

Chapter 6

Groundwater Quality Through Multi-Criteria-Based GIS Analysis: Village Level Assessment



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Abstract Groundwater quality deterioration is becoming a very vital issue among various environmental problems in the present decades. Good quality of groundwater helps in healthy living status and high crop yield. A village level study is the need of the hour. The present study analyzes the groundwater quality of different villages in Kashipur block of Purulia district in West Bengal. Water samples were collected from 52 bore wells in this study area in two different seasons (pre-monsoon and post-monsoon). Chemical properties of the water samples (pH, EC, TDS, TH, TA, Na^+ , Ca^{2+} , Mg^{2+} , SO_4^{2-} , HCO_3^- , CO_3^{2-} , Fe, K^+ , and F^-) were measured by various methods, and these values were analyzed to indicate different irrigation water quality by SSR, SSP, MAR, and KR method. The overall groundwater quality was analyzed by the PIG (Pollution Index of Groundwater) method for both the seasons. PIG values vary from 0.46 to 1.50 in the pre-monsoon season and from 0.38 to 1.38 in the post-monsoon season. 73.07% of the samples indicate insignificant pollution, 26.92% of the samples indicate low pollution, and only 0.01% of the samples show high pollution in the pre-monsoon season. The spatial distribution map was prepared using kriging interpolation technique on ArcGIS platform. PIG values of post-monsoon season show 67.30% of samples fall under the insignificant pollution zone, 32.69% of samples fall under the low pollution zone, and only 0.01% of samples indicate a high pollution zone. A statistical method such as summary statistics and correlation matrix was used to understand the interdependence or magnitude of each variable to the others in two climatic seasons. Results clearly defined that anthropogenic and geogenic conditions mainly determine the quality of

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groundwater. Mapping of the PIG zone by GIS techniques helps to show the influence of geological and anthropogenic sources on the quality of groundwater in the study area.

Keywords Chemical parameters · Correlation matrix · GIS · Irrigation water quality · Ordinary kriging · PIG · Statistical methods

6.1 Introduction

Groundwater is a precious and important resource of water in the earth, naturally occurred by the hydrological processes. Groundwater is less contaminated than the surface water and generally bacteria-free; therefore, it is very useful for drinking and other consumption purposes (Nag and Das 2017). In developing countries, about 80% of diseases are associated with the poor sanitary conditions and unhealthy drinking water (UNESCO 2007). In India, with the rising number of the human population, the demand for groundwater usage is increasing abruptly. Thus, human health is directly related to the quality of groundwater. Surface and subsurface water have been deteriorated by increasing anthropogenic wastes, untreated sewerage, and related unconscious public activities (Shanmugasundharam et al. 2015). This practice changes the overall quality of groundwater which deteriorates the standards of water quality used for drinking and irrigation purposes. Therefore, assessment on the quality of groundwater is important to measure the suitability for different uses especially for drinking and irrigational purpose (Nag and Das 2017).

Several research works have been carried out to measure the groundwater quality as the characteristics of soil and rock media influenced the chemical quality of groundwater (Raji and Alagbe 1997; Acheampong and Hess 1998; Foster et al. 2000). Hydro-chemical characteristics of water quality have been conducted by various researchers in the different river basins (Umar et al. 2006; Raju 2007; Rao et al. 1997; Subramani et al. 2005). The source of groundwater and the ion-exchange process determines the hydrochemistry of water (Mercado 1985). Quality of groundwater and its usefulness to drinking as well as irrigation purpose has been assessed by many scholars (Jalali 2006; Rivers et al. 1996; Nag and Lahiri 2012; Nag and Das 2017). Groundwater quality zonation map has been prepared using GIS techniques in the Nalgonda district (Brindha and Elango 2012). Water quality assessment by hierarchical cluster analysis method and CCME index method of Damodar river in south Bengal was done by Halder et al. (2014). The groundwater potential zone has been documented using MIF (multi-influencing factor) by weighted method in Birbhum district by Thapa et al. (2017). Quality and degree of groundwater pollution have been analyzed by PIG (Pollution Index of Groundwater) and ANOVA test, correlation, and piper diagram in a rural part of Telangana state, India, by Rao et al. (2018). Fluoride laden groundwater appraisal in Suri-I and Suri-II blocks of Birbhum district, West Bengal, was conducted by geochemical model PHREEQC and piper diagram (Das and Nag 2017). An investigation on crystalline rocks for the

development of groundwater resources has been analyzed by Ahmed (2007) and Wright and Burges (1992). Potential lineaments of groundwater and impacts on regional subsidence and vulnerability to groundwater pollution have been analyzed by GIS techniques (Taheri et al. 2015; Singh et al. 2015). Spatial distribution mapping of the different parameters is generated by ordinary kriging (OK) and irrigational water quality threshold limit which is obtained by indicator kriging (IK) (Masoomah et al. 2014).

Several studies have been carried out to investigate the groundwater quality using GIS platform. But the relation between groundwater quality with its geomorphologic structure and various physical factors using GIS techniques has not been done yet. Therefore, the present study is to analyze the quality of groundwater for drinking and irrigation purpose with its different bio-chemical parameter and find the relation of its variation with different geogenic conditions in two different climatic seasons using GIS techniques to determine the suitability of use in domestic as well as agricultural purpose.

The present study area (Kashipur block of Purulia district) is situated on the eastern part of the Chotanagpur plateau of the Indian peninsula with semi-arid climate. People of this area use groundwater for mainly drinking and irrigation purpose. Water samples were collected from the hand-dug wells and bore wells. But the shallow aquifers of this area are mostly contaminated by storm water and human activities, which bring changes in the physio-chemical parameters of water quality. According to WHO and BIS if the dilution of any parameter is above the standard limit, there can be health problems. In the Kashipur block geological, lithological, vegetation, soil, and human livelihood characteristics influenced the quality of groundwater (Kundu and Nag 2018). Therefore, the assessment of the Water Quality Index (WQI) with geospatial techniques is very essential for further management of groundwater resource in this area.

6.2 Study Area

Kashipur block (Purulia district of West Bengal) is located in the part of eastern fringe of Chotanagpur plateau extended between 23°18' N to 23°31' N latitude and 86°34' E to 86°52' E longitude (Fig. 6.1) with an area of 430 km² (Kundu and Nag 2018). Kashipur block lies under the Raghunathpur subdivision, and it consisted of thirteen Gram Panchayats. From the topographical point of view, this block experienced an undulating surface with rough terrain and moderately weathered pediplain in western and south-western part. Some residual denudated hills are also found there. The average altitude of the study area is recorded as 190 m. The general slope lies from the west to east. Climatologically, the study area is semi-arid and drought-prone. The highest temperature hits up to 48 °C in the months of March to June. On the other hand, winter temperature falls up to 4–5 °C between November to February times. Rainfall occurs mainly from S to W Monsoon winds with annual average rainfall from 1000 to 1400 mm. Geologically, Purulia district is the part of

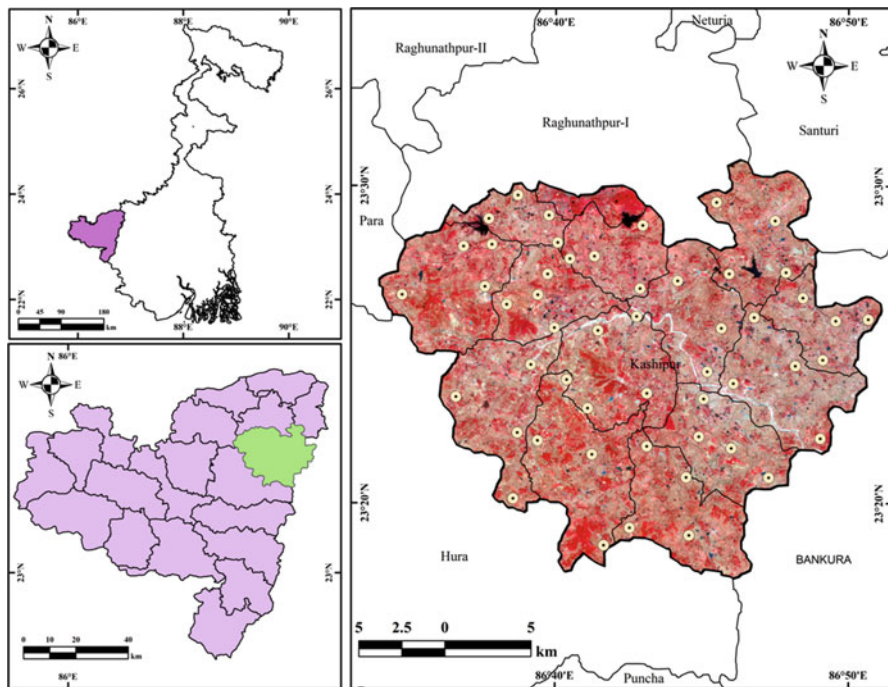


Fig. 6.1 Location map of the study area and sapling sites

Gondwanaland and the rock formation are pre-Cambrian age. In this study area granite gneiss and mica schist are the dominating rock types (Fig. 6.2). The gravel conglomerate of sijua formation is found beside the Dwarakeswar River. Different intrusions as well as lineaments are also found. Amphibolites are also found dispersedly. Various fractures and weathering rocks help to percolate water to reach the groundwater zone more easily. Upper layer of soils is made from weathered granitic rocks, and thus lateritic soils with acidic contents are formed in this region (Fig. 6.2). This creates secondary aquifer in the underlying strata. Many rain faded streams originated from Chotanagpur plateau and are flowing toward the east over this region with numerous short tributaries. Some of those main rivers are Kangsabati, Dwarakeswar, and Silabati are observed with a dendritic drainage pattern (Kundu and Nag 2018).

In the Kashipur block, the main source of water supply for drinking and irrigation are hand-dug wells and bore wells. But human activities polluted the hand-dug wells and surface water by dumping waste which has contaminated the water of lower aquifers. In this semi-arid region most of the surface and dug wells dried up in the dry seasons. Thus, deep tube well or bore well is the most dependable source of groundwater.

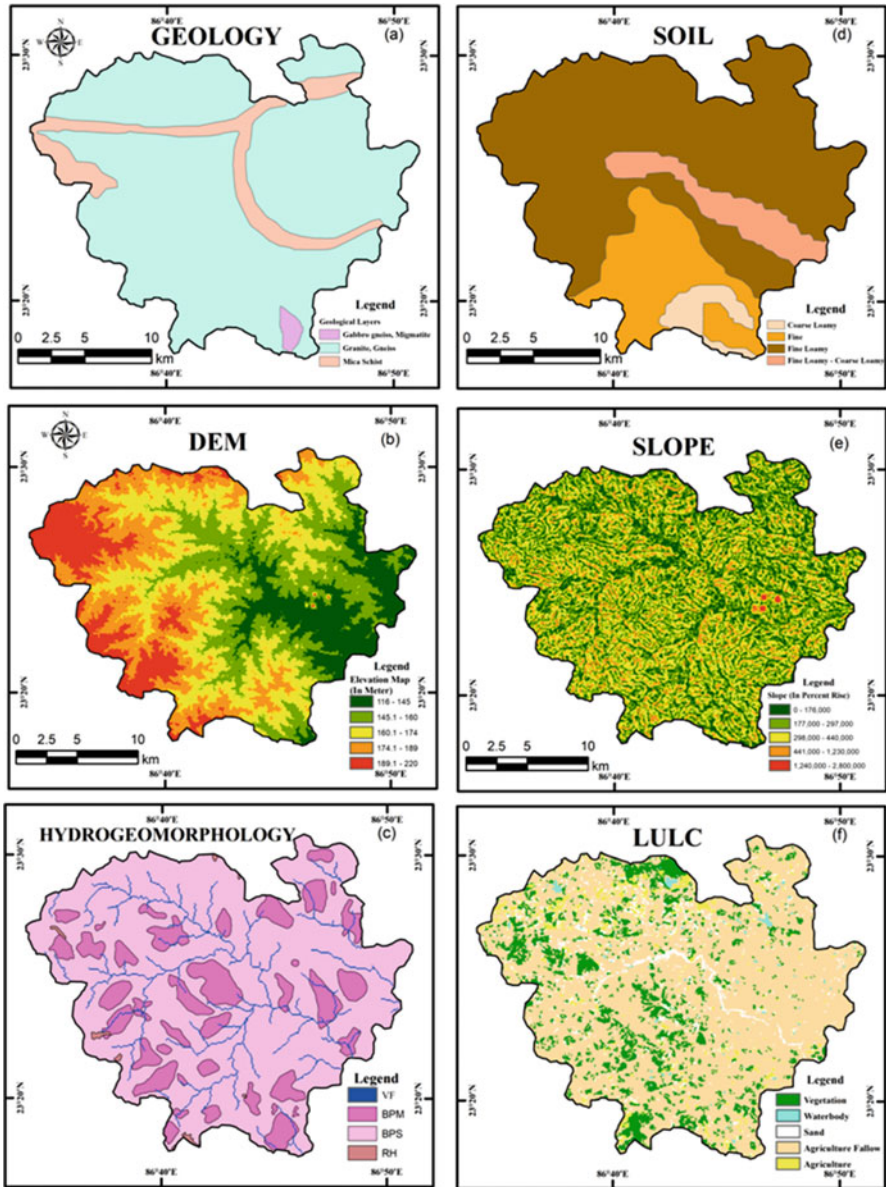


Fig. 6.2 Surface and sub-surface factors maps of the study area

6.3 Materials and Methods

6.3.1 Collection of Samples and Chemical Analysis

Village level groundwater samples were collected from 52 bore wells from 13 Gram Panchayats. These samples were collected for both the pre-monsoon and post-monsoon season. Half liter of clean containers made by plastics has been used for collecting the water samples. Plastic containers were treated by 1:1 hydrochloric acid (HCL) for about 24 h and then washed by distilled water for deionizing. Each sample location was labelled on each container, and all those were suitably preserved up to chemical analysis in the laboratory.

To assess the quality of groundwater such as pH, EC (electrical conductivity) has been measured by portable meters. Total Dissolved Solids (TDS) were computed after measuring the EC of each sample (Hem 1991). EDTA Titration method was used for calculating the quantity of total hardness (TH) of the groundwater samples. The concentration of sodium, calcium, chloride, magnesium, carbonate, fluoride, and potassium was analyzed by the standard methods of the American Public Health Association (APHA 2012). The HCO_3 was analyzed by HCl volumetric method. Na and K were calculated by the flame photometer method. UV spectrophotometric techniques are used for measuring SO_4 , NO_3 , and F. All concentration was expressed in mg/l, except pH.

6.3.2 Pollution Index of Groundwater (PIG)

Pollution Index of Groundwater (PIG) was used for measuring the impact of each chemical property in the groundwater quality for irrigation and drinking purpose by Subba Rao (2012). To compute PIG, each parameter was assigned by its relative weight (R_w) from 1 to 5. These weights were given by the relative impact of chemicals to the suitability of drinking and irrigation purpose. Table 6.1 shows the details relative weight (R_w) and weight parameter (W_p).

Weight parameter (w_p) was calculated for each chemical component in the second step to assess the impact on overall water quality. In the third step, S_c (status of concentration) was calculated by dividing the quantity of each chemical parameter of each sample by its respective safe limit for drinking water quality. In the next step o_w (overall chemical quality of water) was measured by the product of W_p and S_c . Finally, all o_w values for each parameter were added (sum total).

$$W_p = R_w / \sum R_w \quad (6.1)$$

$$S_c = C / D_s \quad (6.2)$$

Table 6.1 List of relative weight (R_w), weight parameter (W_p), and drinking water quality standards (D_s)

Chemical parameter	R_w	W_p	D_s
pH	5	0.104	7.5
TDS	5	0.104	500
Ca^{2+}	2	0.042	75
Mg^{2+}	2	0.042	30
Na^{+}	4	0.083	200
K^{+}	1	0.021	10
HCO_3^{-}	3	0.062	300
Cl^{-}	4	0.083	250
So_4	5	0.104	150
F	5	0.104	1.5
EC	2	0.042	730
TA	2	0.042	200
TH	2	0.042	200
Fe	3	0.062	3
CO_3	3	0.062	100
SUM	48	1.000	

Source: Subba Rao (2012), BIS (2012)

Table 6.2 Classification of pollution index of groundwater (PIG) (Subba Rao 2012)

PIG Range	Classification
<1.0	Insignificant pollution
1.0–1.5	Low pollution
1.5–2.0	Moderately pollution
2.0–2.5	High pollution
>2.5	Very high pollution

$$O_w = W_p * S_c \tag{6.3}$$

$$PIG = O_w \tag{6.4}$$

For calculating PIG, the contribution of each chemical parameter to the groundwater quality of each sample was taken into account (Table 6.2). If overall quality of water (chemical) is greater than 0.1 (O_w), it means 10% value of 1.0 of the PIG. There are four categories that have been put for analyzing PIG.

To analyze the irrigation water quality, different exponents were calculated such as sodium adsorption ratio (SAR), soluble sodium percentage (SSP), magnesium adsorption ratio (MAR), and Kelly’s ratio (KR) for suitability of groundwater for agriculture usages in the study area. For details measurement of variation in water quality of various chemical parameters was analyzed by descriptive statistics and correlation matrix tools.

6.3.3 *Spatial Interpolation*

The dataset of physico-chemical parameters was imported into the GIS database. Kriging interpolation model was used to generate a set of predicted values at known location. Kriging model was used subjected to semivariogram with smoothing factor under exponential and spherical tuning techniques (Fahid et al. 2011).

6.3.4 *Statistical Analysis*

Descriptive statistics was calculated for all the physico-chemical parameters of groundwater samples. The correction analysis is also performed among the groundwater samples through Pearson's correlation co-efficient (r). The statistical analysis has been performed through Microsoft Excel. All the statistical analysis was performed at 0.05 significance level.

6.4 Results and Discussion

6.4.1 *Groundwater Quality and Chemistry*

The physio-chemical analysis of water parameters is compared with the standard drinking water quality measured by BIS (2012). The use of the ordinary kriging method helps to generate a spatial distribution of those chemical parameters (Figs. 6.3, 6.4, 6.5, and 6.6).

6.4.1.1 pH

Water quality very much depends on the characteristics of dissolved hydrogen ion in the water. In this study area, pH values vary between 6.15 to 7.94 and 6.24 to 7.35 with an average value of 6.88 and 6.75 in pre-monsoon and post-monsoon season correspondingly. Thus, the quality of groundwater seems to be neutral to saline condition. According to BIS, the permissible limit of pH is 7.5. In the study area, 4 (7.69%) groundwater samples are found as higher values than the standard limit. Otherwise, 48 (92.30%) samples are below than standard limit in the pre-monsoon season. In the post-monsoon season, samples are not higher than the permissible limit. Thus 100% of samples lie under the safe limit to drinking purpose. The ordinary kriging tool helps to detect the concentration of pH in the study area which indicates central and north of this block (parts of Sonathale, Rangamati, Gourangdi, Gagnabad, Kaliada, Kashipur, Gram Panchayat), and a few villages of Sonajuri GP are affected by a higher concentration of pH value. A wide portion of

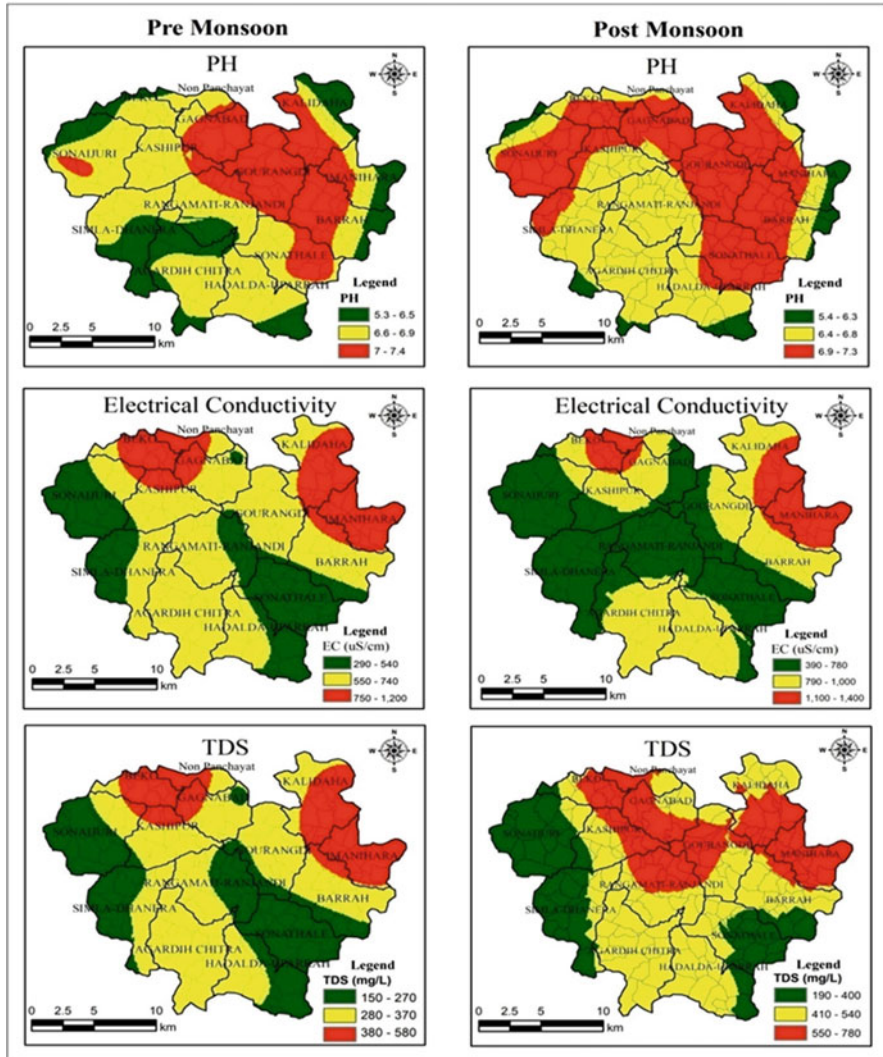


Fig. 6.3 Physio-chemical parameters (pH, EC, and TDS) zonation using ordinary kriging method

western, southern, and few villages of north, eastern, central locations (e.g., villages of Sonajuri, Beko, Kashipur, Gagnabad, Rangamati-Ranjandi, Simla-Dhanara, Agardih-Chitra, Hadalda-Uparrah, Sonathale, Barrah, Manihara, and Kaliada) shows their pH values in moderate condition. Some villages of south-western, north-eastern, and eastern fringe of Kashipur block, few villages of Simla-Dhanara, Sonajuri, Beko, Kaliada, Manihara, Barrah and Hadalda-Uparrah show low concentration of pH in their groundwater samples in pre-monsoon season. On the other hand, most of the villages of Kashipur block were located in eastern, northern, north-

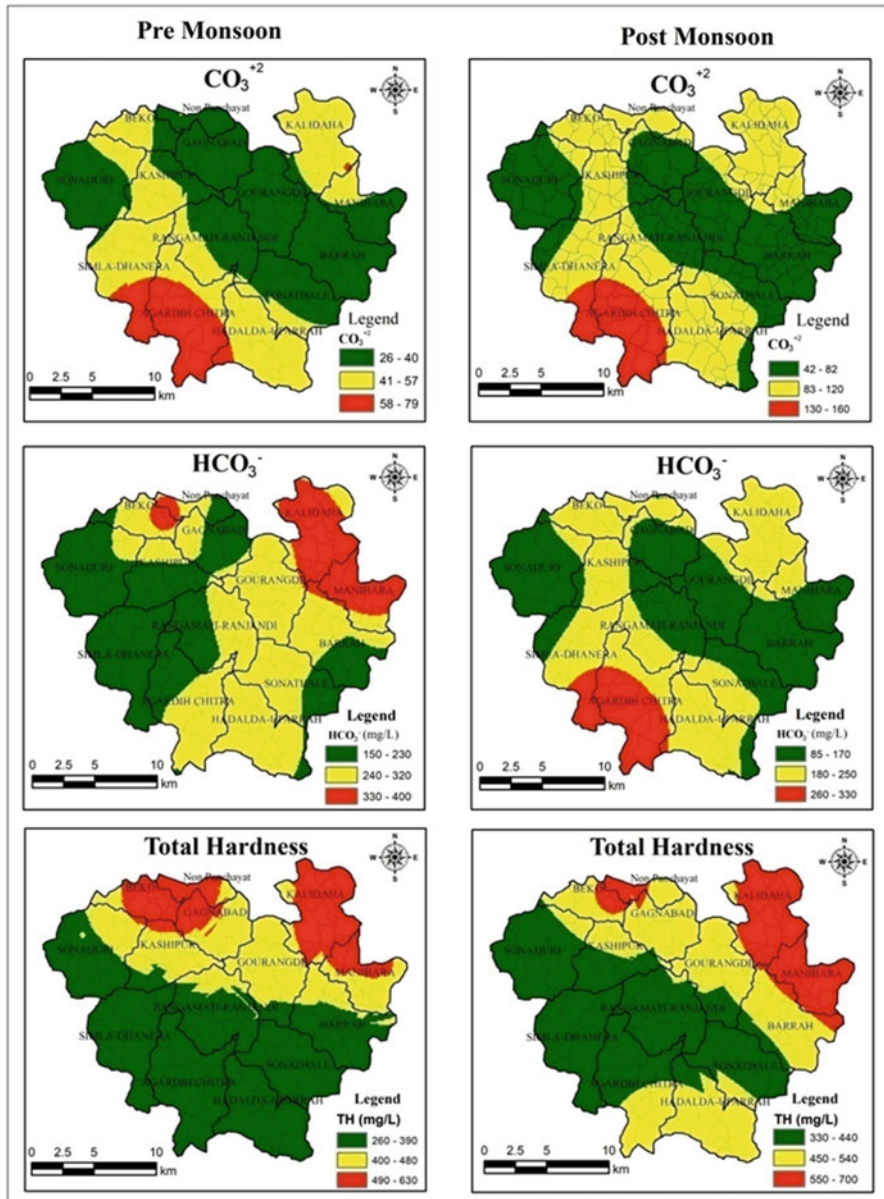


Fig. 6.4 Physio-chemical parameters (CO_3 , HCO_3 , and total hardness) zonation using ordinary kriging method

eastern, and western parts of the villages of Sonajuri, Beko, Gagnabad, Gourangdi, Barrah, Sonathale, Manihara, and Kaliada GP and are affected in the high concentration of pH. Other wide parts of central, southern, and few villages of eastern and

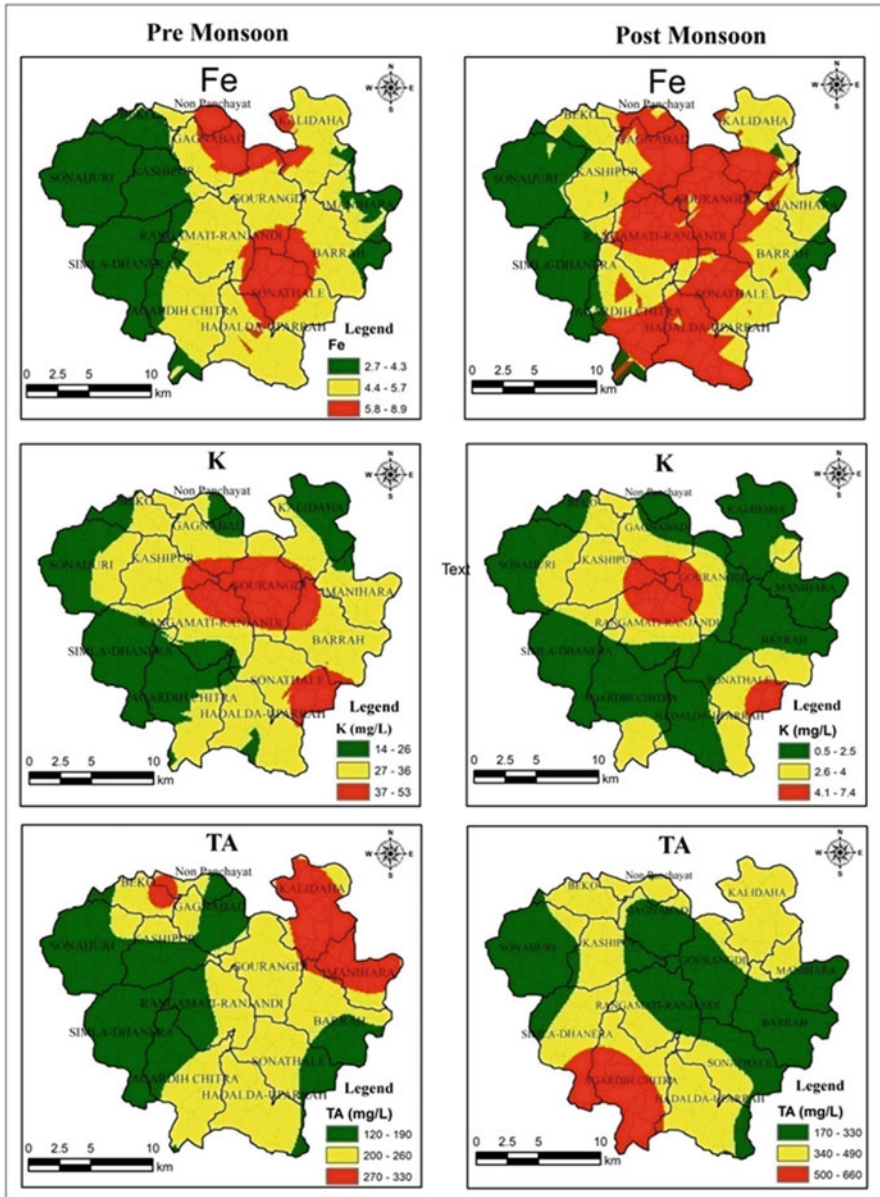


Fig. 6.5 Physico-chemical parameters (Fe, K, and TA) zonation using ordinary kriging method

north-western parts of various Gram Panchayats such as Kashipur, Rangamati-Ranjandi, Agardih-Chitra, Simla-Dhanara, Hadalda-Uparrah, Sonajuri, Barrah, Manihara, Beko, and Kaliada GP have moderate concentration of pH. Very few villages of this Kashipur block mainly located in fringing parts of eastern, southern,

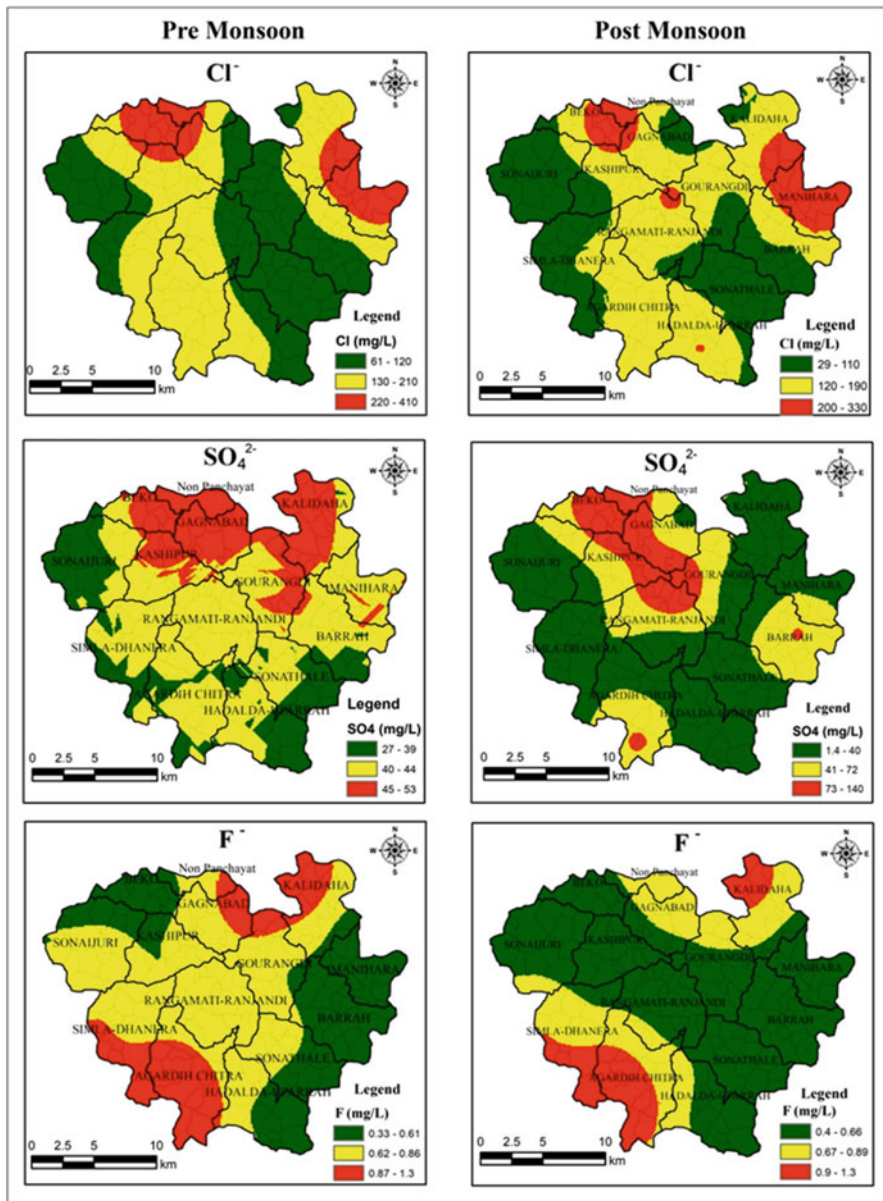


Fig. 6.6 Physico-chemical parameters (Cl^- , SO_4 , and F^-) zonation using ordinary kriging method

north-western locations (Sonajuri, Simla-Dhanara, Agardih-Chitra, Hadalda-Uparrah, Barrah, Manihara, Kaliada GP) have lower pH values than safe limit in post-monsoon season (Fig. 6.3).

6.4.1.2 TDS

Total dissolved solids (TDS) are directly related to electric conductivity. Mainly animal waste, dumping, and soluble minerals enhance the concentration of TDS in groundwater (Kumar et al. 2014). The range of TDS in post-monsoon season is varying between 130 and 1170 mg/l with average value of 555.76 mg/l and 100–910 mg/l with average value of 350.38 mg/l in pre-monsoon and post-monsoon season, respectively. According to BIS, the safe limit of TDS in water is 500 mg/l. In pre-monsoon season 10 (19.23%) samples are found as higher than safe limit in Kashipur block, and 42 (80.77%) samples are found as below than the standard limit. In the post-monsoon season, 22 (42.30%) water samples lie above the permissible limit, and 30 (57.69%) water samples lie below the permissible limit in the study area. It is clearly identified that high mixing of polluted water with the groundwater in the rainy season increases the concentration of TDS in the post-monsoon season. In the pre-monsoon season, kriging shows some part of the northern region and some part of the eastern region of Kashipur block (many villages of Kaliada, Manihara, Beko, Gagnabad, Kashipur GP) have groundwater with high TDS particles. In this season, mostly the central and southern parts of this block (villages of Kashipur, Gagnabad, Sonajuri, Simla-Dhanara, Rangamati-Ranjandi, Agardih-Chitra, Hadalda-Uparrah, Barrah, Gourangdi, Kaliada, GP) fall under the medium concentration of TDS. Subsequently, the western and south eastern parts of Kashipur block (i.e., the villages of Sonajuri, Simla-Dhanara, Agardih-Chitra, Sonathale GP) and Kuardi village of Gagnabad GP have lower concentration of TDS in their groundwater samples. In the post-monsoon season, some villages of the northern, eastern, and central regions (Beko, Gagnabad, Kashipur, Gourangdi, Rangamati-Ranjandi, Manihara, and Kaliada GP) show high values of TDS in their groundwater sample. Most of the samples collected from southern and some pockets of northern and eastern parts (Beko, Kashipur, Rangamati-Ranjandi, Agardih-Chitra, Hadalda-Uparrah, Sonathale, Gourangdi, Kaliada, Gagnabad GP) of Kashipur block indicate moderate concentration of TDS in water samples. Few villages of western and south-eastern location (Sonajuri, Simla-Dhanara, Sonathale, Hadalda-Uparrah GP) lie under low concentration of groundwater TDS in Kashipur block in post-monsoon season (Fig. 6.3).

6.4.1.3 EC

BIS identified as 730 μ s/cm of electric conductivity is the standard limit for drinking purpose of groundwater. In the pre-monsoon and post-monsoon season, the values range from 200 to 1820 μ s/cm and 260 to 2210 μ s/cm, respectively. The average value of EC in pre-monsoon and post-monsoon season is calculated as 700.19 μ s/cm and 976.34 μ s/cm, respectively. 37 (71.15%) samples are found beyond the permissible limit, and 15 (28.84%) samples lie under the limit which are safe for drinking purpose in post-monsoon season. On the other hand, 14 (26.92%) samples are higher

than the BIS limit, and 38 (73.07%) samples fall under the limit in the pre-monsoon season. In the pre-monsoon season, the spatial distribution of EC by kriging shows about the same pattern as TDS. In pre-monsoon season some villages of north and north-eastern parts (Beko, Gagnabad, Manihara, Kaliada GP) show higher concentration of EC in water samples (Fig. 6.3). Most of the villages under Kashipur block which are located mainly in northern, central, southern, and eastern locations (Rangamati- Ranjandi, Simla-Dhanara, Agardih-Chitra, Barrah, Gourangdi, Kaliada GP) indicate moderate concentration of EC, and some parts of western, south-eastern locations (villages of Sonajuri, Simla-Dhanara, Rangamati-Ranjandi, Sonathale, Agardih-Chitra GP) and Kuardi village of Gagnabad GP have low concentration of EC in pre-monsoon season. In the post-monsoon season, the spatial distribution of high EC concentration in groundwater shows quite the same as pre-monsoon season. The moderate concentration of EC is distributed in various parts of south, north-eastern, eastern, and northern areas (Beko, Kashipur, Gagnabad, Kaliada, Gourangdi, Barrah, Agardih-Chitra, Hadalda-Uparrah GP) of Kashipur block. However, the distribution of low concentration of EC spread continues over northern, central, western, and south-eastern areas (villages of Sonajuri, Simla-Dhanara, Rangamati-Ranjandi, Sonathale, Barrah, Gourangdi, Gagnabad GP).

6.4.1.4 TA

Total alkalinity (TA) is measured for showing the power of water to neutralize strong acid. Pipe lines and dumping waste are the main sources of alkalinity in the study area. 200 mg/l is the permissible limit for TA in drinking water (BIS 2012). TA value ranges between 130 and 750 mg/l with an average of 395.21 mg/l in pre-monsoon season. In the post-monsoon season, estimated TA values range between 134 and 938.2 mg/l, with an average of 433.95 mg/l in the study. In the Kashipur block 43 (82.69%) samples are higher than standard value for drinking and irrigation purpose, and 9 (17.30%) samples lie under the permissible limit in pre-monsoon season. In the post-monsoon season 38 (73.07%) samples are higher than standard value, and 14 (26.92%) are lower than permissible value. If the value of TA increases than 60 mg/l, then the water becomes hard. The spatial distribution (OK) of TA shows that the eastern parts (villages of Kaliada, Manihara GP) are more affected by a high amount of TA in the pre-monsoon season. Few villages of Beko GP also show high concentration of TA in the Kashipur block. Moderate range of TA is concentrated in central, northern, and eastern portions (villages of Gourangdi, Rangamati-Ranjandi, Barrah, Sonathale, Agardih-Chitra, Kashipur, Beko GP) . Most of the western side and a small portion of south-eastern side of Kashipur block (Sonajuri, Simla-Dhanara, Rangamati-Ranjandi, Sonathale, Barrah GP) and some villages of Gagnabad GP located in the north side show low amount of TA concentration . In the post-monsoon season, kriging shows only the south-western part of Kashipur block (villages of Agardih-Chitra and Simla-Dhanara GP) which shows high concentration of TA .Villages in central part and northern part (Beko, Kashipur, Simla-Dhanara, Rangamati-Ranjandi, Agardih-Chitra, Sonathale, Manihara, Kaliada, Gagnabad GP)

indicate moderate concentration of TA in water samples. Some villages of western and central and south-eastern parts (Sonajuri, Gagnabad, Sonathale, Manihara, Rangamati-Ranjandi, Manihara, Gourangdi GP) have low concentration of TA (Fig. 6.5).

6.4.1.5 TH

Total hardness (TH) is the concentration of calcium and magnesium which is supplied to the groundwater by leaching process. It reduces by the cleansing power of soap. In pre-monsoon season, the estimated TH values in the study area range between 100.9 and 1435.2 mg/l with an average value of 504.08 mg/l. In the post-monsoon season, the TH value varies between 146.3 and 1265.6 mg/l with an average of 2.04 mg/l. 200 mg/l is the permissible limit of TH as per BIS (2012) standard. In the pre-monsoon season, 40 (76.92%) samples fall above the permissible limit, and 12 (23.07%) samples fall below the permissible limit. 44 (84.61%) samples are higher than the permissible value, and 8 (15.38%) samples are lower than the permissible value in Kashipur block. The spatial map shows the distribution of high values of TH is located in north and north-eastern sections (villages of Beko, Gagnabad, Kaliada, Manihara GP) of Kashipur block in pre-monsoon season (Fig. 6.4). In this season, moderate concentration of TH is found in a longitudinal section spread from west to east (villages of Sonajuri, Kashipur, Gourangdi, Gagnabad, Manihara, Barrah, GP) of the Kashipur block. Entire villages of southern part (Sonajuri, Simla-Dhanara, Agardih-Chitra, Sonathale, Hadalda-Uparrah, Rangamati-Ranjandi, Barrah GP) extending from east to west of the Kashipur block show low concentration of TH of their spatial distribution in pre-monsoon season. In the post-monsoon season, the spatial distribution of high concentration is more or less same as the pre-monsoon period. The extreme southern part (Hadalda-Uparrah, Agardih-Chitra GP) and a linear patch from north-west to north-east (Beko, Gagnabad, Kashipur, Gourangdi, Barrah, GP) of Kashipur block show medium values of TH. Subsequently, the western and central area of the Kashipur block shows low concentration of TH (Sonajuri, Simla-Dhanara, Agardih-Chitra, Sonathale, Rangamati-Ranjandi GP) in post-monsoon season.

6.4.1.6 Ca and Mg

Two most important cations which affect the water quality are calcium (Ca) and magnesium (Mg). The main cause of calcium contamination with groundwater is the limestone especially crystalline and feldspars (Hem 1991; Todd 1980). Traditional activities of agriculture may also help increase calcium contamination in groundwater (Bohlke 2002). In the pre-monsoon season, the Ca varies from 21.84 to 387.4 mg/l with an average value of 100.94 mg/l. In the post-monsoon season, the Ca varies from 11.76 to 288.96 mg/l with an average value of 97.88 mg/l. According to BIS standard (2012), the upper limit of Ca should not be exceeding 75 mg/l. In our study

area, 32 (61.54%) samples of Ca crossed the boundary limit, and 20 (38.46%) samples lie under the safe zone in pre-monsoon season.

Weathered minerals such as dolomite, hornblende, and mica are the influential source of magnesium in the groundwater (Nag and Suchetana, 2016). It decreases the power of the detergent. The magnesium in pre-monsoon varies from 3.1 to 166.72 mg/l, with an average concentration of 61.79 mg/l. In the post-monsoon season, the value of Mg is varied between 16.61 and 159.63 mg/l with an average of 60.66 mg/l. BIS set the upper limit of magnesium as 30 mg/l. Our results suggest that 43 (82.69%) groundwater samples exceed the highest limit and only 9 (17.30%) samples come under the safe limit in both the pre-monsoon and post-monsoon season.

6.4.1.7 Na and K

Sodium (Na) and potassium (K) are important cations of groundwater among all those components. Excess intake of sodium may increase kidney problems, heart disease, etc. (Kundu and Nag, 2018). Feldspars evaporate the sodium bearing minerals (Kundu and Nag, 2018). According to BIS, the maximum permissible limit of sodium is 200 mg/l. In the post-monsoon season, the concentration of sodium in groundwater varies from 14 to 104 mg/l with an average value of 68.84 mg/l. On the other hand, the concentration of sodium varies from 9 to 56 mg/l, with an average of 32.44 mg/l in the pre-monsoon. In the Kashipur block, all these samples are within the permissible limit in both pre-monsoon and post-monsoon season (Fig. 6.5).

Potassium (K) is a very vital nutrient for human growth as it control muscles and normalizes blood pressure. BIS set the upper limit of K as 10 mg/l in pre-monsoon season, and the concentration of K varies from 9 to 63 mg/l with a mean value of 28.48 mg/l. In the study area, 51 (98.07%) samples exceed the highest limit, and only one sample (1.92%) lies under the permissible limit in pre-monsoon season. In the post-monsoon, the value ranges from 0.5 to 7.4 mg/l with an average value of 2.92 mg/l. In this season, all samples are within the safe limit. The spatial distribution map derived through kriging shows high concentrations of K are found in the central and south-east (villages of Gourangdi, Rangamati-Ranjandi, Barrah, Sonathale GP) of Kashipur block. The moderate values of K are found in eastern, southern, northern, and central parts (Beko, Sonajuri, Kashipur, Rangamati-Ranjandi, Sonathale, Hadalda-Uparrah, Barrah, Manihara, Gagnabad GP) of this block, and low values are found in some areas of western and north-eastern parts (Sonajuri, Simla-Dhanara, Agardih-Chitra, Beko, Kaliada, Gagnabad GP) in pre-monsoon season. In the post-monsoon season, high concentration is found in central and south-eastern parts (villages of Rangamati-Ranjandi, Gourangdi, Kashipur, Gagnabad, Sonathale GP) of this study area. Moderate concentrations of K are found in some areas of northern, central, eastern, and southern parts (villages of Beko, Kashipur, Rangamati-Ranjandi, Gourangdi, Gagnabad, Sonathale, Hadalda-Uparrah, Agardih-Chitra GP) of Kashipur block. Subsequently, the low

concentration of K in the post-monsoon season is distributed in western, eastern, north-eastern, and southern regions (villages of Beko, Sonajuri, Simla-Dhanara, Agardih-Chitra, Sonathale, Hadalda-Uparrah, Barrah, Manihara, Kaliada, Gagnabad, Gourangdi GP) at Kashipur block.

6.4.1.8 Cl and CO₃

Chloride (Cl) generally occurred from weathered sedimentary rocks and leaching of salts. Saline water is created due to a mixture of sodium (Na) and Cl minerals. The concentration of Cl in the post-monsoon ranges from 10 to 374.88 mg/l with an average of 147.49 mg/l. In the pre-monsoon season, the calculated value of Cl varies from 59.98 to 414.87 mg/l with an average of 203.58 mg/l. The permissible limit of Cl is 250 mg/l set by BIS (2012). In Kashipur block 18 (34.00%) samples crossed the limit of Cl, and another 34 (65.38%) samples fall under the safe limit in pre-monsoon season. Otherwise, 11 (21.15%) samples fall above the safe limit, and 41 (78.84%) samples are under the safe limit in the post-monsoon season.

High concentrations of Cl⁻ are found in north and eastern parts (villages of Beko, Gagnabad, Kashipur, Kaliada, Manihara GP) of Kashipur block in pre-monsoon season. Moderate concentrations of Cl are shown in southern, small pockets of north-eastern, eastern, and northern regions (Beko, Kashipur, Rangamati-Ranjandi, Gagnabad, Simla-Dhanara, Agardih-Chitra, Hadalda-Uparrah, Sonathale, Kaliada, Barrah, Manihara GP) of Kashipur block, and low values are found in western (Sonajuri, Simla-Dhanara GP) and central parts along with north-south direction (Gourangdi, Gagnabad, Rangamati-Ranjandi, Barrah, Sonathale, Hadalda-Uparrah GP) and Lohat village of Kaliada GP in pre-monsoon season. On the other hand, high concentration of Cl⁻ are found in small parts of north, east, and central regions (villages of Beko, Kashipur, Manihara, Kaliada, Rangamati-Ranjandi GP) in post-monsoon season of Kashipur block. A vast area of central, southern, and some parts of north-eastern, northern, and eastern regions indicates moderate concentration of Cl ion in groundwater samples. Regions of west, south-east, and northern parts of Kashipur block show lower value of Cl⁻ in water sample.

High concentrations of CO₃ are found in the south-western part (Agardih-Chitra, Simla-Dhanara GP) of Kashipur block. The moderate concentrations of CO₃ are found in southern, western, north-western, and north-eastern areas (Simla-Dhanara, Rangamati-Ranjandi, Beko, Kaliada, Kashipur, Agardih-Chitra GP), and low concentrations are found in western, northern, central, and eastern parts (Beko, Gagnabad, Sonajuri, Kashipur, Gourangdi, Rangamati-Ranjandi, Sonathale, Barrah, Manihara GP) in pre-monsoon season. The spatial distribution of CO₃ is about the same as pre-monsoon period in the study block.

6.4.1.9 HCO_3^- , SO_4 , and F^-

The concentrations of bicarbonate (HCO_3^-), sulfate (SO_4), and fluoride (F^-) are collected as 146.4–402.6 mg/l, 5.15–143.44 mg/l, and 0.24–1.69 mg/l, respectively. In the pre-monsoon season, the calculated average values of HCO_3^- , SO_4 , and F^- are 271.68 mg/l, 49.99 mg/l, and 0.81 mg/l, respectively. The value of HCO_3^- , SO_4 , and F^- ranges between 73.2 and 478 mg/l, 1.14 and 143.09 mg/l, and 0.25 and 2.05 mg/l in the post-monsoon season. The estimated average values of HCO_3^- , SO_4 , and F^- are recorded as 216.47 mg/l, 46.97 mg/l, and 0.96 mg/l, respectively, in the post-monsoon in Kashipur block. The standard limit of HCO_3^- is 300 mg/l, and 19 (36.53%) samples are beyond the critical limit in the pre-monsoon season, and 33 (63.46%) samples are under the safe limit set by BIS. 12 (23.07%) samples exceed the critical limit, and 40 (76.92%) samples are under the safe limit in the post-monsoon season. The upper limit of SO_4 is 150 mg/l. In the study area, all the samples are under the safe limit according to BIS in both pre- and post-monsoon season.

Fluoride is a very essential element for strong teeth and bones. But the excess concentration of it causes harm to humans. The upper limit of F^- is 1.5 mg/l. In Kashipur block 4 (7.69%) samples exceed fluoride contamination, and 48 (92.30%) samples are under the safe limit in the pre-monsoon season. 13 (25%) samples are higher than the safe limit, and 39 (75.00%) samples are shown below the safe limit in the post-monsoon season. The spatial distribution map shows high values of HCO_3^- are portrayed in the north-eastern region (Kaliada, Manihara GP) and some villages of Beko GP in pre-monsoon season. Moderate concentration of HCO_3^- is noticed in central and southern Gourangdi, Rangamati-Ranjandi, Agardih-Chitra, Hadalda-Uparrah, and Sonathale GP and few parts of northern and eastern regions (Beko, Kashipur, Gagnabad, Barrah, Manihara GP) of the study area. Low values of HCO_3^- are found in western part and eastern part (villages of Sonajuri, Simla-Dhanara, Rangamati-Ranjandi, Kashipur, Sonathale, Barrah GP) of Kashipur block in pre-monsoon season. In post-monsoon season, high concentrations of HCO_3^- are found in south-western part of Kashipur block (villages of Simla-Dhanara, Agardih-Chitra GP). Moderate concentrations of HCO_3^- are shown in northern, central, and southern parts of this block (Beko, Kashipur, Rangamati-Ranjandi, Simla-Dhanara, Hadalda-Uparrah, Sonathale, Kaliada, Manihara GP), and lower values of HCO_3^- are found in western, central, and eastern parts (villages of Sonajuri, Gagnabad, Rangamati-Ranjandi, Barrah, Sonathale, Manihara, Gourangdi GP) of Kashipur block in post-monsoon season (Fig. 6.6).

High concentration of SO_4 is found in the northern part (villages of Beko, Gagnabad, Kashipur, Gourangdi, Kaliada GP) of Kashipur block in pre-monsoon season. The entire central and eastern, western, southern areas (Rangamati-Ranjandi, Sonajuri, Simla-Dhanara, Sonathale, Barrah, Manihara, Gourangdi GP) indicate moderate concentration of SO_4 , and parts of western, south-west, and south-eastern regions (Sonajuri, Simla-Dhanara, Hadalda-Uparrah, Sonathale GP) indicate lower concentration of SO_4 in the pre monsoon season. In the post-monsoon season, high

values of SO_4 are found in north-western part (Beko, Kashipur, Rangamati-Ranjandi, Gourangdi, Gagnabad GP), Sirjam village of Barrah GP, and Pabra Pahari village of Agardih-Chitra GP of Kashipur block. Moderate concentrations of SO_4 are found in eastern, south-western, and central parts of this block (Barrah, Agardih-Chitra, Rangamati-Ranjandi, Kashipur, Sonajuri, Gourangdi GP), and low values of SO_4 are found in western, south-eastern, and north-eastern parts (some villages of Sonajuri, Simla-Dhanara, Agardih-Chitra, Sonathale, Manihara, Kaliada, Barrah GP) of Kashipur block.

The spatial distribution map shows the concentration of F^- higher in north-eastern and south-western parts (villages Of Gagnabad, Gourangdi, Kaliada, Simla-Dhanara, Agardih-Chitra GP) of the Kashipur block in pre-monsoon season. The entire central and some parts of west, south, north, and north-east indicate moderate values of fluoride concentration in this Kashipur block. The low concentrations of F^- are found in north-western and south-eastern parts (villages of Sonajuri, Beko, Kashipur, Hadalda-Uparrah, Sonathale, Barrah, Manihara GP) of the study area in pre-monsoon period. On the other hand, high concentrations of F^- are found in few parts of north-eastern and south-western regions (villages of Kaliada, Simla-Dhanara, Agardih-Chitra GP) in the Kashipur block in post-monsoon season. Moderate concentrations are found in two crescentic shape area located southwest and northeast (villages of Simla-Dhanara, Agardih-Chitra, Hadalda-Uparrah GP And Gagnabad, Gourangdi, Kaliada GP) in Kashipur block. Low concentrations of F^- are found in north-west and east (villages of Sonajuri, Beko, Kashipur, Gagnabad, Gourangdi, Rangamati-Ranjandi, Hadalda-Uparrah, Sonathale, Barrah, Manihara GP) in pre-monsoon season.

6.4.2 Statistical Analysis

The descriptive statistics of physico-chemical parameters in pre-monsoon and post-monsoon seasons are illustrated in Tables 6.3 and 6.4, respectively. In this analysis, it is found that except pH, Na, and SO_4 , all other parameters have maximum values than the permissible limit in the pre-monsoon season. As such, except Na and SO_4 all other parameters have the maximum values than the safe limit of drinking and irrigational water in the post-monsoon season. The mean values of EC, TA, TH, Ca, Mg, Fe, and K are higher than the upper limit of drinking water. Thus, it is clearly understood that the most samples of those parameters lie under the unsafe quality of groundwater in the pre-monsoon season. In the post-monsoon season, the mean values of TDS, EC, TA, TH, Ca, and Mg lie above the permissible limit, according to BIS.

The correlation analysis for pre- and post-monsoon season groundwater quality parameters is presented in Tables 6.5 and 6.6, respectively. In the study area, pH has negative correlation with TDS, EC, TA, TH, Na^+ , Ca^{2+} , Mg^{2+} , CO_3^{2+} , HCO_3^- , and SO_4^{2-} and positive relation with Fe, K^+ , Cl, and F^- in the pre-monsoon season. TDS is highly correlated (regression value greater than 0.5) with EC, TH, Ca, Mg, HCO_3^- ,

Table 6.3 Descriptive statistics of pre-monsoon season of Kashipur block

	pH	TDS	EC	TA	TH	Na+	Ca ²⁺	Mg ²⁺	Fe	K+	CO ₃ ²⁻	HCO ₃	Cl-	SO ₄	F-
Mean	6.89	350.38	700.19	395.21	504.09	32.44	100.94	61.79	4.03	28.48	49.27	271.68	203.59	49.99	0.82
Standard error	0.06	27.87	53.48	23.75	46.32	1.43	11.85	5.73	0.35	1.83	4.43	10.17	16.04	4.02	0.06
Median	6.84	305	635	352	417.7	32	78	51.44	3.34	25	44.5	269.65	161.8	50.64	0.72
Mode	6.84	340	660	254	#N/A	40	55.44	#N/A	3.24	15	28	219.6	59.98	48.2	1.24
Standard deviation	0.4	201.01	385.66	171.27	334	10.28	85.42	41.3	2.53	13.19	31.94	73.36	115.7	28.96	0.43
Sample variance	0.16	40403.77	148731.33	29333.82	111558.4	105.7	7296.95	1705.68	6.39	173.94	1020.4	5381	13385.8	838.86	0.18
Kurtosis	-0.22	1.17	1.69	-0.65	1.24	-0.36	2.49	1.08	7.84	0.81	0.51	-1	-1.21	1.72	-0.95
Skewness	0.49	1.3	1.39	0.45	1.33	0.1	1.81	1.34	2.73	1.06	0.91	0.03	0.49	0.88	0.51
Range	1.79	810	1620	624	1334.3	47	365.56	163.62	13.59	54	136	256.2	354.89	138.29	1.45
Minimum	6.15	100	200	130	100.9	9	21.84	3.1	0.7	9	0	146.4	59.98	5.15	0.24
Maximum	7.94	910	1820	754	1435.2	56	387.4	166.72	14.29	63	136	402.6	414.87	143.44	1.69
Sum	358.14	18,220	36,410	20,551	26212.5	1687	5249.04	3213.24	209.72	1481	2562	14127.4	10586.48	2599.67	42.56

Table 6.4 Descriptive statistics of post-monsoon season of Kashipur block

	pH	TDS	EC	TA	TH	Na+	Ca2+	Mg2+	Fe	K+	CO3 + 2	HCO3	Cl-	SO4	F-
Mean	6.76	555.77	976.35	433.96	561.09	68.85	97.89	60.67	2.05	2.93	79.54	216.47	147.50	46.98	0.97
Standard error	0.04	41.71	70.08	36.17	43.53	3.13	8.40	4.58	0.18	0.21	5.64	15.15	15.54	5.02	0.08
Median	6.71	465.00	865.00	375.10	467.40	73.50	88.20	53.75	1.63	2.55	69.00	176.90	97.78	36.27	0.78
Mode	6.58	450.00	760.00	145.20	#N/A	98.00	57.12	64.20	1.19	2.50	84.00	73.20	64.98	8.47	1.74
Standard deviation	0.28	300.75	505.33	260.84	313.93	22.55	60.61	33.06	1.32	1.54	40.68	109.25	112.04	36.20	0.56
Sample variance	0.08	90452.34	255356.98	68039.33	98553.14	508.45	3673.21	1093.04	1.73	2.38	1655.12	11935.79	12553.79	1310.34	0.32
Kurtosis	-0.56	-0.99	-0.14	-0.58	-0.68	-0.29	0.88	1.25	0.25	0.14	2.25	-0.87	-0.83	0.18	-1.13
Skewness	0.48	0.39	0.70	0.79	0.58	-0.58	0.94	1.15	1.08	0.73	1.50	0.50	0.74	0.86	0.52
Range	1.11	1040.00	1950.00	849.20	1119.30	90.00	277.20	143.02	4.98	6.90	187.00	404.80	364.88	141.95	1.80
Minimum	6.24	130.00	260.00	134.00	146.30	14.00	11.76	16.61	0.28	0.50	17.00	73.20	10.00	1.14	0.25
Maximum	7.35	1170.00	2210.00	983.20	1265.60	104.00	288.96	159.63	5.26	7.40	204.00	478.00	374.88	143.09	2.05
Sum	351.29	28900.00	50770.00	22565.80	29176.90	3580.00	5090.18	3154.62	106.40	152.30	4136.00	11256.60	7669.77	2442.94	50.39

Table 6.5 Correlation matrix of pre-monsoon season

	pH	TDS	EC	TA	TH	Na ⁺	Ca ²⁺	Mg ²⁺	Fe	K ⁺	CO ₃ ²⁺	HCO ₃ ²⁻	Cl ⁻	SO ₄ ²⁻	F ⁻
pH	1.00														
TDS	-0.09	1.00													
EC	-0.11	0.99	1.00												
TA	0.00	0.15	0.16	1.00											
TH	-0.07	0.97	0.97	0.19	1.00										
Na ⁺	-0.45	0.39	0.43	0.04	0.34	1.00									
Ca ²⁺	-0.32	0.63	0.64	0.30	0.72	0.28	1.00								
Mg ²⁺	-0.17	0.92	0.92	0.15	0.93	0.30	0.74	1.00							
Fe	0.09	-0.29	-0.29	-0.03	-0.33	-0.12	-0.27	-0.32	1.00						
K ⁺	0.18	-0.05	-0.03	0.15	-0.03	-0.12	0.03	-0.06	-0.09	1.00					
CO ₃ ²⁻	-0.12	0.24	0.26	0.23	0.23	0.23	0.17	0.24	-0.12	-0.02	1.00				
HCO ₃	-0.02	0.54	0.54	0.30	0.49	0.16	0.35	0.48	-0.17	0.11	0.13	1.00			
Cl ⁻	0.14	0.25	0.27	0.20	0.24	0.16	0.09	0.24	-0.37	-0.24	0.14	0.12	1.00		
SO ₄ ²⁻	-0.13	0.51	0.50	0.29	0.52	0.36	0.59	0.51	-0.26	-0.05	0.18	0.32	0.51	1.00	
F ⁻	0.19	-0.21	-0.21	0.17	-0.17	-0.13	-0.09	-0.20	0.08	-0.10	0.20	-0.21	0.16	0.07	1.00

Table 6.6 Correlation matrix of post-monsoon season

	pH	TDS	EC	TA	TH	Na+	Ca ²⁺	Mg ²⁺	Fe	K+	CO ₃ ²⁺	HCO ₃ ²⁻	Cl ⁻	SO ₄ ²⁻	F ⁻
pH	1.00														
TDS	-0.43	1.00													
EC	-0.29	0.82	1.00												
TA	-0.12	-0.05	-0.11	1.00											
TH	-0.37	0.89	0.84	0.05	1.00										
Na ⁺	-0.36	0.78	0.68	0.12	0.70	1.00									
Ca ²⁺	-0.30	0.59	0.56	0.36	0.69	0.54	1.00								
Mg ²⁺	0.01	0.45	0.52	-0.05	0.51	0.32	0.34	1.00							
Fe	0.12	-0.12	-0.27	0.20	-0.07	0.02	0.07	-0.35	1.00						
K ⁺	0.12	0.19	-0.03	0.02	0.13	0.19	0.06	-0.04	0.02	1.00					
CO ₃ ²⁻	-0.11	-0.13	-0.01	0.31	-0.03	0.11	0.09	0.00	-0.11	-0.15	1.00				
HCO ₃	-0.30	0.25	0.23	0.34	0.24	0.27	0.02	0.06	0.07	0.06	0.26	1.00			
Cl ⁻	-0.16	0.62	0.64	-0.21	0.56	0.41	0.32	0.61	-0.38	0.13	0.04	0.14	1.00		
SO ₄ ²⁻	-0.20	0.44	0.26	0.15	0.29	0.51	0.37	0.20	-0.12	0.26	0.09	0.22	0.22	1.00	
F ⁻	-0.13	0.05	-0.04	0.27	0.09	0.07	0.12	-0.27	0.26	0.27	0.01	0.32	-0.04	-0.06	1.00

and SO_4 . Total hardness (TH) is highly correlated to Ca^{2+} , Mg^{2+} , and SO_4 . Concentration of CO_2 is positively related with Mg^{2+} , SO_4^{2-} , K^+ , HCO_3 , and Cl . Mg and Cl have very strong positive correlation with SO_4 in the pre-monsoon season. In the post-monsoon season, pH has positive correlation with TA , Mg^{2+} , Fe , and K^+ . TDS is strongly correlated with EC , TH , Na^+ , Ca , and Cl . TH values are highly influenced by Na^+ , Ca^+ , Mg^{2+} , and Cl^- . Sodium is positively correlated with calcium ($r = 0.54$). Magnesium is positively correlated with Cl values in Kashipur block in post-monsoon season.

6.4.3 Irrigation Water Quality Assessment

Saline or alkaline quality of water determines the agricultural production of an area. Assessment of the overall quality of water used in agriculture for irrigation purpose are derived by certain indicators, namely, SAR, SSP, MAR, and KR (Obeifuna and Sheriff 2011). The calculated parameters are shown in Tables 6.7 and 6.8.

6.4.3.1 Sodium Adsorption Ration (SAR)

The hazard of alkaline water is generally known as sodium adsorption ratio (SAR). Analysis of sodium concentration is necessary for irrigation purpose because it's deformed soil structure and the permeability capacity of water (Todd 1980). The following equation was used to find the SAR values of water quality for irrigation of different GP in Kashipur block (Richards 1954).

$$\text{SAR} = (\text{Na}^+) / \left\{ \frac{[(\text{Ca}^{2+}) + (\text{Mg}^{2+})]}{2} \right\}^{1/2}.$$

All ion concentrations have been defined in mg/l .

High concentration of sodium leads to alkaline type soil which is difficult to crop production. In the study area, the low infiltration capacity of soils makes water to runoff, and thus in dry period of crop production it is very tough without proper irrigation and well drainage system. SAR values are categorized under two sub-groups. Values less than 10 are indicated as suitable, and values greater than 10 are considered as unsuitable. In the present study, village level SAR values range from 1.23 to 9.13 in the pre-monsoon season and varied between 2.27 and 15.89 in post-monsoon season. All SAR values of pre-monsoon seasons are below 10 and all fall under suitable category, and 10 samples of post-monsoon show SAR values higher than 10 (Rugri, Chakalta, Kapistha, Lapara, Lajhna, Jiara, Haridih, Kalapathar, Sirjam, and Rampur) which are highlighted by using Arc GIS treated as unsuitable. The zonation mapping shows that the villages with unsuitable water are distributed scatteredly in the central and eastern region of Kashipur block in post-monsoon season (Fig. 6.7).

Table 6.7 Estimation of irrigation water quality in pre-monsoon season of different blocks in Kashipur

GP	Villages name	SAR	SSP	KR	MAR
Kalidaha	Lohat	4.08	28.63	0.24	40.59
	Kelahi	3.73	26.85	0.22	46.57
	Bhatulkend	3.23	15.64	0.13	55.36
	Indrabil	3.00	23.89	0.17	46.28
Manihara	Manihara	2.76	21.92	0.14	71.49
	Adali	1.96	14.53	0.09	49.15
	Rampur	1.53	14.98	0.08	52.57
	Agrabad	3.76	24.90	0.18	44.39
Barrah	Sirjam	6.91	42.71	0.50	42.59
	Rajra	3.37	40.09	0.27	41.70
	Kadori	5.50	37.31	0.42	49.94
	Paharpur	6.29	42.94	0.52	45.96
Sonathale	Kalapatthar	9.13	61.38	1.04	8.08
	Balarampur	2.76	56.02	0.25	40.08
	Jibanpur	5.92	41.18	0.50	40.86
	Sonathol	4.23	47.85	0.37	39.04
Hadalda-Upparah	Hadalda	2.80	22.42	0.15	37.86
	Kaliada	3.94	21.70	0.16	27.82
	Ichamara	3.01	13.61	0.12	24.29
	Jiara	1.23	7.72	0.04	26.32
Agardih-Chitra	Pabra Pahari	5.78	38.57	0.36	39.01
	Chaka	4.82	37.98	0.34	45.38
	Saharbera	1.87	18.06	0.07	20.59
	Tara	2.31	12.49	0.09	21.36
Simla-Dhanara	Simla	4.77	28.12	0.28	40.26
	Damankiri	5.02	30.04	0.30	43.49
	Liya	4.10	38.62	0.40	39.13
	Shiulibari	5.77	41.81	0.45	56.52
Simla-Dhanara	Rudra	2.99	36.58	0.21	42.19
	Kalyajhor	1.45	23.71	0.12	41.27
	Bhalagara	5.40	61.84	0.61	38.73
	Daldali	6.25	60.85	0.67	29.47
Beko	Jorisha	4.20	25.45	0.23	38.55
	Palaskola	3.66	16.89	0.12	35.67
	Rugri	3.63	15.34	0.12	35.60
	Jibanpur	3.04	14.52	0.10	35.86
Gagnabad	Kuardi	4.27	39.81	0.46	50.18
	Chakalta	5.86	56.63	0.55	50.81
	Dhobari	3.25	33.24	0.21	39.75
	Gagnabad	3.19	28.46	0.21	38.64
Kashipur	Lapara	5.83	45.61	0.44	39.89
	Rangiladi	4.47	37.56	0.32	32.88

(continued)

Table 6.7 (continued)

GP	Villages name	SAR	SSP	KR	MAR
	Sidpur	5.19	38.66	0.34	34.62
	Gopalpur	6.32	35.92	0.42	35.71
Rangamati-Ranjandi	Ranjandi	4.61	29.50	0.30	36.58
	Patpur	3.87	40.23	0.23	37.53
	Tilabani	5.07	32.18	0.31	40.66
	Lajhna	4.55	32.60	0.28	40.89
Gourangdi	Kapistha	4.26	48.99	0.31	40.17
	Talajuri	3.23	37.78	0.19	38.35
	Sutabani	2.86	26.79	0.16	35.16
	Jamkuri	2.44	27.75	0.14	37.74

6.4.3.2 Soluble Sodium Percentage (SSP)

Irrigation water with high concentration of sodium ion is absorbed by clay components in the soil which decreased the porosity of soil and affects the agricultural production (Nag and Das 2017). Thus the soluble sodium percentage is calculated by the following equation:

$$SSP = [(Na^+ + K^+) \times 100] / [Ca^{2\pm} + Mg^{2\pm} + Na^+ + K^+]$$

In Kashipur block, the values of SSP range from 7.72 to 61.83 in the pre-monsoon season and from 16.69 to 62.72 in the post-monsoon season. The SSP values which are <50 are indicated “good,” and values >50 are indicated “unsafe” for irrigation purpose (USDA 1954). In the present study, 5 (9.62%) samples of pre-monsoon season (Lohat, Rampur, Manihara, Ichamara, Hadalda) and 4 (7.69%) samples of post-monsoon season (Rampur, Kalapathar, Haridih, Jaira) have SSP values of >50. The details of calculated SSP values are given in Table 6.9. It is clearly observed that concentrations of villages with high SSP values are situated in extreme southern and north-eastern parts of Kashipur block in pre-monsoon season. In the post-monsoon season higher concentrations of SSP values are distributed in south-eastern region (Fig. 6.7).

6.4.3.3 Magnesium Adsorption Ratio (MAR)

Magnesium (Mg) is a very important component for plant growth. But higher concentration of Mg leads to damage of leaves, reduces plant growth, and decreases the crop production. It is calculated by the following equation followed by (Raghunath 1987):

Table 6.8 Estimation of water quality in relation to irrigation in post-monsoon of different blocks in Kashipur

GP	Village name	SAR	SSP	KR	MAR
Kalidaha	Lohat	8.42	34.64	0.52	36.94
	Kelahi	7.19	29.92	0.42	43.17
	Bhatulkend	5.62	18.15	0.21	43.31
	Indrabil	8.01	28.99	0.40	41.17
Manihara	Manihara	8.53	26.30	0.35	53.68
	Adali	6.71	25.34	0.33	23.21
	Rampur	11.17	50.72	1.01	58.12
	Agrabad	7.35	27.61	0.36	33.71
Barrah	Sirjam	10.95	44.40	0.78	42.19
	Rajra	6.72	26.77	0.35	48.13
	Kadori	5.38	20.69	0.25	37.24
	Paharpur	8.53	35.05	0.51	33.77
Sonathale	Kalapatthar	15.89	62.72	1.64	74.95
	Balarampur	5.15	37.11	0.49	45.09
	Jibanpur	7.38	38.98	0.58	64.98
	Sonathol	13.20	52.05	1.03	77.44
Hadalda-Uparrah	Hadalda	6.99	24.27	0.31	38.67
	Kaliada	8.03	30.05	0.41	45.17
	Ichamara	9.37	43.92	0.72	49.88
	Jiara	13.13	53.13	1.05	25.00
Agardih-Chitra	Pabra Pahari	8.47	32.35	0.46	37.67
	Chaka	8.08	31.55	0.43	35.94
	Saharbera	8.37	31.83	0.44	10.14
	Tara	8.49	27.74	0.37	9.54
Simla-Dhanara	Simla	8.93	35.83	0.55	37.21
	Damankiri	9.99	37.67	0.59	37.07
	Liya	6.90	41.97	0.70	34.23
	Shiulibari	4.17	23.25	0.28	69.08
Simla-Dhanara	Rudra	4.92	29.49	0.38	42.45
	Kalyajhor	2.27	16.69	0.18	35.78
	Bhalagara	3.25	19.95	0.21	54.22
	Daldali	4.42	21.54	0.26	66.03
Beko	Jorisha	8.37	34.83	0.52	38.32
	Palaskola	6.75	19.41	0.23	31.44
	Rugri	12.17	43.01	0.73	79.94
	Jibanpur	8.41	26.88	0.36	46.90
Gagnabad	Kuardi	7.07	43.48	0.76	53.70
	Chakalta	10.86	38.53	0.62	11.44
	Dhobari	8.11	34.09	0.51	26.75
	Gagnabad	9.49	35.34	0.54	60.09
Kashipur	Lapara	10.92	44.98	0.78	41.03
	Rangiladi	6.92	30.41	0.41	39.06

(continued)

Table 6.8 (continued)

GP	Village name	SAR	SSP	KR	MAR
Rangamati-Ranjandi	Sidpur	6.39	22.39	0.28	23.52
	Gopalpur	8.92	29.80	0.41	19.54
	Ranjandi	7.28	29.16	0.40	20.32
	Patpur	4.51	24.56	0.31	51.82
	Tilabani	8.42	28.02	0.37	27.14
Gourangdi	Lajhna	10.49	36.68	0.56	24.16
	Kapistha	11.45	41.85	0.67	42.65
	Talajuri	7.69	33.75	0.49	28.21
	Sutabani	5.82	24.72	0.31	43.35
	Jamkuri	7.94	32.60	0.46	38.95

$$\text{MAR} = (\text{Mg}^{2\pm} \times 100) / (\text{Ca}^{2\pm} + \text{Mg}^{2\pm})$$

The concentration of MAR is calculated in mg/l.

The computed MAR values ranged from 8.07 to 71.49 mg/l in the pre-monsoon and 9.54 to 79.94 mg/l in the post-monsoon season. MAR values <50 mg/l are taken as suitable for irrigation, while MAR values of >50 mg/l are considered as unsuitable for irrigation. In the present study, 6 (11.54%) samples of MAR in Kashipur block are >50 in pre-monsoon season (Bhatulkend, Manihara, Rampur, Shiulibari, Kuardi, Chakalta) and are indicated as unsuitable for irrigation. On the other hand, 12 (23.07%) samples in post-monsoon season are >50 mg/l (Manihara, Rampur, Kalapathar, Jibanpur, Sonathol, Shiulibari, Bhalagara, Daldali, Rugri, Kuardi, Gagnabad, Patpur) (Table 6.9). The spatial distribution map shows villages with high MAR values located at northern, eastern, and western parts of the Kashipur block in pre-monsoon season.. In this post-season, spatial distribution map shows that unsafe villages are distributed scatteredly over the Kashipur block. (Fig. 6.8).

6.4.3.4 Kelly's Ratio

This is used to calculate the sodium concentration with respect to Ca and Mg in water (Nag and Das 2017; Kelly 1976) as follows:

$$\text{KR} = \text{Na}^{\pm} / (\text{Ca}^{2\pm} + \text{Mg}^{2\pm})$$

KR value of <1 is taken as suitable for crop production. 99% of the sample value is lower than the safe limit. 48 (92.31%) samples of post-monsoon season are less than the safe limit, and 7.69% of samples (Kalapathar, Haridih, Jaira, Rampur) are >1 in the study area, indicating unsuitable condition for agriculture production (Table 6.9). The spatial mapping shows that only one village (Kalapathar) situated

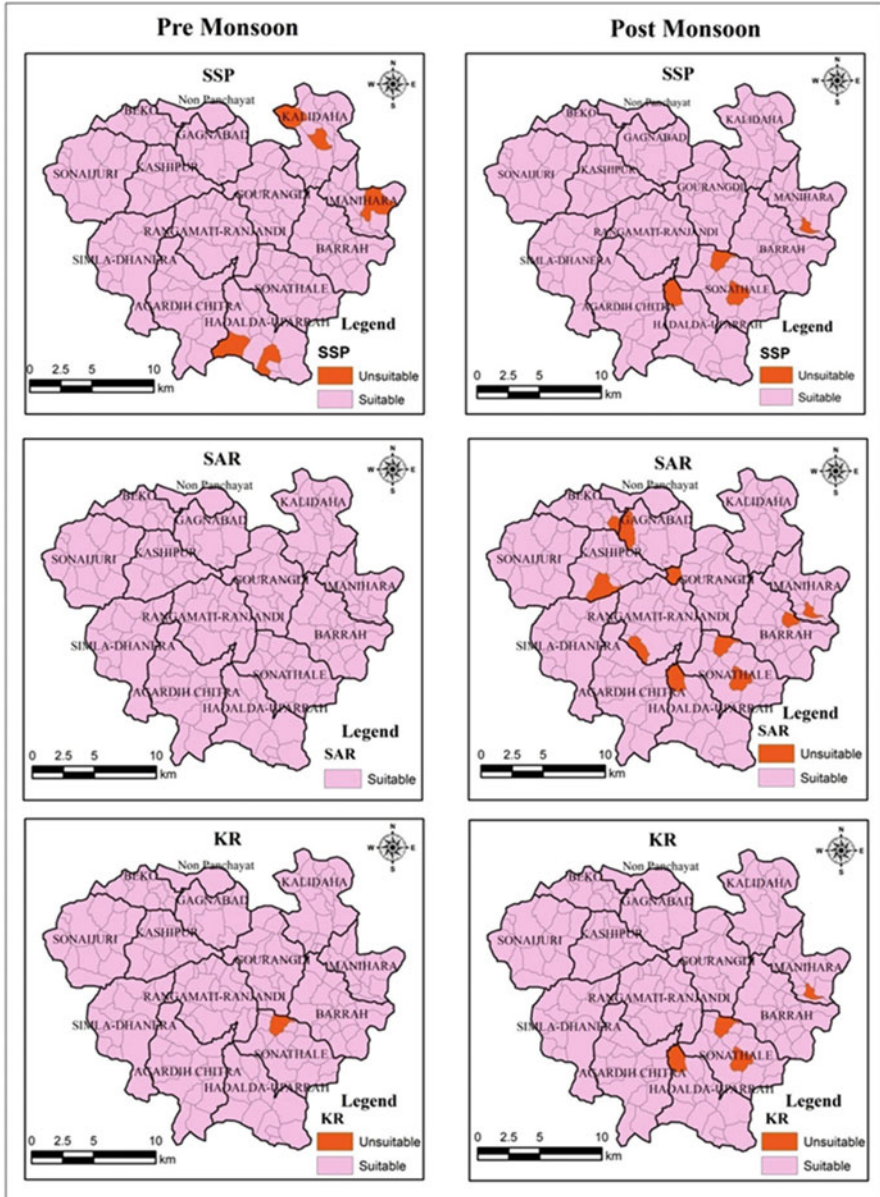


Fig 6.7 Village level irrigation water quality parameters zonation by using ArcGIS software

at south-east location of the study area is affected by higher KR and is indicated as unsuitable for agriculture in pre-monsoon season. In post-monsoon season, the unsafe villages are located in the south-eastern part of Kashipur block (Fig. 6.7).

Table 6.9 Standardized parameters of irrigation water quality classification

Parameters	Range (mg/l)	Category	No. of samples (pre-monsoon)	No. of samples (post-monsoon)
SAR	<10	Suitable	52	42
	>10	Unsuitable	0	10
SSP	<50	Suitable	47	48
	>50	Unsuitable	5	4
KR	<1	Suitable	51	48
	>1	Unsuitable	1	4
MAR	<50	Suitable	46	40
	>50	Unsuitable	6	12

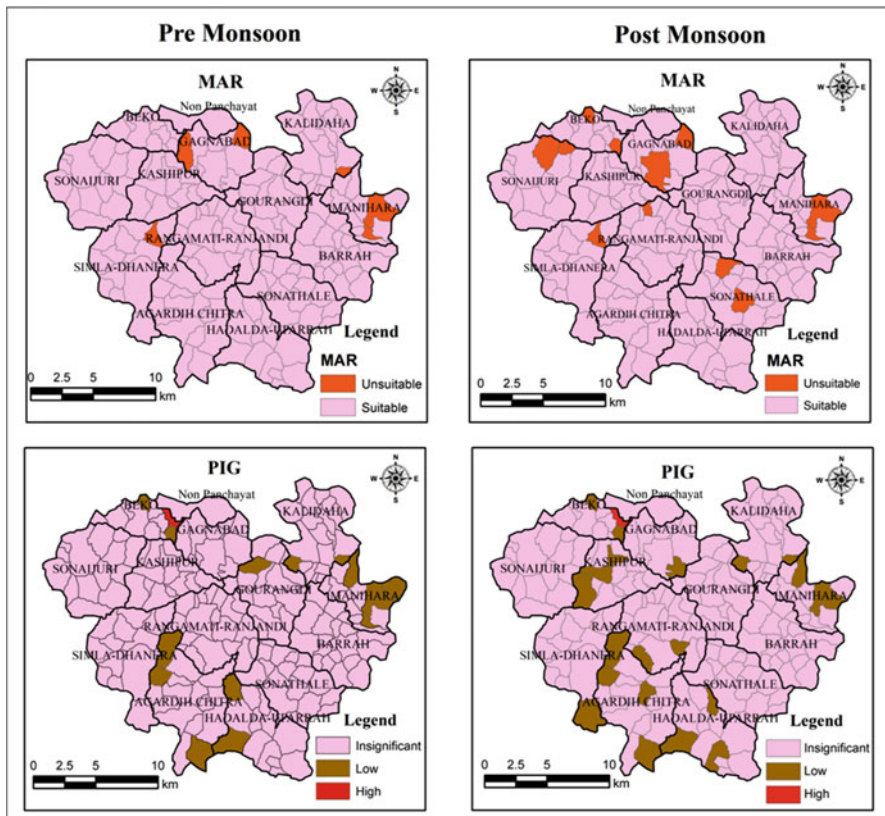


Fig. 6.8 Village level PIG zonation using ArcGIS software

6.4.4 Analysis of Groundwater Pollution Zone by PIG Method

For the assessment of groundwater quality, contribution of each chemical variable was considered to calculate the PIG of each sample. A higher value of PIG indicates greater pollution intensity of groundwater sample. Here, the PIG value was divided into three major divisions, such as (i) <1 as insignificant pollution zone, (ii) $1-1.5$ as low pollution zone, and (iii) >1.5 as high pollution zone (Tables 6.10 and 6.11). In this study area, PIG values range between 0.46 and 1.50, with an average value of 0.85 in the pre-monsoon period. 38 (73.07%) samples scored <1 , and these zones fall under insignificant pollution and which are very safe to drink or for irrigation. 14 (26.92%) samples come under the low pollution zone, and only one sample (Palaskola) is above the value of 1.5 which is a highly polluted zone indicated by PIG method in the pre-monsoon season.

In the post-monsoon season, the PIG values range from 0.38 to 1.38, with an average value of 0.84. About 35 (67.30%) groundwater samples indicate insignificant pollution in Kashipur block with good water quality. 17 (32.69%) groundwater samples indicate low pollution. One sample (Palaskola) shows higher than 1.5. It may be due to dense population with high living standards and effects by sewage runoff from nearby railway settlement colony. Thus, it clearly indicates that groundwater quality of Palaskola village is highly polluted by various anthropogenic sources such as metallic wastes of railway department, liquid sewage of residential settlement, etc. in the soil (Fig. 6.8).

6.4.5 Water Quality Assessment in Relation with Physical Condition of the Study Area

In the present study area, overall water quality has been assessed by the various physico-chemical conditions. The chemical parameters such as pH, TDS, EC, and TH are directly related to high elevation region. Greater elevation indicates highlands with weathered granitic gneissic formation with low to moderate pH in most regions and low elevation with high to moderate pH and TH condition. Weather-resistant rocks supply low amount of TDS and EC to the groundwater, and these resistant rocks produce uplands; thus, elevation with greater values shows low TDS and EC in the water samples of the study area. Fine loamy soils of the study area also indicate low concentration of cations such as CO_3^{2-} , HCO_3^- , and Fe^- in the groundwater samples. Potassium is highly found in the fine loamy to coarse loamy soil zone in the study area. The geogenic condition directly affects the soil formation, and types of rocks and minerals greatly influenced the quality of groundwater and its usability to drinking and irrigation purpose.

Table 6.10 Groundwater Pollution Zones (PIG) classification of different GP of Kashipur block, Purulia district in pre-monsoon season

Insignificant pollution (<1)	Low pollution (1–1.5)	High pollution (>1.5)
Lohat	Bhatulkend	Palaskola
Kelahi	Indrabil	
Sirjam	Manihara	
Rajra	Adali	
Kadori	Rampur	
Paharpur	Agrabad	
Kalapathar	Jiara	
Balarampur	Saharbera	
Jibanpur, Sonathale	Tara	
Sonathol	Rugri	
Hadalda	Jibanpur, beko	
Kaliada	Ichamara	
Bhalagara	Pabra - pahari	
Chaka	Jamkuri	
Simla		
Damankiri		
Liya		
Shiulibari		
Rudra		
Kalyajhor		
Bhalagara		
Daldali		
Jorisha		
Kuardi		
Chakalta		
Dhobari		
Gagnabad		
Lapara		
Rangiladi		
Sidpur		
Gopalpur		
Ranjandi		
Patpur		
Tilabani		
Lajhna		
Kapistha		
Talajuri		
Sutabani		

Table 6.11 Groundwater Pollution Zones (PIG) classification of different GP of Kashipur block, Purulia district in post-monsoon season

Insignificant pollution (<1)	Low pollution (1–1.5)	High pollution (>1.5)
Lohat	Bhatulkend	Palaskola
Kelahi	Indrabil	
Adali	Manihara	
Rampur	Agrabad	
Sirjam	Chaka	
Rajra	Pabra- pahari	
Kadori	Tara	
Paharpur	Damankiri	
Kalapathar	Dhobari	
Balarampur	Rugri	
Jibanpur (Sonathale)	Jibanpur , (beko)	
Sonathol	Tilabani	
Kaliada	Lajhna	
Hadalda	Saharbera	
Ichamara	Rangiladi	
Jiara	Sidpur	
Simla	Gopalpur	
Liya		
Shiulibari		
Rudra		
Kalyajhor		
Bhalagara		
Daldali		
Jorisha		
Kuardi		
Chakalta		
Dhobari		
Gagnabad		
Lapara		
Ranjandi		
Patpur		
Kapistha		
Talajuri		
Sutabani		
Jamkuri		

6.5 Conclusion

The assessment of overall groundwater quality of different villages in Kashipur block of Purulia district gives some important knowledge about its spatial variation in the study area: A total of 52 samples were collected from bore wells of 52 different villages. Physico-chemical parameters were analyzed in laboratory by authentic

methods. The analysis shows that the concentration of pH is moderate to safe for drinking use.

Concentration of TDS is positively correlating with the EC values which are affected by various anthropogenic activities in the study area (agricultural, industrial, domestic runoff). The cationic and anionic concentrations are determined by geochemical characteristics of the aquifer zone.

In this study area, the values of Na^+ and SO_4^{+} are safe to drinking and agricultural usages, where the high concentration of Mg indicates richness of ferromagnesian minerals in the underlying rocks and mixing of waste or sewage water to the underground water in both pre-monsoon and post-monsoon seasons. Concentration of calcium in the groundwater generally depends upon the source of calcium feldspars. The groundwater samples of the study area indicate most of the samples are rich in calcium concentration for its geogenic conditions. High percentage of Ca and Mg increases the values of TH. Due to low presence of biotitic, hornblende-like minerals, the mixing of fluoride is limited in some parts of the study area. The PIG method shows the overall quality of groundwater where most of the samples are under insignificant pollution zone (73.07%) and few are moderately polluted (26.92%) and only one sample (0.01%) falls under high pollution zone in pre-monsoon season. On the other hand, 67.30% samples of post-monsoon season fall under the insignificant pollution zone, 32.69% samples show low pollution, and 0.01% of samples indicate high pollution in the Kashipur block. The irrigation water quality assessment techniques (SAR, SSP, KR, MAR) show that most of the samples are safe to use for agricultural production. Some samples indicate high values of SSP, MAR, KR, and SAR which are unsafe for irrigation practice in the study area.

Ordinary kriging method is used to generate spatial concentration of different chemical parameters in the Kashipur block. Modern GIS techniques are used to delineate the overall groundwater quality in the study area. Zonation by PIG method indicates northern, north-eastern, and southern parts of Kashipur block are moderately affected by their physico-chemical conditions in the pre-monsoon season. Eastern, central, southern, and south-western parts of Kashipur block are affected by moderate to high groundwater pollution zone. Thus, it is helpful to further assess groundwater quality and measures to enhance the usefulness of the valuable groundwater resource to the Kashipur block of Purulia district.

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