IOSR Journal of Engineering (IOSRJEN) **www.iosrjen.org**
ISSN (e): 2250-3021, ISSN (p): 2278-8719
Vol. 11, Issue 7, July 2019, ||Series -I|| PP 45-91

Water Quality and Hydro-chemical Assessment for Irrigation on Baitarani River Basin, Odisha

Abhijeet Das [a], Dr. Bhagirathi Tripathi [b]
[a] Guest Faculty, Civil Engineering Department, Odisha.
[b] Assistant Professor, Civil Engineering Department, IGIT, Sarang, Odisha.
Received 20 December 2018; Accepted 05 July 2019

ABSTRACT
In order to achieve a better understanding of the nature of the factors influencing surface water composition as well as to specify them quantitatively, various techniques were used to evaluate temporal and spatial variations in and to interpret large and complex water quality data sets collected from the Baitarani River Basin. It constitutes a dump of industrial and domestic rejections which contribute to the degradation of water quality. The objective of this study is to evaluate the water quality of the river and to analyze the suitability for drinking, agricultural and industrial uses. Surface water samples were analyzed for their physical and chemical properties using standard laboratory methods. Physical and chemical parameters such as PH, Turbidity, TDS, TSS, EC, DO, Alkalinity, BOD, TH, HCO_3^-, SO_4^{2-}, NO_3^-, PO_4^{3-}, Cl^-, Ca^{2+}, Mg^{2+}, Na^+, K^+, TC, FC, Fe and Cr were determined. The first aim is to evaluate the state of the water in this river. The second aim is to calculate the parameters of the quality of water destined for irrigation such as SAR, RSC, RSBC, MH, KR, PI and PS. A high mineralization and high concentration of major chemical elements and nutrients indicate normal value of WQI index. The PH values for all sampling locations are alkaline in nature. EC values of all the water samples are below 750, indicating good quality of irrigation water. Plotting the values of conductivity (EC) and sodium absorption ratio (SAR) on the US Salinity diagram illustrated that most of the samples fall in the category C1S1 indicates medium salinity/low sodium and C2S1 indicates low salinity/low sodium in all seasons. There exhibits a positive correlation between SSP and SAR with a coefficient of 0.7762 in both pre-monsoon and post-monsoon periods. It is reported that salinity and sodicity are the principal water quality concerns in irrigated areas, receiving such water. Saline-sodic irrigation water, coupled with limited rainfall and high evaporation, may increase soil sodicity significantly. In general, when sodium is an important component of the salts, there can be a significant amount of adsorbed sodium making the soil sodic. It shows a positive correlation between EC and SAR with a correlation coefficient (R^2) = 0.2834 in case of pre-monsoon season and R^2 = 0.266 in case of post-monsoon season. The positive value of R^2 shows that there is a lesser variation in the EC values and vice versa. Binary diagrams were also drawn to evaluate the origin of salts dissolved in water and it shows from the analysis that the plot of Na^+ versus Cl^- showed a good correlation between sodium and chloride concentration for most of the points. This confirms that the halite dissolution is behind water salinity. The plots representing Ca^{2+} versus SO_4^{2-} concentrations yielding a good correlation between most of the points. The line representing gypsum dissolution ($Ca\ SO_4 .2H_2O$) indicating that gypsum dissolution is a second source of minerals in these waters after halite. Water Quality Index study reveals that close to 92.30 % of the water samples are suitable for drinking. For determination of the drinking suitability standard of surface water, parameters have been considered – TH, Piper's trilinear diagram and water quality index study. It has been found to be excellent in all sampling locations except one station which can be ignored in both seasons and hence poses no health risk which could arise due to excess consumption of calcium and magnesium. Hydro-geochemical facies in the form of Piper's trilinear diagram plot which helps in identification of the water type which can render a particular taste or odor to water, indicates that surface water is majorly of $CaMgHCO_3$ and $NaHCO_3$ type (fresh type) during both pre-monsoon and post-monsoon seasons barring a couple of samples which are of $CaMgSO_4$ / $CaMgClSO_4$ type in pre-monsoon. RSC values of all the samples are less than 1.25 meq/L, indicating that there is no complete precipitation of calcium and magnesium and the water samples are safe for irrigation purposes. However, all irrigation indices allow the water for use in irrigation purposes. This study highlights the importance of applying the water quality indices which indicate the total effect of the ecological factors on surface water quality and which gives a simple interpretation of the monitoring data to help local people in improving water quality. It provides the necessity and practicality for evaluating and interpreting the large and complex data sets, with a view to obtaining better information about water quality and the design of monitoring networks to effectively manage water resources.

KEYWORDS: Baitarani River, sodium absorption ratio, US Salinity diagram, Piper's trilinear diagram, Water Quality Index

I. INTRODUCTION

Water is very vital for nature and can be a limiting resource to men and other living beings. Without a well-functioning water supply, it is difficult to imagine productive human activity be it agriculture or livestock. The quality of water is almost importance to quantity in any water supply planning. Water quality is influenced by natural and anthropogenic effects including local climate, geology, and irrigation practices. The chemical character of any surface water determines the quality and utilization. The quality is a function of the physical, chemical and biological parameters and could be subjective, since it depends on a particular intended use.

Surface water is a vital natural resource. Depending on its usage and consumption it can be a renewable or a non-renewable resource. It is estimated that approximately one third of the world's population use surface water for drinking (Nickson et al., 2005). It is the major source of water supply for domestic purposes in urban as well as rural parts of India. Among the various reasons, the most important are non-availability of potable surface water and a general belief that water is purer and safe than surface water due to the protective qualities of the soil cover (Mishra et al. 2005). Since river water is devoted to agricultural uses, its quality should be assessed to safeguard public health and environment (Igbinosa and Okoh 2009). Thus, Comprehensive River water quality monitoring is a helpful tool not only to evaluate the suitability of surface water for irrigation, but also to ensure an efficient management of water resources and the protection of aquatic life (kannel et al. 2007). Although Baitarani River is the most important and is used for potable water supply and agriculture as well as an important aquatic life place, very few studies dealt with the assessment of its water quality. Most of the availability water is used for agricultural purposes. It also exposed to urban and industrial pollution. Therefore, the monitoring of environmental parameters is one of the highest priorities in the evaluation of the environmental status of water resources and in environmental protection policy (Wua and Chen 2013). Therefore, it is imperative to have reliable information on the characteristics of water quality for assessing its safety for irrigation as well as an effective pollution control and water resource management (Fan et al 2010).

The river represent the major source of water used for human consumption, culture irrigation and industrial purposes. Efficient management of these water resources requires information about the river water quality and its variability. This is need is quite marked in many areas whose water resources are becoming increasingly difficult to renew, due to their overexploitation by rapidly growing population. The deterioration of river water quality water can result from natural processes and more recently due to anthropogenic activities through the discharge of industrial and domestic wastewater as well as agricultural drainage to the rivers. However, the big bulk of rivers pollution comes from industrial and domestic wastewater and agricultural drainage (Carpenter et al 1998; Jarvie et al., 1998). Anthropogenic activities can alter the relative contribution of the natural causes of variations and also introduce the effects of pollution (Whittemore et al. 1989). Standard urban surface water problems like inadequately controlled surface water abstraction, excessive urban infiltration and excessive subsurface contaminant load are initiated by the requirement of water supply, wastewater or solid waste disposal (Pokrajac 1999). Lateral contaminant from stationary sources occur in several situations. Streams, lakes, drainage channels, waste water disposal sites or stagnant ponds which contain contaminated water. For the purposes of surface water management, there is a requirement for improved understanding of the controlling process and where possible, the naturally, geologically controlled baseline chemistry. Water needed for irrigation of cultivated land is being degraded in terms of quantity and quality due to growing demand for the use of water. Moreover, the crop productivity is associated with the quality of soil and the quality of the water available for irrigation. Normally, investigation of irrigation water quality should focus on salt, content, sodium concentration, the occurrence of nutrients and trace elements, alkalinity, acidity and hardness of the water. Salinity problem has led to the loss of fertile soils every soil all over the world (Kirda 1997; Nishanthiny et al. 2010; Numaan 2011). Further, water quality deterioration associated with the ever increasing demand on irrigation water supply leads to the irrigation of farmlands with poor quality water reducing cropland productivity. Water quality for agricultural purposes is determined on the basis of the effect of water on the quality and yield of the crops, as well as the effect on soil characteristics (Ayers and west cot 1985). The most commonly encountered soil problems used for evaluating water quality are salinity, water infiltration, toxicity and miscellaneous problems (Longe and Ogundipe 2010). However, even water with considerably high salt concentration can be used for irrigation without endangering soil productivity, provided selected irrigation management. The key point is how to maintain existing salt balance in plant root zone (El Ayni et al., 2012). In addition, the increase in salinity of surface waters stems from the discharge of high salt concentration of waste effluents (Chapman 1996; Thilagavathi et al., 2012). Thus, river water quality can be deteriorated by a heavy load of nutrients and contaminants coming from industrial activity discharge of wastewater, domestic sewage and agricultural practices. The aquatic ecosystem can thus be threatened by the presence of potentially toxic, mutagenic or carcinogenic compounds from sewage discharges inducing various ecological impacts on aquatic life (Igbinosa and Okoh 2009; Nhapiand Tirivaromba 2004; Kanu and Achi 2011). In this study, we evaluate the water quality along the main streamline and its branches at different locations from its upstream to its downstream. This survey allows a hydro-chemical characterization and an assessment of the suitability of this surface water for irrigation based on chemical analysis. On a broader scope, this study contributes to the assessment of water resources and the development of local information systems to support decision making in adopting the appropriate measures for the management of water resources. This study was conducted along the monitoring stations of Baitarani River. It not only plays an important role in assimilating or removing urban and industrial wastewater and farmland runoff, but is also the main inland water resources used for household, industrial, and irrigation purposes. Therefore, it is necessary to prevent and control river pollution and have reliable water quality information for effective management. Given the spatial and temporal changes in river water chemistry, regular monitoring pro-grammes are needed to reliably estimate water quality. This leads large and complex data matrices composed of a large number of physical and chemical parameters, which are often difficult to interpret, making it challenging to draw meaningful conclusions. For these reasons, this study on the Baitarani River has to be done. In this context, we took the river as the research object for the first time, set up 13 main detection sampling points along the river and detected and analyzed 22 physical and chemical parameters in water samples.

The main objectives of this study are to

1. To assess the physicochemical properties of the river water.

2. To determine the similarities and differences between the sampling stations.

3. Evaluate the contribution of water quality parameters to temporal variations in surface water quality.

4. Identify the contamination affecting water quality and their potential sources.

5. Discuss the suitability of the water for drinking, agricultural and industrial purposes by determining water quality of the river, through WQI analysis, and create WQI map based on GIS for three different seasons.

6. The results are expected to evaluate the spatial-temporal evolution of Baitarani River water quality and consequently enable managers to understand the main sources of pollution at the different locations along the river basin.

7. Relative ionic plots are being drawn in the form of binary diagrams which were used to better identify the origin of the salts dissolved in river water.

8. In the study of hydro-chemistry, box and whisker plots of the water parameters have also been drawn for the two seasons to show the variation of the given parameter values.

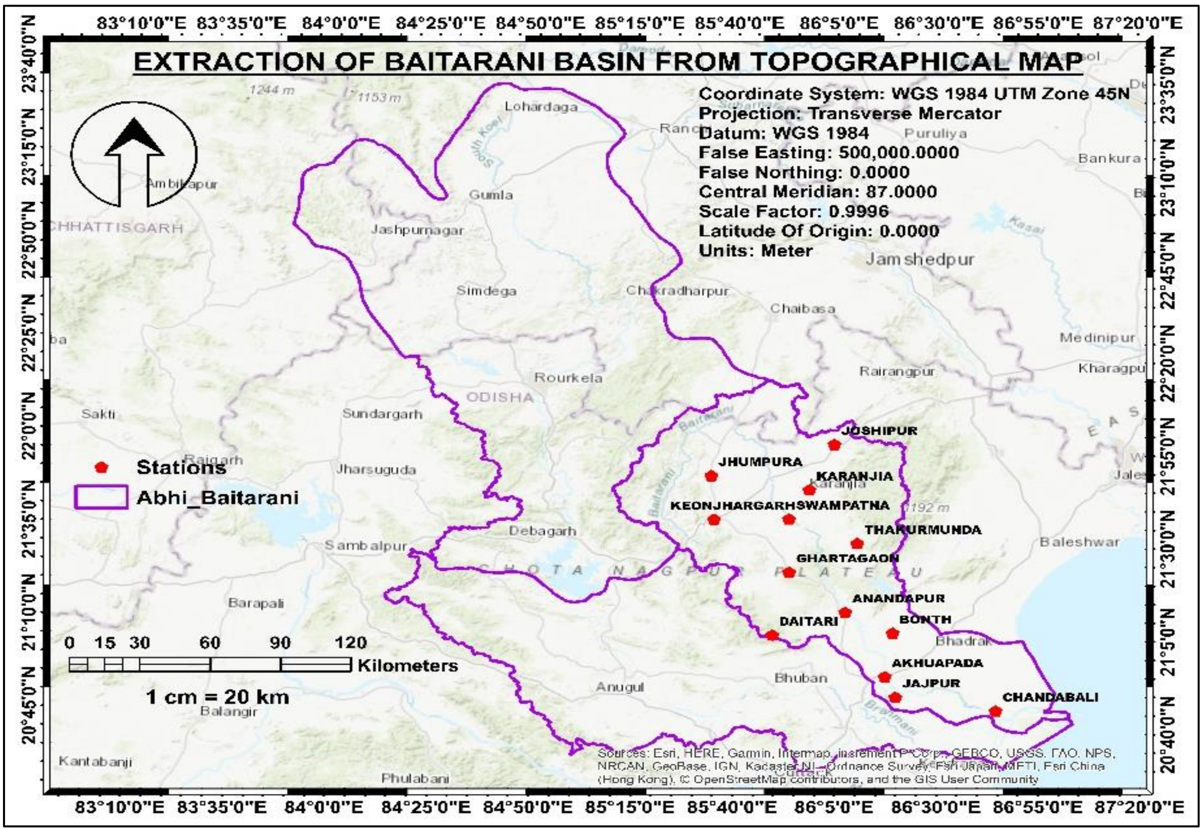
9. US Salinity Laboratory (USSL) diagrams were used to evaluate the suitability of water for irrigation use for both the seasons.

10. To know the hydro geochemical characteristics of the study area and water, the analytical values were plotted on piper diagram which help us to draw inference and to classify the water on the basis of hydro geochemical characteristics.

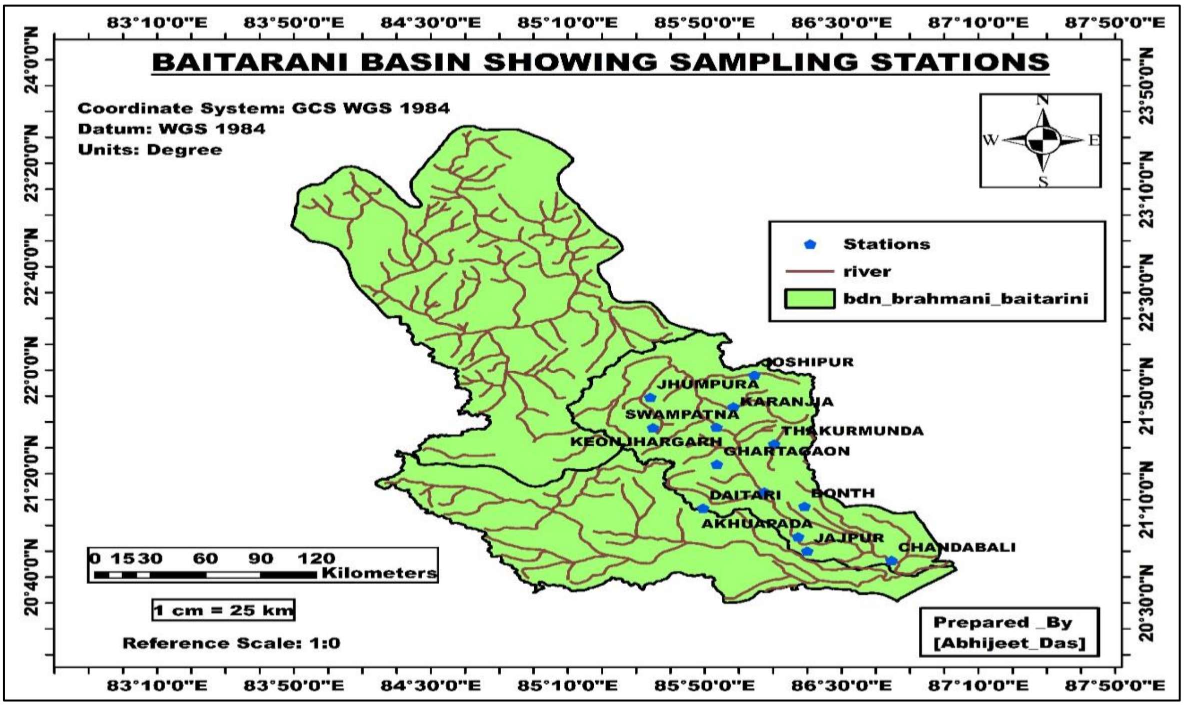
11. Evaluate various agricultural parameters such as soluble sodium percentage (SSP), sodium adsorption ratio (SAR) and Residual sodium carbonate (RSC).

II. DESCRIPTION OF THE STUDY AREA

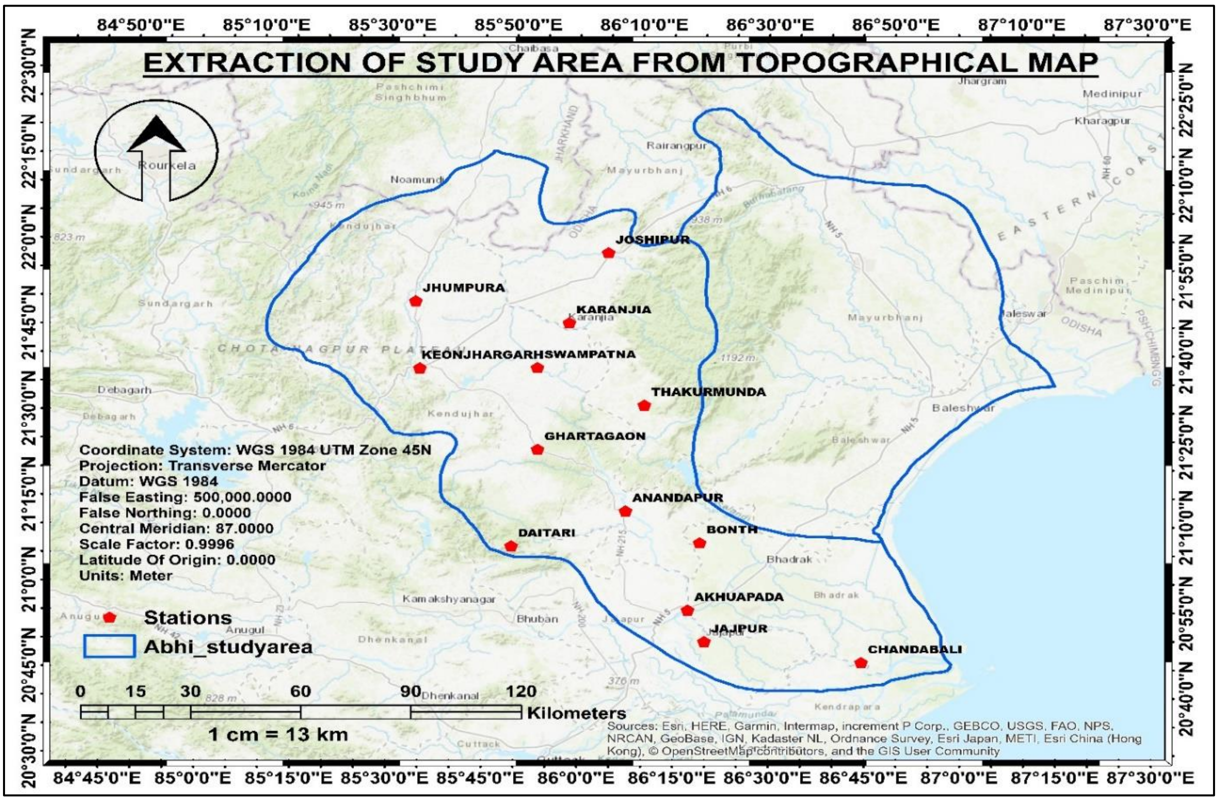
Baitarani River Basin has a total catchment area of 14,218 sq.km spreading over the two states of Odisha and Jharkhand in India. A major portion of the river basin with 13482 sq.km of catchment lies in the state of Odisha while Jharkhand have the rest of 736 sq.km. The river originates at the Gonasika / Gupta Ganga hills at 21°32'20'' N **-** 85°30'48 E and starts flowing over a stone which looks like the cow's nostril. The river at its origin has the elevation of 900 meters (3000 ft) above sea level. It originates at an elevation of 900 m above mean sea level from Guptaganga hills of Gonasika of Keonjhar district. The beginning portion of Baitarani acts as the boundary between Odisha Jharkhand states. It flows in a north-easterly direction for about 80 km and then takes a south-east direction for the next about 170 km to reach Jajpur. Here the river turns left to flow towards east and enter the littoral plain or delta. The river enters plains at Anandpur and creates deltaic zone below Akhuapada. The river traverses a total distance of 360 km in Odisha before joining with Dhamra River and finally into the Bay of Bengal, Deo, Salandi, Kanjhari, Musal, Arredi, Siri, Kukurkata, Kusei, Gahira and Remal are major tributaries of Baitarani River. A major portion of the basin (94.8%) lies within the state of Odisha, while a small patch of up reach (5.2%) lies in Jharkhand state. The basin covers 8 revenue districts of the state. The main urban centres in Baitarani basin are keonjhar, Joda, Jajpur, Vyasana, Bhadrak, Anandpur, Chandabali and Dhamnagar. The below (**Figure 1, 2, 3, 4**) showing extraction of basin boundary along with study area showing all monitoring stations by the application of GIS Software.



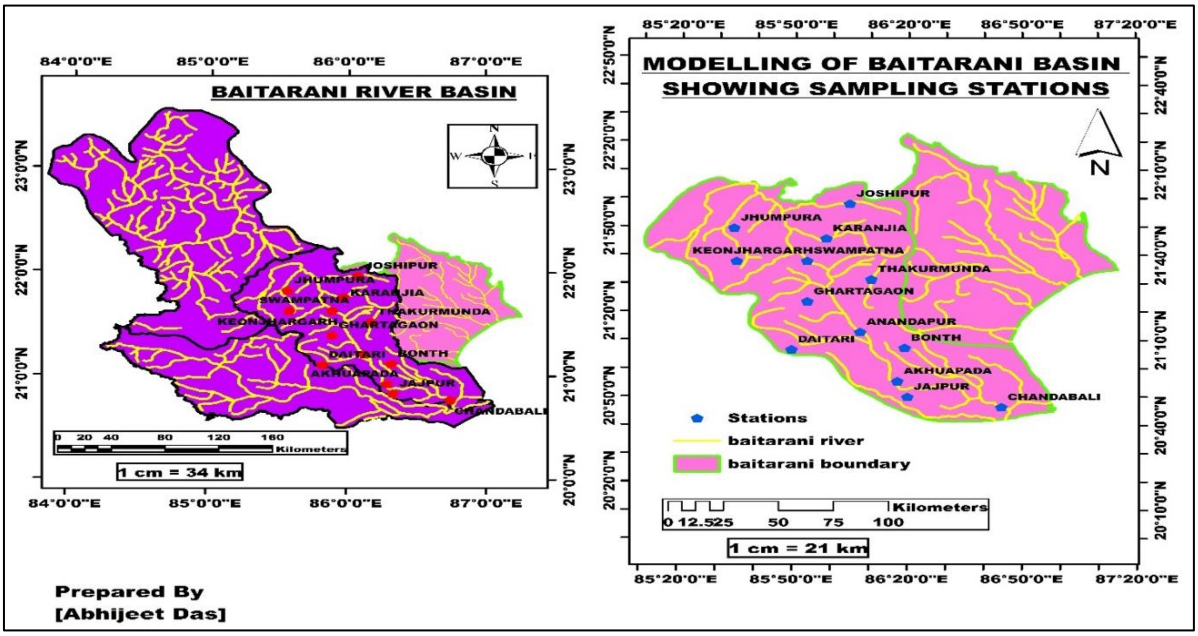
(**Figure 1**. Extraction of Baitarani River Boundary from topographical map)



(**Figure 2**. Map of study area presenting Baitarani River along with sampling locations)



(**Figure 3**. Extraction of study area Boundary from topographical map)



(**Figure 4**. Baitarani river network covering all sampling stations along the flow path)

III. METHODOLOGY AND DATA USED

The water samples were collected in pre-monsoon, monsoon and post-monsoon period of 2000 - 2020 from previously selected 13 (Thirteen) sampling stations (**Table 1**) in washed polypropylene bottles (manufactured by Tar son, India). The sampling stations were selected on the basis of uniform distance, with slight deviation depending upon the geographic condition and ease of access. Coordinates of the sampling stations were recorded by Global Positioning System (GPS). Some physicochemical parameters like temperature and pH were determined in the sampling sites by laboratory mercury thermometer and pocket pH meter (HANNA, USA), respectively. The water samples were collected manually from a depth of 20 cm from the surface of the water, preferentially where the flow of the water was high, to obtain good homogenized samples

(Rakotondrabe et al. 2018). After collecting the samples and making the bottles airtight, the samples were transported to the laboratory with favorable temperature (< 4°C) following the procedures described in APHA (2012). In the laboratory, dissolved oxygen (DO), electrical conductivity (EC) and total dissolved solid (TDS) were determined immediately by Thermo-Scientific Orion 5 Star instrument (Thermo-Scientific Inc.). All the reagents used for analytical purposes were of analytical grade (Merck, India) for higher accuracy and precision. Some samples were sent to water quality laboratory of Central Water Commission, Bhubaneswar for analysis of physico-chemical parameters like pH, turbidity, EC, TDS, TSS, total hardness, cations like Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, and anions like HCO_3^-, SO_4^{2}- , NO_3^-, PO_4^{3-}. Analysis of heavy metals like Fe and Cr were done by AAS (Shimadzu AA6300) and ICP-OES (PerkinElmer Optima 2100 DV) in IMMT, Bhubaneswar.

Table 1. Water Sampling Locations

SAMPLING CODES	MONITORING STATIONS
1	CHANDABALI
2	JAJPUR
3	AKHUAPADA
4	DAITARI
5	BONTH
6	ANANDAPUR
7	GHARTAGAON
8	THAKURMUNDA
9	SWAMPATNA
10	KEONJHARGARH
11	KARANJIA
12	JHUMPURA
13	JOSHIPUR

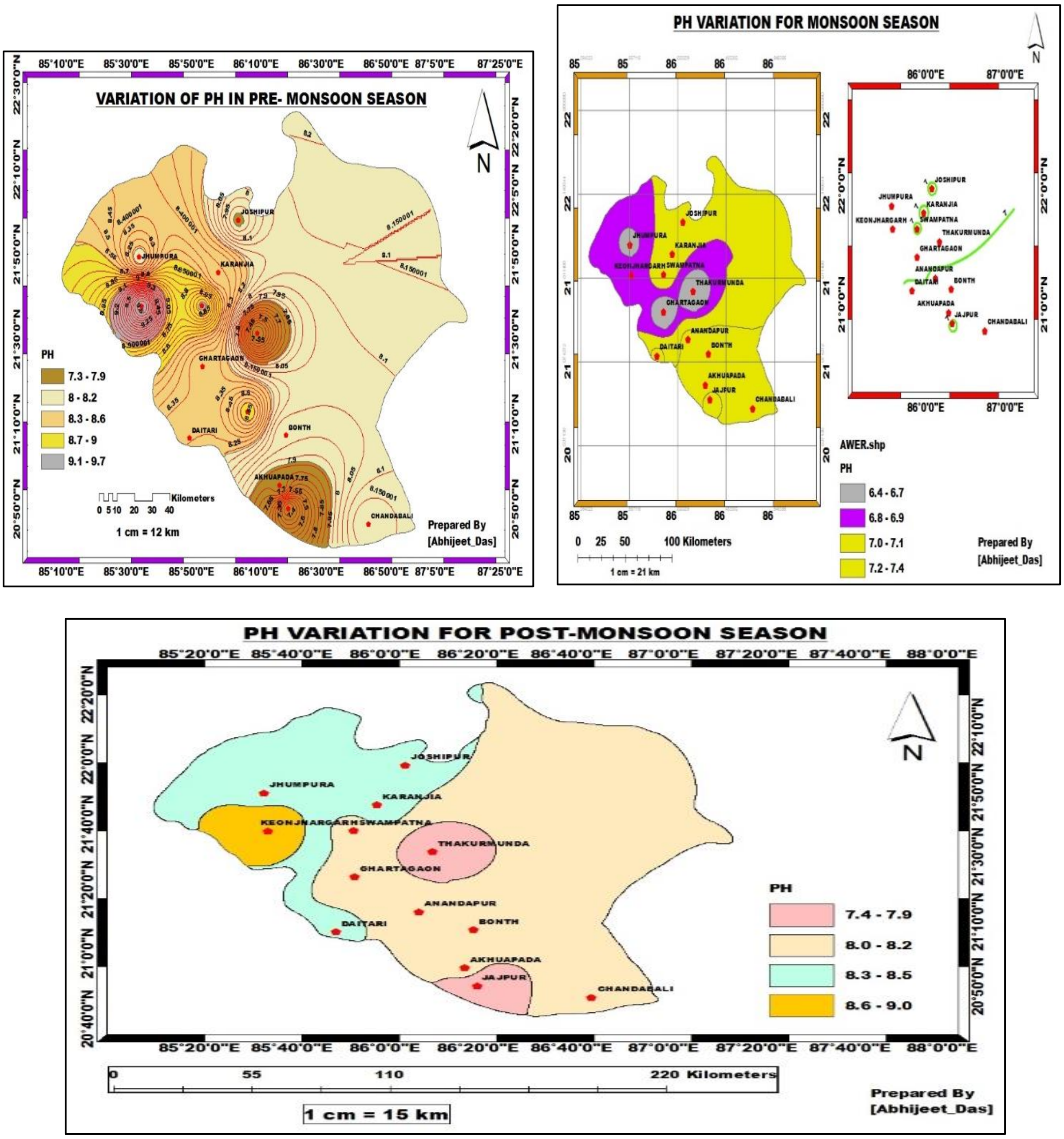
IV. RESULTS AND DISCUSSION

Physico-chemical parameters of surface water

Understanding the surface water quality is important as it is the main factor determining its suitability for drinking, domestic, agricultural and industrial purposes (Subramanian et al. 2005). The spatial variations of different water quality parameters like PH, Turbidity, TDS, TSS, EC, DO, Alkalinity, BOD, TH, HCO_3^-, SO_4^{2-}, NO_3^-, PO_4^{3-}, Cl^-, Ca^{2+}, Mg^{2+}, Na^+, K^+, TC, FC, Fe and Cr for pre-monsoon, monsoon and post-monsoon season over a period of 20 years are being represented in the geospatial map which determines overall water quality status of a certain time and locations. It is used to assess water quality relative to the standard for domestic use and to provide insight into the degree to which water quality is affected by human activity.

A. Hydrogen Ion Activity (pH)

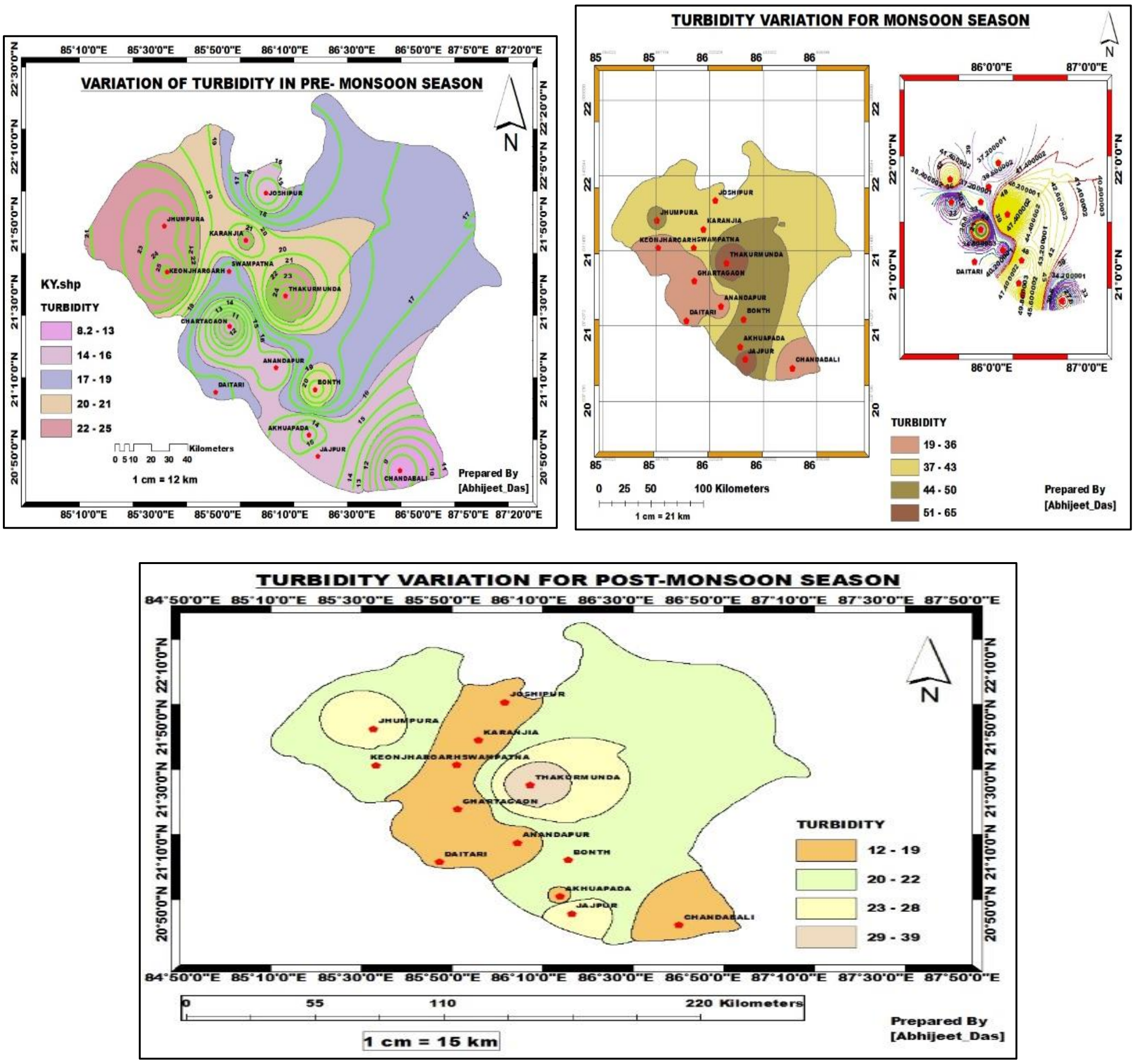
The PH indicates the degree of acidity or alkalinity of water. The normal PH range required for irrigation water is 6.5 – 8.4 (Ayers and West cot 1976). The PH ranges for domestic and other purposes are: 6.5 – 8.5, maximum desirable limit; 6.5 – 9.2, maximum permissible limit by WHO (2008); and 6.5 – 8.5, maximum desirable limit by BIS (2012) (Singh et al 2008). All the PH values of the water samples are greater than 7 indicating slight alkaline water. The PH values **(Figure 5)** range from 7.3 to 9.7 in the pre-monsoon period, 6.44 to 7.43 in monsoon period and 7.4 to 9 in the post-monsoon period.



(**Figure 5.** Spatial variations of PH in pre-monsoon, monsoon and post-monsoon season)

B. Turbidity

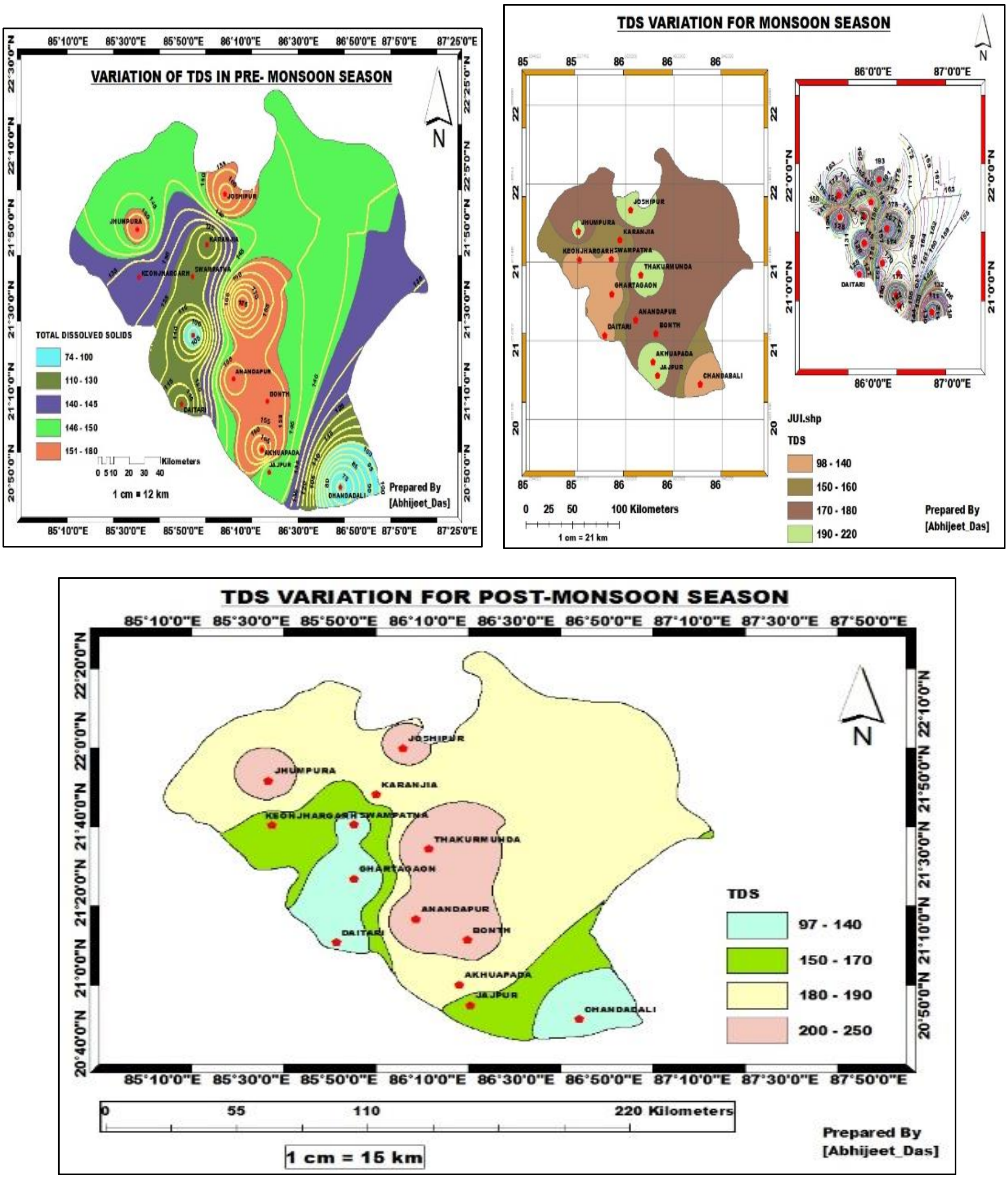
The normal turbidity range required for irrigation water is < 15 NTU indicates excellent, 16 – 35 indicates good, 36 – 70 indicates moderately polluted, 70 – 100 indicates polluted and >100 indicates highly polluted. So in this study, it varies in a range from 8.20 to 25.20 with a mean of 17.49 in pre-monsoon season, 18.7 to 65.40 with a mean of 39.62 in monsoon season and 11.80 to 38.70 with a mean of 20.06 in post-monsoon season. As it is seen that all the sampling locations performs good to excellent in pre-monsoon and moderately polluted to excellent in monsoon and post-monsoon season. Spatial variations is being represented by geospatial map **(Figure 6).**



(**Figure 6.** Spatial variations of turbidity in pre-monsoon, monsoon and post-monsoon season)

C. Total Dissolved Solids (TDS)

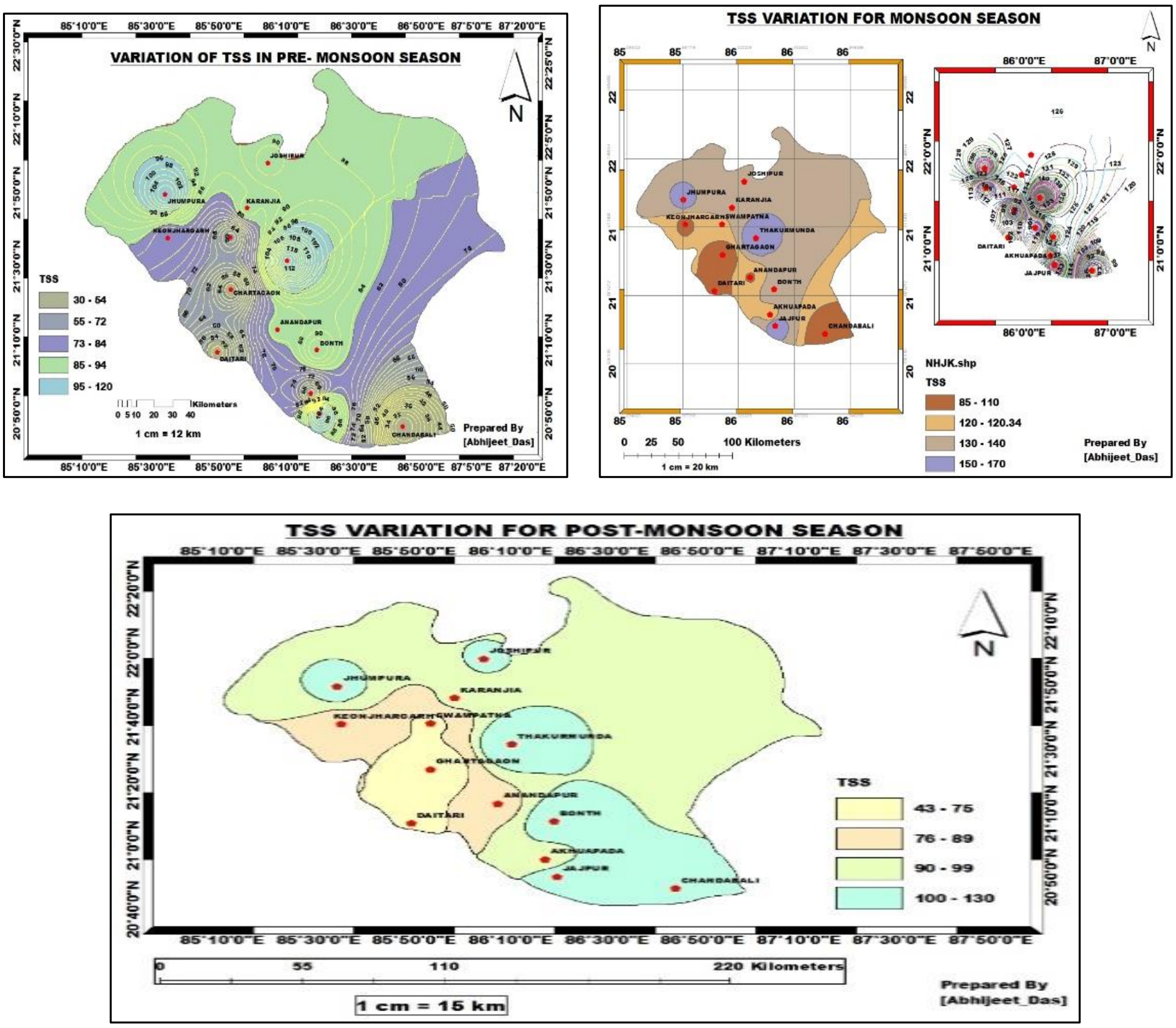
Normally, TDS in water may originates from natural sources and sewage discharges. To ascertain the suitability of surface water of any purposes, it is essential to classify the ground water depending upon their hydro-chemical properties based on their TDS values (Davis and De Wiest 1966; Freeze and Cherry 1979) which are represented as < 500 indicates desirable for drinking, 500 – 1000 indicates permissible for drinking, 1000 – 3000 indicates useful for irrigation and > 3000 indicates unfit for drinking and irrigation. According to Freeze, < 1000 indicates fresh water type, 1000 – 10,000 indicates brackish water type and > 100,000 indicates Brine water type. The average concentration of Total Dissolved Solids (TDS) ranged from 74 to 178 with a mean of 135.31 in pre-monsoon season, 98 to 218 with a mean of 156 in monsoon season and 97 to 247 with a mean of 171.23 in post-monsoon season. All the values are within the limits and hence suitable for both drinking and irrigation. Spatial variations is being represented by geospatial map **(Figure 7).**



(**Figure 7.** Spatial variations of TDS in pre-monsoon, monsoon and post-monsoon season)

D. Total Suspended Solids (TSS)

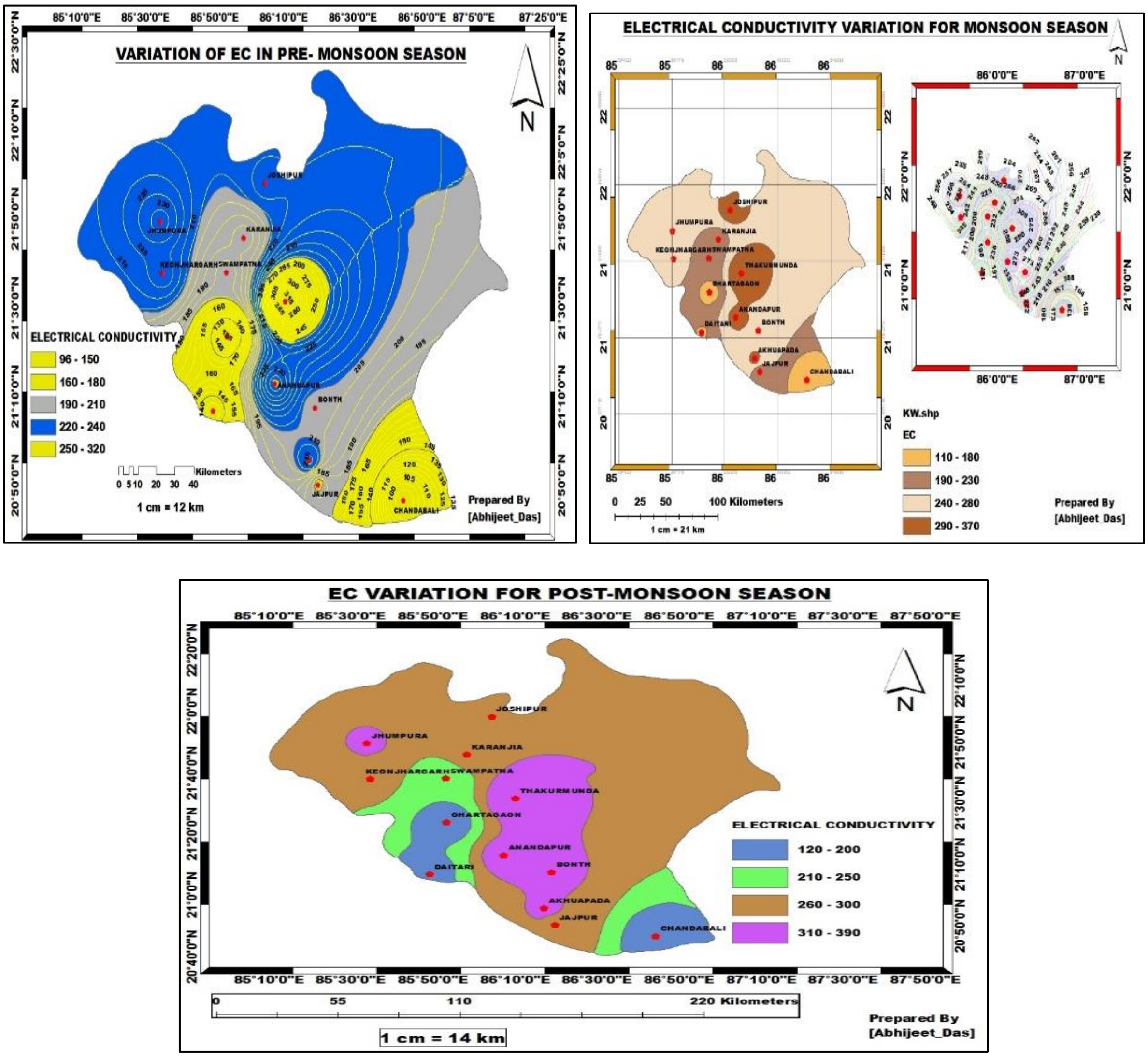
The average concentration of Total Suspended Solids (TDS) ranged from 30 to 121 with a mean of 79.15 in pre-monsoon season, 85 to 168 with a mean of 120 in monsoon season and 43 to 127 with a mean of 91.62 in post-monsoon season. All sampling locations are within the permissible limits. Spatial variations is being represented by geospatial map **(Figure 8).**



(**Figure 8.** Spatial variations of TSS in pre-monsoon, monsoon and post-monsoon season)

E. Electrical Conductivity (EC)

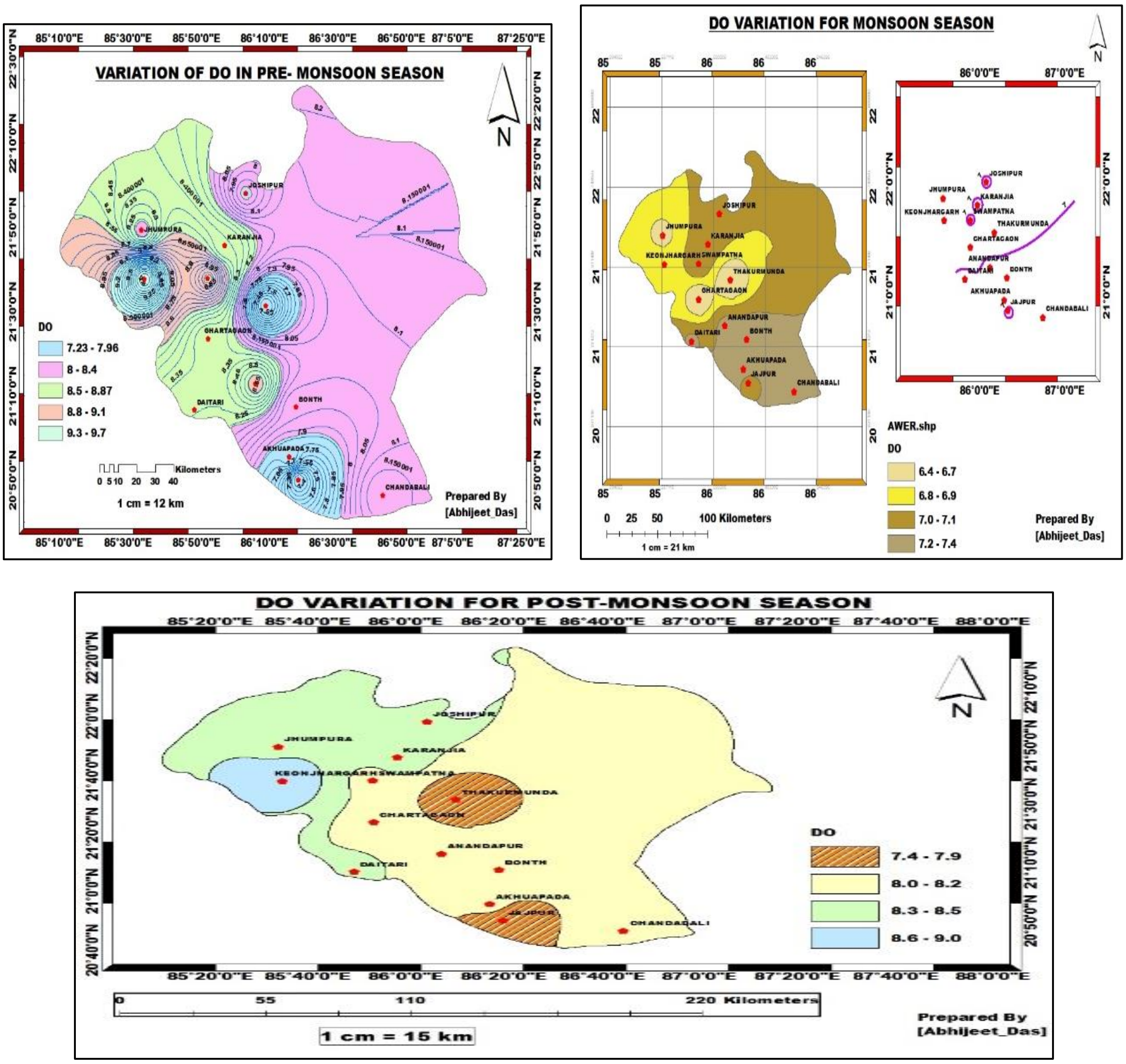
It is the most important parameter in determining the suitability of water for irrigation use and it is a good measurement of salinity hazard to crop as it reflects the TDS in waste water. The most important negative effect on the environment caused by agricultural waste water is the increases in soil salinity which if not controlled, can decrease productivity in long term. Salinity hazard occurs when salts start to accumulate in the crop root zone reducing the amount of water available to the roots. This reduced water availability sometimes reaches to such levels that the crop yield is adversely affected. These salts often originate from dissolved minerals in the applied irrigation water or from a high saline water table. The reductions in crop yield occur when the salt content of the root zone reaches to the extent that the crop is no longer able to extract sufficient water from the salty soil. When this water stress is prolonged, plant slows its growth and drought like symptoms start to develop. In our study, EC values varied from 96 to 318 with a mean value of 197.62 in the pre-monsoon season, 108 to 372 with a mean of 237 in monsoon season and varied from 121 to 393 with a mean value of 261.54 in the post-monsoon season. EC values **(Figure 9)** of all the water samples are below 750, complying beautifully with both Richards's value and FAO regulation and indicating good quality of irrigation water. If the values are more than the prescribed limits then the water can be used on the soils with restricted drainage. Special salinity control management with selection of good salt tolerant plants is required. The primary effect of high EC reduces the osmotic activity of plants and thus interferes with the absorption of water and nutrients from the soil.



(**Figure 9.** Spatial variations of EC in pre-monsoon, monsoon and post-monsoon season)

F. Dissolved Oxygen (DO)

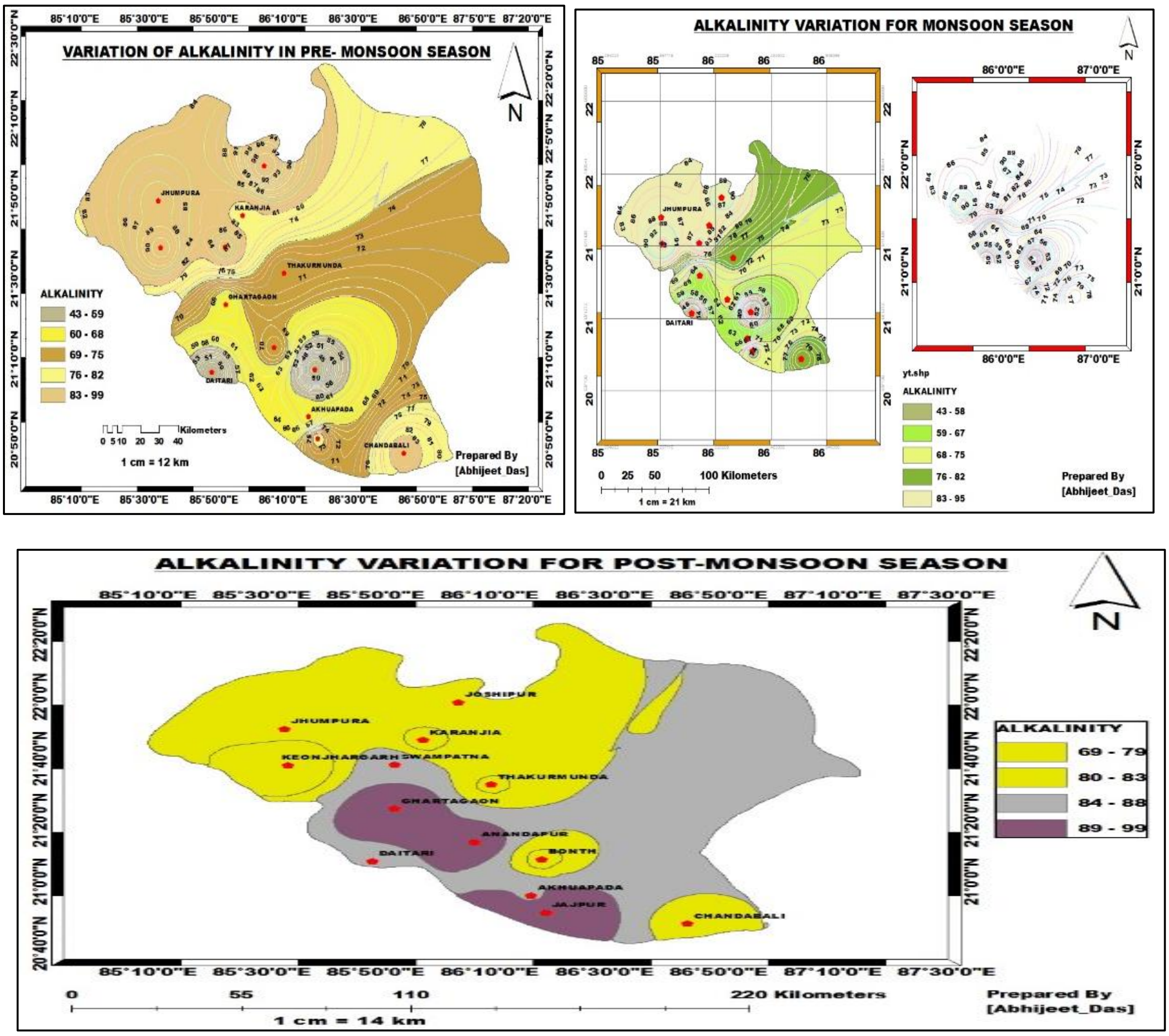
DO content is an essential parameter that maintains the equilibrium of aquatic ecosystems. It is commonly used to assess the water resource quality (Qadir et al., 2002; Sanchez et al., 2006). As documented by Kumari et al., 2013, this was explained by the fact that increasing temperature reduces the dissolution of ambient DO in river water. Also, Yang et al., 2007 hypothesized that the low DO values were linked to the high activities of microorganisms require large amounts of oxygen for metabolizing activities and for organic matters degradation. In our study, the average concentration of Dissolved Oxygen (DO) ranged from 4.78 to 8.01 with a mean of 6.91 in pre-monsoon season, 5.87 to 7.87 with a mean of 6.98 in monsoon season and 5.03 to 7.69 with a mean of 6.84 in post-monsoon season. All sampling locations are within the prescribed limits according to the WHO standards. Spatial variations is being represented by geospatial map **(Figure 10).**



(**Figure 10.** Spatial variations of DO in pre-monsoon, monsoon and post-monsoon season)

G. Alkalinity

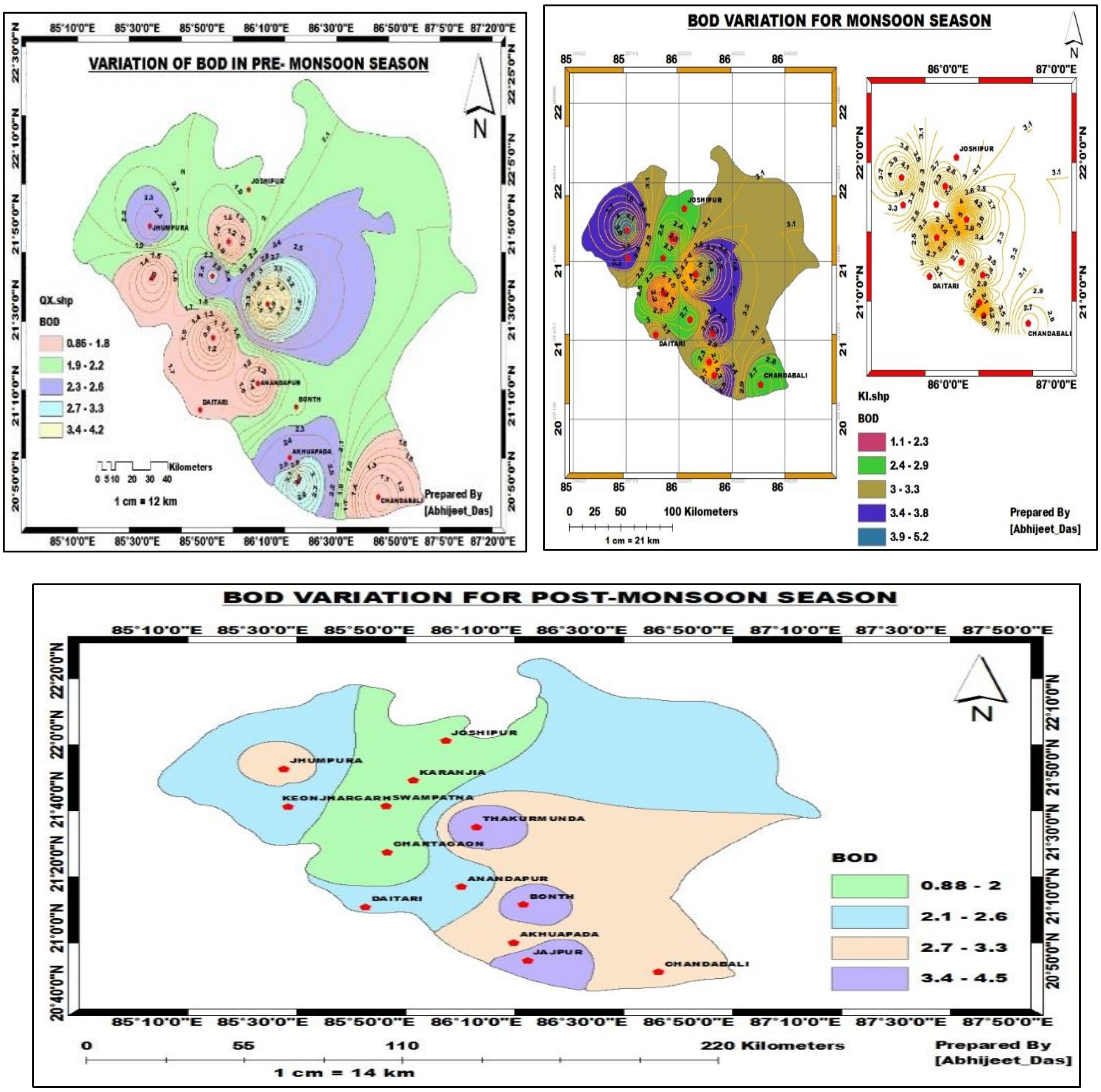
Alkalinity is measure of the capacity of water to neutralize an added acid. Being the major component of alkalinity, carbonate and bicarbonate ions are generally responsible for high PH values (i.e. above 8.5) of water. Elevated level of carbonates cause's calcium and magnesium ions to form insoluble minerals leaving sodium as the dominant ion in solution. Hence, it is indirectly responsible from the hazards that high sodium concentrations cause on the irrigated crops and the soil. Thus, it is possible to conclude that highly alkaline irrigation waters could intensify sodic soil conditions. It is recommended to calculate an adjusted SAR to reflect the increased sodium hazard. It is recommended that the bicarbonate concentration values below 90 mg/l are considered to be ideal for irrigation. The average concentration of Alkalinity ranged from 43 to 99 with a mean of 74.23 in pre-monsoon season, 43 to 95 with a mean of 74.15 in monsoon season and 69 to 99 with a mean of 84.23 in post-monsoon season. All sampling locations are within the prescribed limits according to the WHO standards. Spatial variations is being represented by geospatial map **(Figure 11).**



(**Figure 11.** Spatial variations of alkalinity in pre-monsoon, monsoon and post-monsoon season)

H. Biochemical Oxygen Demand (BOD)

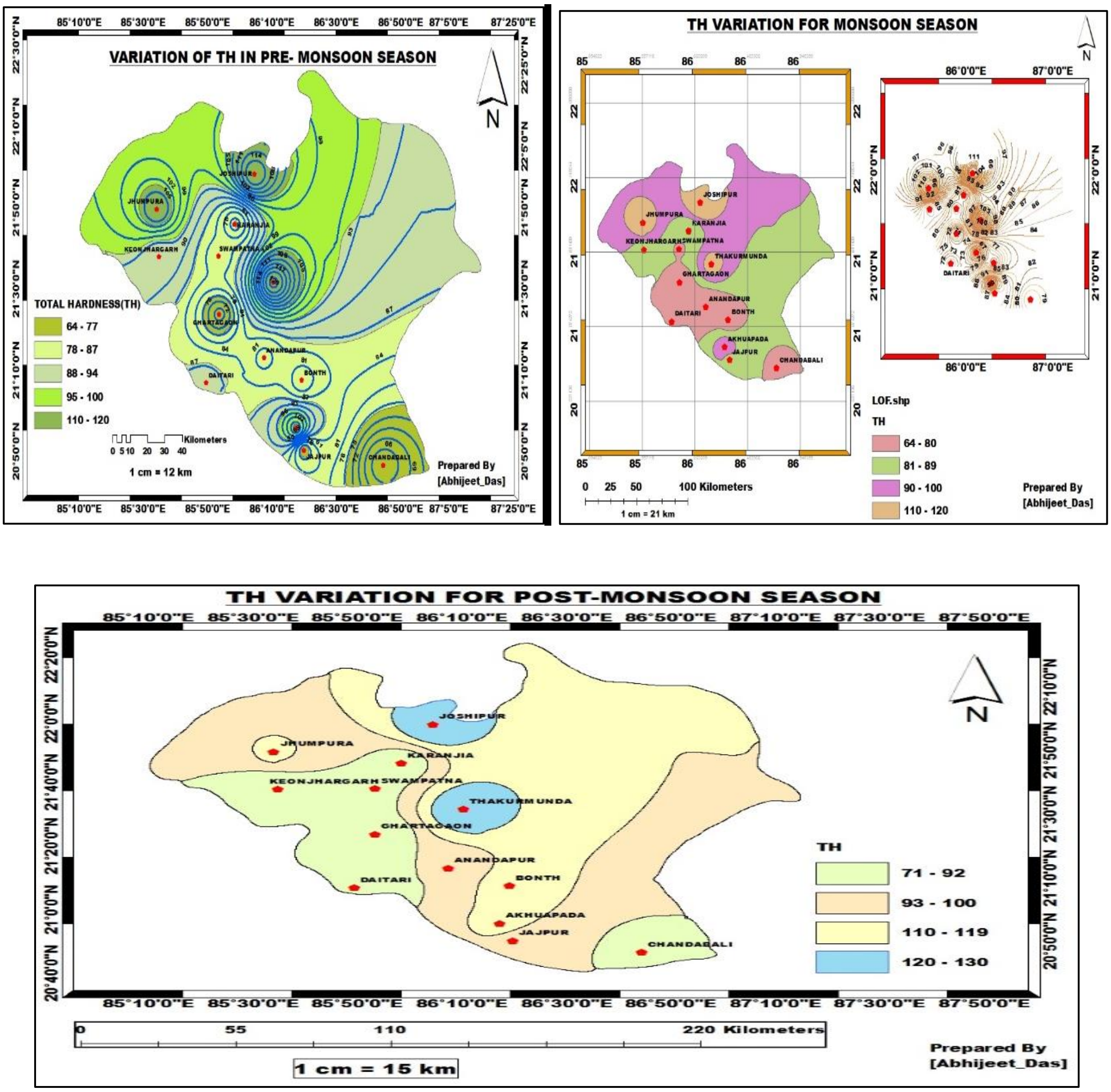
Biochemical oxygen demand is the quantity of oxygen necessary for the decomposition of organic matter under aerobic conditions (Sawyer and Mc Carty 1978). These are indirect measurements of dissolved oxygen quantity in water and represent the amount of organic compounds in water. This load is the result of urban and industrial waste which volume varies according to the density of population, the nature and the importance of industries. According to WHO standards, BOD did not exceed 6 mg/l. In our study, BOD concentration ranges from 0.86 to 4.23 with a mean of 2.01 in pre-monsoon period, 1.05 to 5.16 with a mean of 3.08 in monsoon season and 0.88 to 4.54 with a mean of 2.46 in post-monsoon period. All the sampling locations are with the prescribed limits and hence, it is suitable for all purposes. Spatial variations is being represented by geospatial map **(Figure 12).**



(**Figure 12.** Spatial variations of BOD in pre-monsoon, monsoon and post-monsoon season)

I. Total Hardness (TH)

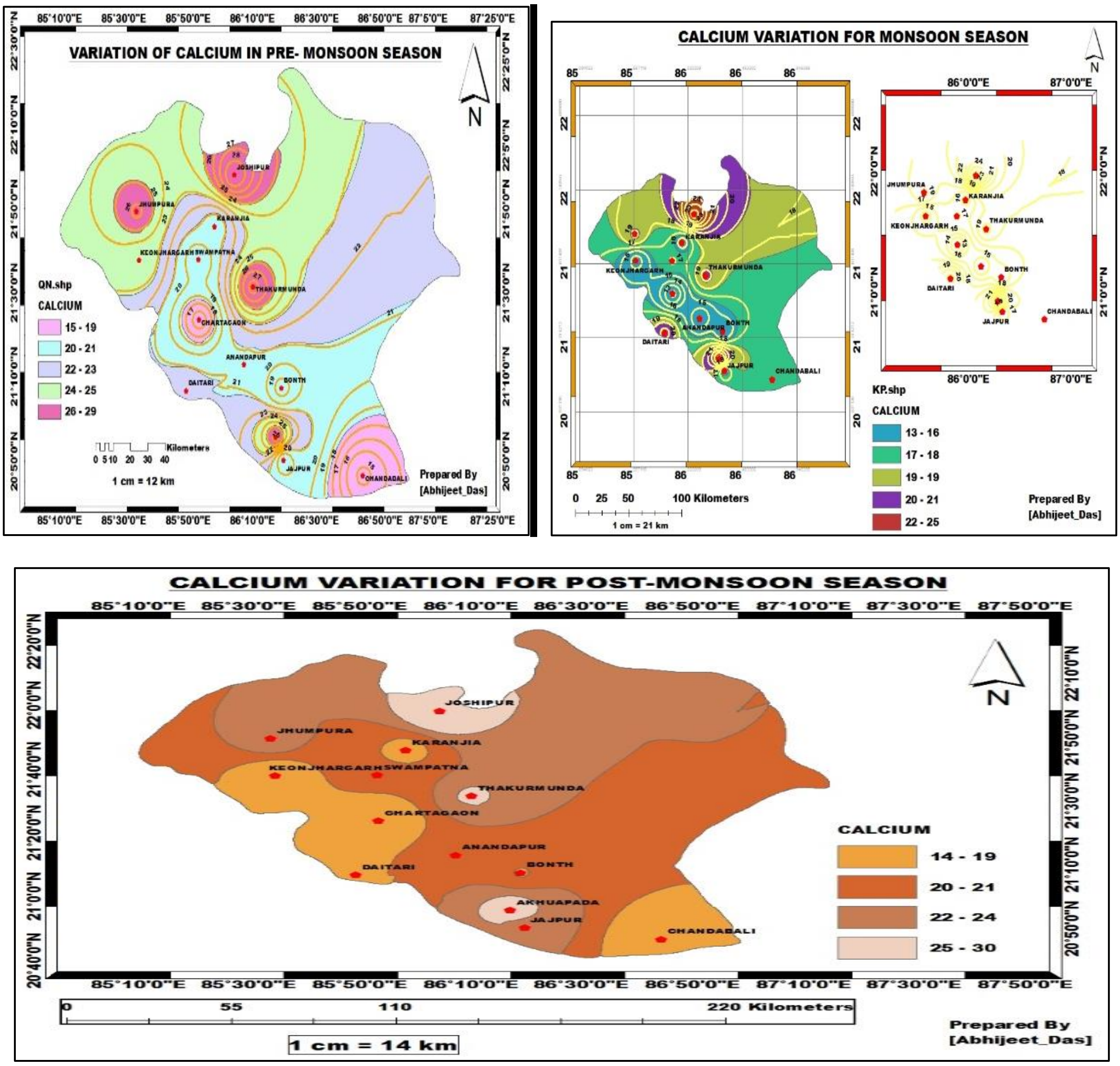
The total hardness (TH) of water is a measure of mainly calcium carbonate and magnesium carbonate dissolved in surface water. The general acceptance level of hardness is 300 mg/l although WHO has a set an allowable limit of 600 mg/l. According to WHO 2004 classification, 0 – 75 indicates soft, 75 – 150 indicates medium hard, 150 – 300 indicates hard and > 300 indicates very hard. The most desirable limit is 100 mg/l. The total hardness in this study area ranges between 64 to 121 with an average of 89.08 in pre-monsoon season, 64 to 119 with a mean of 86 in monsoon season and 71 to 135 with an average value of 96.46 in post-monsoon season. All the values are less than 300 mg/l, it is suitable for all activities for all sampling locations. So it can be concluded from the values that the classification of hardness is “medium hard”. Spatial variations is being represented by geospatial map **(Figure 13).**



(**Figure 13.** Spatial variations of TH in pre-monsoon, monsoon and post-monsoon season)

J. Calcium

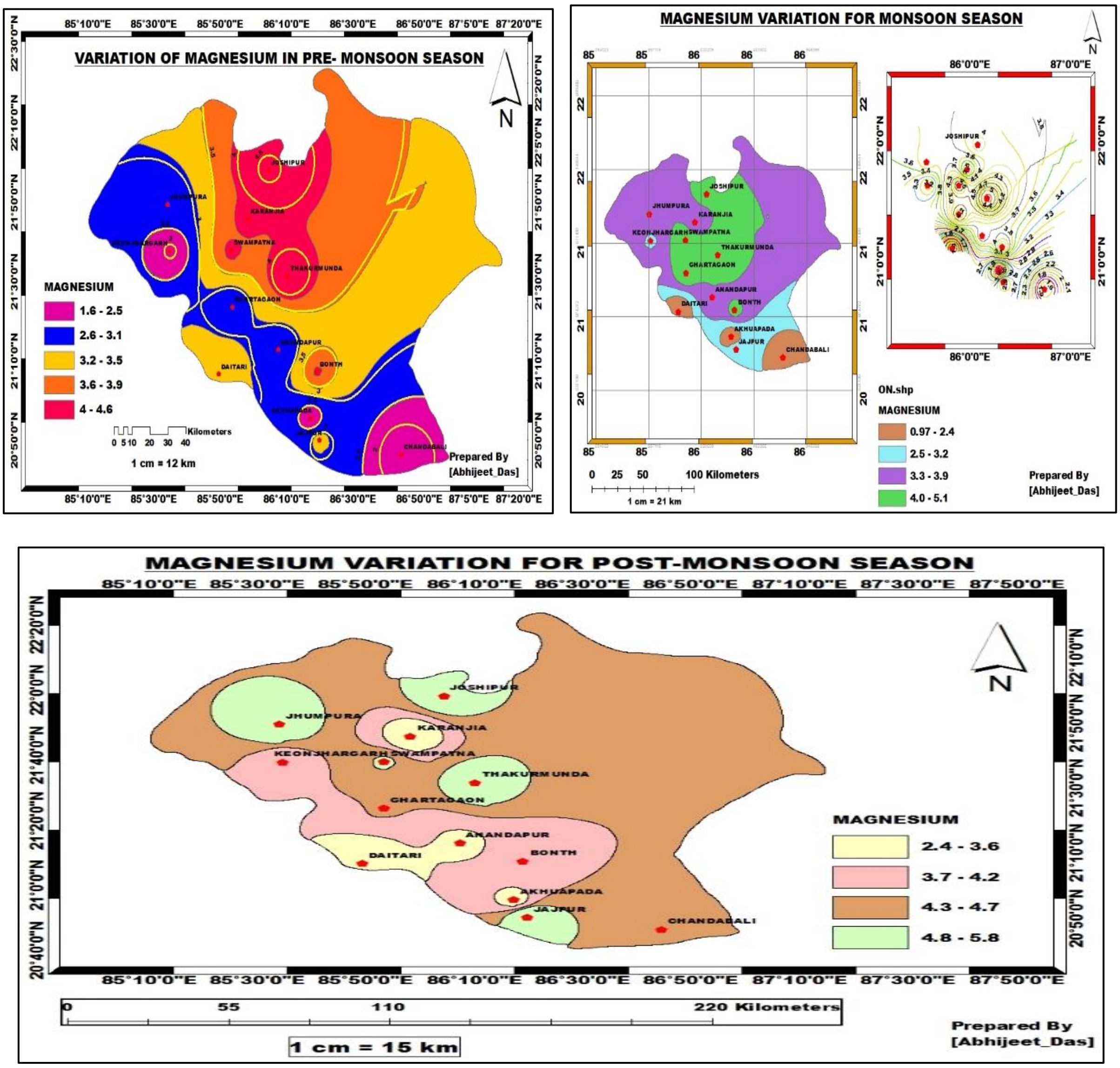
Calcium concentration ranged from 14.83 to 28.27 with a mean of 21.79 mg/l in pre-monsoon, 12.83 to 25.35 with a mean of 17.67 in monsoon season and 14.03 to 29.74 with a mean of 20.58 mg/L in post-monsoon periods. Acceptable limit in drinking water is 75 mg/l (200 mg/l in case no other alternative sources) (BIS 2012). Calcium ion is necessary for proper mineralization of bones and bone strength. Deficiency in intake of calcium leads to eventual demineralization of bones for complementing the inadequate amounts of calcium in the body. All the sampling locations are with the prescribed limits and hence, it is suitable for all purposes. Spatial variations is being represented by geospatial map **(Figure 14).**



(**Figure 14.** Spatial variations of calcium in pre-monsoon, monsoon and post-monsoon season)

K. Magnesium

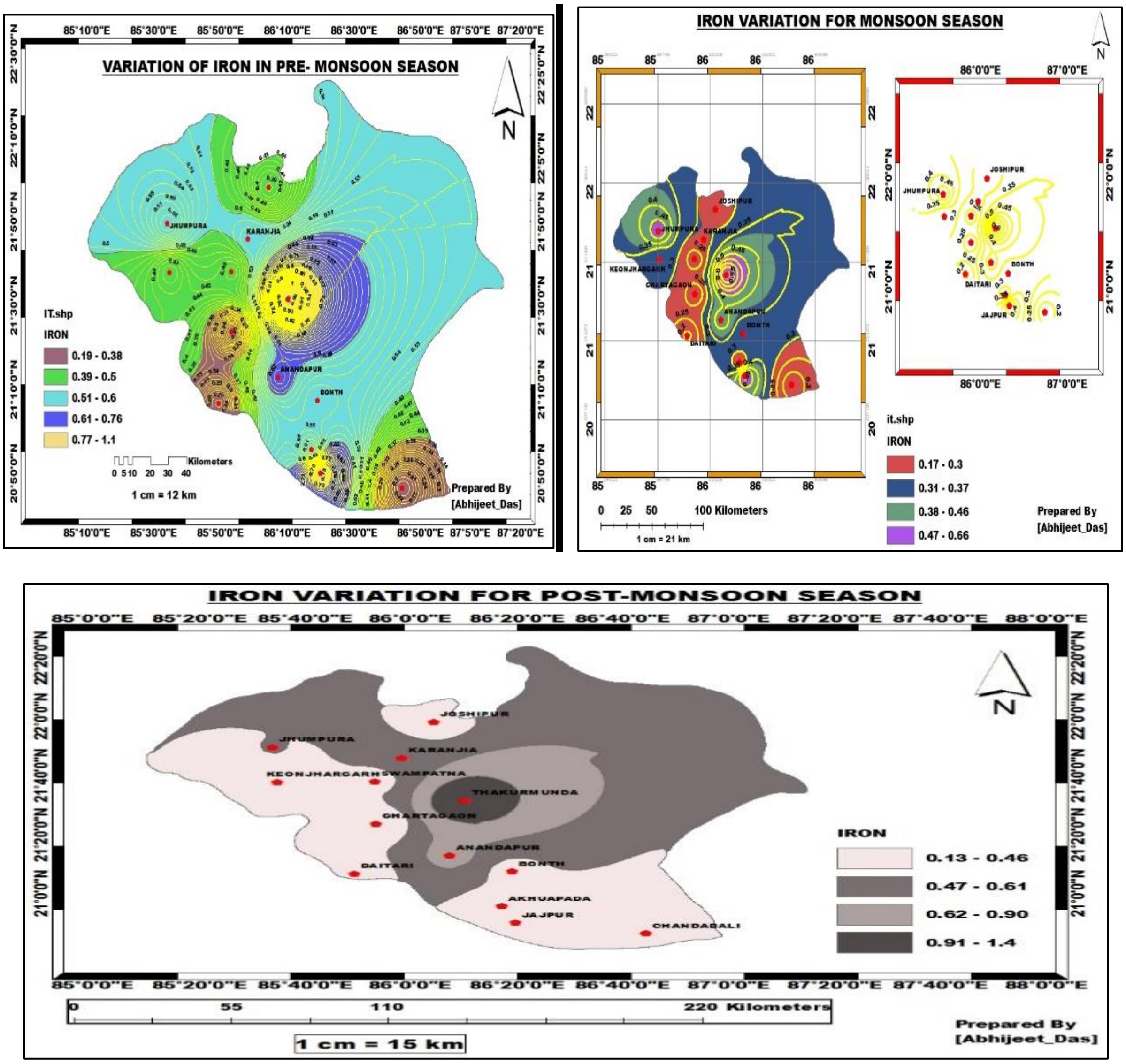
Acceptable limit of magnesium in drinking water is 30 mg/l (100 mg/l in case of no other alternative source) (BIS 2012). Magnesium ion helps in maintaining normal nerve and muscle function, a healthy immune system and helps bones remain strong. It also helps in regulation of blood glucose levels and aid in the production of energy and protein. Deficiency of magnesium in the human diet might lead to anxiety, fatigue or anorexia. The magnesium concentration ranges between 1.58 to 4.63 with a mean of 3.15 mg/l in pre-monsoon, 0.97 to 5.11 with a mean of 3.35 mg/l in monsoon and 2.36 to 5.83 with a mean of 4.24 mg/l in post-monsoon period. All the sampling locations are with the prescribed limits and hence, it is suitable for all purposes. Spatial variations is being represented by geospatial map **(Figure 15).**



(**Figure 15.** Spatial variations of magnesium in pre-monsoon, monsoon and post-monsoon season)

L. IRON

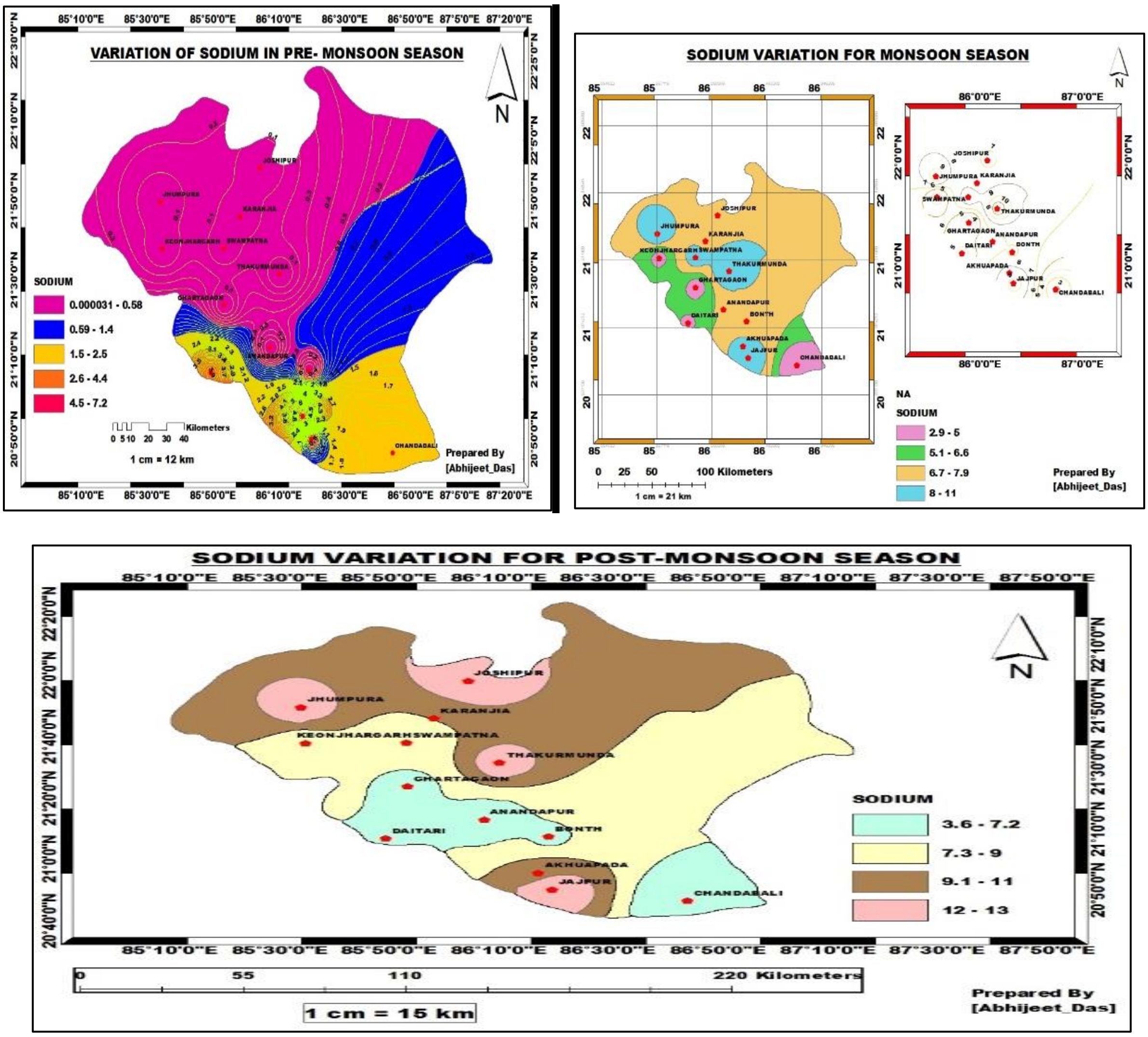
Iron is an essential element in the human body and is required physiologically on various aspects (Moore 1973). Although iron has little concern as a health hazard, it is still considered as a nuisance in excessive quantities (Dart 1974). It causes staining of clothes and utensils. It is also not suitable for processing of food, beverages, dyeing, bleaching etc. The concentration limits of iron in drinking water ranges between 0.3 (maximum acceptable) and 1.0 mg/l (maximum allowable) (Sharma and Chawla 1977). Iron concentrations range between 0.19 to 1.08 with a mean of 0.51 in pre-monsoon, 0.17 to 0.65 with a mean of 0.32 mg/l in monsoon and 0.13 to 1.43 with a mean of 0.48 mg/l in post-monsoon season. Sampling location 2, 3,5,6, 9,10, 11,12 and 13 in pre-monsoon and 2,3,4,5,6,9,10,11,12 and 13 in post-monsoon is above the concentration limit which leads to high iron content that affects the taste of water, has adverse effects on domestic uses and promotes growth of iron bacteria. Measures should be taken before consumption by installation of iron removing plants. Spatial variations is being represented by geospatial map **(Figure 16).**



(**Figure 16.** Spatial variations of iron in pre-monsoon, monsoon and post-monsoon season)

M. Sodium Concentration

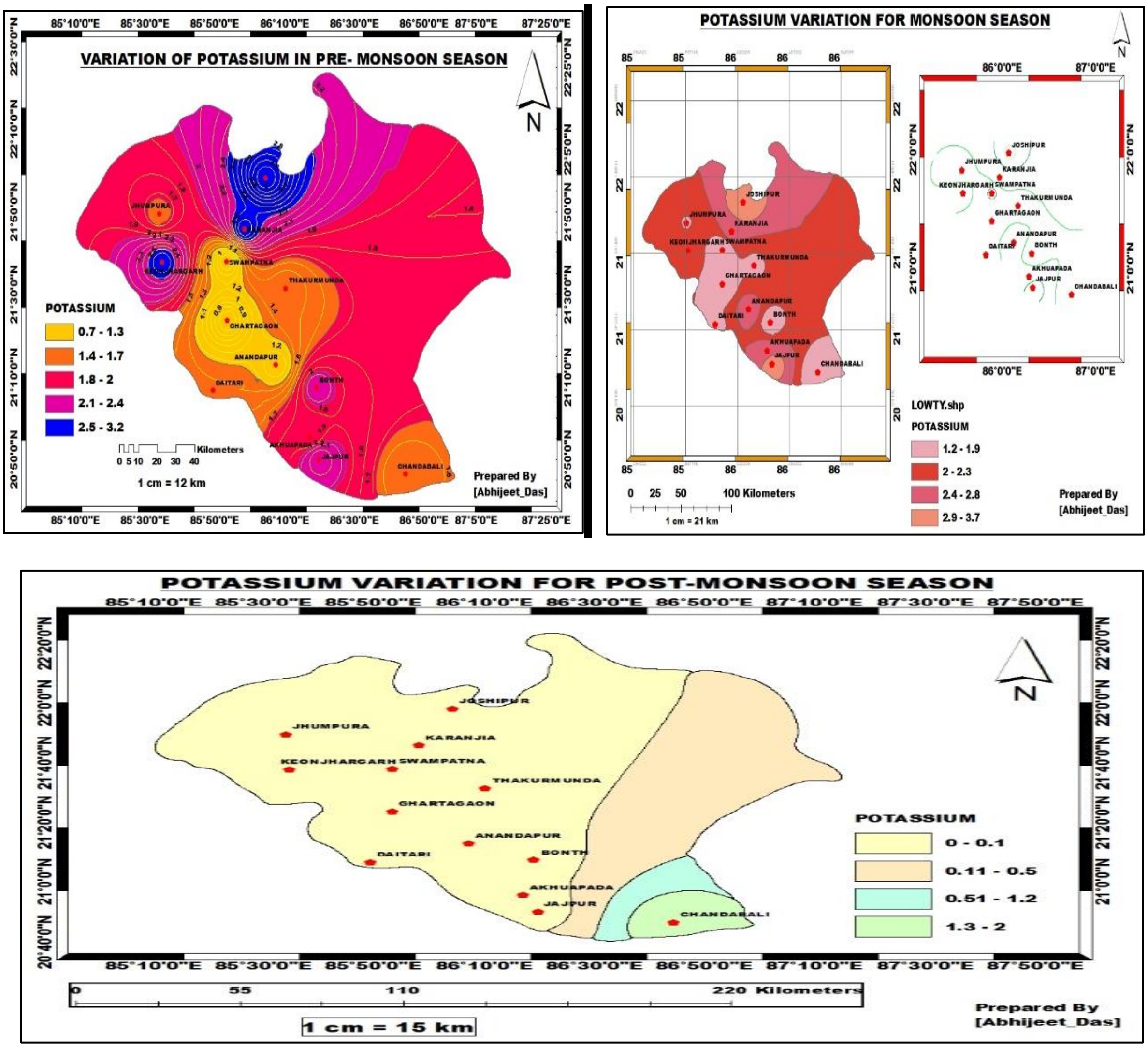
Sodium content is the most troublesome of the major constituents and an important factor in irrigation water quality evaluation. Excessive sodium leads to development of an alkaline soil that can cause soil physical problems and reducing soil permeability. Furthermore, irrigation water containing large amount of sodium is of special concern due to absorbed sodium by plant roots which is transported to leaves where it can accumulate and cause injury. However, there is a restriction in use of overhead sprinklers method with water contained a high level of sodium salts because these salt can be absorbed directly by plant leaves and will produce harmful effects. The water can be used for irrigation purposes when the concentration of sodium is about 8 meq/L (184.0 mg/L). Depending upon the Specific Ion Toxicity, for sodium concentration, the values should be less than 100 mg/L indicates none, > 100 indicates slight to moderate and > 100 indicates severe. Sodium concentration in water varies from 2 to 10 mg/l with an average of 6.72 mg/l in pre-monsoon, 2.9 to 10.7 with a mean of 6.98 mg/l in monsoon and 3.60 to 13.30 with an average of 8.61 in post-monsoon season. Sodium regulates blood pressure levels in the human body and increased levels of sodium in blood leads to rise in blood pressure. All sampling locations in pre and post-monsoon period are within the limits and hence suitable for all activities. Spatial variations is being represented by geospatial map **(Figure 17).**



(**Figure 17.** Spatial variations of sodium in pre-monsoon, monsoon and post-monsoon season)

N. POTASSIUM

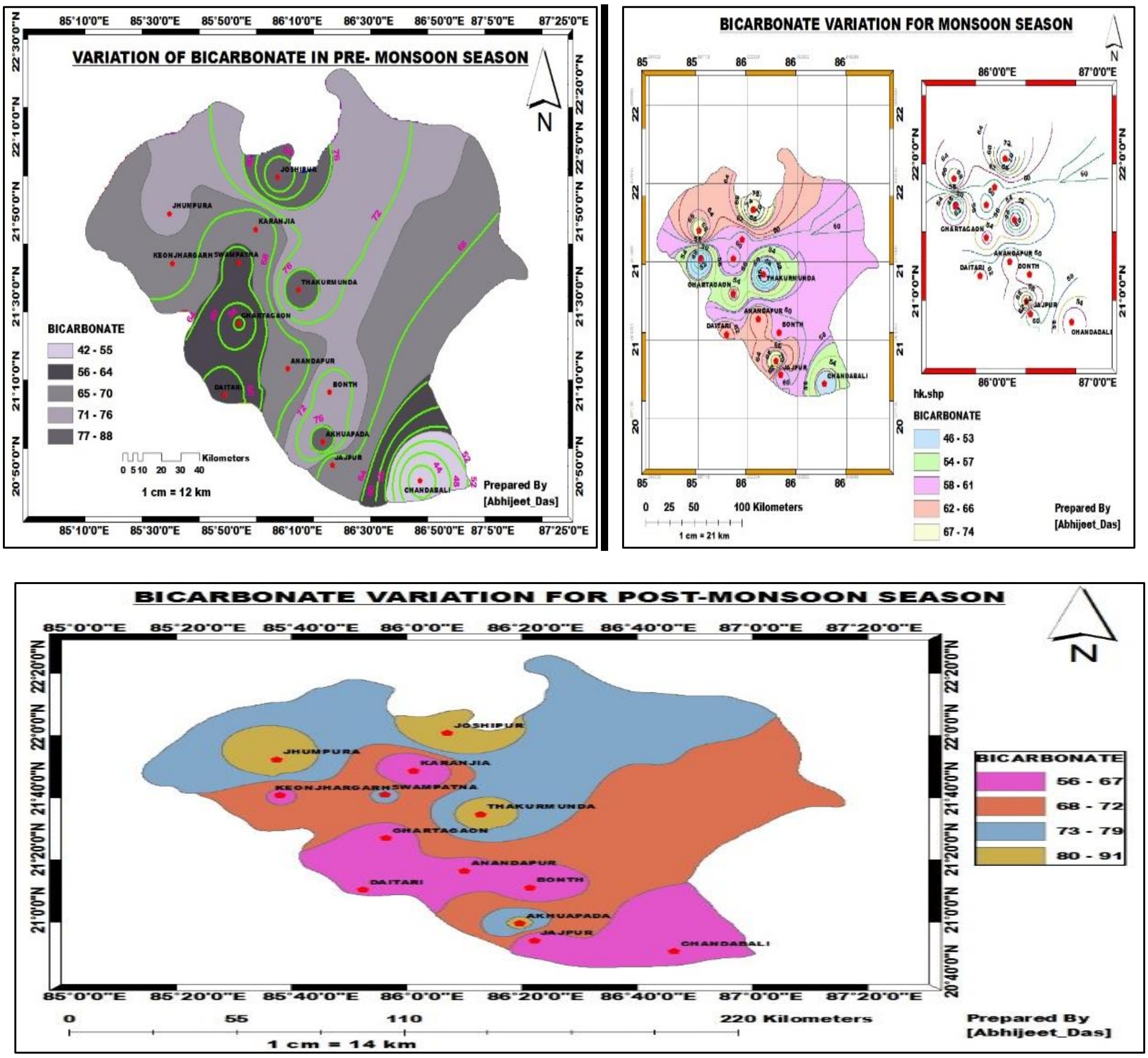
Potassium controls body balance and maintains normal growth of the human body balance and maintains normal growth of the human body. Deficiency of potassium might lead to weakness of muscles and rise in blood pressure. No standard limits have been provided by the Bureau of Indian Standards for level of sodium and potassium in drinking water. Potassium concentration in water varies from 0.70 to 3.2 mg/l with an average of 1.78 mg/l in pre-monsoon, 1.2 to 3.7 with a mean of 2.16 mg/l in monsoon and 0.80 to 2.90 with an average of 1.92 in post-monsoon season. Acceptable limit is 12 mg/L as per WHO 1993. All locations are within the limits. Spatial variations is being represented by geospatial map **(Figure 18).**



(**Figure 18.** Spatial variations of potassium in pre-monsoon, monsoon and post-monsoon season)

O. Bicarbonate (HCO_3^-)

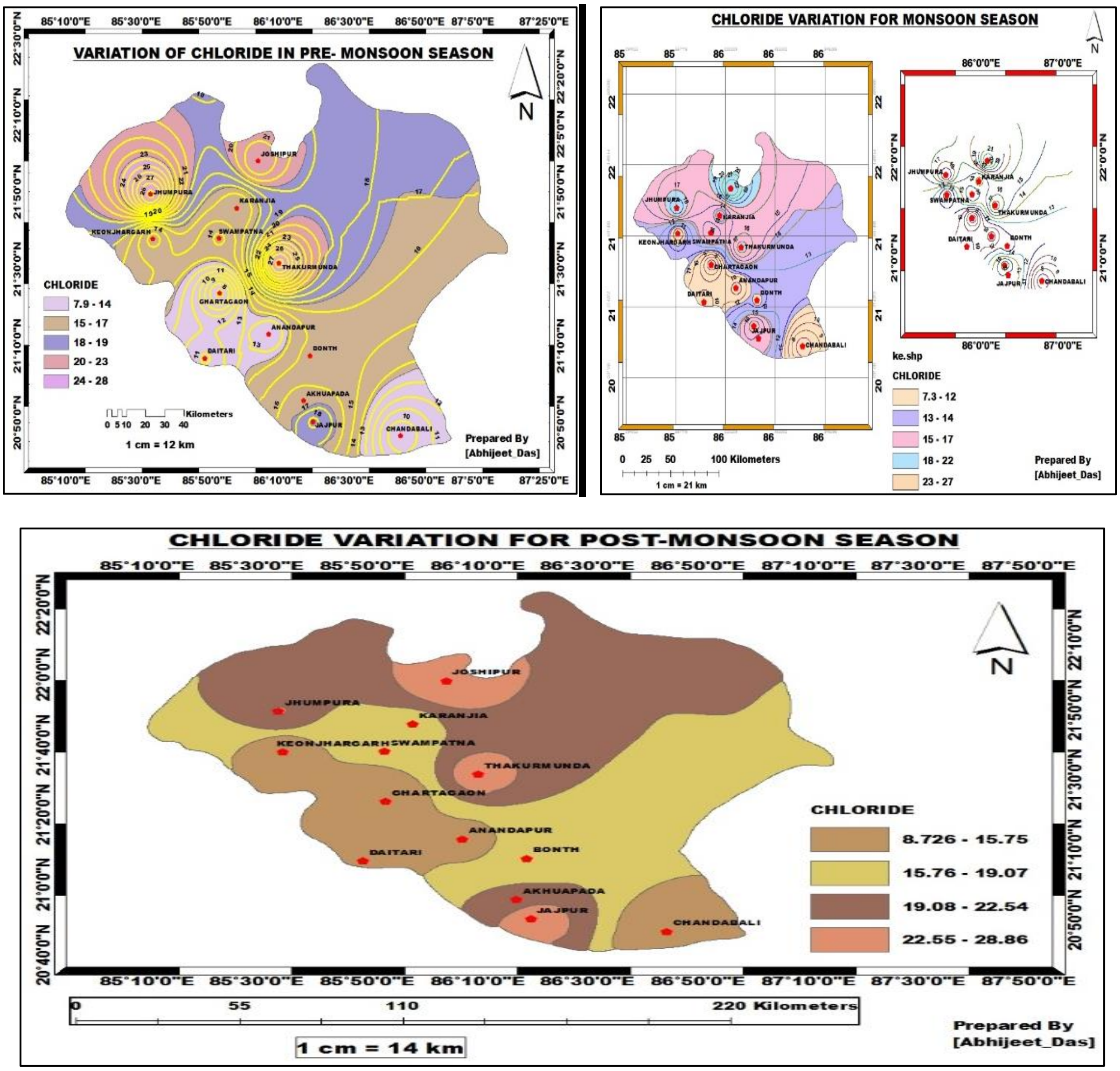
Bicarbonate ion varies from 41.92 to 87.55 mg/l with an average of 67.12 mg/l in pre-monsoon, 45.83 to 74.31 with a mean of 59.69 mg/l in monsoon and 55.64 to 91.46 with an average of 69.80 in post-monsoon season respectively. No standard limits have been provided by the Bureau of Indian Standards for level of carbonate and bicarbonate in drinking water. Spatial variations is being represented by geospatial map **(Figure 19).**



(**Figure 19.** Spatial variations of bicarbonate in pre-monsoon, monsoon and post-monsoon season)

P. Chloride

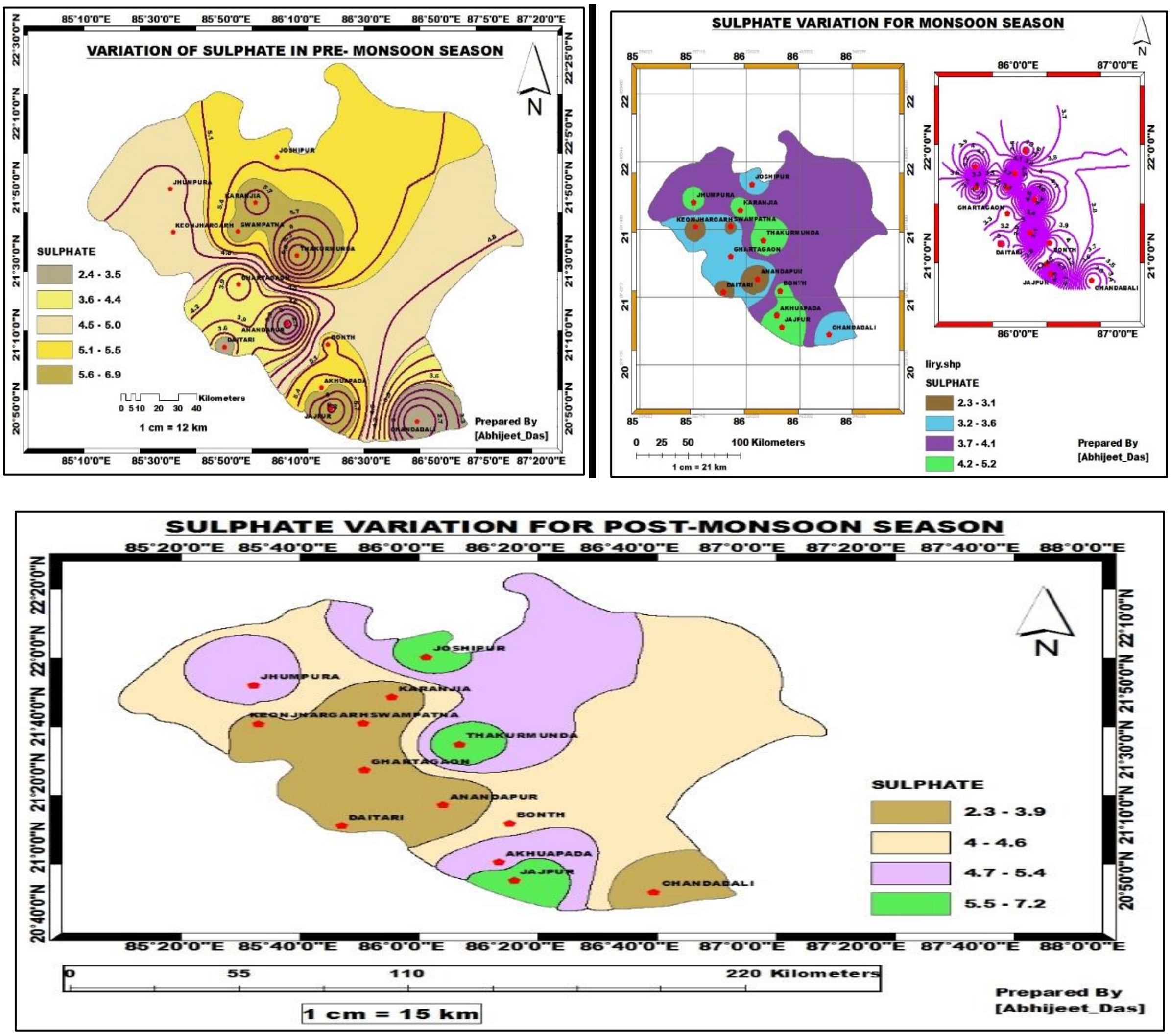
Chloride is another ion commonly found in irrigation waters. Although it is essential to crops at low concentrations, it can cause toxicity to sensitive crops at higher levels. Its toxic effects are immediately seen as leaf burns or leaf tissue deaths. Normally injury to plant occurs at the leaf tips and progresses from the tip back along the edges as severity increases. In excessive cases, early leaf drop or defoliation occurs. The most common toxicity is from chloride in the irrigation water. Chloride is not adsorbed or held back by soils, therefore, it moves readily with the soil water, is taken up by the crop, moves in the transpiration stream, and accumulates in the leaves. If the chloride concentration in the leaves exceeds the tolerance of the crop, injury symptoms develop such as leaf burn or drying of leaf tissue. Acceptable limit of chloride in drinking water is 250 mg/L (1000 mg/l in case of no other alternative source) (BIS 2012). Chloride concentration in surface water samples in the study area ranged from 7.87 to 28.18 with an average of 16.14 mg/L in pre-monsoon, 7.3 to 22.12 with a mean of 13.47 mg/l in monsoon and 8.72 to 28.86 with an average of 17.97 mg/L in post-monsoon season. Too much of chloride leads to bad taste in water and also chloride ion combines with Na (that is being derived from the weathering of granitic terrains) and forms Na Cl, whose excess presence in water makes it saline and unfit for both irrigational and drinking purposes. Increase in chloride levels in our body might lead to increase in blood pressure levels and rise in body fluids. All sampling locations are within the limits in both pre-monsoon, monsoon and post-monsoon season. Spatial variations is being represented by geospatial map **(Figure 20).**



(**Figure 20.** Spatial variations of chloride in pre-monsoon, monsoon and post-monsoon season)

Q. Sulphate

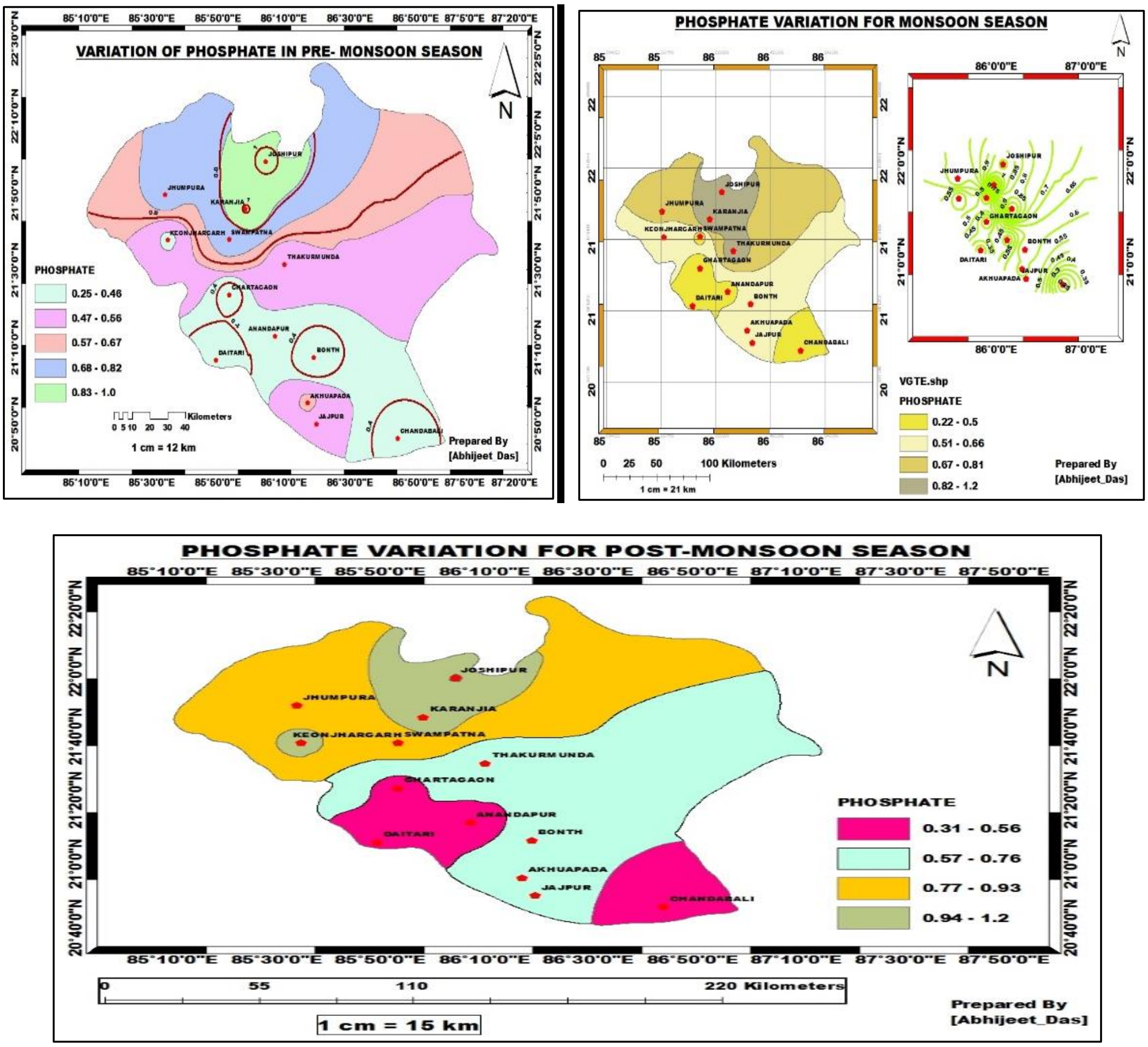
The sulphate ion causes no particular harmful effects on soils or plants; however, it contributes in increasing the salinity in the soil solution. Sulphate ion varied from 2.40 to 6.87 with an average of 4.79 mg/L in pre-monsoon, 2.26 to 5.19 with a mean of 3.69 mg/l in monsoon and 2.31 to 7.16 with an average of 4.31 mg/L in post-monsoon season. Acceptable limit of sulphate in drinking water is 200 mg/L (400 mg/L in case of no other alternative source) (BIS 2012). Excess sulphate consumption through water might lead to occurrence of diarrhea in humans and causes a laxative effect on human system with the excess magnesium in surface water. In our study, all sampling locations are within the limits and hence suitable for drinking and irrigation activities. Spatial variations is being represented by geospatial map **(Figure 21).**



(**Figure 21.** Spatial variations of sulphate in pre-monsoon, monsoon and post-monsoon season)

R. Phosphate

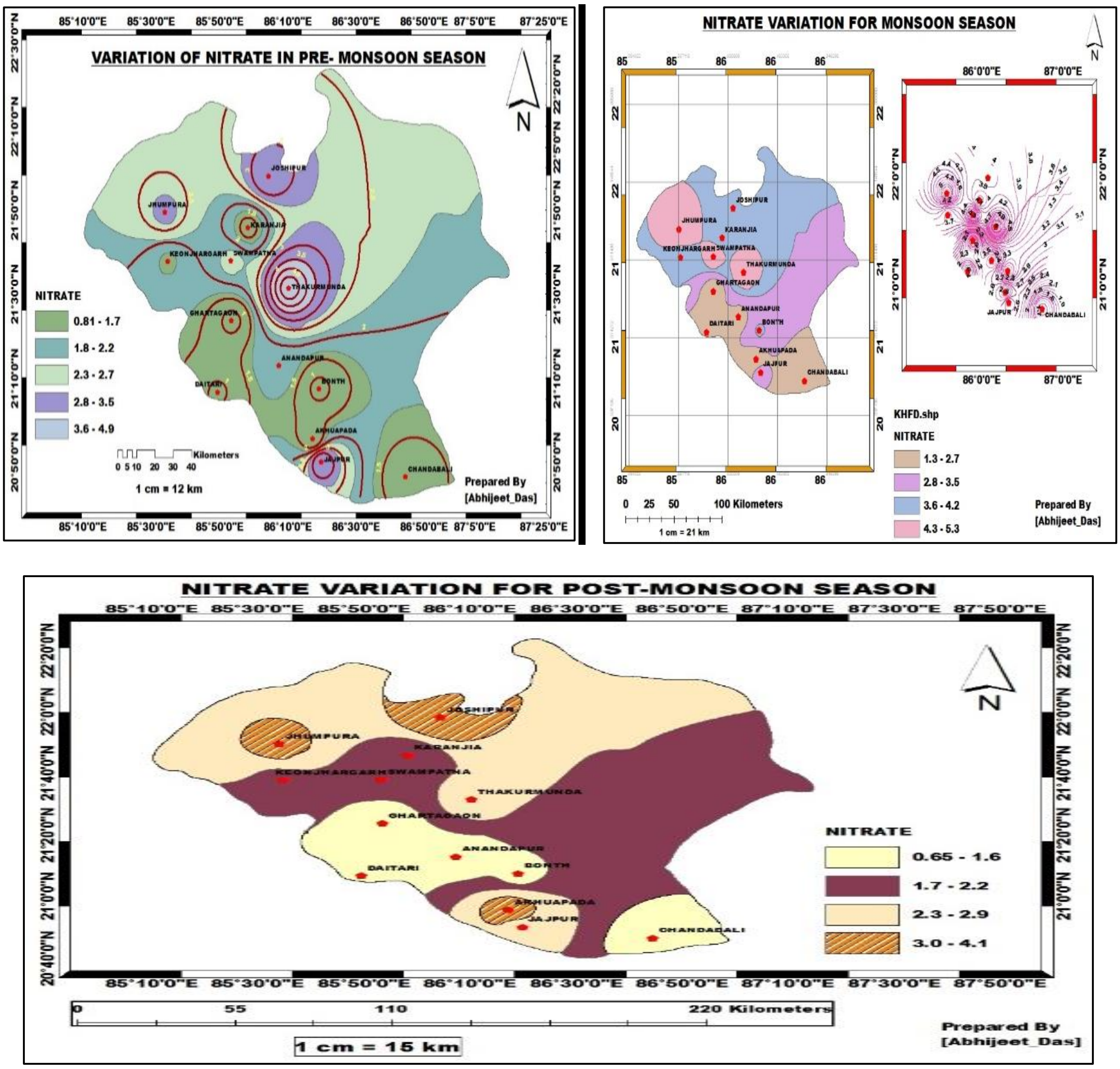
Phosphate ion varied from 0.25 to 1.04 with an average of 0.55 mg/L in pre-monsoon, 1.2 to 3.7 with a mean of 2.16 mg/l in monsoon and 0.31 to 1.17 mg/L with an average of 0.71 mg/L in post-monsoon season. If exceeds the permissible limit of 0.3 mg/L, and hence risk of eutrophication is not excluded in this part of the river favored by the domestic wastewater (Vyas et al. 2006). Spatial variations is being represented by geospatial map **(Figure 22).**



(**Figure 22.** Spatial variations of phosphate in pre-monsoon, monsoon and post-monsoon season)

S. Nitrate

It is well known that nitrate is the primary source of nitrogen to most plants and is commonly used as a fertilizer. Nevertheless, excessive amounts of nitrate could result in the reduction in yield or quality of the crop as a result of delayed crop maturity, untimely growth or unsightly deposits on the fruit or foliage. In our study, nitrate ion varied from 0.81 to 4.86 with an average of 2.04 mg/L in pre-monsoon, 1.31 to 5.3 with a mean of 3.28 mg/l in monsoon and 0.65 to 4.15 mg/L with an average of 2.03 mg/L in post-monsoon season. Acceptable limit of nitrate in drinking water is 45 mg/L as per WHO (1993). In our study, all sampling locations are within the limits and hence suitable for drinking and irrigation activities. The high concentration of nitrates in surface water are the result of intensive agricultural activity or a contaminated by human or animal wastes (Nas and Berktay 2006). The high concentration of nitrates in drinking water is toxic and causes blue baby disease/ methaemoglobinaemia in children and gastric carcinomas (Comly 1945; Gilly et al 1984). It is due to intensive urbanization and industrialization. However, many of these problems can usually be overcome by proper fertilizer and irrigation management. Furthermore, nitrate application to soils should be done with utmost care since it could easily cause nitrate pollution in local water resources. Spatial variations is being represented by geospatial map **(Figure 23).**



(**Figure 23.** Spatial variations of nitrate in pre-monsoon, monsoon and post-monsoon season)

Ionic Balance

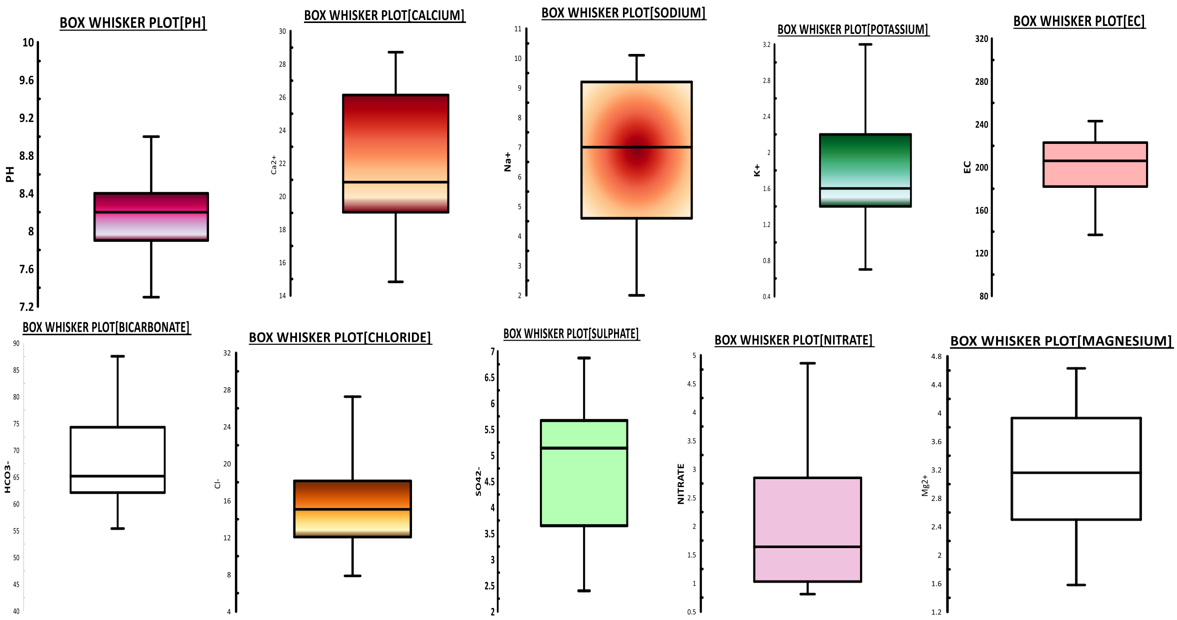
Ionic balance of a water sample is calculated to identify the dominant ionic type i.e. cationic or anionic in the water sample. For calculation of ion balance in water, concentration of each cation and anion in surface water sample is calculated in mg/L. Ion balance of surface water represents the fractional difference between the total cations and total anions and also indicates quality of water keeping in mind the dissolved solids of a water sample. According to the standard rules, the ion balance of a fresh water sample with low TDS is considered to be good if the value is between – 10 % and + 10 %. In this study, the average concentration of Total Dissolved Solids (TDS) ranged from 74 to 178 with a mean of 135.31 in pre-monsoon season and 97 to 247 with a mean of 171.23 in post-monsoon season. All the values are within the limits and hence suitable for both drinking and irrigation.

Hydro-chemistry Analaysis

The hydro-chemical parameters PH, EC, cations and anions were characterized by their median, quartiles, maximum and minimum are represented by box plots for pre-monsoon and post-monsoon season (**Figure 24, 25**).

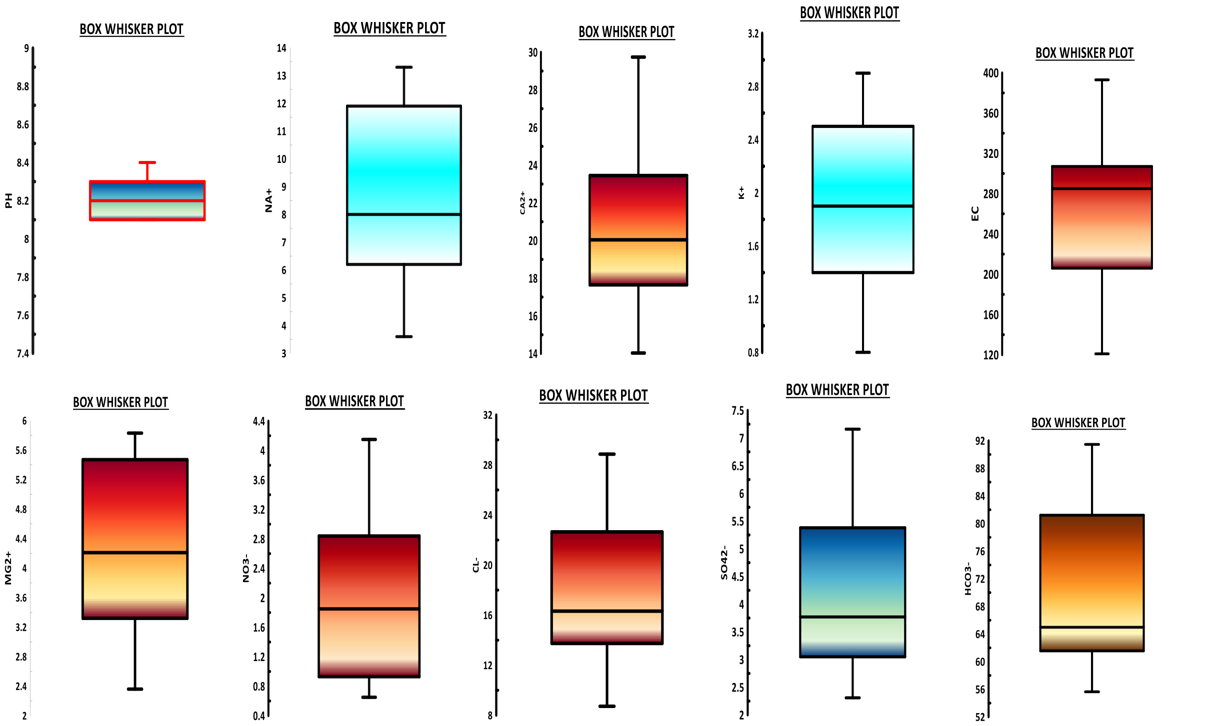
The anion chemistry of the analyzed samples shows that the bicarbonate is the dominant ion in most samples. The order of anionic abundance (in mg/L) is HCO_3^- > Cl^- > SO_4^{2-} > NO_3^-. Concerning the cationic chemistry, the order of cationic abundance (in mg/L) is Ca^{2+} > Na^+ > Mg^{2+} > K^+. Water showed a greater variability in the river affluent rather than in the main streamline. The highest values of bicarbonate and calcium were achieved simultaneously for water samples collected during pre-monsoon and post-period period. Sampling points showed a relatively steady trend for the remaining ion concentration patterns. The concentration of calcium composes more than 95 % of the total cations in all samples. The dominant anion is bicarbonate which covers 95 % of the total anion in all samples.

The main chemistry of the river system is controlled by the dissolution of gypsum, halite, anhydrite, aragonite, calcite and dolomite with a precipitation of carbonate minerals in the sampling points. The high dissolution rate of carbonate rocks allows water that are close to saturation with respect to calcite, dolomite and evaporate minerals (gypsum and halite) to remain under saturated. It leads to a continuing dissolution along the flow paths. The river water has thus has capacity to dissolve gypsum and halite along the flow paths and hence, concentrations of calcium, sulphate, sodium and chloride in the river water would increase. This phenomenon has also been discussed by many researchers (Alexakis 2011; Hui et al 2011; Sappa et al 2012). These findings can be explained by the geology of the study area, in particular the variation of the mineralogical composition of the bedrock from upstream to downstream. A similar impact of the bed rock composition to the water quality has also been described by Gamvroula et al (2013). It is commonly known that the ionic composition of water is the result of several factors during water-rock interaction (Hamzaoui Azaza et al 2011). The water samples under saturated with dolomite indicate that dolomite may also dissolve in this system, adding calcium ion, magnesium ion and bicarbonate ion to the solution. Furthermore, the under saturation by calcite indicates a chemically aggressive water able to dissolve limestone. As the water moves along the river, carbon dioxide is lost in such quantities that the calcite shifts from an under saturated to a saturated state where water can dissolve limestone anymore and the calcite can precipitate to form secondary calcite (Hui et al. 2011, Sappa et al 2012; Wanda et al. 2013).



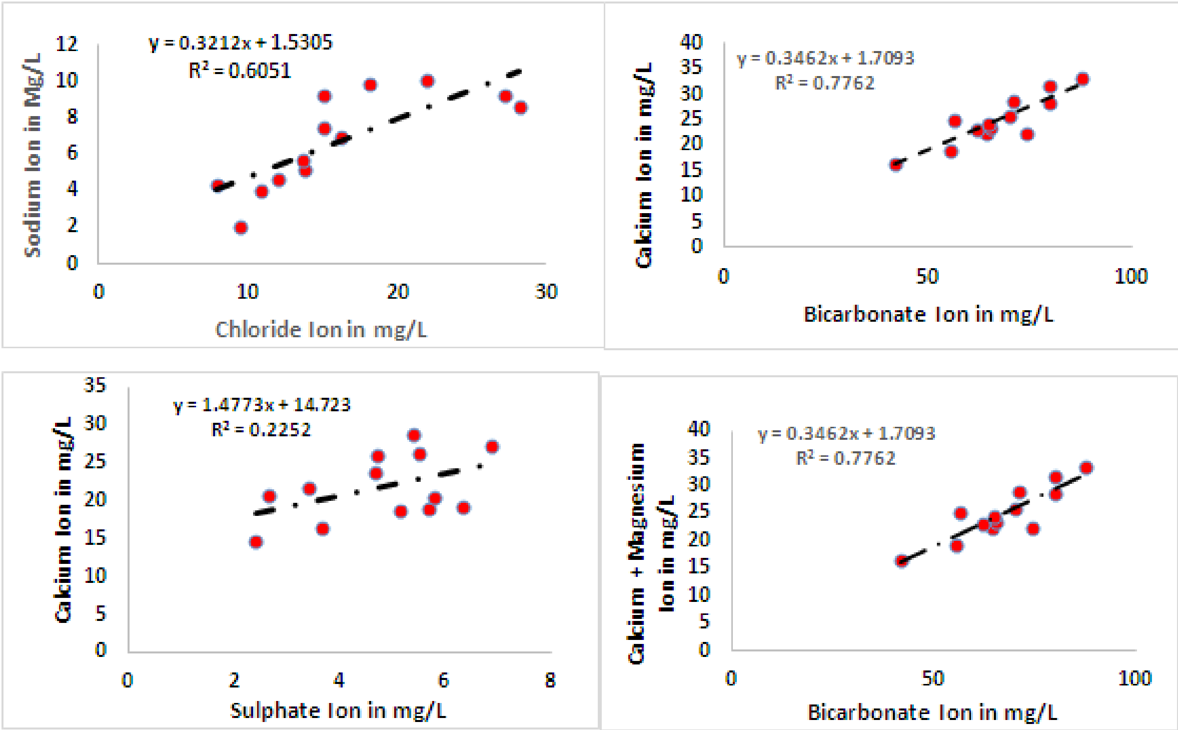
(**Figure 24.** Box plot of pre-monsoon analysis)

Box plot of post-monsoon analysis

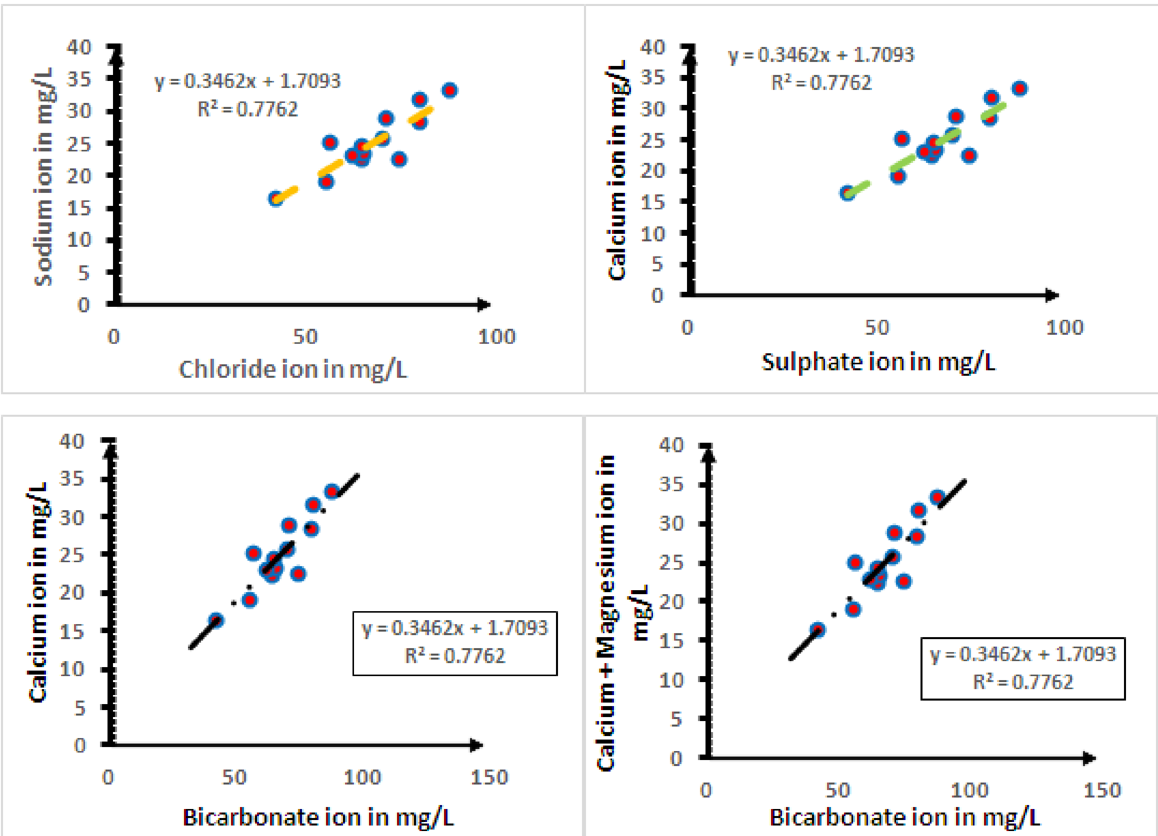


(**Figure 25.** Box plot of post-monsoon analysis)

Binary diagrams were used to better identify the origin of the salts dissolved in the river water. In case of pre-monsoon and post-monsoon season, it is seen that in both the cases (**Figure 26, 27**) that the plot of Na^+ versus Cl^- showed a good correlation between sodium and chloride concentration for most of the points. This confirms that the halite dissolution is behind water salinity. The plots representing Ca^{2+} versus SO_4^{2-} concentrations yielding a good correlation between most of the points. The line representing gypsum dissolution (Ca SO_4 .$2H_2O$) indicating that gypsum dissolution is a second source of minerals in these waters after halite. In all the samples, calcium and magnesium concentrations were correlated to bicarbonate concentrations. This indicates that these ions do not originate from calcite ($CaCO_3$) and dolomite ($CaMgCO_3$) dissolution. The dissolution of halite and gypsum are the dominant process controlling water salinity.



(**Figure 26.** Relative ionic plots in pre-monsoon season)



(**Figure 27.** Relative ionic plots in post-monsoon season)

Water Quality for irrigation purposes

To evaluate the suitability of the water quality for agricultural purposes, the parameters such as SAR, SSP, and RSC were calculated using standard formula mentioned in the text. The values were plotted over the

US Salinity diagram against the EC values (log scale axis); SSP values were plotted over the Wilcox diagram against EC values; the spread of SAR, SSP, and RSC values have been represented in the form of spatial distribution maps for both seasons. Besides total hardness results, the suitability of surface water for drinking purposes has been determined by the use of hydro geochemical facies (Piper trilinear diagram) (Piper 1944) and water quality index study (Tiwari and Mishra 1985). GIS software packages 10.3 have been used to map and analyze the data for the evaluation of surface water data.

Sodium adsorption ratio (SAR)

It is a measure of the sodicity of the soil determined through quantitative chemical analysis of water in contact with it. An excess of bicarbonate and carbonate ions in water react with sodium ion in soil, resulting in a sodium hazard (Wadie and Abduljalil 2010). The proportion of sodium ions present in the soils, is generally measured by a factor called Sodium Absorption ratio (SAR) and represents the sodium hazards of water. It is also expressed as sodium content or alkali hazard is an important index for determining the suitability of water used in irrigation (Srinivasamoorthy et al. 2014). Actually, SAR reflects the sodium hazard and is computed using the formula in eq. (1) given by U.S. Department of Agriculture Salinity Laboratory in 1954 (Wilcox 1955; Hem 1970) as:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Mg^{2+}+Ca^{2+}}{2}}} \qquad \rightarrow \quad 1$$

Ionic concentrations are measured in meq/L. Based on the SAR values, water is classified into four classes, SAR < 10 is considered as excellent (sodium hazard class S-I), SAR = 10 – 18 is considered as good (sodium hazard class S – II), SAR = 19 – 26 is considered as doubtful/fair poor (sodium hazard class S – III), and SAR > 26 of water is considered unsuitable (sodium hazard class S – IV) (Richards 1954; Wilcox 1955)

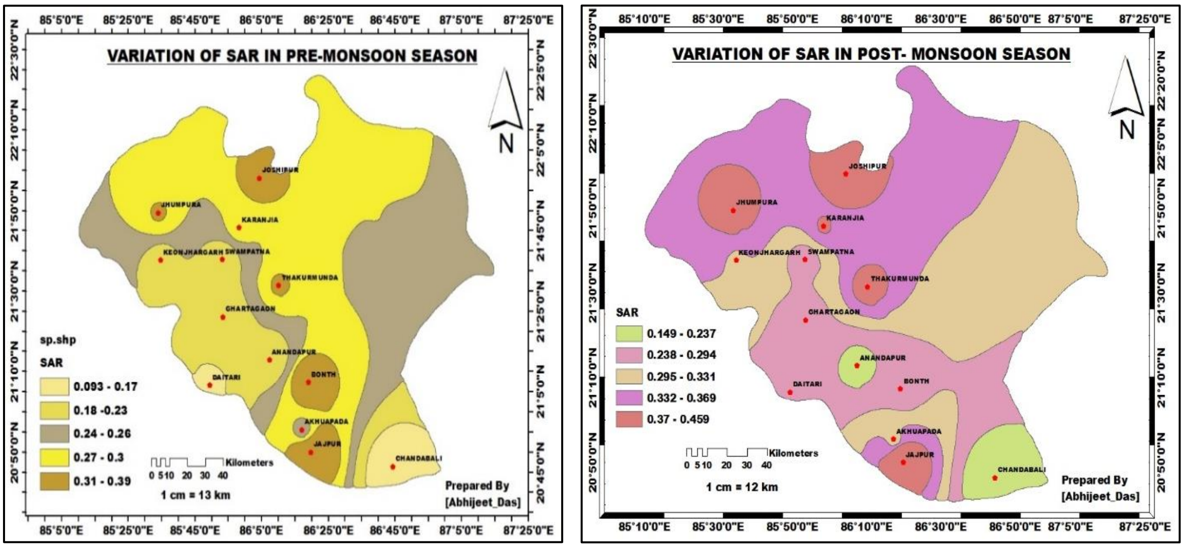
S – I = can be used for all soils and for all crops

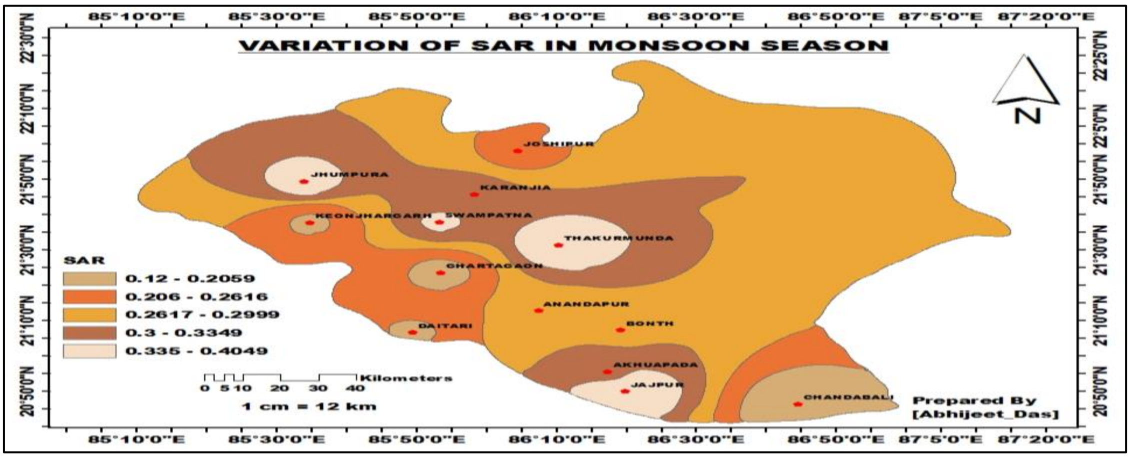
S – II = used in coarse grained or organic soil with good permeability

S – III = may be harmful to all the soils and do require good drainage, high leaching with gypsum.

S – IV = Not suitable (Very high sodium water)

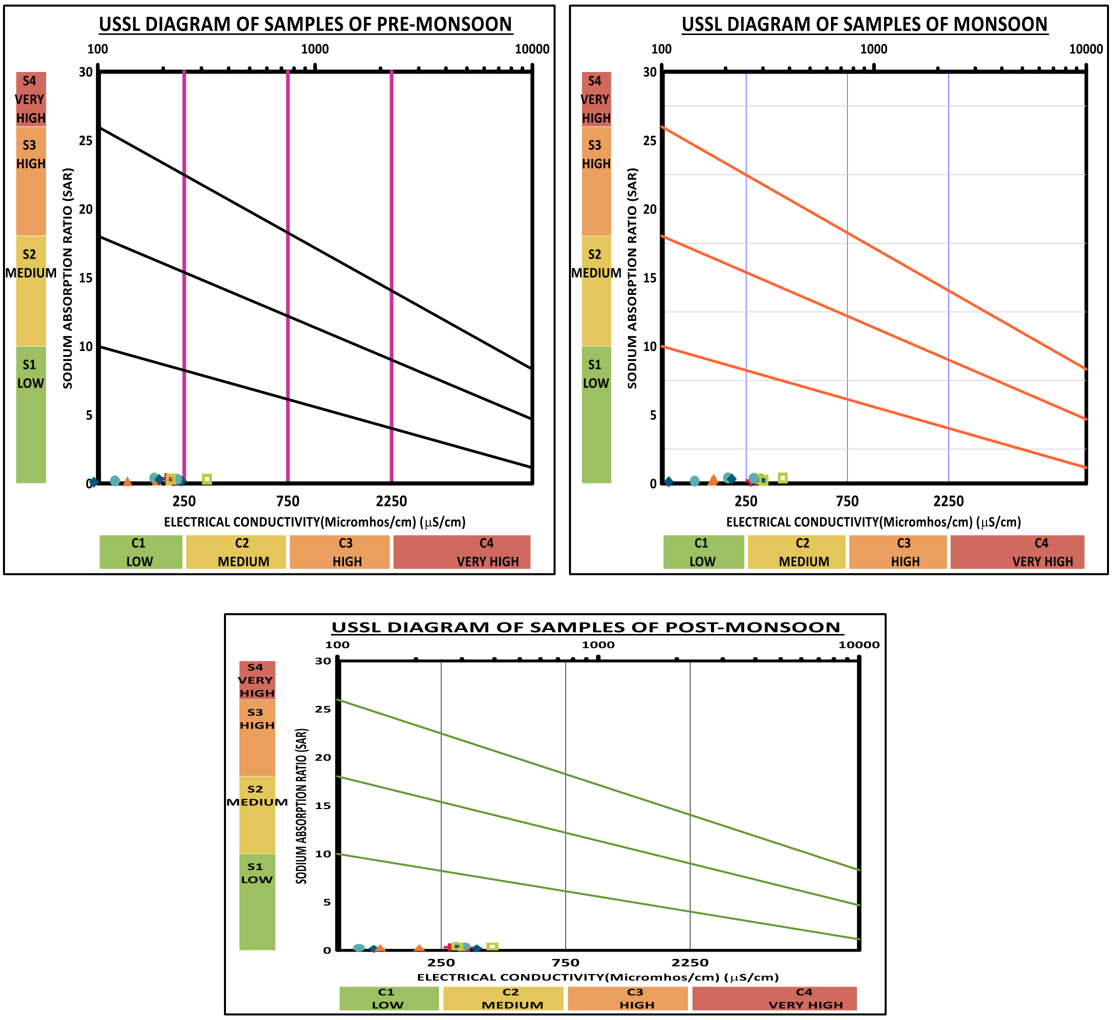
The waters are classified for irrigational purposes according to the SAR values (Richards 1954). The SAR values of the Baitarani River water range from 0.09 to 0.39 in pre-monsoon season, 0.13 to 0.41 in monsoon and 0.15 to 0.46 in post-monsoon season. According to Richard's classification, all the samples number 1 to 13 classified as "excellent (sodium hazard class S-I)" for irrigation (Sundaray et al 2009). Spatial variations of the SAR values of both the seasons along the sampling stations have been shown by geospatial map **(Figure 28)**.





(**Figure 28.** Spatial variations of SAR in pre-monsoon, monsoon and post-monsoon season)

US Salinity Laboratory (USSL) diagrams **(Figure 29)** were used to evaluate the suitability of water for irrigation use for both the seasons. These are made by plotting the sodium absorption ratio (SAR) values against electrical conductivities data on a two-dimensional graph (Richards 1954). In this study, only 1 sample (7.69 %) out of 13 samples of pre-monsoon season, 5 sample (38.46 %) out of 13 samples of monsoon and 9 samples (69.23 %) out of 13 samples fall in the category of C2S1, indicating medium salinity/low sodium type water. Rest 12 samples (92.30 %) of pre-monsoon season, 8 samples (61.53 %) of monsoon and 4 samples (30.76 %) of post-monsoon season fall in the category in low salinity/low sodium types, indicating the water suitable for irrigation uses (Singh et al 2008; Harish et al 2016).



(**Figure 29.** US Salinity diagrams of pre-monsoon, monsoon and post-monsoon season)

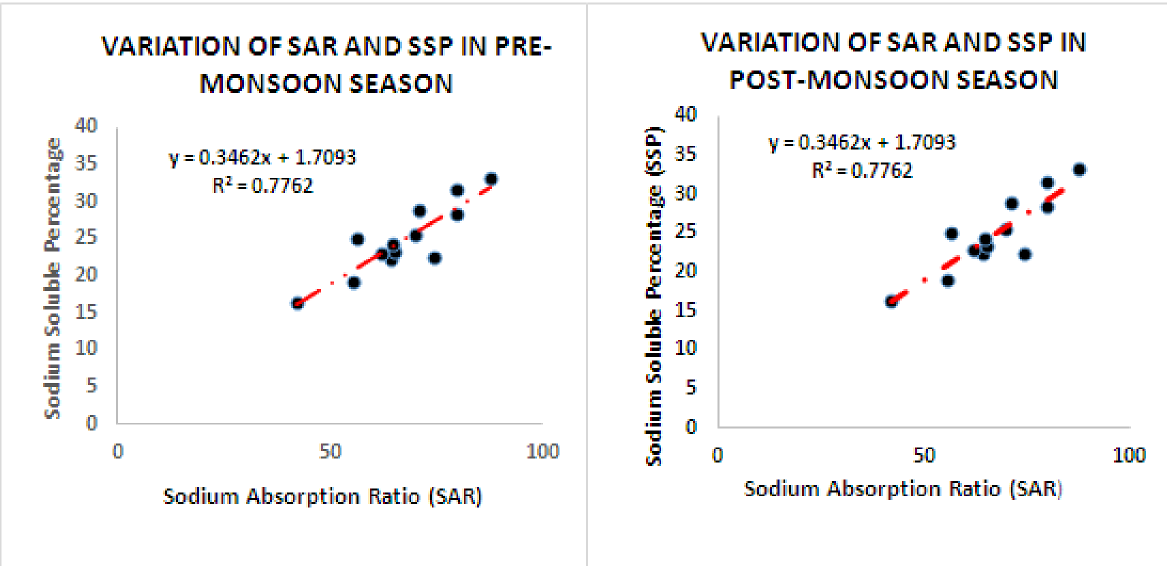
Sodium percentage (Na %)

It is used to evaluate sodium hazard. High sodium ion concentration in soil can take a toll on internal drainage patterns in soil as release of calcium and magnesium ions are facilitated due to absorption of sodium by clay particles. Water with SSP greater than 60 % may result in sodium accumulations that will cause breakdown in the soil's physical properties (Khodapanah et al. 2009). The irrigation water is also classified on the basis of soluble sodium content, because higher sodium content in irrigation water reduces the permeability (Todd 1980; Sundaray et al. 2009). Percentage of Na (Na %) is widely used to determine the suitability of water for agricultural purposes. This term is also referred to as the soluble sodium per cent (SSP) (Wilcox 1955). It is defined and is also calculated by the following eq. (2)

$$Na\% = \frac{Na^{+} \times 100}{(Ca^{2+} + Mg^{2+} + Na^{+} + K^{+})} \longrightarrow \quad (2)$$

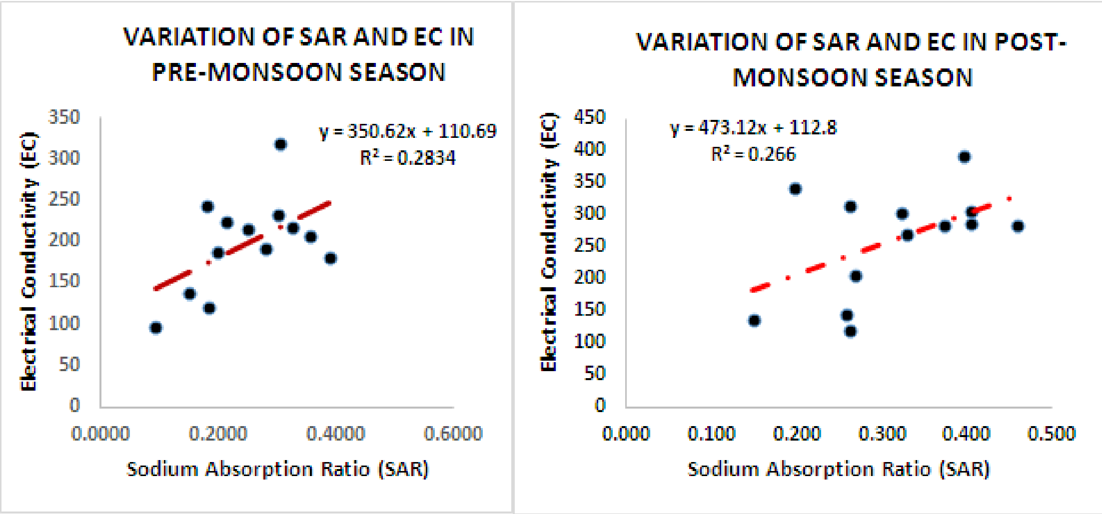
All the concentrations are expressed in meq/L. Based on sodium per cent, water is classified as safe or unsafe. Na % > 60 is considered unsafe, and Na % < 60 is considered safe for agricultural activities (Eaton 1950; Ravikumar et al 2011).

Baitarani River water samples are classified with respect to percent sodium. According to Wilcox 1995 classification, depending upon the sodium percentage **(Figure 30)** 12.56 % to 28.43 % in case of pre-monsoon, 13.88 to 32.33 % monsoon and 15.73 to 29.76 % in post-moon are within the permissible limits and all sampling locations are fit for irrigation purposes and also for agricultural activities. Sometimes it is seen in case of monsoon season, the effect of dilution or the washing out of sodium with the flow of heavy water is not significant. The possible reason of higher sodium in post-monsoon water may be the input of sodium through surface runoff of the basin area.



(**Figure 30.** Correlation between SAR and SSP in pre-monsoon and post-monsoon season)

From the above (**Figure 30**), it shows that there is a positive correlation between SSP and SAR with a coefficient of 0.7762 in both pre-monsoon and post-monsoon periods. Irrigation with waters that have high concentrations of sodium ion relative to divalent cations may cause an accumulation of exchangeable sodium ion on soil colloids. Continued uses of alkaline waters for irrigation in a closed system may have adverse effects on soil physical properties, deteriorate the soil and water resources of the region and affect the sustainability of crop production in the long run. It is reported that salinity and sodicity are the principal water quality concerns in irrigated areas, receiving such water. Saline-sodic irrigation water, coupled with limited rainfall and high evaporation, may increase soil sodicity significantly. In general, when sodium is an important component of the salts, there can be a significant amount of adsorbed sodium making the soil sodic.



(**Figure 31.** Correlation between SAR and EC in pre-monsoon and post-monsoon season)

From the above (**Figure 31**), it shows a positive correlation between EC and SAR with a correlation coefficient (R^2) = 0.2834 in case of pre-monsoon season and R^2 = 0.266 in case of post-monsoon season. The positive value of R^2 shows that there is a lesser variation in the EC values and vice versa.

Residual sodium carbonate (RSC)

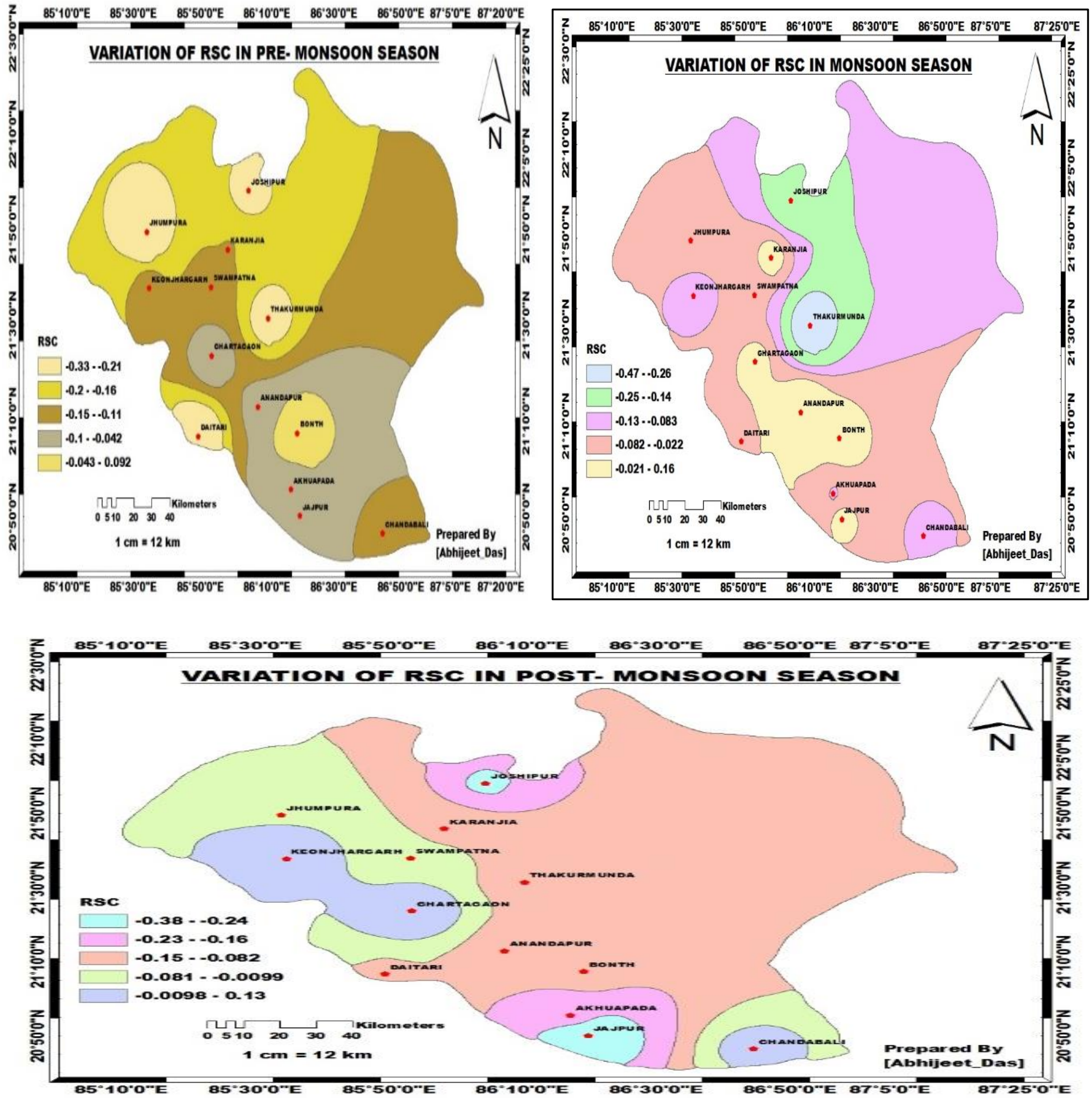
RSC index of irrigation / soil water is used to indicate the alkalinity hazard of soil. This index is used to find the suitability of water for irrigation in clay soils which has high cation exchange capacity. When dissolved sodium in comparison with dissolved calcium and magnesium is high in water, clay soil swells or undergoes dispersion which drastically reduces its infiltration capacity. The residual sodium carbonate index of water / soil signifies the alkalinity hazard posed by it and it finds the suitability of water for irrigation in case of clay soils (Raghunath 1987). Concentrations of carbonate and bicarbonate play an important role in determining the suitability of water for irrigation purposes. When the total carbonate concentration exceeds the total concentrations of calcium and magnesium and the excess carbonate (residual) concentration is too high, the carbonate ions combine with the calcium and magnesium ions to form a scale, a solid material, which then settles out of the water. As the calcium and magnesium settle out of the water as solid scales, the relative abundance of sodium increases creating deteriorating consequences on the plants. The quantity of carbonate and bicarbonate in excess of alkaline earth metals (calcium and magnesium) is denoted by ‘residual sodium carbonate’ (RSC) (Sundaray et al. 2009; Ravikumar et al. 2011). The term was proposed by Eaton (1950) and is determined by the method as suggested by Richards (1954). Residual sodium carbonate is calculated by the following formula i.e., eq. (D) (Wilcox 1955).

$$RSC = \left(CO_3^{-2} + HCO_3^{-}\right) - \left(Ca^{2+} + Mg^{2+}\right) \longrightarrow \quad 3$$

All the concentrations are expressed in meq/L.

According to Wilcox (1995) of US Salinity Laboratory, a RSC value of less than 1.25 meq/L is safe for irrigational activity, a value of 1.25 – 2.5 meq/L is marginally suitable, and a value greater than 2.5 meq/L is unsuitable for irrigation (Wilcox 1995).

In this study, the water samples have been found to have RSC values from -0.33 to 0.09 meq/L with a mean value of -0.15 meq/L in pre-monsoon, -0.47 to 0.16 with a mean value of -0.07 meq/L in monsoon and -0.38 to 0.13 with a mean of -0.10 meq/L in post-monsoon seasons. RSC values of all the samples are less than 1.25 meq/L, indicating the water samples are safe for irrigation purposes. Sometimes, the RSC values of water samples are negative, which indicate that the calcium and magnesium have not been precipitated out (Tiwari and Manzoor 1988). Exact variations of RSC values of both seasons have been shown by geospatial map **(Figure 32).**



(**Figure 32.** Spatial variations of RSC in pre-monsoon, monsoon and post-monsoon season)

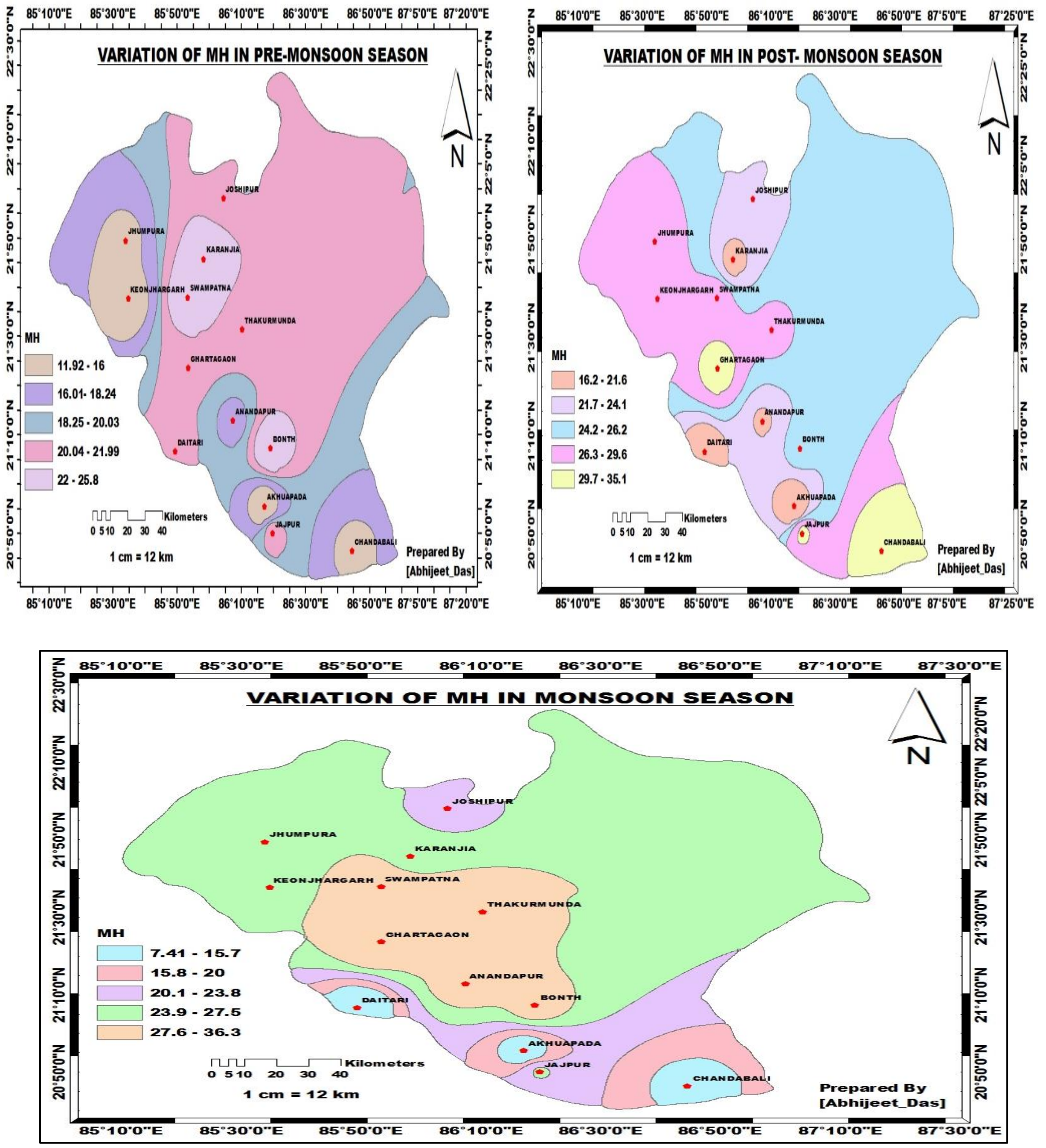
Magnesium Hazard (MH)

Generally in most surface waters, Calcium and magnesium ions maintain a state of equilibrium in most natural water (Hem 1989). Calcium and magnesium are not chemically equivalent especially in the soil system. A higher concentration of Mg ion in water is usually due to the higher exchangeable Na ion present in irrigated soils. High concentration of Mg ion present in water adversely affects the soil quality, making the soil alkaline, which results in low crop yield (Sundaray et al. 2009). The adverse effect of magnesium in irrigated water is measured as the magnesium ratio. Paliwal (1972) introduced an index 'magnesium hazard' for determining the adverse effects of magnesium in irrigation water and is calculated as magnesium ratio (MH) using the (eq. F) (Sundaray et al. 2009; Ravikumar et al. 2011). The concentrations of calcium and magnesium ions are measured in meq/L.

$$MH = \frac{Mg^{+}}{Ca^{2+} + Mg^{2+}} \times 100 \qquad \longrightarrow \quad 4$$

Since higher concentration of magnesium present in water adversely affects the soil quality and crop yield, magnesium hazard (MH) was also evaluated for all the water samples. The MH values above 50% adversely affect the crop yield and are not suitable for irrigation (Sundaray et al. 2009). MH values below 50% are suitable for irrigation purposes and hence it is considered to be safe.

The values range from 11.92 % to 25.81 % with a mean value of 19.42 % in pre-monsoon season, 7.39 % to 36.26 % with a mean value of 24.19 % and 16.20% to 35.12% with a mean of 25.70 % in post-monsoon season. MH values above 50 % adversely affect the crop yield and its productivity and are not suitable for irrigation (Sundaray et al 2009). All the values of this study of pre monsoon and post-monsoon season are below 50 % and hence suitable for irrigation activities. Geospatially, the variations of values are being shown in spatial map **(Figure 33).**



(**Figure 33.** Spatial variations of MH in pre-monsoon, monsoon and post-monsoon season)

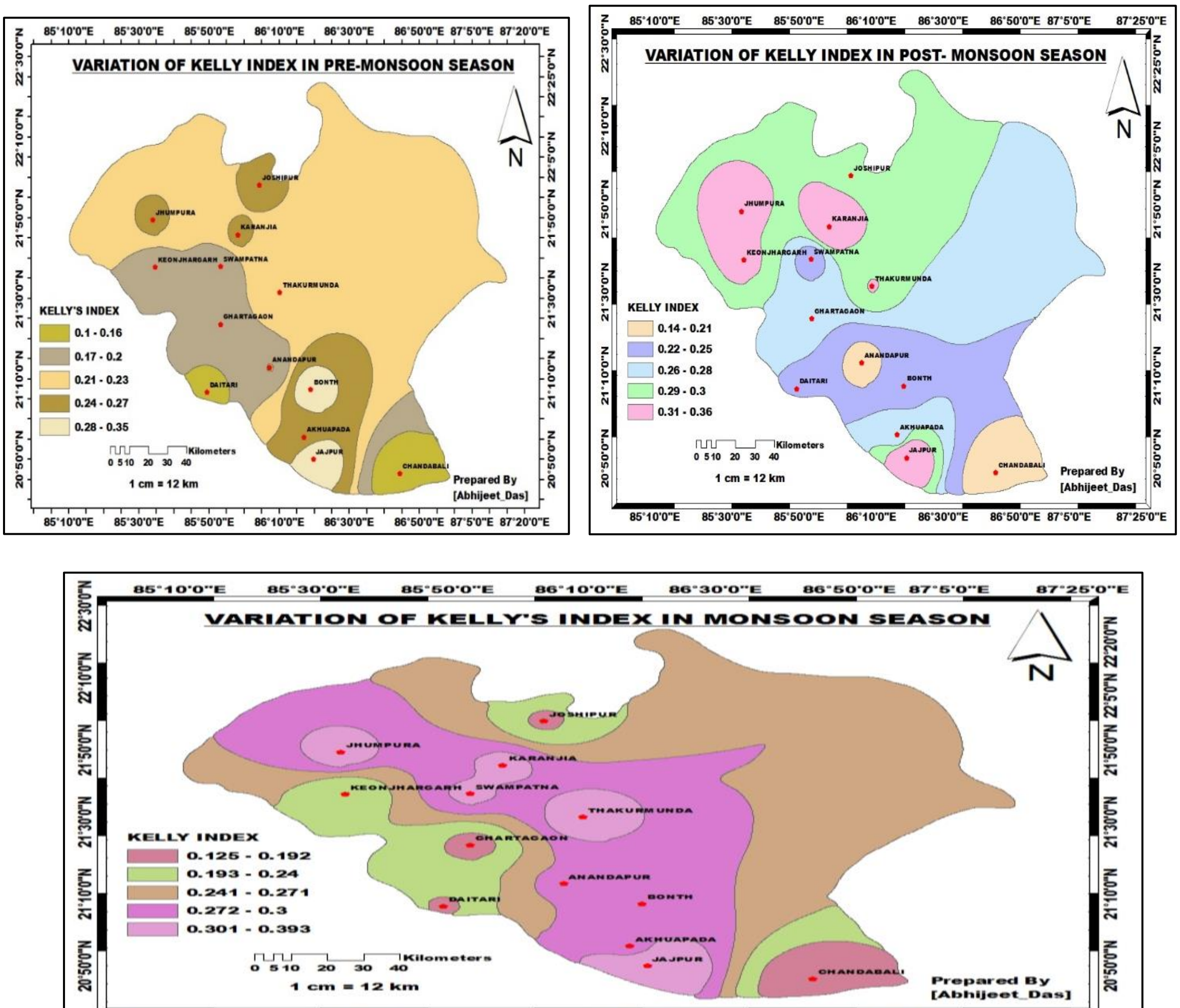
Kelly's index / Kelly's ratio (KI / KR)

Suitability of water quality for irrigation purposes is also determined on the basis on Kelly's index. In Kelly's index, sodium measured against calcium and magnesium (Kelly 1940). KI is calculated by the following eq. (G) (Srinivasamoorthy et al. 2014)

$$KI = \frac{Na^{+}}{Ca^{2+} + Mg^{2+}} \qquad \longrightarrow \quad 5$$

Where ion concentrations are expressed in meq/L.

Kelly's index indicates an excess quantity of sodium in water. Therefore, water with Kelly's index value less than one (KI < 1) is acceptable for irrigation, whereas value greater than one (KI>1) indicates excess sodium in water and value less than two (KI < 2) indicates sodium deficiency in water (Kelly 1940; Sundaray et al. 2009). In this study, the values ranges from 0.10 to 0.35 with a mean of 0.21 in case of pre-monsoon season and values ranges from 0.14 to 0.36 with a mean of 0.27 in case of post-monsoon season. All the values are less than 1 and all sampling locations are suitable for irrigation and agricultural purposes and can be used for cultivation, land preparation in case of both pre and post-monsoon season. Geospatially, the variations of values are being shown in spatial map **(Figure 34).**



(**Figure 34.** Spatial variations of Kelly Index in pre-monsoon, monsoon and post-monsoon season)

Permeability index (PI)

Permeability index (PI) is also used to determine the suitability of the irrigation water. The permeability of soil is affected by long-term exposure of irrigation water containing high quantity of sodium, calcium, magnesium and bicarbonate ions (Ravikumar et al. 2011; Srinivasamoorthy et al. 2014). Doneen (1964) introduced permeability index (PI) for assessing the suitability of irrigation water and is calculated by the following formula (Eq. H) (Arumugam and Elangovan 2009).

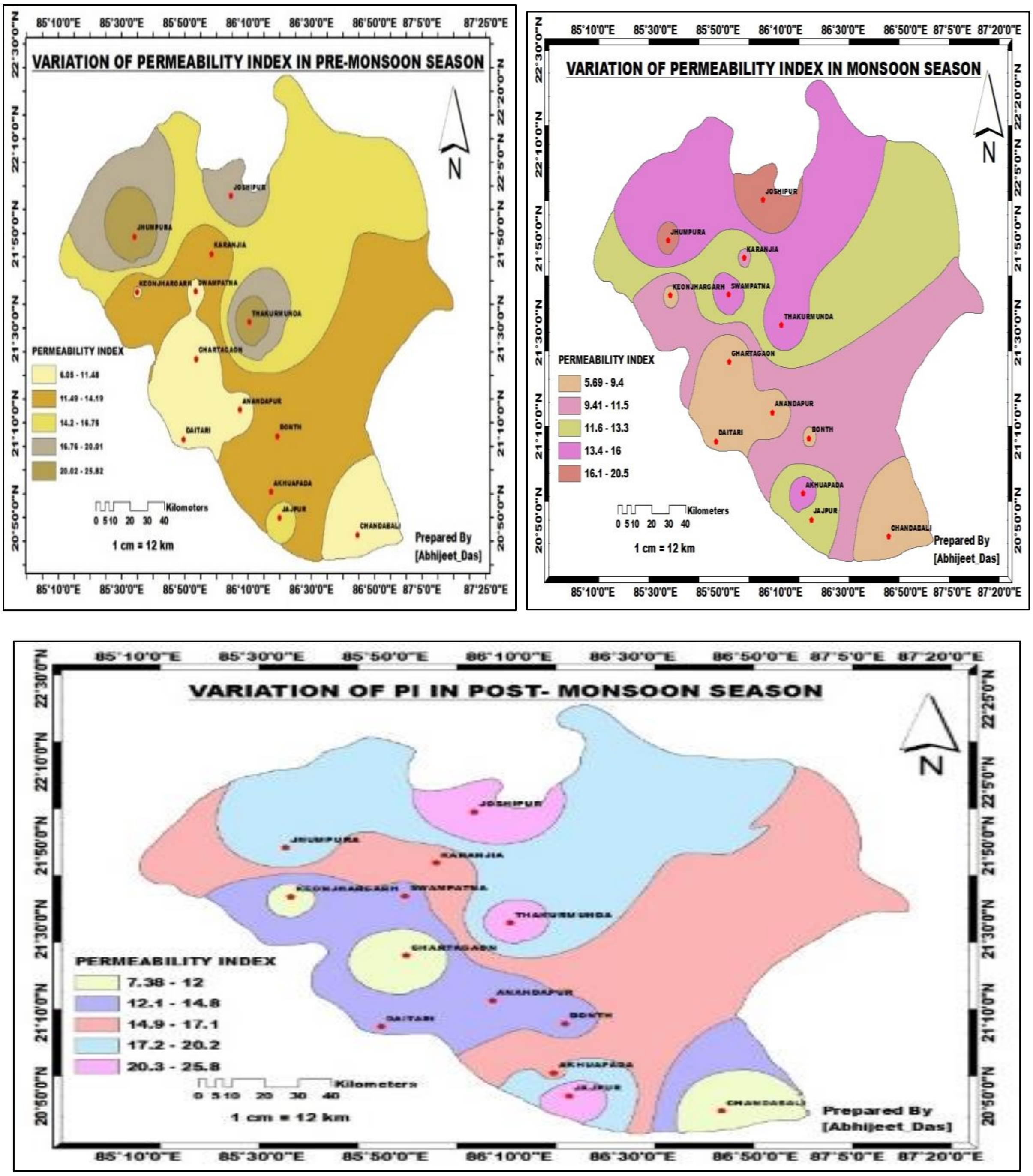
$$PI = \frac{(Na^{+} + \sqrt{HCO_3^{-}}) \times 100}{(Ca^{2+} + Mg^{2+} + Na^{+} + K^{+})} \qquad (6)$$

The concentrations are expressed in meq/L.

Water is classified into three classes based on the PI values. Class I (PI>75%) is considered as suitable for irrigation, class II (PI=25–75%) is considered as moderately suitable for irrigational uses, and class III (PI < 25%) is unsuitable (Sundaray et al. 2009; Das and Nag 2015).

Permeability Index (PI) values of Baitarani River water ranged from 41.80 to 65.70 % in pre-monsoon season, 38.07 5 to 62.97 % and from 30.04 to 60.68 % in the post-monsoon season. All the values lies in between 25 to

75 %, that depicts all sampling locations in pre and post monsoon season are suitable for moderate irrigation purposes i.e. it comes under Class II. Variations of PI values along the sampling stations are shown by geospatial map **(Figure 35).** According to PI analysis, post monsoon water is better than pre monsoon water, possibly because of the addition of large amount of fresh rain water. But in this study, all the seasons are moderate for all sampling stations.



(**Figure 35.** Spatial variations of Permeability Index in pre-monsoon and post-monsoon season)

Potential salinity (PS)

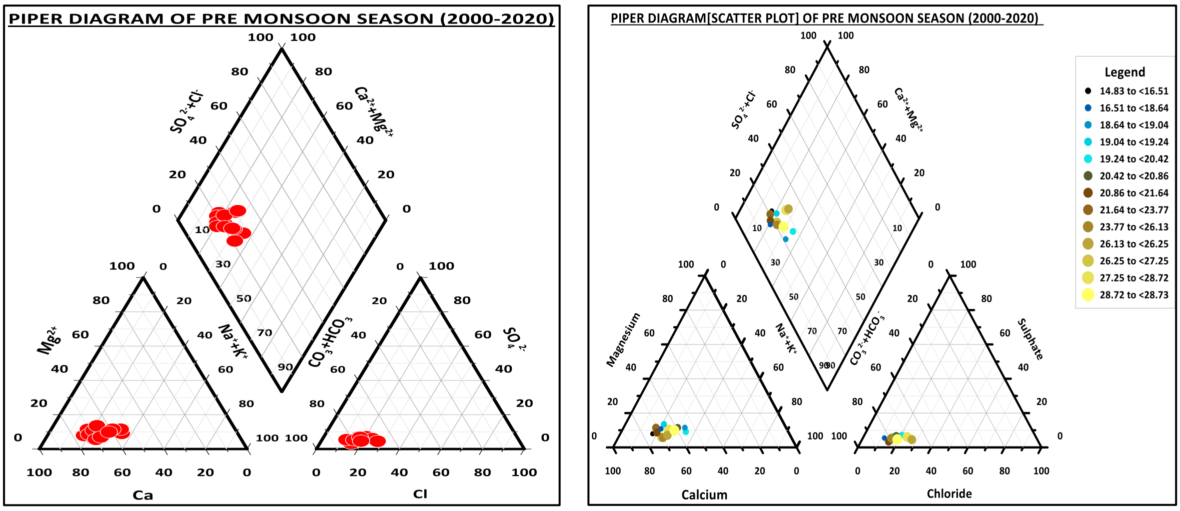
Salts of low solubility in the irrigation water are precipitated out and accumulated on the soil by each successive cultivation. Only the highly soluble salts remain dissolved in the water and increase the salinity. Each year, the salinity of the river is gradually increasing and has now been recognized as a major problem to the downstream water users (Kumarasamy et al. 2013a). 'Potential salinity is defined as the chloride concentration plus half of the sulphate concentration' (Doneen 1962; Ravikumar et al. 2011) and it is calculated by the following eq. (I).

$$\text{Potential Salinity (PS)} = Cl^- + \frac{1}{2}SO_4^{2-} \tag{7}$$

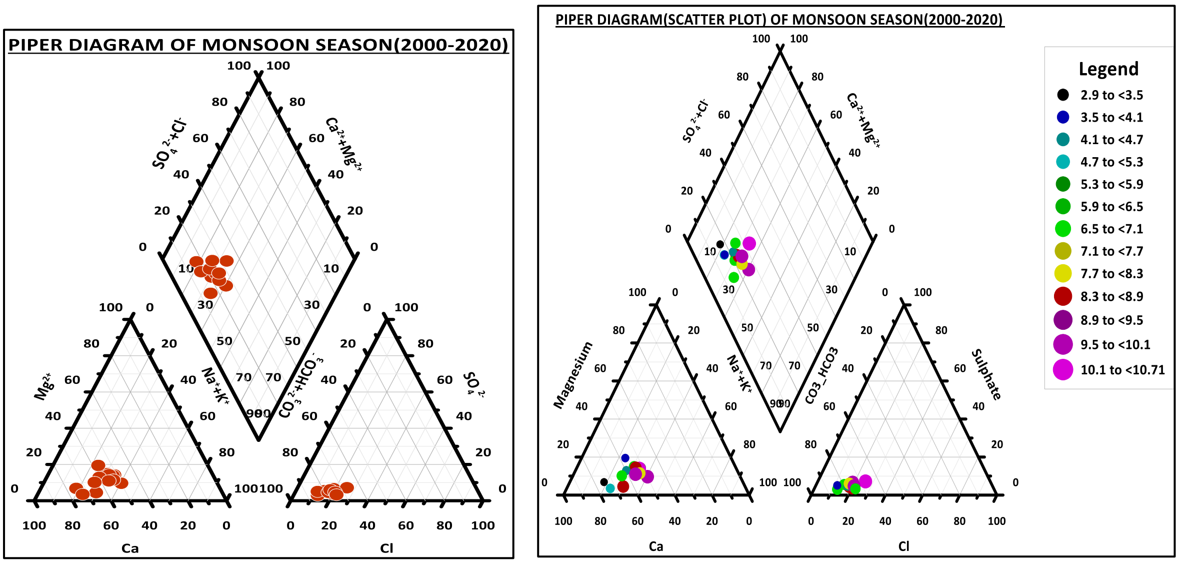
The concentrations are expressed in meq/L.
It is generally more prominent in the estuarine zone than in the freshwater zone, due to the presence of excessive chlorides of the sea water (Kumarasamy et al. 2013a)
Potential Salinity (PS) of the water samples of the Baitarani River varied from 0.09 to 0.30 in the pre-monsoon season, 0.06 to 0.20 in monsoon and from 0.07 to 0.26 in post-monsoon season. All the values are considerably fair low. It is very must significant in the estuarine region because of the high salt content from sea water. Doneen (1964) explained that suitability of water for irrigation is not dependent on the total concentration of soluble salts, as low solubility salts precipitate out and deposited on the soil every year. In this case, all are within the prescribed limits.

PIPER DIAGRAM ANALYSIS

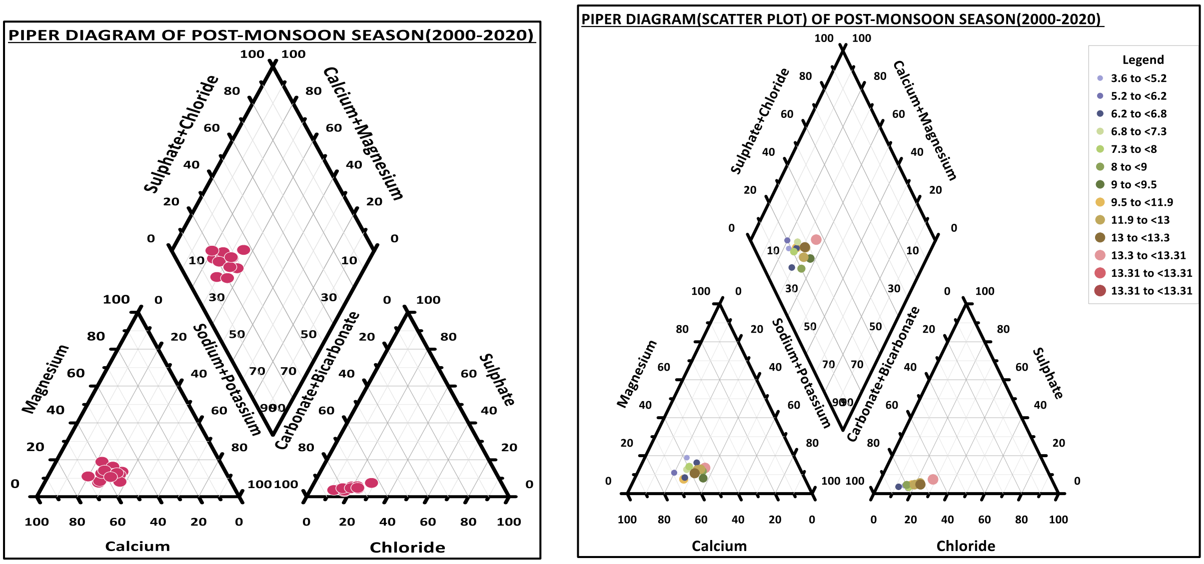
To know the hydro geochemical characteristics of the study area and water, the analytical values were plotted on piper diagram (Piper 1944). Piper trilinear diagram **(Figure 36, 37, 38)** includes two triangles, one showing cations and other showing anions, and a diamond shaped area to show a combined position of cations and anions. The combined single position of the diamond shaped area helps us to draw inference and to classify the water on the basis of the hydro geochemical characteristics. The diamond shaped area of Piper diagram is divided into four major parts, each part representing and explaining a particular type of variation or domination of cations and anions. The four parts are calcium-magnesium-chloride-sulphate, sodium-potassium-chloride-sulphate, sodium- potassium-bicarbonate and calcium-magnesium-bicarbonate. All the samples of this study of both the seasons fall in the category of calcium-magnesium-bicarbonate representing a dominance of calcium, magnesium and carbonate ions in the water. The sources of this type of waters may be a typical shallow fresh water stations with rooted aquatic vegetation along the banks.



(**Figure 36.** Piper Diagram for Pre-monsoon season)

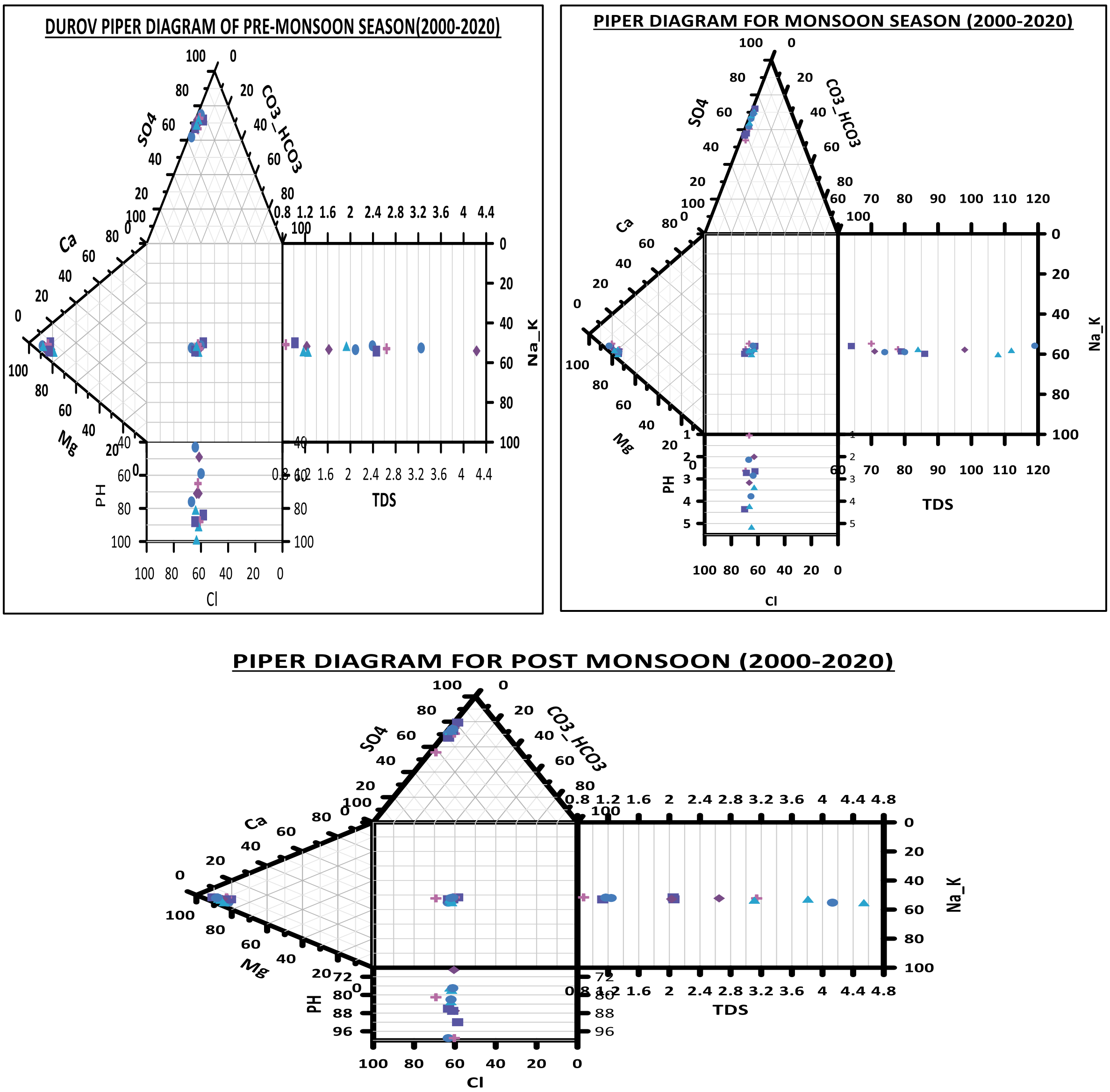


(**Figure 37.** Piper Diagram for monsoon season)



(**Figure 38.** Piper Diagram for Post-monsoon season)

Durov piper diagram **(Figure 39)** for pre-monsoon, monsoon and post-monsoon are being drawn for clear explanation of all the sampling locations and it's a typical method which will classify the law behind the trilinear piper diagram and also exhibit same results as that of piper diagram results. Hence, all the sampling locations are safe and suitable for irrigation and cultivation purposes.



(**Figure 39.** Durov Piper Diagram for Pre-monsoon and Post-monsoon season)

Water quality index (WQI)

Water quality index (WQI) is useful in assessing the suitability of river waters for a variety of uses such as agriculture, aquaculture and domestic use. The WQI was first proposed by Horton (1965) and was used for drinking water quality analysis (Brown et al. 1970; Misaghi et al. 2017; Kumar et al. 2018). Later on, Pesce and Wunderlin (2000) also proposed a WQI method which is used by many researchers. Some WQIs proposed by some countries are National Sanitation Foundation Water Quality Index (NSFWQI) by USA, the Florida Stream Water Quality Index (FWQI), the British Columbia Water Quality Index (BCWQI) by Britain, the Canadian Water Quality index (CWQI) and the Oregon Water Quality Index (OWQI) as described by Cude (2001). WQI, here, has been calculated following the method given by Pesce and Wunderlin (2000) and is given by

$$\mathrm{WQI_{sub}} = k\frac{\sum_{i=1}^{n} C_i.P_i}{\sum_{i=1}^{n} P_i}$$

Where Ci is the normalised value assigned to each parameter and Pi is the relative weight of each parameter. K is a subjective constant and may have values ranging from 1.0 to 0.25 depending on the visual impression of river contamination of the researcher. The value 1.0 is assigned to water without apparent contamination, and 0.25 is assigned to highly contaminated water.

These parameters were compared with the standard guideline values, recommended by BIS-10500 (2012) and WHO (2006). WQI (Water quality index) was calculated (Kalavathy *et al.*, 2011), (Reza and Singh, 2005), (Mukherjee *et al*., 2012), (Ravikumar *et al*., 2013) for pre-monsoon, monsoon and post-monsoon periods to assess the suitability of water for drinking purposes and for biotic communities (**Table 2**). For WQI calculation, total 22 parameters such as pH, turbidity, dissolved oxygen (DO), biological oxygen demand (BOD), total dissolved solids (TDS), total suspended solid (TSS), total hardness (TH), calcium (Ca) ions, magnesium (Mg) ions, total Fe, Cr, SO_4^{2-} , NO_3^- etc were considered and desirable limit of each parameter was used as per BIS standard.

Table 2. Water Quality Rating as per different Water Quality Index method

WQI LEVEL	WATER QUALITY RATING
0-25	EXCELLENT
26-50	GOOD
51-75	POOR
76-100	VERY POOR
>100	UNFIT FOR DRINKING PURPOSES

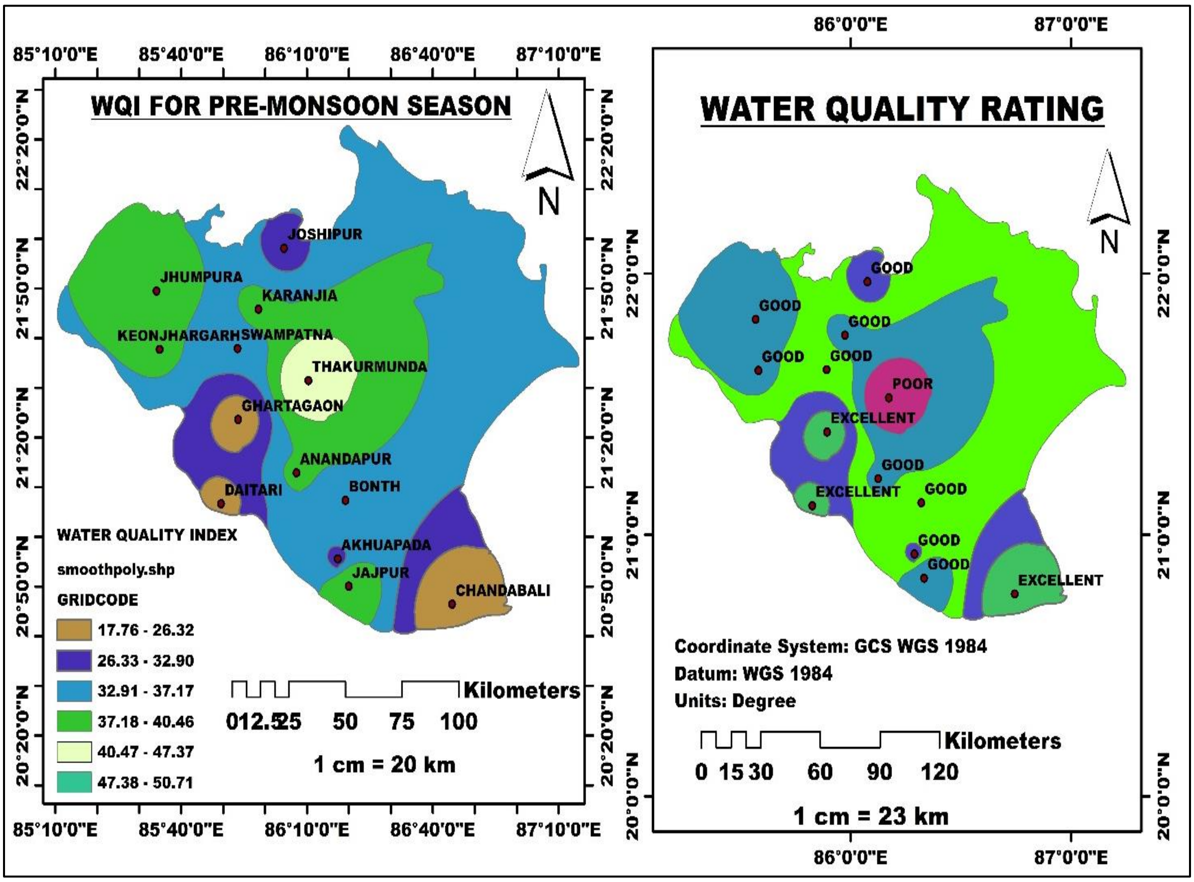
From the above table, it is clearly seen that the water quality index does not show exact degree of pollution, rather it is used to assess water quality trends for the management purpose. The WQI results represent the level of water quality in a given water basin. The computed WQI values are classified into five types, namely, excellent water (WQI<25) denotes lowest concern that generally meet state water quality standards, good water (26>WQ<50) depicts marginal concern, poor water (51<WQI<75), very poor water (76<WQI<100) both depicts moderate concern and water unsuitable for drinking (WQI>100) signifies highest concern as described by Ravikumar (2013), Mukherjee *et al*. (2012) and Dubey *et al*. (2014). Therefore, Baitarani River water ranges from "unfit for drinking" to "excellent" quality.

To calculate the WQI, water quality variables i.e., **PH, Turbidity, TDS, TSS, EC, DO, Alkalinity, BOD, TH,** $\mathbf{HCO_3^-}$**,** $\mathbf{SO_4^{2-}}$**,** $\mathbf{NO_3^-}$**,** $\mathbf{PO_4^{3-}}$**,** $\mathbf{Cl^-}$**,** $\mathbf{Ca^{2+}}$**,** $\mathbf{Mg^{2+}}$**,** $\mathbf{Na^+}$**,** $\mathbf{K^+}$**, TC, FC, Fe and Cr** were considered. The overall water quality index value for all the sampling stations is being shown in **Table 3**.

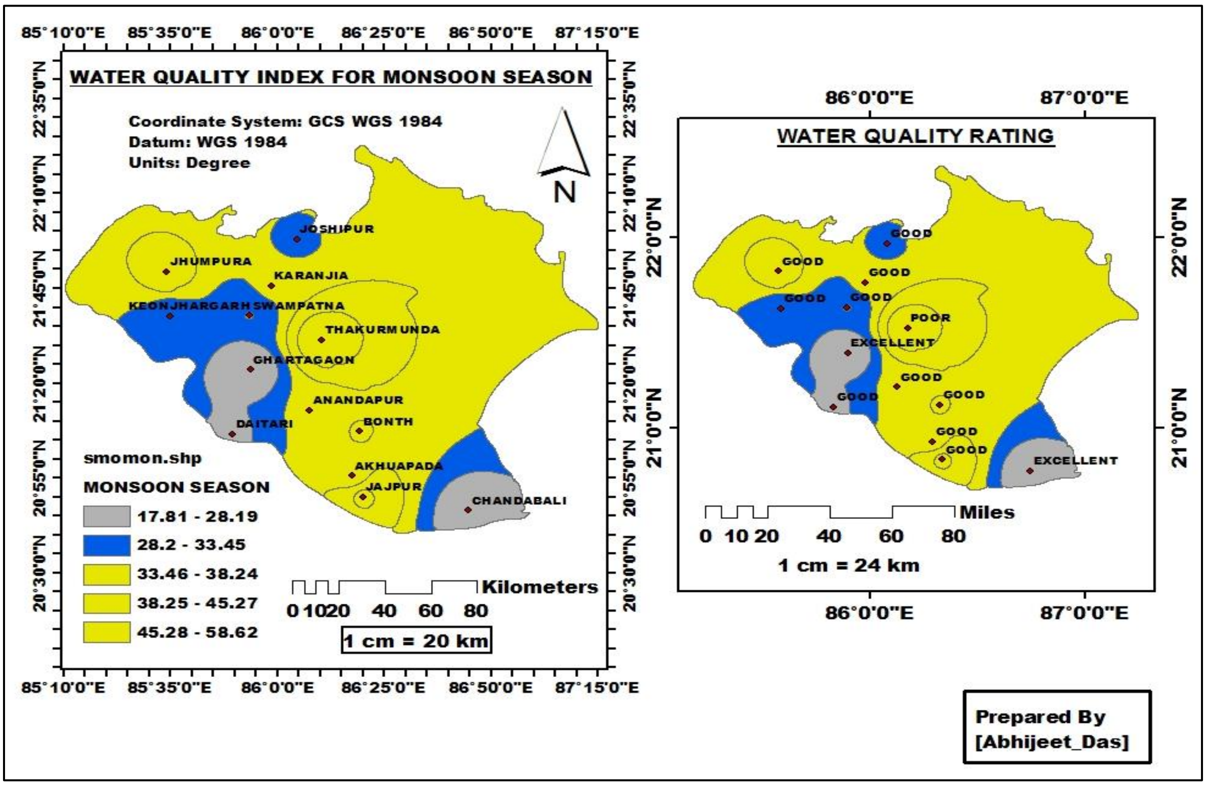
Table 3: Water quality status and WQI values at sampling stations

STATION NAME	WQI					
	PRE-MONSOON	DESCRIPTION	MONSOON	DESCRIPTION	POST-MONSOON	DESCRIPTION
CHANDABALI	17.76	EXCELLENT	21.62	EXCELLENT	19.25	EXCELLENT
JAJPUR	45.49	GOOD	47.10	GOOD	36.44	GOOD
AKHUAPADA	32.59	GOOD	34.65	GOOD	30.87	GOOD
DAITARI	23.94	EXCELLENT	26.03	GOOD	28.94	GOOD
BONTH	38.47	GOOD	38.59	GOOD	35.20	GOOD
ANANDAPUR	39.29	GOOD	34.86	GOOD	40.46	GOOD
GHARTAGAON	19.44	EXCELLENT	17.80	EXCELLENT	22.32	EXCELLENT
THAKURMUNDA	59.72	POOR	58.53	POOR	77.69	VERY POOR
SWAMPATNA	34.95	GOOD	28.10	GOOD	32.29	GOOD
KEONJHARGARH	39.71	GOOD	29.49	GOOD	34.70	GOOD
KARANJIA	40.00	GOOD	34.53	GOOD	36.63	GOOD
JHUMPURA	42.22	GOOD	43.26	GOOD	41.27	GOOD
JOSHIPUR	31.56	GOOD	32.57	GOOD	34.79	GOOD

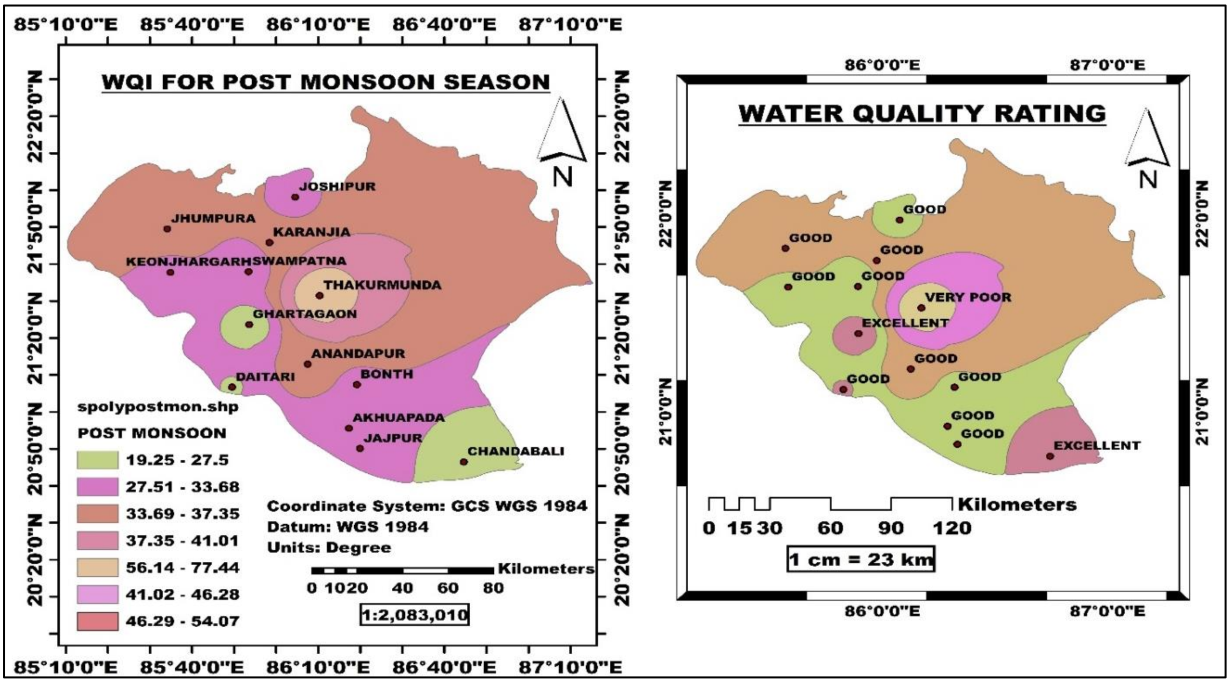
In this study, 22 parameters were chosen to calculate the WQI using the standards for drinking water. This index enables to know the suitability of water for human consumption (Sahu and Skidar 2008). Water quality of Baitarani River water was calculated for each sampling stations and for three seasons i.e., Pre-monsoon, Monsoon and Post-monsoon over a period of 20 years (2000-2020). There was a little difference between parameter values measured in this study for the sampling stations as a result of the similar atmospheric conditions and source of water, yet there were significant differences according to the season. The exact variations of the WQI of all the seasons i.e., pre-monsoon, monsoon and post monsoon) are shown in the geospatial map in (**Figure 40, 41 and 42)** respectively.



(**Figure 40**. Spatial variations of water quality index (WQI) for Pre-monsoon season)

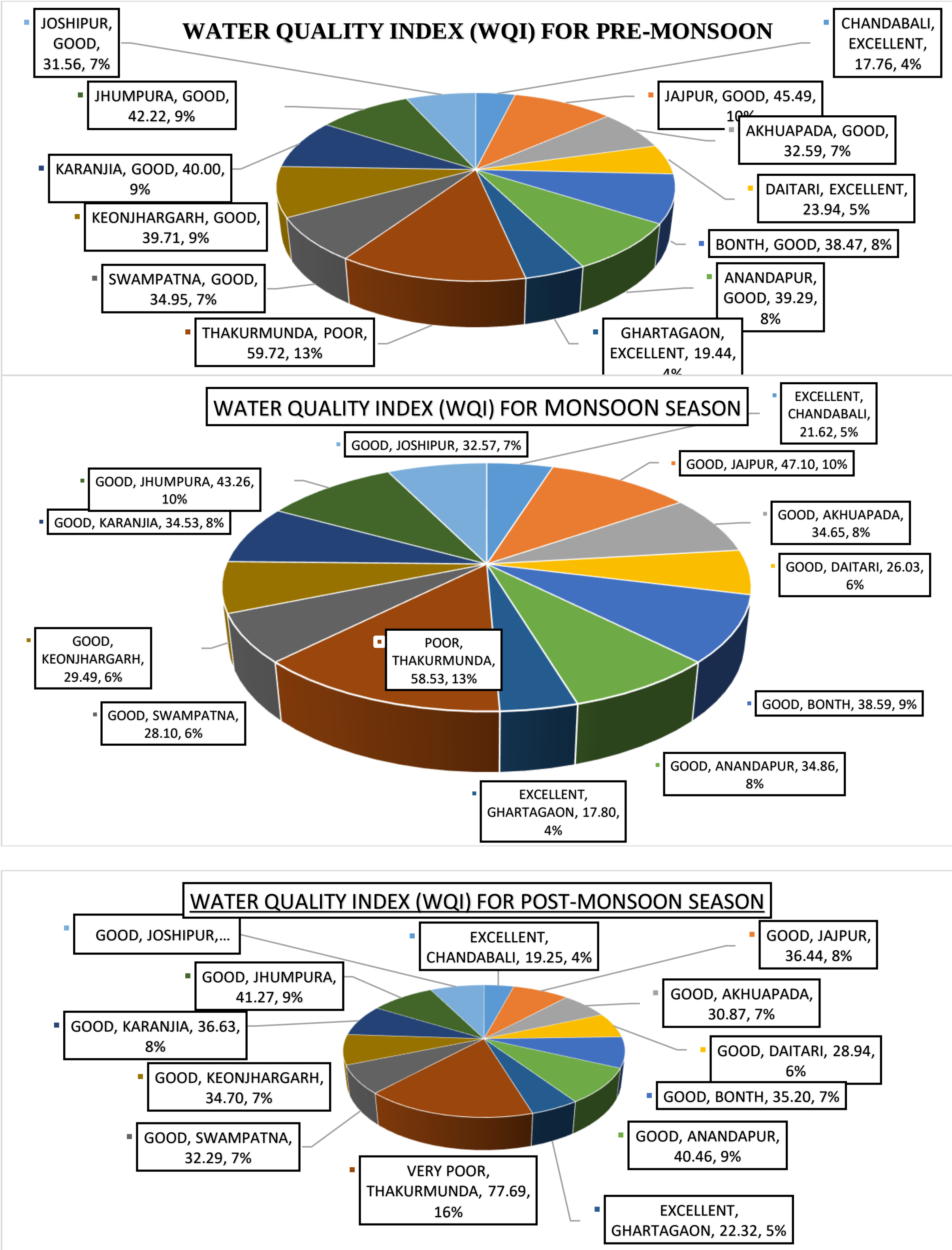


(**Figure 41**. Spatial variations of water quality index (WQI) for Monsoon season)



(**Figure 42**. Spatial variations of water quality index (WQI) for Post-monsoon season)

From the overall analysis of three different seasons i.e., (pre-monsoon, monsoon and post-monsoon), the WQI as shown in pie charts (**Figure 43**) varied from 17.76 to 59.72 in the pre-monsoon season, 17.80 to 58.53 in monsoon season and 19.25 to 77.69 in the post-monsoon season. Sampling stations 1, 4 and 7 designated as excellent, 2, 3, 5, 6, 9, 10, 11, 12 and 13 designated as good in the pre-monsoon season. In monsoon season, sampling station 1 and 7 designated as excellent and 2, 3, 4, 5, 6, 9, 10, 11, 12 and 13 designated as good. In case of post-monsoon season, sampling stations 1 and 7 designated as excellent and 2, 3, 4, 5, 6, 9, 10, 11, 12 and 13 designated as good and station 8 designated as very poor because it is situated in the downstream and is thought to receive the municipal effluents.



(**Figure 43**. Water Quality Index (WQI) variation as shown in pie charts for pre-monsoon, monsoon and post-monsoon season)

V. CONCLUSION

The overall study of water quality clearly indicates that the water sources of the concerned study area cannot be used for public consumption without any treatment through all samples are of good quality for irrigation purpose on the basis of physio-chemical parameter values. It is crucial to investigate the status of Baitarani River water pollution to ensure its suitability for agricultural use. All the PH and DO values of the water samples are greater than 7 indicating slight alkaline water. The results of PH and DO are also in good concordance with the maximum desirable limit of WHO (2008) and BIS (2012). EC values of all the water samples are below 750, complying beautifully with both Richards's value and FAO regulation and indicating good quality of irrigation water. With respect to TDS, it is seen that all the sampling locations performs good to excellent in pre-monsoon and moderately polluted to excellent in monsoon and post-monsoon season. For TSS and TDS, all sampling locations are within the permissible limits. For all sampling locations, EC values of all the water samples are below 750, complying beautifully with both Richards's value and FAO regulation and indicating good quality of irrigation water. Alkalinity ranged from 43 to 99 with a mean of 74.23 in pre-monsoon season, 43 to 95 with a mean of 74.15 in monsoon season and 69 to 99 with a mean of 84.23 in post-monsoon season. All sampling locations are within the prescribed limits according to the WHO standards. BOD concentration ranges from 0.86 to 4.23 with a mean of 2.01 in pre-monsoon period, 1.05 to 5.16 with a mean of 3.08 in monsoon season and 0.88 to 4.54 with a mean of 2.46 in post-monsoon period. All the sampling locations are with the prescribed limits and hence, it is suitable for all purposes. In case of TH, all the values are less than 300 mg/l, it is suitable for all activities for all sampling locations. So it can be concluded from the values that the classification of hardness is "medium hard". Calcium concentration ranged from 14.83 to 28.27 with a mean of 21.79 mg/l in pre-monsoon, 12.83 to 25.35 with a mean of 17.67 in monsoon season and 14.03 to 29.74 with a mean of 20.58 mg/L in post-monsoon periods. Acceptable limit in drinking water is 75 mg/l (200 mg/l in case no other alternative sources) (BIS 2012). Magnesium concentration ranges between 1.58 to 4.63 with a mean of 3.15 mg/l in pre-monsoon, 0.97 to 5.11 with a mean of 3.35 mg/l in monsoon and 2.36 to 5.83 with a mean of 4.24 mg/l in post-monsoon period. Both are within the prescribed limits in case of all the three seasons. In case of toxic metal like iron, Sampling location 2, 3,5,6, 9,10, 11,12 and 13 in pre-monsoon and 2,3,4,5,6,9,10,11,12 and 13 in post-monsoon is above the concentration limit which leads to high iron content that affects the taste of water, has adverse effects on domestic uses and promotes growth of iron bacteria. Measures should be taken before consumption by installation of iron removing plants. Sodium concentration in water varies from 2 to 10 mg/l with an average of 6.72 mg/l in pre-monsoon, 2.9 to 10.7 with a mean of 6.98 mg/l in monsoon and 3.60 to 13.30 with an average of 8.61 in post-monsoon season. Sodium regulates blood pressure levels in the human body and increased levels of sodium in blood leads to rise in blood pressure. Potassium concentration in water varies from 0.70 to 3.2 mg/l with an average of 1.78 mg/l in pre-monsoon, 1.2 to 3.7 with a mean of 2.16 mg/l in monsoon and 0.80 to 2.90 with an average of 1.92 in post-monsoon season. Acceptable limit is 12 mg/L as per WHO 1993. Both the parameters are within the limits. HCO_3^- varies from 41.92 to 87.55 mg/l with an average of 67.12 mg/l in pre-monsoon, 45.83 to 74.31 with a mean of 59.69 mg/l in monsoon and 55.64 to 91.46 with an average of 69.80 in post-monsoon season respectively. Chloride concentration in surface water samples in the study area ranged from 7.87 to 28.18 with an average of 16.14 mg/L in pre-monsoon, 7.3 to 22.12 with a mean of 13.47 mg/l in monsoon and 8.72 to 28.86 with an average of 17.97 mg/L in post-monsoon season. Too much of chloride leads to bad taste in water and also chloride ion combines with Na (that is being derived from the weathering of granitic terrains) and forms Na Cl, whose excess presence in water makes it saline and unfit for both irrigational and drinking purposes. Sulphate, Phosphate and Nitrate has been analyzed through geo-spatial maps and it has been observed that sampling locations are well within the limits and incase of nitrate, high concentration makes the drinking water toxic and causes blue baby disease/ methaemoglobinaemia in children and gastric carcinomas. For the study of ionic balance in case of all three seasons, the average concentration of Total Dissolved Solids (TDS) ranged from 74 to 178 with a mean of 135.31 in pre-monsoon season and 97 to 247 with a mean of 171.23 in post-monsoon season. All the values are within the limits and hence suitable for both drinking and irrigation. The hydro chemical analysis of the study reveals that the bicarbonate is the dominant ion in most samples. The order of anionic abundance (in mg/L) is $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^-$. Concerning the cationic chemistry, the order of cationic abundance (in mg/L) is $Ca^{2+} > Na^+ > Mg^{2+} > K^+$. Sampling points showed a relatively steady trend for the remaining ion concentration patterns. They were under saturated with carbonates and evaporates and in some cases it is seen that some locations are slightly super saturated with carbonate minerals (calcite, dolomite and aragonite).

To identify the origin of the salts dissolved in the river water, binary diagrams are drawn to understand the relative ionic plots which depicts Ca^{2+} versus SO_4^{2-} concentrations yielding a good correlation between most of the points. Based on the water quality parameters analyzed like SAR, SSP, MAR, PI and KR, the suitability of samples for irrigation is good to medium in almost all cases, indicating low sodium water. According to Richard's classification in case of sodium absorption ratio, all the samples number for 1 to 13 classified as "excellent (sodium hazard class S-I)". For better explanation and to draw a good information, US Salinity Laboratory (USSL) diagrams are being drawn to evaluate the water suitability for agriculture and irrigation activities. Only 1 sample (7.69 %) out of 13 samples of pre-monsoon season, 5 sample (38.46 %) out of 13 samples of monsoon and 9 samples (69.23 %) out of 13 samples fall in the category of C2S1, indicating medium salinity/low sodium type water. Rest 12 samples (92.30 %) of pre-monsoon season, 8 samples (61.53 %) of monsoon and 4 samples (30.76 %) of post-monsoon season fall in the category in low salinity/low sodium types.

The surface water will thus, neither cause salinity hazards nor have an adverse effect on the soil properties and is largely suitable for cultivation purposes. Depending upon the sodium percentage, 12.56 % to 28.43 % in case of pre-monsoon, 13.88 to 32.33 % monsoon and 15.73 to 29.76 % in post-moon are within the permissible limits. Sometimes it is seen in case of monsoon season, the effect of dilution or the washing out of sodium with the flow of heavy water is not significant. The possible reason of higher sodium in post-monsoon water may be the input of sodium through surface runoff of the basin area. RSC values of all the samples are less than 1.25 meq/L, indicating the water samples are safe for irrigation purposes. Sometimes, the RSC values of water samples are negative, which indicate that the calcium and magnesium have not been precipitated out. Since higher concentration of magnesium present in water adversely affects the soil quality and crop yield, magnesium hazard (MH) was also evaluated for all the water samples. All the values of this study of pre monsoon and post-monsoon season are below 50 % and hence suitable for irrigation activities. Kelly's index indicates an excess quantity of sodium in water. All the values are less than 1 and all sampling locations are suitable for irrigation and agricultural purposes and can be used for cultivation and land preparation. According to PI analysis, post monsoon water is better than pre monsoon water, possibly because of the addition of large amount of fresh rain water. But in this study, all the seasons are moderate for all sampling stations. Potential Salinity of the water samples of the Baitarani River varied from 0.09 to 0.30 in the pre-monsoon season, 0.06 to 0.20 in monsoon and from 0.07 to 0.26 in post-monsoon season. All the values are considerably fair low. It is very must significant in the estuarine region because of the high salt content from sea water. For analysis of hydro geochemical characteristics of the study area, piper diagrams are being plotted and the results shows that all the samples for the seasons fall in the category of calcium-magnesium-bicarbonate representing a dominance of calcium, magnesium and carbonate ions in the water. The sources of this type of waters may be a typical shallow fresh water stations with rooted aquatic vegetation along the banks. To classify the law behind the trilinear piper diagram and to compare the outcomes as that of piper diagram, Durov piper diagram are being drawn for clear explanation for all the seasons or periods. In case of WQI, Sampling stations 1, 4 and 7 designated as excellent, 2, 3, 5, 6, 9, 10, 11, 12 and 13 designated as good in the pre-monsoon season. In monsoon season, sampling station 1 and 7 designated as excellent and 2, 3, 4, 5, 6, 9, 10, 11, 12 and 13 designated as good. In case of post-monsoon season, sampling stations 1 and 7 designated as excellent and 2, 3, 4, 5, 6, 9, 10, 11, 12 and 13 designated as good and station 8 designated as very poor because it is situated in the downstream and is thought to receive the municipal effluents. It could be attributed to improper disposal of wastes, large quantity of agricultural and urban runoff, sewage, over application of inorganic fertilizer, improper operation and maintenance of septic system. It refers to possible decline of environmental properties. A small difference between values in different seasons could be attributed to discharge of pollutants to a water resource system from domestic sewers, water discharges, industrial waste discharges, agricultural runoff and other sources which can have significant effects of both short term and long-term duration on the quality of a river system.

The water that is suitable for irrigation is located in two of the affluent of Baitarani River. Fed by adjacent water sheds, these affluent empty into mainstream. The only suitable point for irrigation from Baitarani mainstream is located in the mid-valley. Mid tolerant crops should be encouraged in such areas. For the remaining locations, only plants tolerant to salt could be grown. It is useful for the irrigation of salt-tolerant and mid-tolerant crops under favorable drainage conditions while the remaining locations were classified as doubtful to unsuitable making the river water use limited to plants with high salt tolerance. This survey would assist managers to prioritize and make rational decisions for improving water quality used for irrigation. Some solutions can be recommended in accordance with the results of this study. Water salinity may be lessened by mixing salty waters with low salt concentration waters taken from other dams characterized by low water salinity. The mixing process is already adopted by the national water suppliers when they use Baitarani River water for drinking purposes; they mix treated waters from Baitarani River to treated waters from the dams. Additionally, the managers should use the optimal amount of irrigation water in order to satisfy leaching requirements, considering that these waters are salty and preventing the induced buildup of salts in the soil. This approach considers the electrical conductivity of the river water, the choice of the field crops as well as meteorological local conditions. Finally, the crop choice should be adapted to the water quality used for irrigation, by using salt-tolerant crop such as barley when irrigating with these salty waters.

Based on these results that proper management of wastewater irrigation and periodic monitoring of quality parameters are required to ensure successful, safe and long term reuse of wastewater for irrigation. It is recommended as a matter of high priority that treated wastewater is considered and made a reliable alternative source in water resources management. Agricultural wastewater reuse can effectively contribute to fill the increasing gap between water demand and water availability particularly in semi-arid areas. In future, further work is needed to examine organic and toxic constituents in wastewater and more intensive sampling and studies to measure any change of chemical elements in wastewater, irrigated soil and plant.

REFERENCES

[1]. Alexakis D (2011) Assessment of water quality in the Messolonghi- Etoliko and Neochorio region (West Greece) using hydro- chemical and statistical analysis methods. Environ Monit Assess 182:397–413
[2]. Ayers RS, Westcot DW (1985) Water quality for agriculture. FAO Irrigation and Drainage Paper No. (29), Rev. (1), U.N. Food and Agriculture Organization, Rome
[3]. Bouksila F, Bahri A, Berndtsson R, Persson R, Rozema J, Van der Zee S (2013) Assessment of soil salinization risks under irrigation with brackish water in semiarid Tunisia. Environ Exp Bot 92:176–185
[4]. Bouraoui F, Benabdallah S, Jrad A, Bidoglio G (2005) Application of the SWAT model on the Medjerda river basin (Tunisia). Phys Chem Earth 30:497–507
[5]. Chabchoub MA (2011) Evaluation des systems de production me ´diterrane ´ens dans un context de changement climatique. Cas de la basse valle ´e de la Medjerda en Tunisie, Institut Agronomique Me ´diterrane ´en de Montpellier. Master of Science CIHEAM-IAMM 113:31–36
[6]. Chapman D (1996) Water Quality Assessments—a guide to use of biota, sediments and water in environmental monitoring. Second Edition Published by E&FN Spon, an imprint of Chapman & Hall, UNESCO/WHO/UNEP, London SE1 8HN, UK, p 651 CIHEAM (1972)
[7]. La mise en valeur de la basse-valle ´e de la Medjerda. L'ame ´nagement des eaux Paris Options Me ´diterr 16:49–59
[8]. El Ayni F, Cherif S, Jrad A, Trabelsi-Ayadi M (2012) A new approach for the assessment of groundwater quality and its suitability for irrigation: a case study of the Korba Coastal Aquifer (Tunisia, Africa). Water Environ Res 84:673–681
[9]. Ezlit YD, Smith RJ, Raine SR (2010) Review of salinity and sodicity irrigation. CRC for Irrigation Futures Irrigation Matters Series No. 01/10, IF technologies Pty Ltd
[10]. Fan X, Cui B, Zhao H, Zhang Z, Zhang H (2010) Assessment of river water quality in Pearl River Delta using multivariate statistical techniques. Procedia Environ Sci 2:1220–1234
[11]. Faust D, Zielhofer C, Escudero RB, del Olmo FD (2004) High- resolution fluvial record of late Holocene geomorphic change in northern Tunisia: climatic or human impact? Quat Sci Rev 23:1757–1775
[12]. Gamvroula D, Alexakis D, Stamatis G (2013) Diagnosis of ground- water quality and assessment of contamination sources in the Megara basin (Attica, Greece). Arab J Geosci 6(7):2367–2381
[13]. Guasmi I, Hadji F, Jabri L (2013) Water quality of Medjerda wadi used for irrigation purpose (Eastern Algeria). Dev Soil Sal Assess Reclam 2013:701–716
[14]. Hamzaoui-Azaza F, Ketata M, Bouhlila R (2011) Hydrogeochemical characteristics and assessment of drinking water quality in Zeuss–Koutine aquifer Southeastern Tunisia. Environ Monit Assess 174(1–4):283–298.
[15]. Abdul HM, Jaward A, Bahram KM, Abass JK (2010) Evaluating raw and treated water quality of Tigris River within Baghdad by index analysis. J Water Resour Prot 2:629–635
[16]. Ameen SMM, Wilde SA, Kabir MZ, Akon E, Chowdhury KR, Khan MSH (2007) Paleoproterozoic granitoids in the basement of Bangladesh: a piece of the Indian shield or an exotic fragment of the Gondwana jigsaw? Gondwana Res 12:380–387. https:// doi.org/10.1016/j.gr.2007.02.001
[17]. APHA (2012) Standard methods for the examination of water and wastewater, 22nd edn. American Public Health Association, American Water Works Association, Water Environment Federation, Washington
[18]. Arumugam K, Elangovan K (2009) Hydrochemical characteristics and groundwater quality assessment in Tirupur Region, Coimbatore District, Tamil Nadu, India. Environ Geol 58:1509–1520. https://doi.org/10.1007/s00254-008-1652-y
[19]. Ayers RS, Westcot DW (1976) Water quality for agriculture. FAO irrigation and drainage. Paper no. (29), rev. (1). U.N. Food and Agriculture Organization, Rome
[20]. Banerjee T (1955) Progress report for 1955–1956 feld season (Continuation of geological mapping in Sikkim and Kalimpong hills). Geological Survey of India. F. no. 398(10)
[21]. Barakat A, Baghdadi ME, Rais J, Aghezzaf B, Slassi MM (2016) Assessment of spatial and seasonal water quality variation of Oum Er Rbia River (Morocco) using multivariat statistical techniques. Int Soil Water Conserv Res. https://doi. org/10.1016/j.iswcr.2016.11.002
[22]. Carpenter S, Caraco NF, Correll DL, Howarth RW, Sharpley AN, Smith VH (1998) Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecol Appl 8(3):559–568
[23]. Etteieb S, Cherif S, Tarhouni J (2017) Hydrochemical assessment of water quality for irrigation: a case study of the Medjerda River in Tunisia. Appl Water Sci 7:469–480. https://doi.org/10.1007/ s13201-015-0265-3
[24]. Giridharan L, Venugopal T, Jayaprakash M (2010) Identifcation and evaluation of hydrogeochemical processes on river Cooum, South India. Environ Monit Assess 162:277–289
[25]. Jarvie HP, Whitton BA, Neal C (1998) Nitrogen and phosphorus in east coast British rivers: speciation, sources and biological signifcance. Sci Total Environ 210(211):79–109

[26]. Sánchez E, Colmenarejo MF, Vicente J, Rubio A, García MG, Travieso L, Borja R (2007) Use of the water quality index and dissolved oxygen defcit as simple indicators of basins pollution. Ecol Indic 7:315–328
[27]. Sener S, Sener E, Davraz A (2017) Evaluation of water quality using water quality index (WQI) method and GIS in Aksu River (SW-Turkey). Sci Total Environ 584–585:131–144. https://doi.org/10.1016/j.scitotenv.2017.01.102
[28]. Simeonov V, Stratis JA, Samara C, Zachariadis G, Voutsa D, Anthemidis A, Sofoniou M, Kouimtzis T (2003) Assessment of the surface water quality in Northern Greece. Water Res 37:4119–4124 Singh H (1983) Crop production in India. Agric Situat India. 38:635–63
[29]. Singh UK, Kumar B (2017) Pathways of heavy metals contamination and associated human health risk in Ajay River basin, India. Chemosphere 174:183–199. https://doi.org/10.1016/j.chemospher e.2017.01.103.