Evaluation of Water Quality using Water Quality Index (WQI) Method and GIS (Baitarani Basin, Odisha)

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***Abstract*— The proposed study assesses the quantity of water for drinking use, to find out the principal contributing factor responsible for the pollution in River Baitarani, Odisha. These factors help the management and policy makers to set a marginal water quality standard. Water samples were collected from the 13 strategic locations of the river for a period of one year i.e., 2021-2022. Physicochemical parameters like pH, BOD, TH, Turbidity, TC, FC, TDS, TSS, EC, DO, Alkalinity, major anions like HCO_3^-, SO_4^{2-}, NO_3^-, PO_4^{3-}, Cl^-, and major cations like Ca^{2+}, Mg^{2+}, Na^+, K^+, Fe^{++} and Cr^{++} are taken for the study. The analysis results were compared with maximum permissible limit values recommended by drinking water standards. Due to the notable dissimilarity in water quality parameters and spatiotemporal variability, significant objectives are proposed to assess the river water quality. The work presents an index which can be implemented for the comparative assessment of water quality across the river basin controlled by several factors. Water quality index (WQI) being a valuable and unique rating scale to depict the overall water quality status in a single term has been employed to determine the feasibility of using the river water as a source for various activities. Results showed significant deterioration in quality of water at some of the sampling stations. WQI ranged from 17.76 to 59.72 in pre-monsoon, 17.80 to 58.53 in monsoon and 19.25 to 77.69 in the post-monsoon which falls in the range of good to poor quality of water. 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.**

Keywords— ***River Baitarani, Physicochemical parameters, Major ions, Spatiotemporal, Water quality index.***

1. INTRODUCTION

Fresh and clean water is a vital commodity for the well-being of human society, and damage of inland aquatic systems is one of the most serious environmental problems of the last century (Tudesque et al. 2008; Babiker et al. 2007). A river water monitoring program can provide a representative and definitive estimation of surface water quality due to spatiotemporal variations in river water geochemistry (Simeonov et al. 2003). Water quality, which is influenced by various natural processes and anthropogenic activities, is worldwide current environmental issue in research (Jaiswal et al. 2003; Singh et al. 2004, 2010; Ouyang 2005; Mukherjee et al. 2007; Shrestha and Kazama 2007). The developed program can provide precise information about water quality which can be considered as an essential part of overall quality management like biological or human health risk assessment and urban development, planning for pollution control, management and evaluation of temporal trend in water quality. The chemical composition of water is a measure of its suitability for human and animal consumption, irrigation and for industrial and other purposes. Water chemistry describes the seasonal changes in the behavior of the major ions and catchment characteristics. The definition of water quality is not objective but is socially defined depending on the desired use of water. Therefore, monitoring the quality of water is important because clean water is necessary for human health and the integrity of aquatic ecosystems (Babikar et al. 2007). Anthropogenic activities result in a significant decrease in surface water quality of aquatic systems in water sheds (Massoud et al. 2006) and greatly influence hydrological seasonality (Xu and Milliman 2009). However, the quality assessment of freshwater concerning physicochemical and biological characteristics requires comprehensive knowledge about hydro biological data to understand (Molden 2007; Shulkin and Nikulina 2015) along with accepted reinforcement principles. Therefore, effective tools are required to maintain the correspondence among researchers, decision makers and the general public. Implementation of functional management of river water quality requires not only a tool for that can impart precise water quality information, but also it is based on decision system of policy makers. The water quality index based on functional management can provide efficient tools for quality monitoring and interpret the results. The index must be based on water quality standards, information on potential water use efficiency, and toxicity class (Tziritis et al. 2014). The developed indices are used for an extensive scale of applications which includes economics and commerce, water resources, environmental assessment and pollution management, life-cycle assessment, groundwater assessment due to natural and anthropogenic causes (Bodrud-Doza et al. 2016; El-Sayed and Salem 2015), surface water and drinking water quality evaluation (Boyacioglu and Boyaciologlu 2008; Sanchez et al. 2007), characterization of environmental damages and global warming potential, eco-environmental modeling, eutrophication and drainage water impact assessment, regional scale assessment and crop yield evaluation. Also, application of universal water quality index to a particular use may lead to the conclusion that is not absolutely valid, fundamentally because the influence and significance of water quality properties may vary in different utilization. A river and its tributaries transport dissolved matters and nutrients, which sustain fish and the other aquatic life (Shrestha and Kazama 2007; Alkarkhi et al. 2008). Pollution may enter in river system through variety of pathways, which include storm water runoff, discharge from ditches and creeks, leaching and seepage of water and atmospheric deposition (Ouyang et al. 2006). Serious ecological and sanitary problems are associated with pollutants discharged in river inflows (Vega et al. 1998; Singh et al. 2004; Wang et al. 2007). Water pollution has significant effect on human health, balance of aquatic ecosystems, socio-economic development and prosperity (Milovanovic 2007). High toxicity problems are associated with point and non-point sources of pollution (Jain 2002). Nutrient assessment is important since it is linked with multidisciplinary environmental problems that exist over multiple scales. So, there is need to identify and quantify nutrient depositing sources within the river system (Corwin et al. 1998; Jain 2002). Precipitation distribution is directly associated with water quality assessment and its knowledge is very helpful in planning water resources and agricultural practices in a river basin (Jain 2002). As a comprehensive indicator, WQI provides overall summaries of water quality and potential trend on a simple and scientific basis (Kaurish and Younos 2007). It is a very useful and efficient method for assessing the quality of water and for communicating the information on overall quality of water (Pradhan et al. 2001; Das et al. 2001; Chaterjee et al. 2009; Sivasankar and Ramachandramoorthy 2009). To determine the suitability of the surface water for various purposes, WQI is computed by adopting formula given by Tiwari and Mishra (1985). GIS is an effective tool not only for collection, storage, management and retrieval of a multitude of spatial and non-spatial data, but also for spatial analysis and integration of these data to derive useful outputs and modeling (Srivastava et al. 2008). It is a powerful tool for developing solutions for water resources problems for assessing water quality, determining water availability, preventing flooding, understanding the natural environment and managing water resources on a local or regional scale (Tjandra et al. 2003). GIS is widely used for collecting diverse spatial data and for overlay analysis in spatial register domain to represent spatially variable phenomena (Babiker et al. 2004). GIS-based, simple, and robust WQI is an essential tool for rapid transfer of information to water resources managers and the public. This method can be the appropriate tool for a more meaningful data reduction and interpretation of multi-constituent chemical and physical measurements. Baitarani River belt is presently undergoing rapid industrial development and there have been incidences of toxic pollution from industry into the river. Hence, characterization of changes in surface water quality is an important aspect for evaluating variations of river pollution due to natural or anthropogenic inputs of point and non-point sources like urban, agricultural, industrial and domestic wastewaters, industrial wastewaters and sewage of metropolitan centers, small electroplating workshops, repair shops, hospitals and medical and scientific laboratories. In this study, the instantaneous water quality was taken into account since its assessment is an integral element in determining the available in-stream resources of fish and other aquatic life and the available out-of-stream resources for people. The water quality measurements are important for minimizing industrial, mining or navigational accidents that cause short-term pollutant releases into or along river. The monitoring will be beneficial to warn downstream users and to mitigate secondary damages. The research is carried out for the Baitarani River Basin considering twenty-two physicochemical water quality indicators data collected during three seasons for one year i.e. (2021-2022) from the thirteen selected gauging stations. Thus, the main objective of this work focusses on 1) Water quality characterization of the river and generation of WQI of the area; 2) Comparing pre-monsoonal, monsoonal and post-monsoonal physicochemical properties and its distribution characteristics in the river water through spatial interpolation technique; 3) Identify the contamination affecting water quality and their potential sources; and 4) Discuss the suitability of water for drinking use and the results are expected to evaluate the spatial-temporal evolution and enables to understand the main pollution sources at different locations along the river.

2. 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**) showing extraction of basin boundary along with study area showing all monitoring stations by the application of GIS Software.

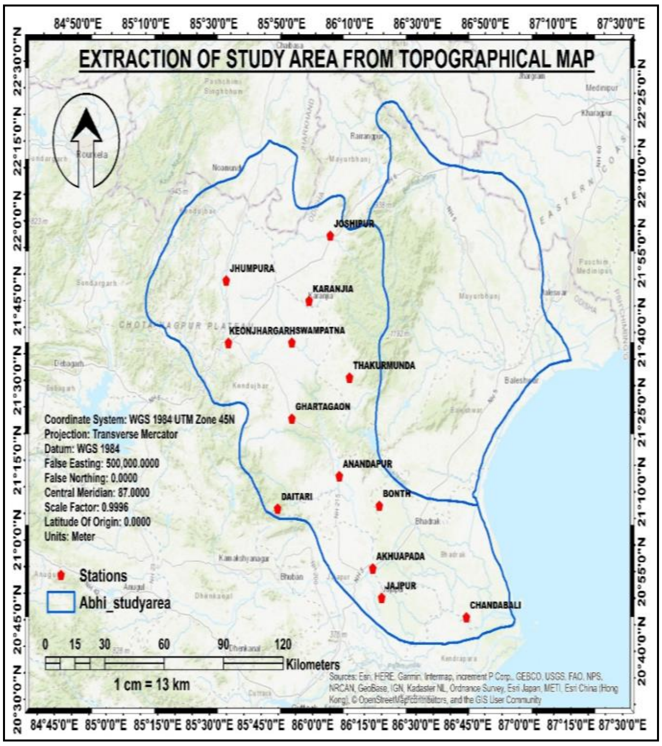


Figure 1. Location map of Baitarani Basin showing stations

3. METHODOLOGY AND DATA USED

3.1.1 Materials: The chemicals used in this study were of analytical grade and obtained from Merck, India. Double distilled water was used throughout the study. All glassware and other sample containers were rinsed with double distilled water and sterilized prior to use.

3.1.2 Sample Collection and Analysis: The seasons chosen for sampling were pre-monsoon, monsoon and post-monsoon. Sampling points taken are (St. 1) Chandabali, (St.2) Jajpur, (St.3) Akhuapada, (St.4) Daitari, (St.5) Bonth, (St.6) Anandpur, (St.7) Ghartagaon, (St.8) Thakurmunda, (St.9) Swampatna, (St.10) Keonjhargarh, (St.11) Karanjia, (St.12) Jhumpura and (St.13) Joshipur. The samples were taken between 10:00 am to 12:00 pm following downstream in three seasons. All samplings represent instantaneous water quality at the particular time. All the samplings were completed approximately in three days. Global reference was obtained for each location through GPS. Samples were collected in polyethylene bottles, transported to the laboratory, and analyzed within 48 hours. Water samples were analyzed for 22 physicochemical parameters, which included PH, BOD, TH, Turbidity, TC, FC, TDS, TSS, EC, DO, Alkalinity, major anions like HCO_3^-, SO_4^{2-}, NO_3^-, PO_4^{3-}, Cl^-, and major cations like Ca^{2+}, Mg^{2+}, Na^+, K^+, Fe^{++} and Cr^{++}. The parameters were determined using the standard methods for the examination of water and wastewater (APHA 1998). pH was measured on the field utilizing the portable meter and rest of the parameters were determined in laboratory. Total dissolved solids were measured by evaporation and calculation methods (Hem 1991). Ca^{++} and Mg^{++} were determined titrimetrically using standard EDTA. Chloride was estimated by $AgNO_3$ titration, Turbidimetric technique was used for the analysis of sulfate, nitrate and Phosphate were analyzed using the UV-visible spectrophotometer (Rowell 1994).

3.2 Data Analysis

3.2.1 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. Later on, Pesce and Wunderlin (2000) also proposed a WQI method which is used by many researchers. WQI, here, has been calculated following the method given by Pesce and Wunderlin (2000) and is given by

$$WQI_{sub} = k \{ \sum_{i=1}^{n} Ci * Pi / \sum_{i=1}^{n} Pi \}$$

Where Ci is the normalized 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. WQI (Water quality index) was calculated (**Reza and Singh, 2005**; Mukherjee 2009; (Ravikumar *et al.*, 2013) for pre-monsoon, monsoon and post-monsoon periods to assess the suitability of water for drinking purposes. 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).** The overall water quality index value for all the sampling stations is being shown in Table 1.

3.2.2 Spatial Interpolation-Inverse Distance Weighted (IDW): One of the spatial interpolation techniques was adopted for generation of thematic layer of the area for all the seasons. It is a process of using sample points with known values to estimate values at other points (Chang 2006). It is an exact method that enforces the estimated value of a point is influenced more by nearby points than those farther away (Chang 2006). It determines the cell values using a linearly weighted combination of a set of sample points. The WQI obtained at the surface water collection sites was interpolated to obtain the index for the study area.

4. RESULTS AND DISCUSSION

4.1 Hydrochemistry of surface water

The descriptive statistics of 22 physicochemical parameters at the 13 locations of the Baitarani River Basin during the pre-monsoon, monsoon and post-monsoon are given in (Table 1). They present the univariate overview of the chemistry of surface water along the river stretch. PH indicates the degree of acidity or alkalinity of water. It 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). The values range from 7.3 to 9.7 mg/l in the pre-monsoon, 6.44 to 7.43 mg/l in monsoon and 7.4 to 9 mg/l in post-monsoon period. All values of pH are greater than 7 implying mild basicity. It may be ascribed due to the discharge of industrial and domestic sewage, which puts large number of alkaline ions into the river system. Normal turbidity range required for irrigation water is < 15 NTU indicates excellent, 16 – 35 indicates well, 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 NTU with a mean of 17.49 in pre-monsoon season, 18.7 to 65.40 NTU with a mean of 39.62 in monsoon season and 11.80 to 38.70 NTU with a mean of 20.06 in post-monsoon season. It is seen that all the locations perform good to excellent in pre-monsoon and moderately polluted to excellent in monsoon and post-monsoon season. To ascertain the suitability of surface water of any purposes, it is essential to classify the 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. The average concentration ranged from 74 to 178 mg/l with a mean of 135.31 in pre-monsoon season, 98 to 218 mg/l with a mean of 156 in monsoon season and 97 to 247 mg/l with a mean of 171.23 in post-monsoon season. Total Suspended Solids (TDS) ranged from 30 to 121 mg/l 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 mg/l with a mean of 91.62 in post-monsoon season. Maximum occurs during the monsoon and post-monsoon period, as a large amount of sediment load was transported from the watershed during the rainy season. EC values varied from 96 to 318 mg/l with a mean value of 197.62 in the pre-monsoon, 108 to 372 mg/l with a mean of 237 in monsoon and varied from 121 to 393 mg/l with a mean value of 261.54 in the post-monsoon season. All values are below 750, complying beautifully with both Richards's value and FAO regulation and indicating good quality of irrigation water. DO content is an essential parameter that maintains the equilibrium of aquatic ecosystems. It is commonly used to assess the water resource quality (Sanchez et al., 2007). It ranges from 4.78 to 8.01 mg/l with a mean of 6.91 in pre-monsoon, 5.87 to 7.87 mg/l with a mean of 6.98 in monsoon and 5.03 to 7.69 mg/l with a mean of 6.84 in post-monsoon season. Alkalinity is measure of the capacity of water to neutralize an added acid. Values ranged from 43 to 99 mg/l with a mean of 74.23 in pre-monsoon, 43 to 95 mg/l with a mean of 74.15 in monsoon and 69 to 99 mg/l with a mean of 84.23 in post-monsoon season. BOD is the quantity of oxygen necessary for the decomposition of organic matter under aerobic conditions (Sawyer and Mc Carty 1978). According to WHO standards, BOD did not exceed 6 mg/l. BOD concentration ranges from 0.86 to 4.23 mg/l with a mean of 2.01 in pre-monsoon, 1.05 to 5.16 mg/l with a mean of 3.08 in monsoon and 0.88 to 4.54 mg/l with a mean of 2.46 in post-monsoon period. 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 2008) 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. It ranges between 64 to 121 mg/l with an average of 89.08 in pre-monsoon, 64 to 119 mg/l with a mean of 86 in monsoon and 71 to 135 mg/l with an average value of 96.46 in post-monsoon season. All the values are less than 300 mg/l. The classification of hardness is "medium hard". Calcium (Ca^{++}) concentration ranged from 14.83 to 28.27 mg/l with a mean of 21.79 mg/l in pre-monsoon, 12.83 to 25.35 mg/l with a mean of 17.67 in monsoon and 14.03 to 29.74 mg/l 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). Acceptable limit of magnesium in drinking water is 30 mg/l (100 mg/l in case of no other alternative source) (BIS 2012). Magnesium (Mg^{++}) ion helps in maintaining normal nerve and muscle function, a healthy immune system and helps bones remain strong. Values 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 mg/l with a mean of 4.24 mg/l in post-monsoon period. Iron (Fe^{++}) is an essential element in the human body and is required physiologically on various aspects (Moore 1973). It causes staining of clothes and utensils. 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). Concentrations range between 0.19 to 1.08 mg/l with a mean of 0.51 in pre-monsoon, 0.17 to 0.65 mg/l with a mean of 0.32 mg/l in monsoon and 0.13 to 1.43 mg/l 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. Sodium (Na^+) content is the most troublesome of the major constituents and an important factor in irrigation water quality evaluation. Depending upon the Specific Ion Toxicity, the values should be less than 100 mg/L indicates none, > 100 indicates slight to moderate and > 100 indicates severe. It varies from 2 to 10 mg/l with an average of 6.72 mg/l in pre-monsoon, 2.9 to 10.7 mg/l 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. Potassium (K^+) 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. High phosphate if found, may be ascribed to vicinity of pollutant source such as chlor-alkali and fertilizer-manufacturing industries, which are dominant in this area. Values 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. Bicarbonate (HCO_3^-) 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 BIS for level of carbonate and bicarbonate in drinking water. Acceptable limit of chloride in drinking water is 250 mg/L (1000 mg/l in case of no other alternative source) (BIS 2012). Chloride (Cl^-) concentration in surface water samples 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. Sulphate (SO_4^{2-}) 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 in drinking water is 200 mg/L (400 mg/L in case of no other alternative source) (BIS 2012), all locations are within the limits. Phosphate (PO_4^{3-}) 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. Nitrate (NO_3^-) 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 (1995). Parameters such as NO_3^-, Cl^-, K^+, Na^+, Mg^{++}, Ca^{++}, HCO_3^-, TC, FC, TH, BOD, DO, Alkalinity, PO_4^{3-} TDS and EC, complying beautifully with the standards (WHO 1993, 2008; BIS 2012). Spatial map distribution of all quality indices has been represented in geospatial paradigm (Figure 2).

4.2. Water Quality Index (WQI) Classification

The WQI table of different stations (Table 2) was compared with the water quality rating and category chart (Ravikumar 2013). All the values calculated are explicitly showing a little difference between parameter values measured 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. Values varied from 17.76 to 59.72 in the pre-monsoon, 17.80 to 58.53 in monsoon and 19.25 to 77.69 in the post-monsoon season. Through application of GIS and spatial interpolation method, pollution zone categorization of river stretch can be done for better management of the river and its catchments. These interpolations were run on three seasons WQI values and classified into the category of stations 1, 4 and 7 designated as excellent, 2, 3, 5, 6, 9, 10, 11, 12 and 13 designated as good in case of pre-monsoon. In monsoon, stations 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, 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. These demarcations showed the spatial extent of effected area which was more exposed to pollutants. It is strongly influenced by household and industrial wastewater followed by run-off from agricultural area. Thus, the result analysis suggests that anthropogenic activities showed significant effects on water quality. As the monsoon in the area progresses, it brings about precipitation, giving life to the lotic ecosystem. The runoff received through precipitation dilutes the nutrient content. But the amount of dilution changes with the spatial extent i.e., the area which was closer to pollutant source showed less dilution. It may be the result of more influx of nutrients from the point and non-point sources. Sometimes it indicates improvement in river health by natural monsoonal variation. In post-monsoon season, Thakurmunda comes under extremely polluted zone, may result due to the lesser amount of precipitation received in this area, high discharge of sewage and industrial waste into the water. Exact variations of WQI of all the seasons are represented in the geospatial map in (Figure 3, 4 and 5) respectively.

5. CONCLUSION

Surface water quality and its suitability for drinking purposes in Baitarani Basin area has been evaluated. The results of this study that the water is known to be alkaline and durable. Parameters such as NO_3^-, Cl^-, K^+, Na^+, Mg^{++}, Ca^{++}, HCO_3^-, TC, FC, TH, BOD, DO, Alkalinity, PO_4^{3-} TDS and EC, complying beautifully with the standards (WHO 1993, 2008; BIS 2012). By conducting analyses and investigating the results, it can be concluded that with wastewater from agricultural activities, gardens, fish farms, construction activities and the resultant wastewater discharge, the Baitarani River's water quality has declined. The sources responsible for contamination are mixing of semi-treated/untreated urban wastewater through many drains, slum areas adjoining the river bank that release its untreated wastewater and garbage directly to the river, direct dumping of religious and household wastes by the localities along with agricultural runoff. The latent reason behind the deterioration in water quality is the lack of awareness among the locals and their cultural practices such as immersion of idols and religious materials during and after various festivals. Also, the river channelization has deteriorated the water quality to a great extent as the waterflow is controlled by barrages and weirs in this stretch. So, the river is unable to replenish itself. This study showed the efficiency of water quality index to analyze and interpret a dataset for effective evaluation of surface waters. The proposed WQI can be considered as an alternative approximation for the evaluation and classification of surface water quality at River Basin system. Coupling of WQI with spatial interpolation technique has allowed categorizing the river into different pollution zones. In serious situation of water pollution, the management of water quality will be more and more important in planning the whole watershed and minimizing the environment losses. In this area, the spatial distribution analysis using the GIS techniques suggests that St. 1, 4 and 7 designated as excellent, St. 2, 3, 5, 6, 9, 10, 11, 12 and 13 designated as good in pre-monsoon. In monsoon, station 1 and 7 designated as excellent and St. 2, 3, 4, 5, 6, 9, 10, 11, 12 and 13 designated as good. In case of post-monsoon, St. 1 and 7 designated as excellent and 2, 3, 4, 5, 6, 9, 10, 11, 12 and 13 designated as good and St. 8 designated as very poor. The results indicate that most of the stations were influenced especially by industrial practices followed by agricultural and household wastewaters. This suggests that it is urgent to control point pollutions, all wastewater should be treated before discharge. It could be helpful to managers and government agencies in water quality management. This helps us to understand a complex nature of water quality issues and determine priorities to improve water quality depending on the WQI. To monitor rivers like Baitarani, short term monitoring and rapid water quality index development are the need of the hour. But at the same time before coming on any conclusion, all the natural ongoing operations like nitrification, inhibition, nitrogenous and carbonaceous BOD, sediment oxygen demand of the river should be considered. Our study emphasized on short term continuous measurements of the water quality and index development of the river so that management decisions could focus on gradual improvements in the water quality. To preserve this water resource against pollution, the implementation of stringent rules and guidelines are needed to enhance health and preserve water resources for future generation.

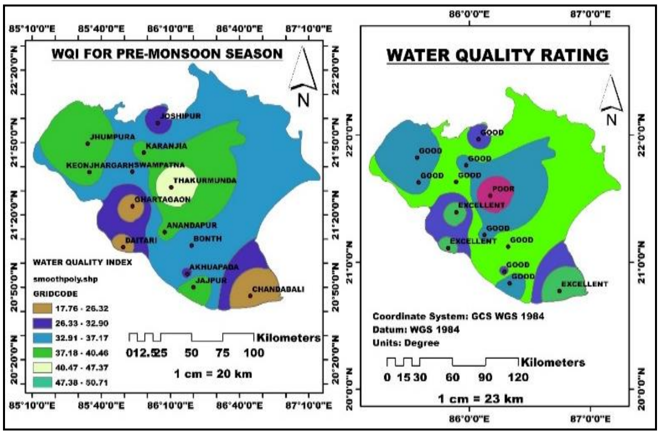


Figure 3. Spatial map of WQI for Pre-monsoon season

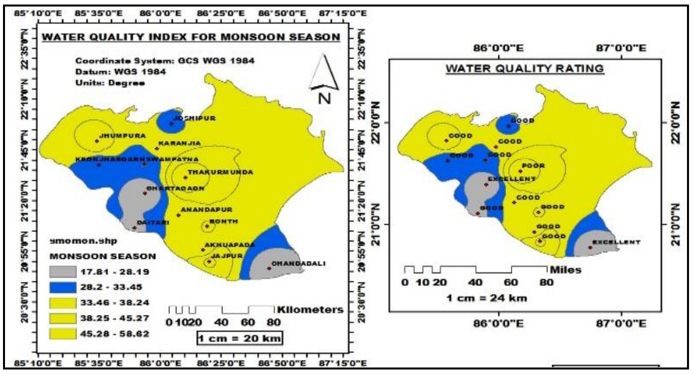


Figure 4. Spatial map of WQI for Monsoon season

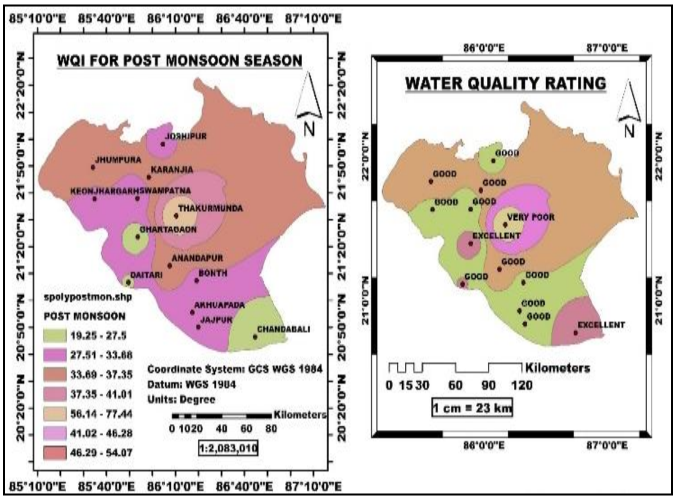


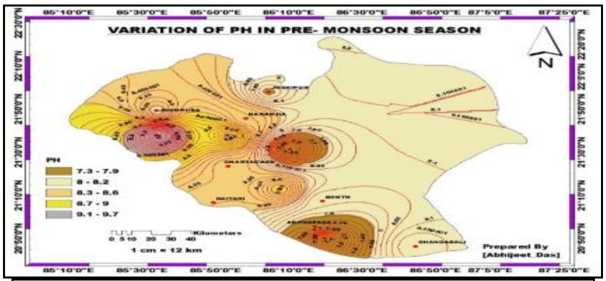
Figure 5. Spatial map of WQI for Post-monsoon season

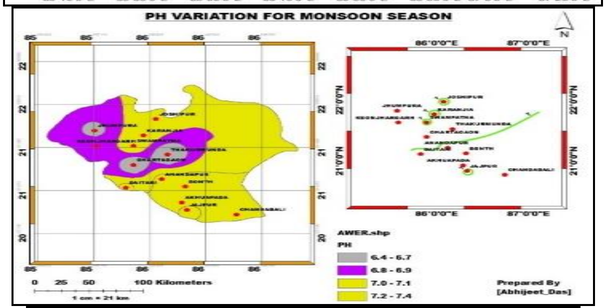
Table 2: WQI values for three seasons (Pre-monsoon, Monsoon and Post-monsoon)

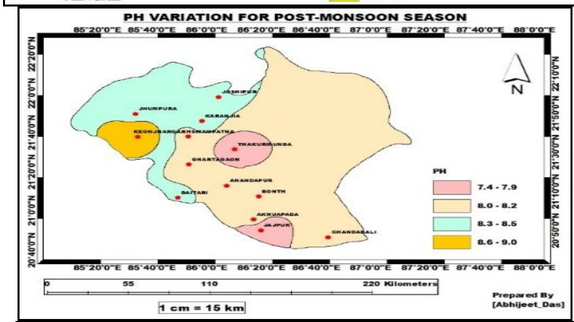
Stations	Pre-monsoon WQI	Rating (Pre-monsoon)	Monsoon	Rating (Monsoon)	Post-monsoon	Rating (Post-monsoon)
Chandabali	17.76	Excellent	21.62	Excellent	19.25	Excellent
Jajpur	45.49	Good	47.1	Good	36.44	Good
Akhuapada	32.59	Good	34.65	Good	30.87	Good
Daitari	23.94	Excellent	26.03	Good	28.94	Good
Bonth	38.47	Good	38.59	Good	35.2	Good
Anandapur	39.29	Good	34.86	Good	40.46	Good
Ghartagaon	19.44	Excellent	17.8	Excellent	22.32	Excellent
Thakurmunda	59.72	Poor	58.53	Poor	77.69	Very Poor
Swampatna	34.95	Good	28.1	Good	32.29	Good
Keonjhargarh	39.71	Good	29.49	Good	34.7	Good
Karanjia	40	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

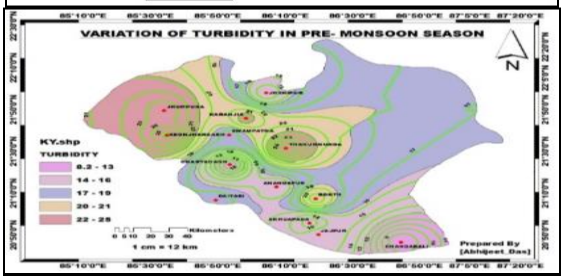
Table 1. Estimated minimum and maximum concentration of physicochemical water quality parameters

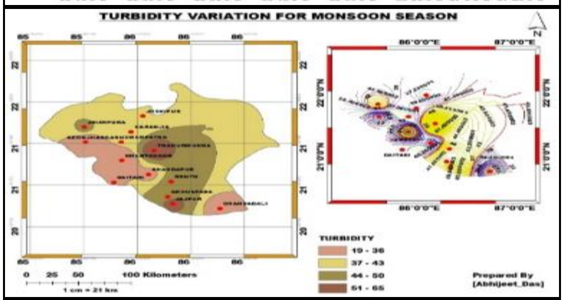
Parameters	Pre-monsoon		Monsoon		Post-monsoon	
	Min	Max	Min	Max	Min	Max
pH	7.3	9.7	6.44	7.43	7.4	9
Turbidity	8.2	25.2	18.7	65.4	11.8	38.7
TDS	74	178	98	218	97	247
TSS	30	121	85	168	43	127
EC	96	318	108	372	121	393
DO	4.78	8.01	5.87	7.87	5.03	7.69
Alkalinity	43	99	43	95	69	99
BOD	0.86	4.23	1.05	5.16	0.88	4.54
TH	64	121	64	119	71	135
HCO_3^-	41.92	87.55	45.83	74.31	55.64	91.46
SO_4^{2-}	2.4	6.87	2.26	5.19	2.31	7.16
NO_3^-	0.81	4.86	1.31	5.3	0.65	4.15
PO_4^{3-}	0.25	1.04	0.22	1.18	0.31	1.17
Cl^-	7.87	28.2	7.3	22.1	8.72	28.86
Ca^{2+}	14.83	28.7	12.83	25.4	14.03	29.74
Mg^{2+}	1.58	4.63	0.97	5.11	2.36	5.83
Na^+	2	10.1	2.9	10.7	3.6	13.3
K^+	0.7	3.2	1.2	3.7	0.8	2.9
TC	970	8000	3000	15000	2500	11000
FC	70	360	150	590	90	510
Fe	0.192	1.08	0.171	0.66	0.132	1.432
Cr	0.051	0.17	0.053	0.19	0.062	0.153

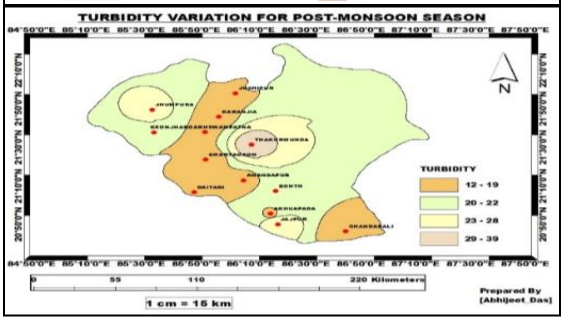

VARIATION OF PH IN PRE- MONSOON SEASON
PH
7.3 - 7.9
8 - 8.2
8.3 - 8.6
8.7 - 9
9.1 - 9.7
1 cm = 12 km
Prepared By
[Abhijeet_Das]

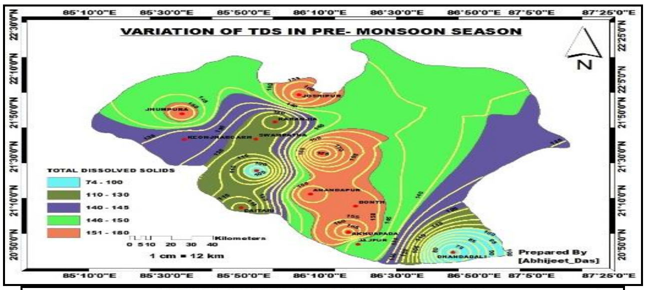

PH VARIATION FOR MONSOON SEASON
AWER.shp
PH
6.4 - 6.7
6.8 - 6.9
7.0 - 7.1
7.2 - 7.4
100 Kilometers
1 cm = 21 km
Prepared By
[Abhijeet_Das]

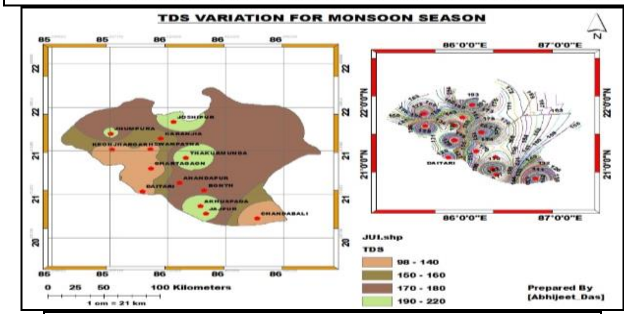

PH VARIATION FOR POST-MONSOON SEASON
PH
7.4 - 7.9
8.0 - 8.2
8.3 - 8.5
8.6 - 9.0
220 Kilometers
1 cm = 15 km
Prepared By
[Abhijeet_Das]

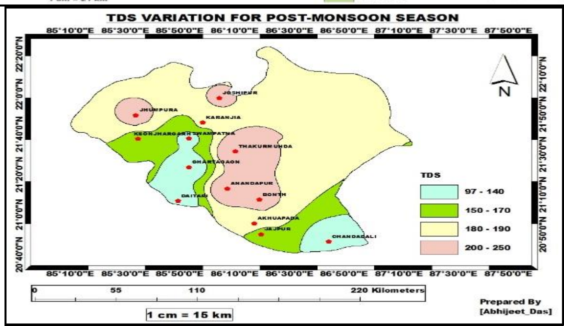

VARIATION OF TURBIDITY IN PRE- MONSOON SEASON
KY.shp
TURBIDITY
8.2 - 13
14 - 16
17 - 19
20 - 21
22 - 25
1 cm = 12 km
Prepared By
[Abhijeet_Das]

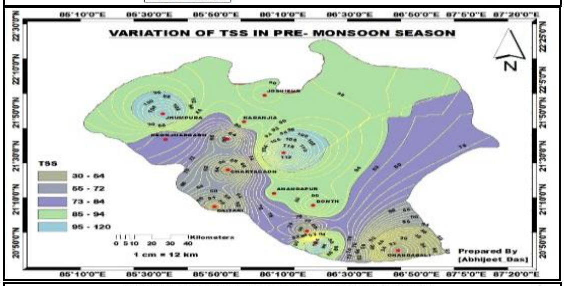

TURBIDITY VARIATION FOR MONSOON SEASON
TURBIDITY
19 - 36
37 - 43
44 - 50
51 - 65
100 Kilometers
1 cm = 21 km
Prepared By
[Abhijeet_Das]

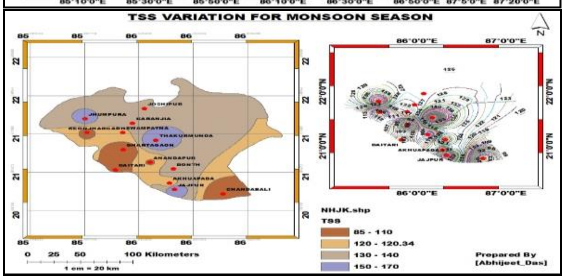

TURBIDITY VARIATION FOR POST-MONSOON SEASON
TURBIDITY
12 - 19
20 - 22
23 - 28
29 - 39
220 Kilometers
1 cm = 15 km
Prepared By
[Abhijeet_Das]

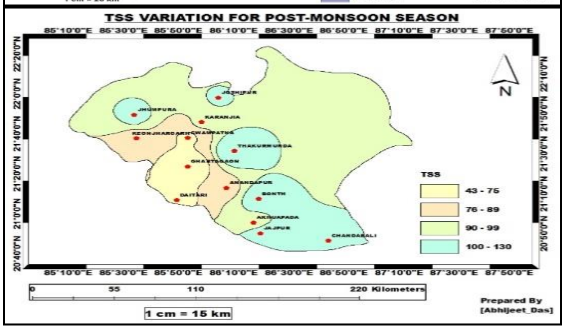

VARIATION OF TDS IN PRE- MONSOON SEASON
TOTAL DISSOLVED SOLIDS
74 - 100
110 - 130
140 - 145
146 - 150
151 - 180
1 cm = 12 km
Prepared By
[Abhijeet_Das]

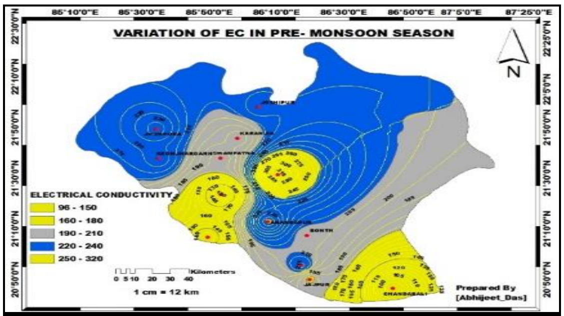

TDS VARIATION FOR MONSOON SEASON
JUI.shp
TDS
98 - 140
150 - 160
170 - 180
190 - 220
100 Kilometers
1 cm = 21 km
Prepared By
[Abhijeet_Das]

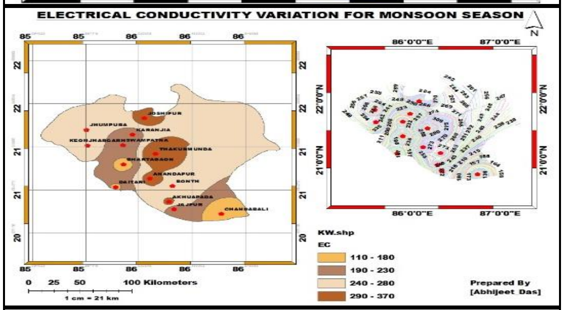

TDS VARIATION FOR POST-MONSOON SEASON
TDS
97 - 140
150 - 170
180 - 190
200 - 250
220 Kilometers
1 cm = 15 km
Prepared By
[Abhijeet_Das]

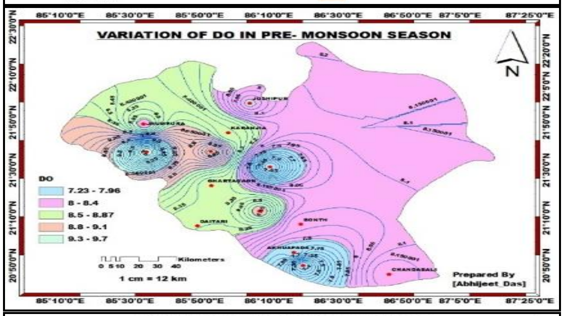

VARIATION OF TSS IN PRE- MONSOON SEASON
TSS
30 - 54
55 - 72
73 - 84
85 - 94
95 - 120
1 cm = 12 km
Prepared By
[Abhijeet_Das]

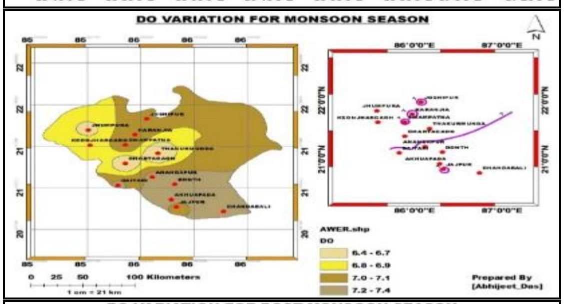

TSS VARIATION FOR MONSOON SEASON
NHJK.shp
TSS
85 - 110
120 - 120.34
130 - 140
150 - 170
100 Kilometers
1 cm = 20 km
Prepared By
[Abhijeet_Das]

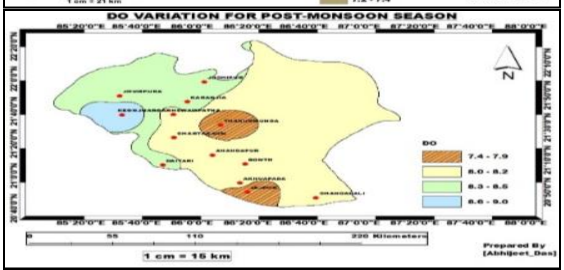

TSS VARIATION FOR POST-MONSOON SEASON
TSS
43 - 75
76 - 89
90 - 99
100 - 130
220 Kilometers
1 cm = 15 km
Prepared By
[Abhijeet_Das]

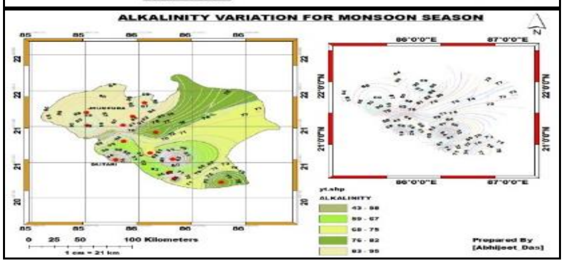

VARIATION OF EC IN PRE- MONSOON SEASON
ELECTRICAL CONDUCTIVITY
96 - 150
160 - 180
190 - 210
220 - 240
250 - 320
1 cm = 12 km
Prepared By [Abhijeet_Das]

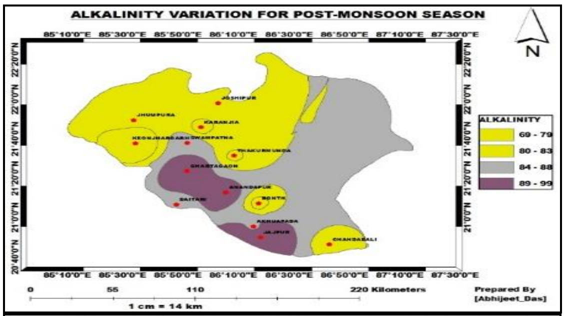

ELECTRICAL CONDUCTIVITY VARIATION FOR MONSOON SEASON
KW.shp
EC
110 - 180
190 - 230
240 - 280
290 - 370
100 Kilometers
Prepared By [Abhijeet_Das]

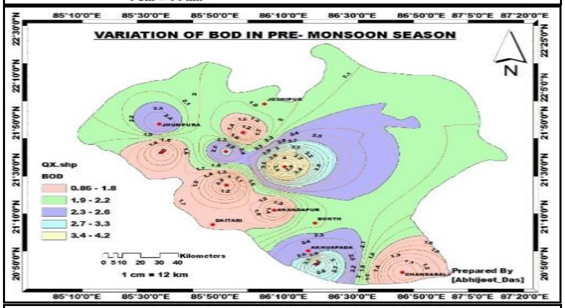

VARIATION OF DO IN PRE- MONSOON SEASON
DO
7.23 - 7.96
8 - 8.4
8.5 - 8.87
8.8 - 9.1
9.3 - 9.7
1 cm = 12 km
Prepared By [Abhijeet_Das]

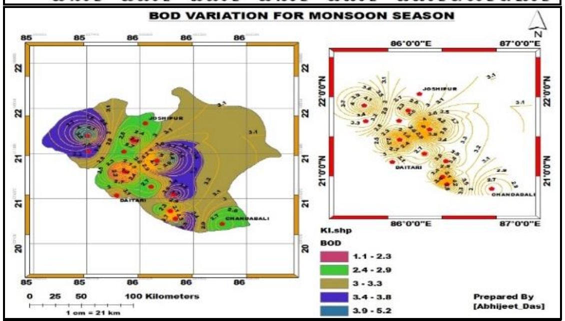

DO VARIATION FOR MONSOON SEASON
AWER.shp
DO
6.4 - 6.7
6.8 - 6.9
7.0 - 7.1
7.2 - 7.4
100 Kilometers
Prepared By [Abhijeet_Das]

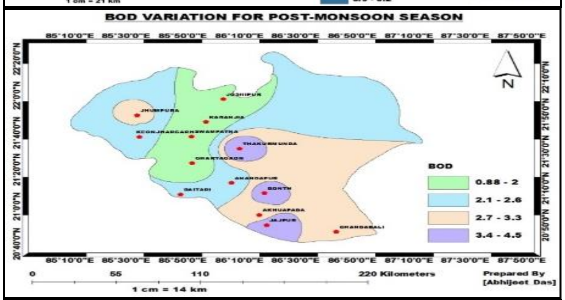

DO VARIATION FOR POST-MONSOON SEASON
DO
7.4 - 7.9
8.0 - 8.2
8.3 - 8.5
8.6 - 9.0
1 cm = 15 km
Prepared By [Abhijeet_Das]

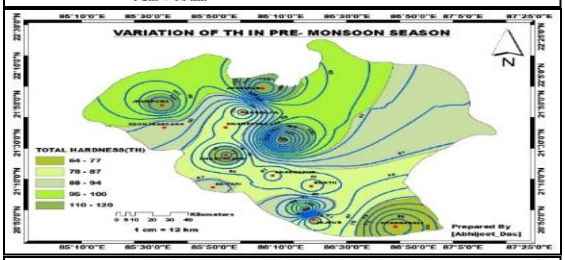

ALKALINITY VARIATION FOR MONSOON SEASON
ALKALINITY
100 Kilometers
Prepared By [Abhijeet_Das]

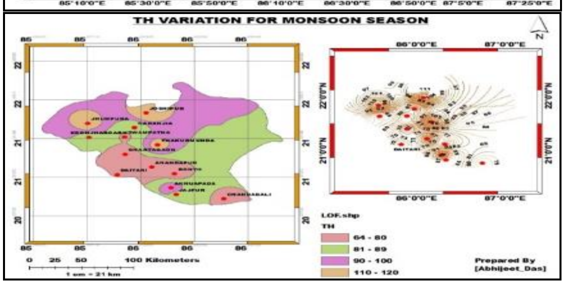

ALKALINITY VARIATION FOR POST-MONSOON SEASON
ALKALINITY
69 - 79
80 - 83
84 - 88
89 - 99
220 Kilometers
1 cm = 14 km
Prepared By [Abhijeet_Das]

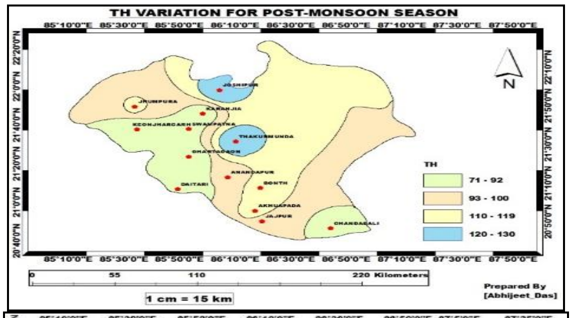

VARIATION OF BOD IN PRE- MONSOON SEASON
QX.shp
BOD
0.86 - 1.8
1.9 - 2.2
2.3 - 2.6
2.7 - 3.3
3.4 - 4.2
1 cm = 12 km
Prepared By [Abhijeet_Das]

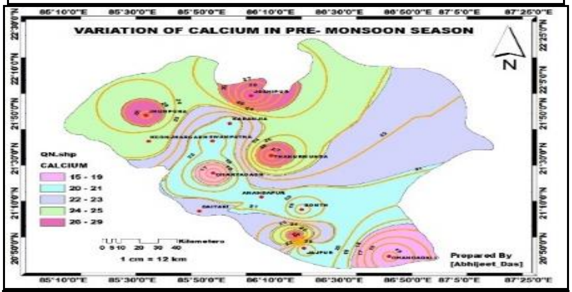

BOD VARIATION FOR MONSOON SEASON
KI.shp
BOD
1.1 - 2.3
2.4 - 2.9
3 - 3.3
3.4 - 3.8
3.9 - 5.2
100 Kilometers
Prepared By [Abhijeet_Das]

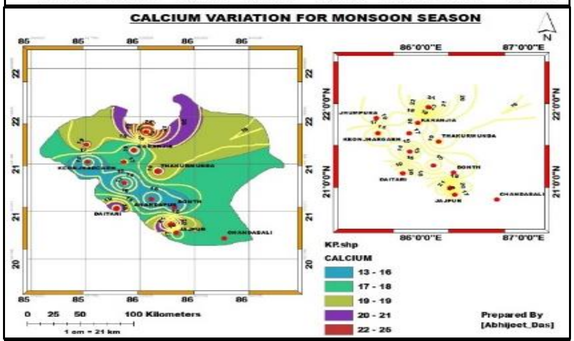

BOD VARIATION FOR POST-MONSOON SEASON
BOD
0.88 - 2
2.1 - 2.6
2.7 - 3.3
3.4 - 4.5
220 Kilometers
1 cm = 14 km
Prepared By [Abhijeet_Das]

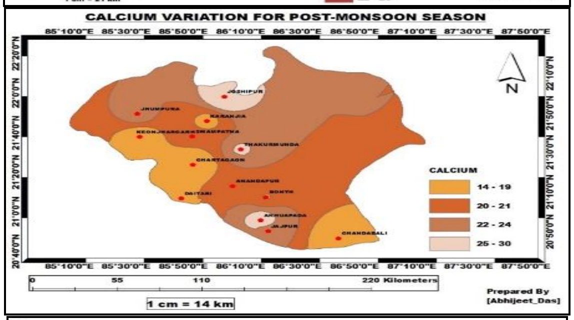

VARIATION OF TH IN PRE- MONSOON SEASON
TOTAL HARDNESS(TH)
64 - 77
78 - 87
88 - 94
95 - 100
110 - 120
1 cm = 12 km
Prepared By [Abhijeet_Das]

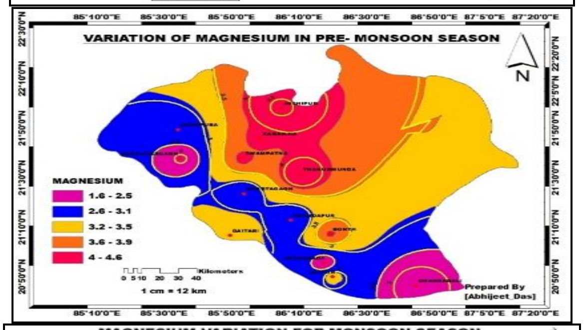

TH VARIATION FOR MONSOON SEASON
LOF.shp
TH
64 - 80
81 - 89
90 - 100
110 - 120
100 Kilometers
Prepared By [Abhijeet_Das]

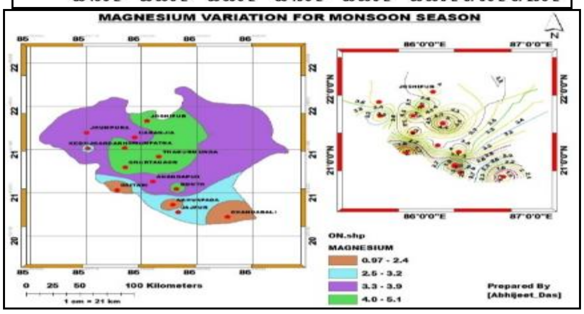

TH VARIATION FOR POST-MONSOON SEASON
TH
71 - 92
93 - 100
110 - 119
120 - 130
1 cm = 15 km
Prepared By
[Abhijeet_Das]

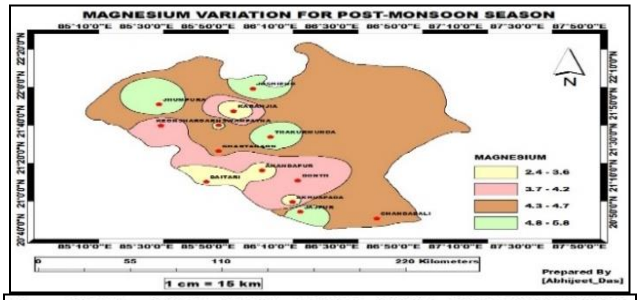

VARIATION OF CALCIUM IN PRE- MONSOON SEASON
CALCIUM
15 - 19
20 - 21
22 - 23
24 - 25
26 - 29
1 cm = 12 km
Prepared By
[Abhijeet_Das]

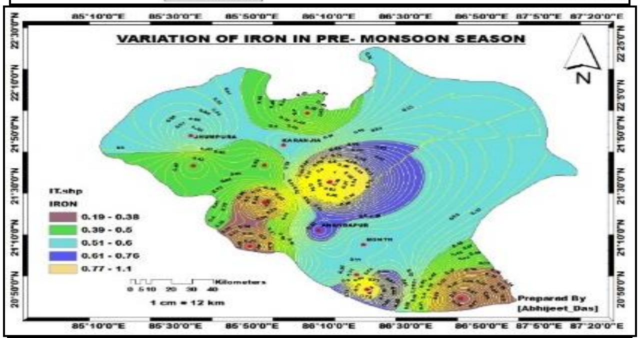

CALCIUM VARIATION FOR MONSOON SEASON
CALCIUM
13 - 16
17 - 18
19 - 19
20 - 21
22 - 26
Prepared By
[Abhijeet_Das]

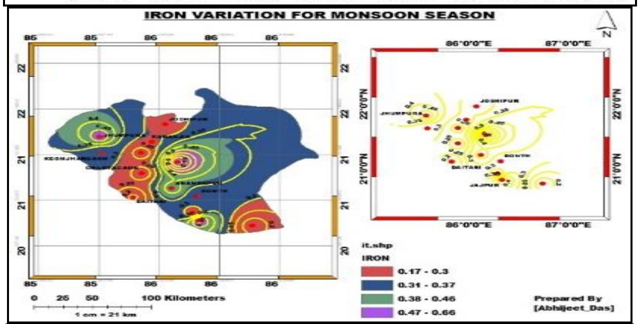

CALCIUM VARIATION FOR POST-MONSOON SEASON
CALCIUM
14 - 19
20 - 21
22 - 24
25 - 30
1 cm = 14 km
Prepared By
[Abhijeet_Das]

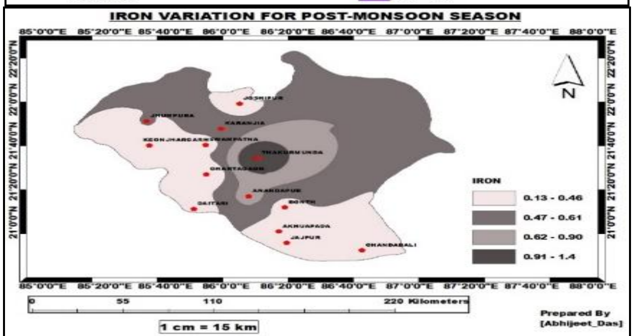

VARIATION OF MAGNESIUM IN PRE- MONSOON SEASON
MAGNESIUM
1.6 - 2.5
2.6 - 3.1
3.2 - 3.5
3.6 - 3.9
4 - 4.6
1 cm = 12 km
Prepared By
[Abhijeet_Das]

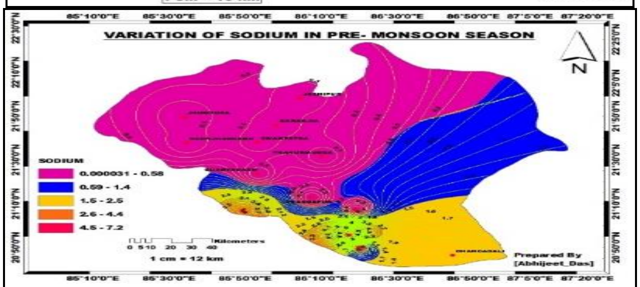

MAGNESIUM VARIATION FOR MONSOON SEASON
MAGNESIUM
0.97 - 2.4
2.5 - 3.2
3.3 - 3.9
4.0 - 5.1
Prepared By
[Abhijeet_Das]

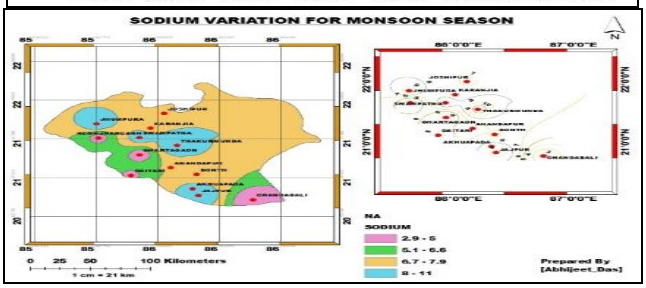

MAGNESIUM VARIATION FOR POST-MONSOON SEASON
MAGNESIUM
2.4 - 3.6
3.7 - 4.2
4.3 - 4.7
4.8 - 5.8
1 cm = 15 km
Prepared By
[Abhijeet_Das]

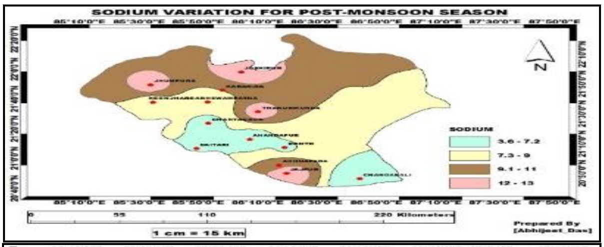

VARIATION OF IRON IN PRE- MONSOON SEASON
IRON
0.19 - 0.38
0.39 - 0.5
0.51 - 0.6
0.61 - 0.76
0.77 - 1.1
1 cm = 12 km
Prepared By
[Abhijeet_Das]

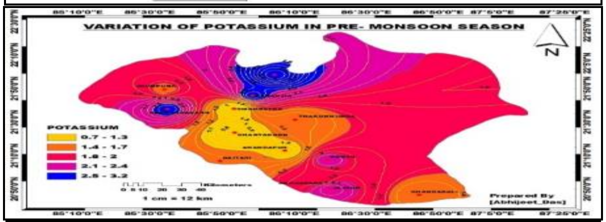

IRON VARIATION FOR MONSOON SEASON
IRON
0.17 - 0.3
0.31 - 0.37
0.38 - 0.46
0.47 - 0.66
Prepared By
[Abhijeet_Das]

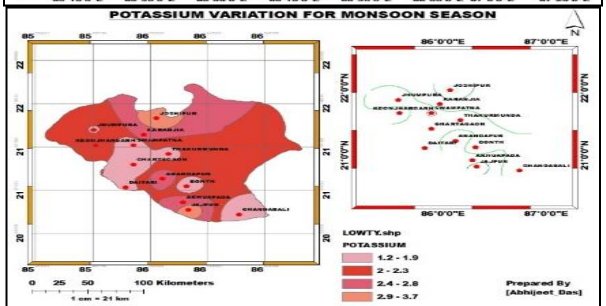

IRON VARIATION FOR POST-MONSOON SEASON
IRON
0.13 - 0.46
0.47 - 0.61
0.62 - 0.90
0.91 - 1.4
1 cm = 15 km
Prepared By
[Abhijeet_Das]

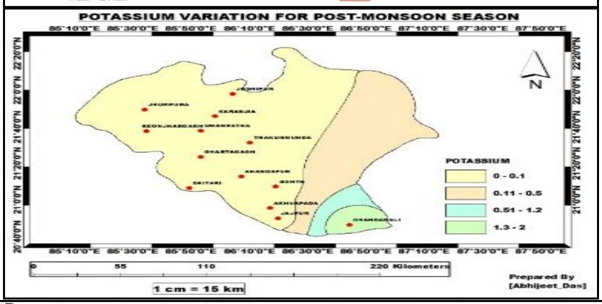

VARIATION OF SODIUM IN PRE- MONSOON SEASON
SODIUM
0.000031 - 0.58
0.59 - 1.4
1.5 - 2.5
2.6 - 4.4
4.5 - 7.2
1 cm = 12 km
Prepared By
[Abhijeet_Das]

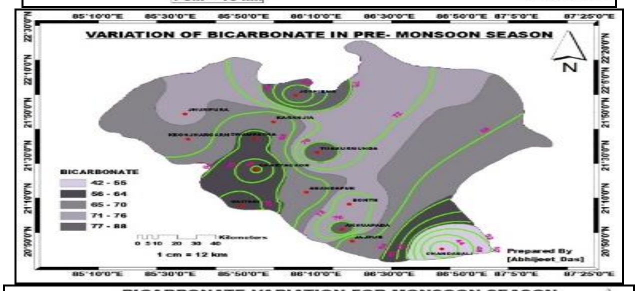

SODIUM VARIATION FOR MONSOON SEASON
SODIUM
2.9 - 5
5.1 - 6.6
6.7 - 7.9
8 - 11
Prepared By
[Abhijeet_Das]

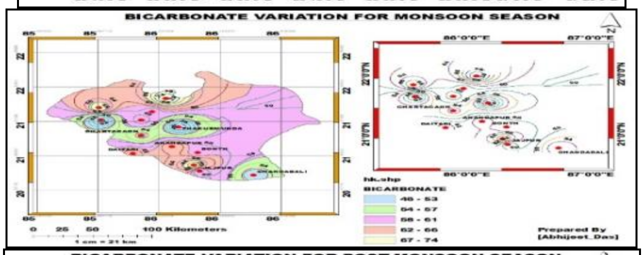

SODIUM VARIATION FOR POST-MONSOON SEASON
SODIUM
3.6 - 7.2
7.3 - 9
9.1 - 11
12 - 13
1 cm = 15 km
Prepared By [Abhijeet_Das]

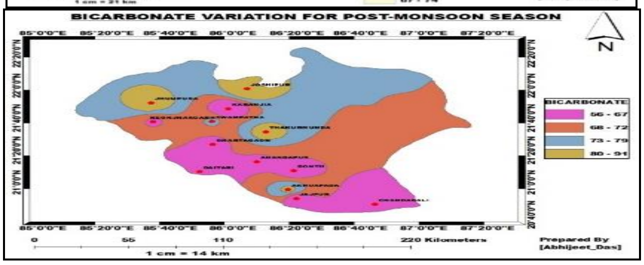

VARIATION OF POTASSIUM IN PRE- MONSOON SEASON
POTASSIUM
0.7 - 1.3
1.4 - 1.7
1.8 - 2
2.1 - 2.4
2.5 - 3.2
1 cm = 12 km
Prepared By [Abhijeet_Das]

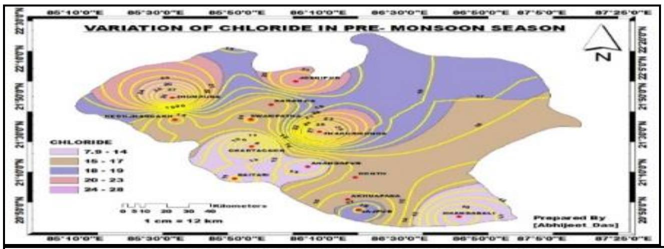

POTASSIUM VARIATION FOR MONSOON SEASON
LOWTY.shp
POTASSIUM
1.2 - 1.9
2 - 2.3
2.4 - 2.8
2.9 - 3.7
100 Kilometers
Prepared By [Abhijeet_Das]

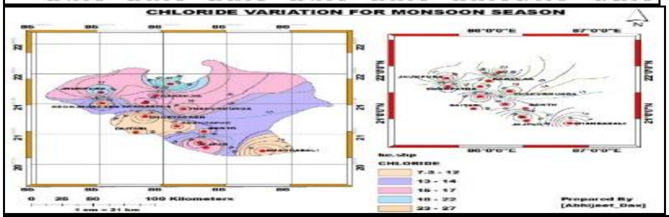

POTASSIUM VARIATION FOR POST-MONSOON SEASON
POTASSIUM
0 - 0.1
0.11 - 0.5
0.51 - 1.2
1.3 - 2
1 cm = 15 km
Prepared By [Abhijeet_Das]

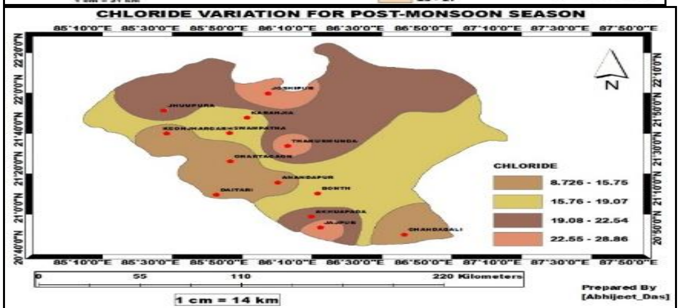

VARIATION OF BICARBONATE IN PRE- MONSOON SEASON
BICARBONATE
42 - 55
56 - 64
65 - 70
71 - 76
77 - 88
1 cm = 12 km
Prepared By [Abhijeet_Das]

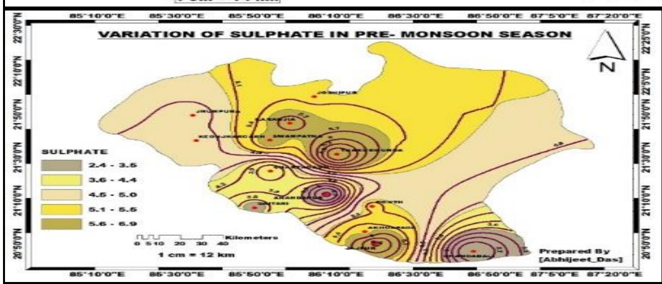

BICARBONATE VARIATION FOR MONSOON SEASON
BICARBONATE
48 - 53
54 - 57
58 - 61
62 - 66
67 - 74
100 Kilometers
Prepared By [Abhijeet_Das]

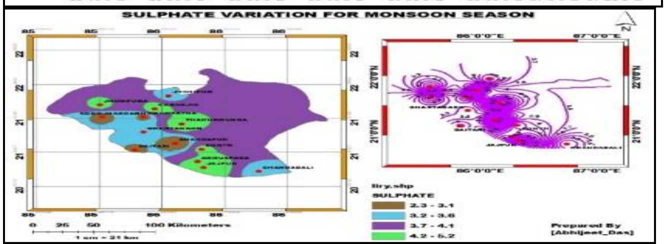

BICARBONATE VARIATION FOR POST-MONSOON SEASON
BICARBONATE
56 - 67
68 - 72
73 - 79
80 - 91
1 cm = 14 km
Prepared By [Abhijeet_Das]

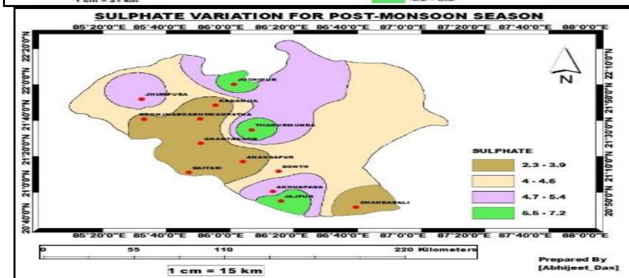

VARIATION OF CHLORIDE IN PRE- MONSOON SEASON
CHLORIDE
7.9 - 14
15 - 17
18 - 19
20 - 23
24 - 28
1 cm = 12 km
Prepared By [Abhijeet_Das]

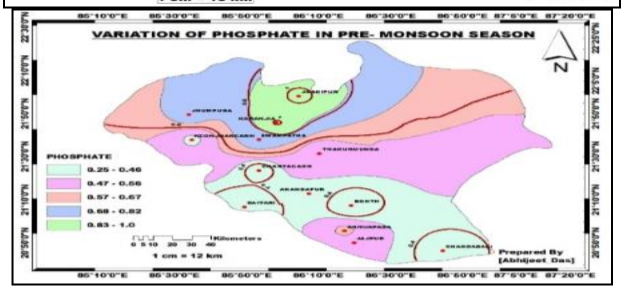

CHLORIDE VARIATION FOR MONSOON SEASON
CHLORIDE
7.3 - 12
13 - 14
15 - 17
18 - 22
23 - 27
100 Kilometers
Prepared By [Abhijeet_Das]


CHLORIDE VARIATION FOR POST-MONSOON SEASON
CHLORIDE
8.726 - 15.75
15.76 - 19.07
19.08 - 22.54
22.55 - 28.86
1 cm = 14 km
Prepared By [Abhijeet_Das]


VARIATION OF SULPHATE IN PRE- MONSOON SEASON
SULPHATE
2.4 - 3.5
3.6 - 4.4
4.5 - 5.0
5.1 - 5.5
5.6 - 6.9
1 cm = 12 km
Prepared By [Abhijeet_Das]


SULPHATE VARIATION FOR MONSOON SEASON
SULPHATE
2.3 - 3.1
3.2 - 3.6
3.7 - 4.1
4.2 - 5.2
100 Kilometers
Prepared By [Abhijeet_Das]


SULPHATE VARIATION FOR POST-MONSOON SEASON
SULPHATE
2.3 - 3.9
4 - 4.6
4.7 - 5.4
5.5 - 7.2
1 cm = 15 km
Prepared By [Abhijeet_Das]


VARIATION OF PHOSPHATE IN PRE- MONSOON SEASON
PHOSPHATE
0.25 - 0.46
0.47 - 0.56
0.57 - 0.67
0.68 - 0.82
0.83 - 1.0
1 cm = 12 km
Prepared By [Abhijeet_Das]

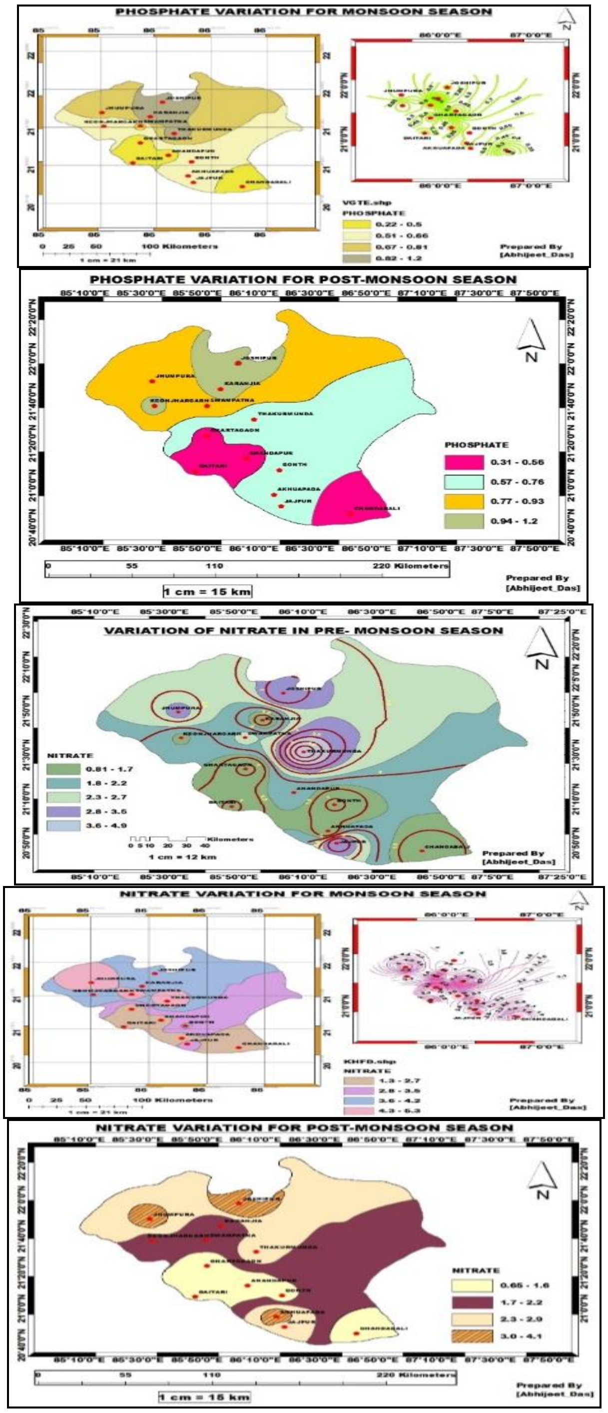


Figure 2. Spatial variations of pH, Turbidity, TDS, TSS, EC, DO, Alkalinity, BOD, TH, Ca^{++}, Mg^{++}, Fe^{++}, Na^{+}, K^{+}, HCO_3^{-}, Cl^{-}, SO_4^{2-}, PO_4^{3-}, NO_3^{-} in pre-monsoon, Monsoon and Post-monsoon Period

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