater chemistry and to study the spatial distribution of the data. (2) Spatial interpolation for groundwater chemistry data was performed using ArcGIS v9.0 software, and the RBF model was used to generation of the groundwater chemistry maps.

Results and discussion

Groundwater quality

Table 2 presents the physico-chemical data of the analysed groundwater samples of the Sabour block, Bhagalpur district (Bihar, India). To ascertain the portability of groundwater for drinking and irrigation purposes, the analytical results have been compared with the standard guideline values recommended by the World Health Organisation
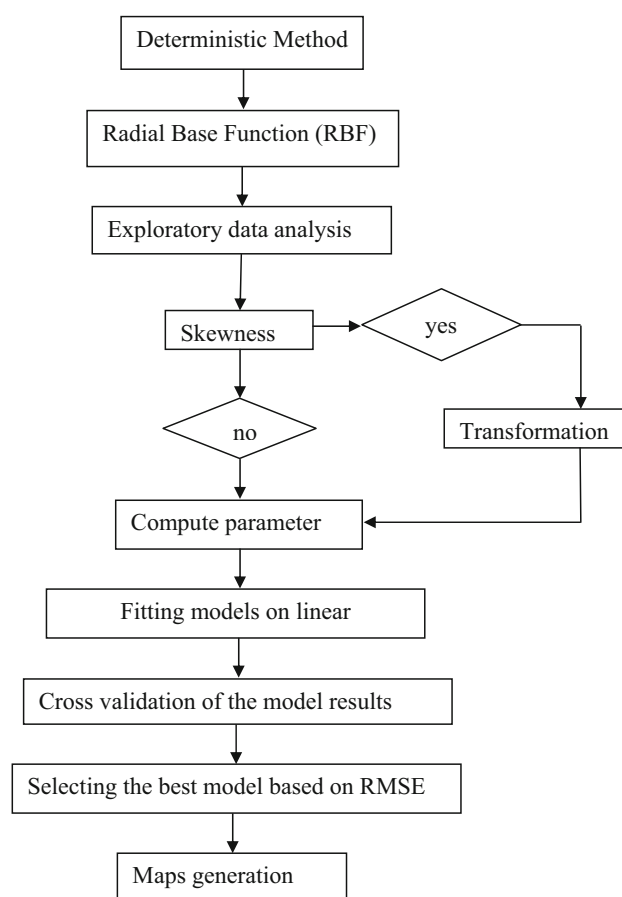
Fig. 2 Flow chart of the steps followed for the deterministic analysis

(WHO 2011) and Bureau of Indian Standards (BIS 1991). Table 2 shows that pH values of the groundwater samples (6.45–8.36) are well within the safe limit of 6.5–8.5, prescribed for drinking water (BIS 1991). The ions are present below the permissible limit. Hardness of the water is the property attributed to the presence of alkaline earths. Total

Table 2 Physico-chemical characteristics of ground water samples collected from Sabour block Bhagalpur district

Descriptive statistics	pH	EC dS m⁻¹	Cl^- mg L⁻¹	CO_3^- mg L⁻¹	HCO_3^- mg L⁻¹	F^- mg L⁻¹	Hardness mg L⁻¹	Ca^{++} mg L⁻¹	Mg^{++} mg L⁻¹	Na^+ mg L⁻¹	K^+ mg L⁻¹	SAR	RSC
Mean	7.26	0.69	72.18	0.01	0.02	0.28	179.12	38.98	34.20	16.92	1.19	2.68	−73.14
Standard Error	0.05	0.04	10.31	0.00	0.00	0.05	5.79	2.09	1.06	0.86	0.08	0.17	2.83
Median	7.10	0.63	39.99	0.01	0.02	0.04	176.00	35.30	33.70	16.90	1.20	2.80	−67.15
Mode	6.97	0.63	12.50	0.01	0.02	0.00	170.00	36.90	33.00	18.40	1.60	3.10	−64.48
Standard Deviation	0.41	0.27	79.16	0.00	0.01	0.42	44.49	16.03	8.11	6.60	0.59	1.28	21.76
Kurtosis	−0.12	0.58	1.96	2.26	−0.61	0.69	6.08	0.15	7.83	−0.79	−0.75	−0.58	2.30
Skewness	0.78	0.96	1.59	−1.25	0.52	1.42	1.67	0.91	1.78	0.38	0.33	0.39	−1.34
Range	1.91	1.23	337.40	0.02	0.02	1.34	280.00	71.40	54.90	23.10	2.34	5.12	113.38
Minimum	6.45	0.18	0.00	0.00	0.01	0.00	100.00	10.40	17.90	6.60	0.16	0.48	−154.52
Maximum	8.36	1.41	337.40	0.02	0.03	1.34	380.00	81.80	72.80	29.70	2.50	5.60	−41.14

hardness (TH) of the analysed sub-surface water varies between 100.00 and 380.00 mg L⁻¹ with a mean value of 179.12 mg L⁻¹, indicating low to moderately hard types of groundwater (Sawyer et al. 2003). Hardness value exceeds the desirable limit of 300 mg L⁻¹ in 2 % of the groundwater samples (BIS 1991). Hardness of water prevents lather formation with soap and increases the boiling point of the water. The high hardness may cause precipitation of calcium carbonate and encrustation on water supply distribution systems. The very hard water requires softening for household or commercial uses.

The contents of HCO_3^- and Cl^- have no known adverse health effects; however, it should not exceed the safe limits of 300 and 250 mg l⁻¹, respectively, in drinking water. The analytical data show that HCO_3^- exceeds the desirable limit in about 3 % and Cl^- in 2 % of the ground water samples. Higher concentration of Cl^- in drinking water gives a salty taste and has a laxative effect for those who are not accustomed to it. Fluoride is an essential element for maintaining normal development of healthy teeth and bones. However, higher F^- concentration causes dental and skeletal fluorosis such as mottling of teeth, deformation of ligaments and bending of spinal chord (Singh et al. 2014b). Concentration of F^- marginally exceeds the permissible limit of 1.5 mg L⁻¹ in about 65 % of the groundwater samples.

Among the cations, Na+ is most important ion for human health. A higher sodium intake may cause hypertension, congenial heart diseases, nervous disorder and kidney problems. The recommended limit for sodium concentration in drinking water is 200 mg L⁻¹ (WHO 2011; BIS 1991). Concentrations of Na^+ no exceed the recommended level of the groundwater samples. Calcium and magnesium is an essential element for bone, nervous system and cell development. One possible adverse effect from ingesting high concentration of Ca^{2+} for long periods may be an increased risk of kidney stones (Magesh et al. 2012). Concentrations of Mg^{2+} and Calcium are not exceeding the maximum permissible limit of 100 and 200 mg L⁻¹, respectively, of the groundwater samples (BIS 1991). Therefore, the groundwater is safe for drinking purpose of the study area.

The total salt concentration, sodium percentage (%Na), Electrical conductivity (EC), residual sodium carbonate (RSC), and sodium adsorption ratio (SAR) are the important parameters used for assessing the suitability of water for irrigation uses (Kumar et al. 2014). Water used for irrigation always contains measurable quantities of dissolved substances as salts. The salts, besides affecting the growth of the plants directly, also affect soil structure, permeability and aeration, which indirectly affect plant growth. Irrigation with high sodium water causes exchange of Na+ in water for Ca^{2+} and Mg^{2+} in soil and reduces the

permeability and eventually results in soil with poor internal drainage (Sarath et al. 2012). As per the Indian Standard, maximum sodium percent (%Na) of 100 % in water is recommended for safe irrigation (BIS 1991). Sodium percent value in the analysed samples range between 48 and 56 % (avg. 26.8 %) and groundwater of the study area is excellent to good and good to permissible quality for irrigation uses according to Wilcox model (1955). The pH of the groundwater lies between 6.45 and 8.36 shows that the groundwater is slightly acidic to alkaline reaction.

EC is one of the most prolific adverse environmental impacts associated with irrigation. Saline condition severely limits the choice of crop, adversely affect seed germination and crop yields. Excessive solutes in irrigation water are a common problem in semi-arid areas where water loss through evaporation is high. Salinity problem encountered in irrigated agriculture area are most likely to arise when the drainage is poor. This allows the water table to rise close to the root zone of plants, causing the accumulation of sodium salts in the soil through capillary rise following surface evaporation of water. EC values range between 0.18 and 1.41 dS m^{-1} and show that the water sample is slightly saline in nature and not have any harmful effect to agricultural land and crop. Hameed et al. (1966) proposed water having EC value less than 1.5 is safe for irrigation. Since, entire water samples EC is less than 1.5, therefore they are safe for irrigation purpose. SAR value ranges from 0.48 to 5.60. Based on Richards (1954) SAR categories to reveal irrigation water quality suggest Sabour block has excellent groundwater quality for irrigation use (SAR < 10). The observed RSC values ranges from −154.52 to −41.14. A negative RSC value indicates that the sodium build-up is unlikely and sufficient calcium and magnesium that can precipitate as carbonates. So, the present results show that good to moderate quality of groundwater for irrigation and correlation among the variables are shown in Table 3.
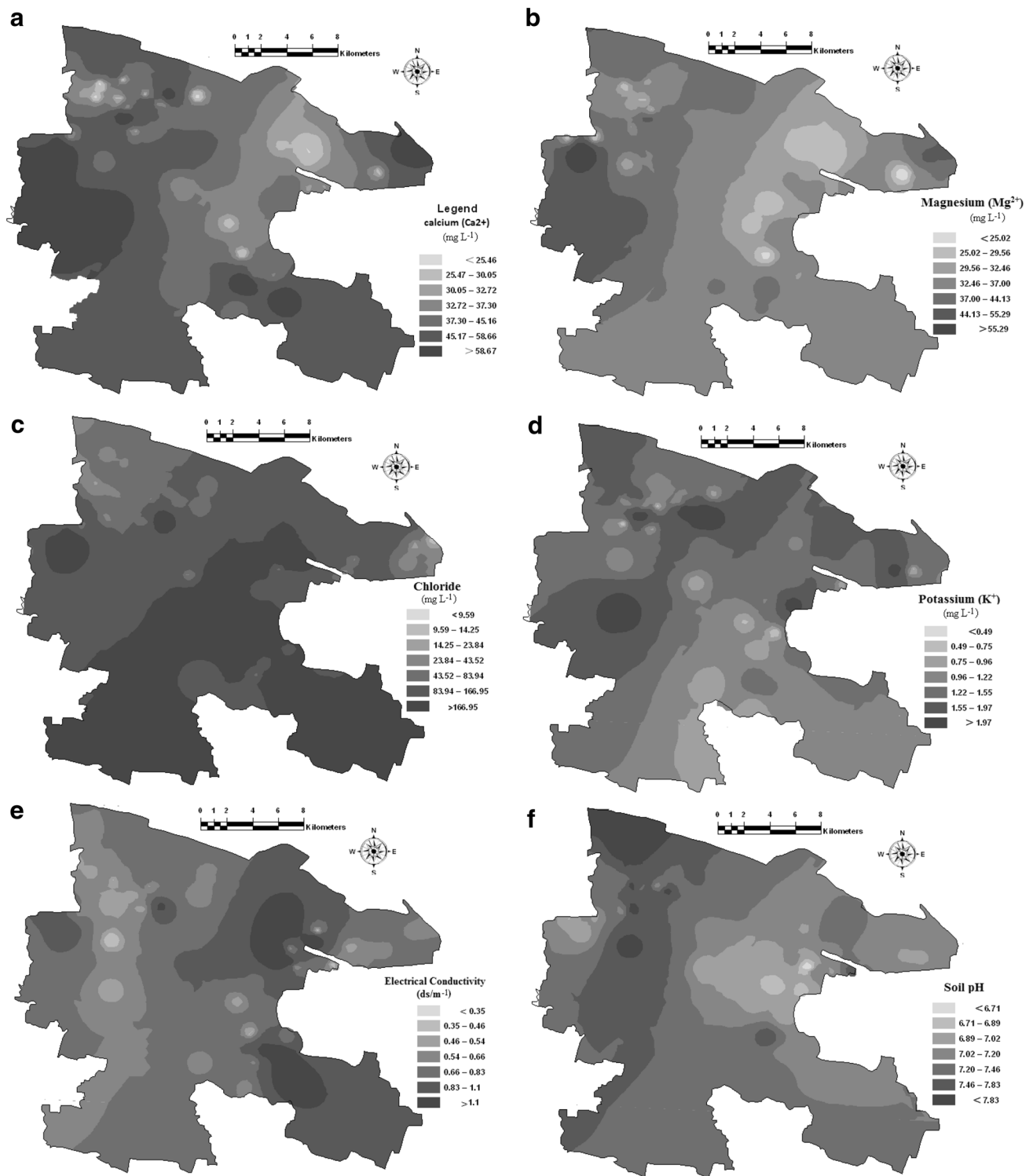
Spatial assessment of groundwater quality

The spatial distribution of groundwater chemistry of the study area was analysed. Calcium concentration in groundwater varies from 10.40 to 81.80 mg L^{-1} with mean and standard deviation of 38.97 and 2.09 mg L^{-1}, respectively. Figure 3a shows that the trend of the distribution of calcium concentration is increasing to the eastern part of the study areas. Small pockets of calcium concentration also portrayed in the northeast and southeast part of the study site. Minimum concentration of calcium was observed in the northern and northwest part of the study site. There are twenty wells (35 %) which have calcium concentration below 30.0 mg L^{-1}. Magnesium are varies from 17.90 to 72.80 mg L^{-1} with mean and standard deviation of 34.20 and 1.06 mg L^{-1} respectively. Figure 3b shows the concentration of Magnesium in the eastern part of the study area.

There are widely varying concentrations of chlorides in all natural waters. The chloride content usually rises as the mineral content enhances. Chloride (Cl$^-$) concentration ranges from 9.59 to 337.40 mg L^{-1} with mean and standard deviation of 72.19 and 79.16 mg L^{-1}, respectively. Cl$^-$ in surface and groundwater from both natural and anthropogenic sources, such as run-off containing road deicing salts, the use of inorganic fertilizers, landfill leachates, septic tank effluents, animal feeds, industrial effluents, irrigation drainage (Ottawa 1978). High absorption of chloride provides a salty savour to water and beverages (WHO 2011). Figure 3c shows the highest trend for the allocation of chloride concentration in central part of

Table 3 Correlation matrix of groundwater quality parameters

|	SAR	RSC	pH	Na$^+$	Mg^{2+}	K$^+$	HCO$_3^-$	Hardness	F$^-$	EC	Cl$^-$	Ca^{2+}
SAR	1											
RSC	0.18	1										
pH	0.18	1	1									
Na$^+$	0.86	0.15	0.15	1								
Mg^{2+}	0.86	0.15	0.15	1	1							
K$^+$	0.21	0.12	0.12	0.14	0.15	1						
HCO$_3^-$	0.03	−0.21	−0.21	−0.04	−0.04	−0.04	1					
Hardness	0.03	−0.21	−0.21	−0.04	−0.04	−0.04	1	1				
F$^-$	0.03	−0.21	−0.21	−0.04	−0.04	−0.05	1	1	1			
EC	0.06	−0.45	−0.45	0.04	0.04	−0.01	0.36	0.36	0.36	1		
Cl$^-$	0.03	−0.20	−0.21	−0.04	−0.04	−0.05	1	1	1	0.36	1	
Ca$^+$	0.96	0.18	0.18	0.70	0.70	0.21	0.06	0.06	0.06	0.06	0.06	1

Fig. 3 spatial variation of groundwater quality. **a** Calcium, **b** Magnesium, **c** Chlorides, **d** Potassium, **e** Electrical conductivity, **f** pH

the study area. It portrays a lessening concentration toward the northeast and northwest part of the study area. In a wide area around the south and southeast part of the city, less than 25.02 mg L^{-1} chloride concentration occurs.

The potassium (K^+) varies from 0.16 to 2.50 mg L^{-1} with mean and standard deviation of 1.19 and 0.58 mg L^{-1}, respectively. Figure 3d shows that the K^+ concentrations raise to the downstream area in the southwestern part of the

study site and small pockets of northwest part were also observed. There is a declining trend of K^+ in the south and southwest part of the study site.

EC is a parameter related to total dissolved solids. Concentrations of EC in water vary considerably in different geological regions owing to differences in the
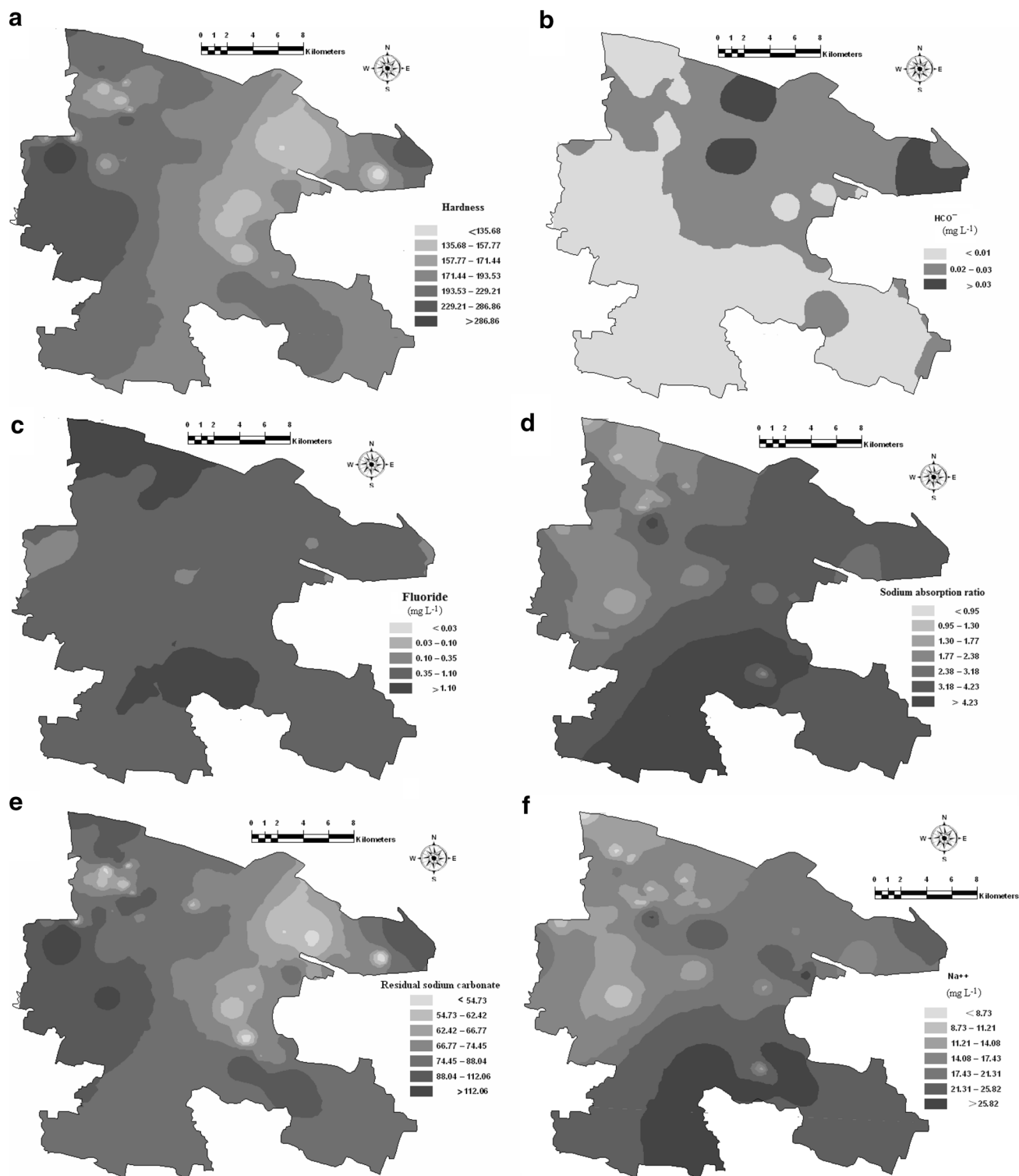
Fig. 4 Spatial variations of groundwater quality. a Hardness, b Bi-carbonate (HCO_3^{2-}), c Fluoride, d sodium absorption ratio (SAR), e Residual sodium carbonate (RSC), and f Nitrate

solubility of minerals (WHO 2011). EC varies from 0.18 to 1.4 dS m^{-1} with mean and standard deviation of 0.69 and 0.24 dS m^{-1}, respectively. Figure 3e shows EC values increasing in the north and southeast part of the study site and minimum value was observed in the western part of the study area.

pH is one of the most important operational water quality parameters, with the optimum pH required often being in the range of 6.5–9.5 (WHO 2011). The minimum and maximum values of pH in the study area were measured as 6.45 and 8.36, respectively. The average value of pH was the study area was 7.24 with standard deviation of ±0.41. Spatial distributions of pH concentrations are shown in Fig. 3f. It is shown that the low pH concentrations (less than 6.71) occur eastern part of the block. Consequently the maximum concentration (more than 7.83) has been recorded from the northwest corner of the study area.

Hardness in water is caused by dissolved calcium and, to a lesser extent, magnesium. It is usually expressed as the equivalent quantity of calcium carbonate (WHO 2011). There is some indication that very soft waters may have an adverse effect on mineral balance, but detailed studies were not available for evaluation. The average hardness value of the study area showed 179.12 with standard deviation of 8.11. Spatial variation of hardness in Sabour block portraying maximum concentration in the western part of the study area, while lesser concentration was observed in the northern and eastern part of the study site (Fig. 4a).

Nitrate concentration fluctuates from 6.60 to 29.70 mg L^{-1} with mean and standard deviation of 16.92 and 6.59 mg L^{-1}, respectively. Figure 4f shows that southern and southeast part of the study area have high nitrate concentration, and they are not healthy for drinking consumption due to the human activities in the study area causing leaching of nitrogen from farm fertilizer, feedlots, and septic tanks. Nitrate concentration tendency is declining to the northwest and western part of the study area. Interflow of shallow groundwater comes out in plain alluvial in riparian areas. On the other hand, nitrates stimulated in infiltrated water from uplands soil into shallow groundwater may emerge in surface water bodies and turn into an environmental quality dilemma. Fluoride varies 0–1.34 mg L^{-1} and an average value is 0.28 mg L^{-1} (Table 2). The concentrations of Fluoride are found to be in northern and southern corners of the region (Fig. 4c).

The HCO$_3^-$ ion concentrations vary from 0.01 to 0.03 mg L^{-1} with an average value of 0.02 mg L^{-1} in the study area (Fig. 4b). Consequently, the bicarbonates originated due to the oxidation and decomposition of organic pollutants and because that CO$_2$ reacts with soil and releases HCO$_3^-$ into the groundwater (Tyagi et al. 2009; Vasanthavigar et al. 2010).

The sodium vulnerability to groundwater is initiated by formative sodium absorption ratio (SAR). The alkalinity hazard was measured by SAR. The SAR was intended via the formula adopted by Karnath (1987). Results shown in the study area maximum SAR (more than 4.23) were recorded in the southern part and minimum SAR (less than 0.95) was recorded in eastern and northeast corner. The mean value of SAR is recorded as 2.68 with standard deviation of 0.59 of the study area (Fig. 4d).

The concentration of Residual sodium carbonate (RSC) in groundwater occurred due to the higher concentration of bicarbonate ions. It precipitates Ca^{2+} and Mg^{2+} ions as their carbonates and amplifies the Na$^+$ ion that raises the sodium carbonate in the groundwater (Srinivasamoorthy et al. 2013; Tiwari et al. 2014). RSC is used to classify

Table 4 Summary statistics of Kernel function (Completely regularized spline model)

Variables	Regression function	Mean	ME	RMSE	Kernel parameter
pH	$Y = 0.27 * X + 5.29$	0.017	0.008	0.40	0.149
EC	$Y = 0.09 * X + 0.60$	0.011	0.009	0.27	0.09
Cl$^-$	$Y = 0.18 * X + 50.01$	0.95	0.114	0.84	0.149
CO$_3^-$	$Y = 0.18 * X + 50.01$	−0.950	0.003	0.11	0.149
HCO$_3^-$	$Y = 0.093 * X + 0.013$	0.002	0.006	0.005	0.23
F$^-$	$Y = 0.048 * X + 0.023$	0.002	0.06	0.007	0.15
Hardness	$Y = 0.056 * X + 180.88$	7.31	0.48	0.98	0.14
Ca^{2+}	$Y = 0.13 * X + 39.79$	4.33	0.61	0.89	0.075
Mg^{2+}	$Y = -0.008 * X + 36.45$	1.24	0.09	0.18	0.14
Na$^+$	$Y = 0.23 * X + 14.40$	1.72	0.03	0.12	0.31
K$^+$	$Y = 0.027 * X + 1.457$	0.28	0.02	0.66	0.011
SAR	$Y = 0.27 * X + 2.25$	0.41	0.02	0.15	0.14
RSC	$Y = 0.11 * X + 71.54$	4.31	0.81	0.93	0.091

X variables of X, *Y* prediction of Y variables, *ME* mean error, *RMSE* root mean square error
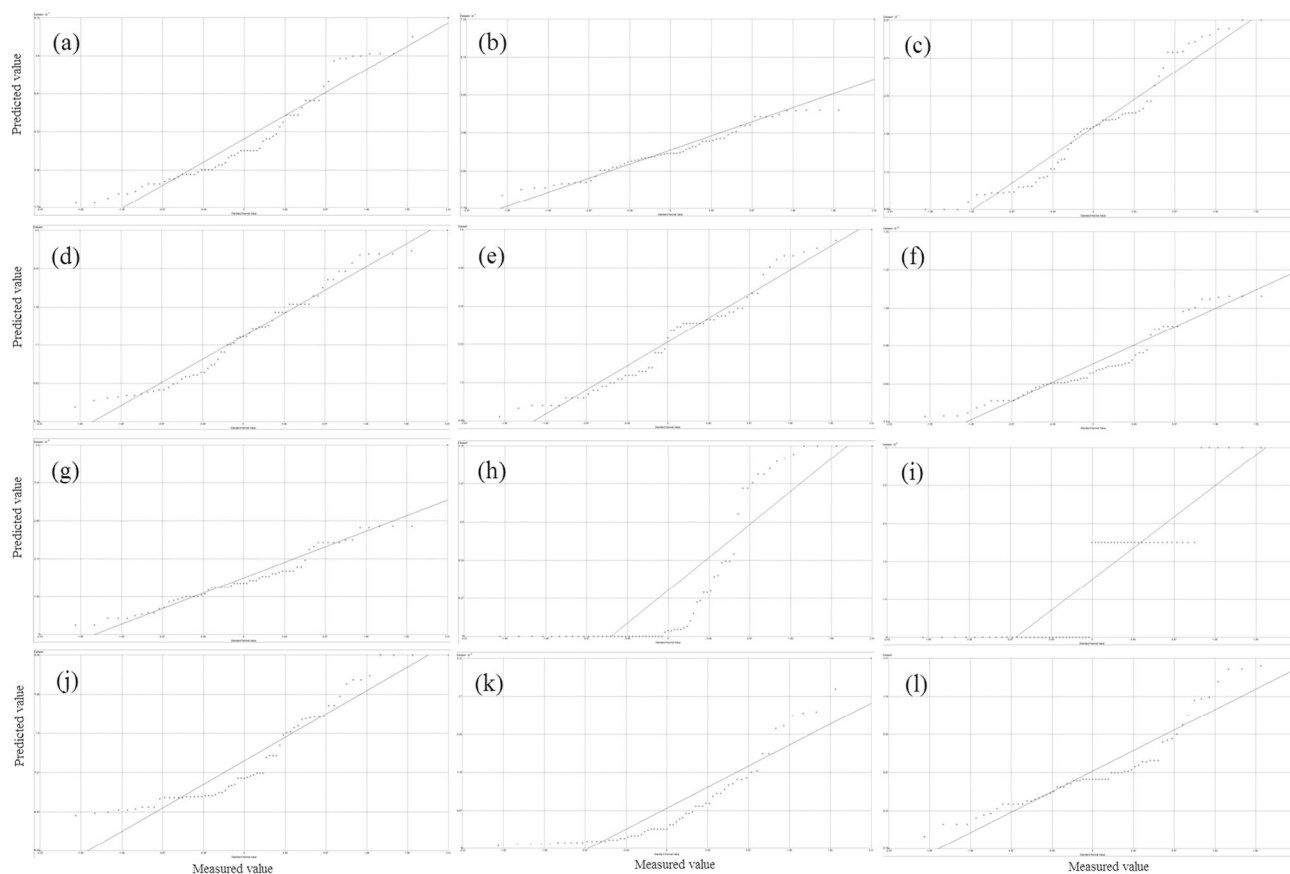
Fig. 5 QQ plot for the predicted values and measured values of groundwater parameters. **a** Calcium, **b** Magnesium, **c** Nitrate, **d** Potassium, **e** SAR, **f** RSC, **g** Hardness, **h** Fluoride, **i** Bi-carbonate (HCO_3^-), **j** pH, **k** Chlorides, and **l** EC

groundwater for irrigation purposes, calculated by the equation developed by Eaton (1950). RSC of the study area ranges from 41.14 to 154.52. The average value of RSC is recorded as 73.14 with standard deviation of 21.76. Spatial distribution of RSC portrayed maximum concentration in the western corner of the study area and very small pockets are found in the northeast and northwest. Low concentration of RSC was observed in the eastern side in Fig. 4e. However, physico-chemical properties of groundwater vary in both the natural and anthropogenic sources like runoff containing inorganic fertilizers, animal feeds, irrigation drainage, etc. (Aghazadeh et al. 2011; Kumar et al. 2014).

The results of cross-validation show the smoothing effect of the spatial prediction map using RMSE value. Table 4 shows that the RMSE values are approximate to 0. Figure 5 shows that the QQ plot of the observed value against predicted value of groundwater chemistry. The results indicate that the predicted maps of groundwater from RBF method are reliable. Therefore, these results are not exceeding for drinking and irrigation uses recommended by World Health Organization (2011) in the whole region.

Conclusion

GIS can provide appropriate platform for convergent analysis of large volume of data and decision making so that groundwater-based studies can be done effectively. The spatial variation maps of major groundwater quality parameters showed groundwater quality zones of the Sabour block, in Bhagalpur district. Thematic maps of parameters distribution are generated by spatial statistical technique. Deterministic method has an improbability and the prediction surfaces were appraised by cross validation. The present result showed that suitability of groundwater for drinking and irrigation purposes. However, regular observation of groundwater table along with chemistry will lessen the probability of further worsening. Further analysis of pre-monsoon and monsoon period of groundwater quality is required to understand the human and natural impact in the study area. The study helps us to understand the quality of the ground water resources to develop suitable management.

necessary laboratory facilities for conducting the research work. We also thank the anonymous referees for their helpful comments and suggestions.

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