

Case Study

Assessment of spatio-temporal characteristics of groundwater quality at Khordha District, India

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Received: 10 April 2024 / Accepted: 28 June 2024

Published online: 03 July 2024

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Abstract

Groundwater is the major basis for drinking in various parts of our country. However, it gets contaminated by the toxic materials found in rocks, because of which it becomes unfit for various domestic and irrigation purposes. In present study, the groundwater quality and its availability for various purposes were examined by the parameters such as pH, DO, EC, TDS, temperature, salinity, Alkalinity, Total hardness, calcium hardness, magnesium hardness, chloride, fluoride, nitrate and phosphate during the post monsoon season of 2022 and pre monsoon season of 2023 from 49 sampling locations. The above mentioned parameters were used for assessing appropriateness of groundwater for irrigation and domestic purposes by comparing them with the Bureau of Indian standards (BIS). The results revealed that groundwater shows wide variations among various parameters between two seasons during 2022–23. Obtained results show that water used for potable purposes by people in various parts of study area doesn't meet necessary standards. In some of the sampling locations, it is found that the water exhibits very poor quality or unfit maybe for one season or both seasons. Analysis of parameters is done for calculating correlation coefficient of specified parameters. Strong linear relationships, both positive and negative, were found between several pairs of water quality measures according to their research.

Keywords Groundwater quality · BIS standards · Spatial variation · Correlation Coefficient Analysis

1 Introduction

The primary drinking water source in both urban and rural areas is groundwater. The most important supply of water for industrial, agricultural, and drinking uses is groundwater. There is less surface and subsurface water due to population growth and associated demands. Because groundwater is suitable for so many uses, its quality is just as important as its quantity. An important topic in groundwater investigations is the examination of water quality. An area's groundwater quality varies depending on a number of physical and chemical factors that are largely controlled by the local geology and human activity.

Hence, it is essential to study physicochemical characteristics of water.

1.1 Literature review

Kumar et al. [12] carried out an investigation on hydrogeo-chemical processes in Delhi, India to identify geochemical procedures and their relationship with groundwater quality for getting a perception about hydrochemical evaluation

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of groundwater. Alam et al., [3] studied different parameters of water quality along rivers involving chemical, physical, and biological components of surface water at various locations. Findings revealed that studied river was found to be extremely turbid during monsoon period. Babiker et al., [5] proposed a GQI based on Geographical Information System (GIS) that synthesises various accessible water quality data by indexing them numerically in relation to standards set by World Health Organisation (WHO). Ramarao et al., (2008) assessed quality of ground water in Thane region, Maharashtra using a correlation study on chemical and physical parameters. Results showed that all chemical and physical parameters of groundwater in Thane are inside highest desired limit or a maximum allowable limit set by WHO, excluding alkalinity values, Chemical Oxygen Demand (COD), and total hardness for most groundwater samples. Bhuiyan et al., [6] attempted a GIS-based water table fluctuation method to model ground water recharge quantitatively of hard-rock Aravalli terrain. Aghazadeh and Mogaddam [2] assessed suitability and quality of groundwater for agricultural and drinking usage in north western Iran. Evaluation of water samples from different techniques specified that groundwater is chemically appropriate for agricultural and drinking purposes in specified study areas. Machiwal et al., [13] proposed a standard approach for delineating groundwater potential zones in Udaipur district of Rajasthan utilising integrated GIS, RS and Multi-Criteria Decision Making (MCDM) methods. Schotand and Pieber [18] focused on analysing short-term temporal and local-scale spatial variations in 15 GW configuration parameters in Netherlands. It was observed that spatial and temporal variability were found to be interrelated. Khan and Kumar [8] used linear regression and correlation analysis to interpret groundwater quality from Namakkal district and Tiruchengodetaluk, Tamil Nadu, India. Correlation analysis indicated that various constraints are interrelated strongly, providing an excellent tool to predict parameter values inside sensible degree of accurateness. Mishra and Borah [15] investigated variations in groundwater quality of western districts of Tripura by assessing indicator constraints utilising correlation and entropy. Khatoun et al., [9] attempted a correlation analysis to evaluate water quality parameters of River Ganga, Uttar Pradesh, India. It was found that high chromium concentration (6.7 mg/l) at Siddhnath Ghat and its variation on a monthly basis indicated highly adverse impact on Ganga because of tanneries waste. Average value of all measured physical and chemical constraints of River Ganga is inside desired limit excluding Biochemical oxygen Demand (BOD). Singh et al., [20] attempted a study on assessment of groundwater quality for irrigation and drinking in south Bathinda district, Punjab, India. After monsoon, an increase in fraction of unfit samples for irrigation indicated accumulation of salts and percolation of rainwater into groundwater. Agarwala et al., [1] conducted correlation study between parameters of groundwater quality in Aurangabad district. Results revealed that collected samples of water showed better correlation coefficient (r) values amid different sets. Uzoije et al., (2014) attempted a study on the presence of saline intrusion, which has been the main basis of groundwater contamination in coastal areas in Buguma city of Rivers State southern Nigerian. Higher proportion of sodium, potassium, and chloride are confirmed salt intrusion. So, the study reveals that adequate treatment is needed to treat water. Arain et al., [4] conducted a multivariate study for evaluating drinking water quality parameters of Bannu district, Pakistan. Studied samples showed considerably higher Electrical Conductivity (EC) and Total Dissolved Solids (TDS) values than that might significantly affect health conditions of inhabitants. Seth et al., (2014) studied water quality in Uttarakhand, India. Their findings indicated that main aspects which contribute to deprivation of water quality are anthropogenic, tourism, geogenic, and eutrophication processes. Machiwal and Jha [14] explored temporal and spatial variations of 15 groundwater quality parameters in Udaipur district, Rajasthan using box-whisker diagrams, detected and quantified trends, and computed GQI based on GIS. Shroff [19] conducted a correlation analysis between groundwater quality constraints in Gujarat, India. Soni and Bhatia [21] analysed drinking water quality of piped water supply and private bore well in Jaipur, Rajasthan, India. The study suggested that water treatment is necessary for obtaining quality drinkable water at domestic level. Suleiman et al., (2015) used Principal Components Analysis to interpret parameters of groundwater quality in Tafileh region for spring season located in southern part of Jordan. Results demonstrated a proper study on monitoring and interpretation of groundwater quality. Yousry et al., [31] applied factor analysis as a tool for identifying parameters of water quality index (WQI) along River Nile, Egypt. Outcomes revealed that all parameters have average values inside permissible boundaries apart from COD in national criteria. Factor analysis indicated that agricultural uses strongly affect water quality of Nile River. Chandra et al. [7] used Polymerase Chain reaction (PCR)-based approach to assess drinking water quality supplied in Jaipur, India. Results showed that water quality criteria on basis of existence of particular pathogens computed with a PCR-based approach could serve as an evaluation technique for assessing organic quality of water. Also, their study confirmed that presence of such pathogenic bacteria in drinking water may stance a severe health problem to users. Tajmunnaher et al., [23] investigated water quality parameters of Bangladesh. Results signified a relationship between variables which indicate dachange in one variable causes change in another. Suvarna et al. (2019) applied WQI for assessment of water

quality nearby cement industrial channel located in Andhra Pradesh, India. The results showed water quality is very poor, which makes it unsuitable for drinking. Singh et al., [22] studied developed indices for assessment of surface and groundwater quality and characterisation of the Indian environment. Proposed study improved understanding of water quality problems by combining intricate data and generated a score describing grade of water quality. Sai-krishnaa et al., [17] evaluated groundwater quality using regression analysis and WQI in parts of Nalgonda district, Telangana, India. Most of the constraints are less or more interrelated, and regression relationships have equivalent correlation coefficient. In order to assess water quality parameters in a real-time setting, Khatri et al., [10] introduced a real-time water quality monitoring system based on a Python framework and the Raspberry Pi-3 development board. Reddy et al., [16] used a Conceptual Site Model (CSM) to study physical effects and hydro-geochemical assessment of abandoned/inactive mines in southwest parts of Cuddapah basin. For drinking purposes groundwater is compared with Indian standards (IS) and WHO. Kothari et al., [11] studied correlation of different water quality parameters and WQI for different districts of Uttarakhand. It was examined that physicochemical properties were in limits set by I.S. and found appropriate for drinking purposes.

Singh (2022) conducted a research by taking 112 groundwater samples in Aurangabad, Bihar. Bore/tube wells and manual pumps were used to collect samples. Physicochemical quality parameters include calcium, magnesium, sulphate, nitrate, chloride, pH, TDS, alkalinity, and hardness. Measurements were made and compared to the Bureau of Indian Standards (BIS10500:2012) for electrical conductivity and oxygen. The water quality index (WQI) of the samples was calculated by analysing their physicochemical characteristics. We looked at and connected a number of water quality measures with other characteristics. The statistical software Rstudio 4.1.1 was used for all of the analysis. Using the PCA approach, four components with a total variance of 75.66% were recovered from the water quality data. WQI of over 98% of the samples, indicating good or outstanding quality. The groundwater is safe to drink overall. Alam et al., [24] conducted a study to assess the water quality of the Ganga River in the several Ghats of the Patna metropolitan area, ranging from Digha to Gai Ghat. Water samples were collected from fifteen different Ghats. The chemical, biological, and due to human activity and excessive municipal garbage discharge, the physical qualities of the water have changed substantially. Every Ghat was deemed unsafe for human consumption, and it was recommended that water be made available only after undergoing extensive treatment. Alam et al., [25] conducted a research by taking measurements of the pH, temperature, TDS, and EC on the site. In the lab, the concentrations of calcium, magnesium, chloride, fluoride, nitrate, sulphate, alkalinity, and hardness were measured. The Langlier saturation index (LSI), Ryznar stability index (RSI), Puckorius scaling index (PSI), Larson-Skold index (Ls), and Aggressivity index (AI) were among the corrosion indices used to determine the stability of the groundwater. According to the statistics, the typical values of LSI, RSI, PSI, LS, and AI were, in order, 0.92 (~0.47), 9.09 (~0.67), 9.50 (~0.73), 1.73 (~0.78), and 11.05 (~0.48). 25% of the samples were outstanding, 50% were fair, 19% were bad, and 6% were extremely poor, according to groundwater WQI estimations. Alam et al., [26] conducted a study to examine whether groundwater in Nawada, Bihar, India, is suitable for human consumption using the entropy water quality index, and also identified potential non-carcinogenic risks for women, men, and children using the hazard index. During the 2017 pre-monsoon, a total of 75 groundwater samples were collected using hand pumps and tube/bore wells. The samples were then analysed for a variety of physicochemical properties. The HQ fluoride was determined to be in the ranges of 0.04–3.69 (male), 0.04–3.27 (female), and 0.05–4 (children) for all sampling locations. This indicates a significantly higher risk than the allowable limits (> 1). For children, women, and men, the fluoride-based noncarcinogenic hazards are 27%, 20%, and 21%, respectively. To assess the safety of drinking water, Alam et al., (2023c) conducted a study taking 156 groundwater samples were collected from the Gaya district of Bihar, India. A water quality index (WQI) was used to evaluate the groundwater's quality. A range of physicochemical traits were utilised to evaluate the analysed samples, and because principal component analysis (PCA) and cluster analysis (CA) are efficient and effective statistical techniques, they were employed. The results of the study shed light on groundwater pollution regimes and provide understanding. These findings were used to the evaluation of water quality, which enhanced environmental planning and management as well as the process of making decisions regarding water quality control.

In a study published in 2023, Jampani et al., examined the groundwater quality in adjacent wastewater and groundwater-irrigated areas on a monthly basis for a hydrological year. Using multivariate statistical analysis, multi-way modelling, and self-organizing maps, the spatiotemporal variability of groundwater quality in the watershed was examined with regard to wastewater irrigation and seasonality. This study highlights how important it is to use different statistical tools in order to thoroughly evaluate the groundwater processes in an agricultural system that is irrigated with wastewater. The findings imply that following the monsoon season, concentrations of the principal ionic compounds rise, particularly in areas that are irrigated with wastewater. Using multi-way modelling, the

watershed's irrigated areas with wastewater were found to be the primary source of contaminated groundwaters. Groups of chemical variables found through the application of using self-organizing maps indicate that groundwater pollution.

The hydrochemical parameters (pH, EC, TDS, Na, Cl⁻, HCO₃⁻, CO₃⁻, As, Mn, Fe, B, NO₃⁻, etc.) that were analysed by Rahman et al., (2017) were found to be higher than the limitations set by various drinking water standards. The weighted arithmetic water-quality index approach has been used to calculate the Groundwater Quality Index (GWQI), which evaluates the appropriateness of groundwater. Taking into account the best-fit model examined for both seasons, the exponential semivariogram model is discovered to be predominant. Furthermore, the average Hazard Quotient and Hazard Index values based on As, Fe, Mn, B, NO₃⁻, and F-indicate that there is a significant health risk associated with the groundwater for both adults and children, and that these values vary seasonally. The research location has a significant risk of As-related cancer in both adults and children during both seasons. The research area's groundwater was distinguished by a high salt level that was both very non-carcinogenic and highly susceptible to cancer in the local population.

In their estimation of the groundwater quality, Ram et al., [27] took into account variables such as pH, electrical conductivity, total dissolved solids, alkalinity, total hardness, calcium, magnesium, sodium, potassium, bicarbonate, sulphate, chloride, fluoride, nitrate, copper, manganese, silver, zinc, iron, and nickel. Policy makers and the general public in the affected area can use the water quality index (WQI) to determine the overall quality of the water by classifying it into excellent, good, poor, and other categories. In the research area, the WQI varies from 4.75 to 115.93. With the exception of a few isolated areas in the Charkhari and Jaitpur Blocks, the study area's general WQI shows that the groundwater is safe and drinkable. The research area's groundwater is classified as sodium, chloride, mixed calcium magnesium chloride, and calcium bicarbonate types according to the Hill-Piper Trilinear diagram. In order to see their notable influence on the evaluation of groundwater quality, a correlation matrix has been constructed and examined. According to the current study, the groundwater in the area with declining water quality needs to be treated before it can be consumed in order to prevent geogenic and anthropogenic pollution.

The physicochemical properties of groundwater samples were studied by Qureshi et al., [28] in order to assess the quality and acceptability of the samples for use. The study's results have clearly shown that, in contradiction to WHO and NEQS drinking water guidelines, excessive quantities of physicochemical parameters are present in the majority of the locations. Within the constraints of the rules, only Boron from all places was the most appropriate. Nonetheless, only a small number of places had quantifiable values found within the limits, and majority of the locations had TDS, pH, EC, TH, turbidity, Cl, Al, SO₄, and NO₃ levels over WHO recommendations. Furthermore unsatisfactory because samples from these regions had a strong hardness and a salty flavour. The results of the correlation study between the various parameters indicated that the observed values grew less significant as the correlations between the parameters weakened. In addition to developing models for forecasting the concentration of groundwater quality indices, a linear regression analysis was conducted. Many metrics had a notably positive connection between them at 1% and 5%. The greatest value of the turbidity regression model was 0.948% of the measured variability.

Microbial content, Mn + 2, Fe + 2, total dissolved solids (TDS), total hardness, nitrite, and turbidity were all taken into consideration in a study done in [29] by Alaa A. Masoud. Factor and cluster analyses were combined with geostatistical semi-variogram modelling in the analysis of the data. While the turbidity and nitrate concentration met local drinking water regulations, the groundwater microbiological, Mn + 2, Fe + 2, TDS, and total hardness values did not. According to factor analysis, the most important component increasing the variability potential is the microbial content, which is followed in decreasing order by Mn²⁺, Fe²⁺, TDS, nitrite, turbidity, and total hardness. Pearson's correlation coefficient (r) was used to evaluate how dependent one variable was on the other for a particular set of monitoring sites.

Three primary hydrochemical facies (mixed Ca–Mg–Cl, Ca–Cl, and Ca–HCO₃) were identified in a study by Selvakumar et al. [30]. According to irrigation suitability indices, there is a moderate to medium alkali hazard and a very high salinity hazard in the groundwater in certain locations. The statistical analysis that is multivariate i.e., correlation analysis (CA), principal component analysis (PCA), and hierarchical cluster analysis (HCA), anthropogenic pollutants mostly caused by population expansion, industrial effluents, and irrigation water return flow account for the majority of the variations. By combining hydrochemical data with multivariate statistical techniques, this study provides improved information about the history of groundwater quality and helps to identify the factors impacting contamination from both natural and man-made sources.

A chapter summarising the ecological aspects of water quality metrics for people and other living organisms was offered by Omer (2019). Water can be divided into four categories based on its quality. A thorough analysis of the significant characteristics that all four types of water quality have in common, such as physical, chemical, and

biological aspects, is presented. This review covers the definition, sources, impacts, effects, and techniques of measurement of these water quality metrics.

A study on the issue of arsenic in groundwater was given by David et al., in 2002 entail examining a sizable number of wells—possibly as many as 11 million in Bangladesh alone. Field-test kits provide the only feasible solution within the necessary timeframe. The most practical method for detecting arsenic in the field is still the "Gutzeit" method, which is based on the interaction of arsine gas with mercuric bromide. When an electronic device is used to measure the colour, a more objective outcome can be obtained. The primary interference to be considered is hydrogen sulphide. Even in the best of circumstances, some well misclassification is unavoidable due to analytical errors from both the field-test kits and the laboratory analysis.

The objective of present research work is to quantify physicochemical parameters of groundwater and determine the Water quality Index at Khordha district, Odisha, India. Also, GIS based spatial distribution of water quality parameters is done to delineate the study areas by using topological maps.

2 Study area

Khordha, the older capital of Odisha occupies an extremely important position in the state map lying over a geographical area of 2813 sq. km. The famous Chilika Lake, the major brackish water lake in Odisha lies in the direction of the last part of the district towards Puri, falling under administrative area of Khordha. The geographic position of Khordha district is at 19°55'to 20°25'N latitude and 84°55' min to 86°05'E Longitude as shown in Fig. 1. Khordha is

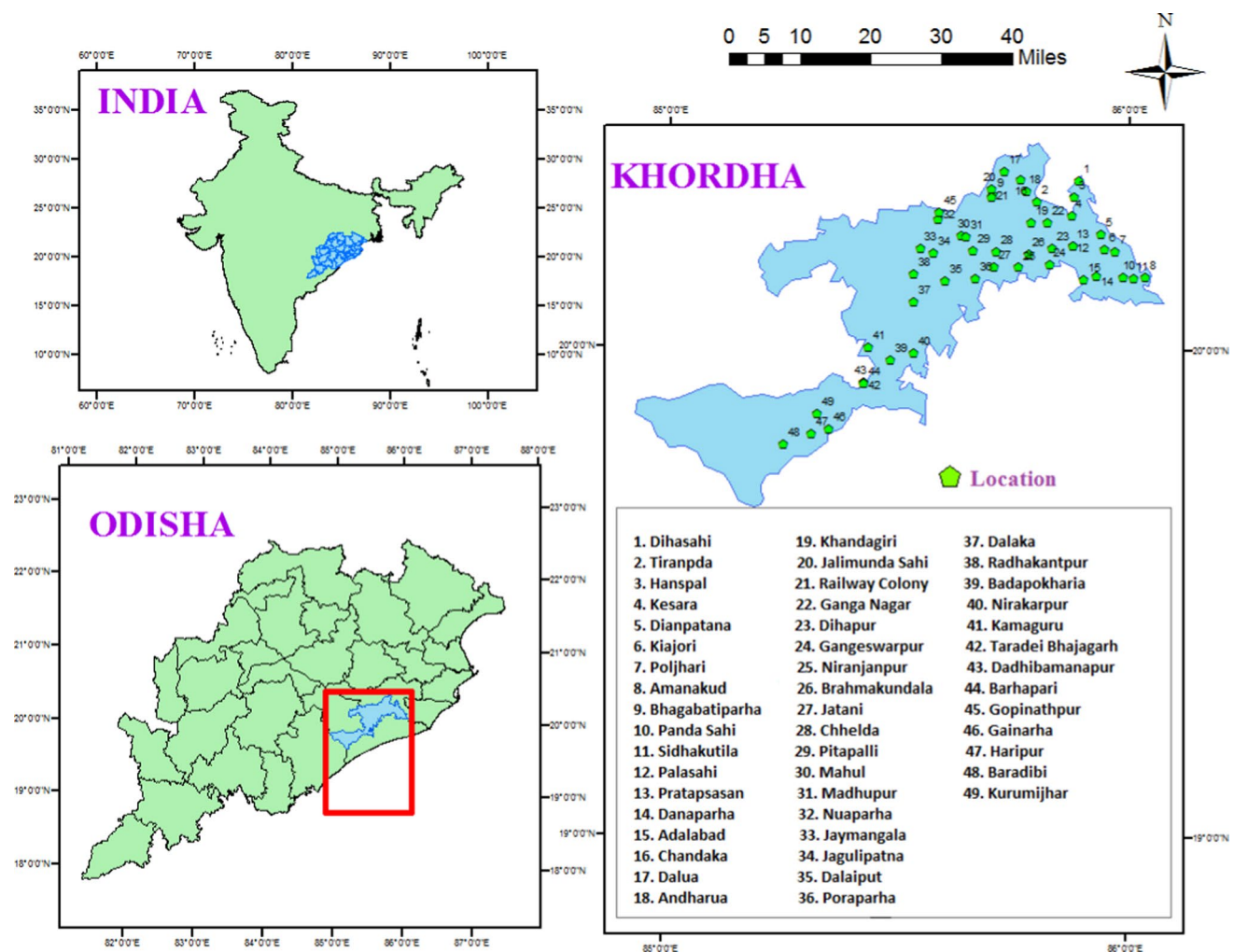


Fig. 1 Location map of study area

enclosed by districts of Cuttack on North and North-east, Puri on south, Nayagarh on west, and by Ganjam on south-west side. Certain streams, mostly distributaries, and tributaries of Mahanadi river and only some other streams discharge into Chilika lake. Major distributaries of Mahanadi are Kushabhadra, Bhargabi, Kuakhai, and Daya River, and its tributaries are Kalijiri and Ran. Streams which drain through southern parts of district are Kharia, Kusumi, and the Sulia.

With regard to Khordha district in Odisha, India, there could be a number of study gaps concerning groundwater quality given its unique geographical, geological, and socioeconomic features. Examining how groundwater quality is affected by the fast urbanisation and industrialisation of the region, especially in and around cities like Bhubaneswar where a higher population density and more industrial activity may lead to contamination. Evaluating the impact of agricultural activities, such as the use of pesticides and fertilisers, on the quality of the groundwater in the rural Khordha district areas, where agriculture plays a major economic role. Since fluoride contamination in groundwater is known to affect many areas of Odisha, including nearby districts like Nayagarh and Cuttack, it is important to understand its prevalence and sources examining the relationship between the groundwater quality metrics, such as mineral composition, aquifer recharge rates, and contamination susceptibility, and the geological features of the aquifers in the Khordha district. Evaluating the possible effects of climate change on Khordha district's groundwater supplies and quality, taking into account modifications to temperature, precipitation patterns, and extreme weather events that could affect contaminant transport paths and recharge rates. Investigating the health impacts of groundwater contamination on nearby populations in the Khordha district, including the socioeconomic ramifications and the frequency of waterborne illnesses such as fluorosis, arsenicosis, and diarrheal disorders. Recognising the beliefs, attitudes, and practices of the local population regarding the usage and management of groundwater in the Khordha district, as well as the variables affecting home water treatment methods, sanitation, and hygiene practices. Recognising the beliefs, attitudes, and practices of the local population regarding the usage and management of groundwater in the Khordha district, as well as the variables affecting home water treatment methods, sanitation, and hygiene practices. Assessing the state of the art institutional frameworks, rules, and policies pertaining to groundwater management in Odisha, spotting implementation gaps and roadblocks, and looking into ways to strengthen governance and encourage sustainable groundwater usage.

2.1 Scientific research gap

Longitudinal studies that monitor changes in groundwater quality over time can be lacking. To detect patterns, comprehend seasonal differences, and evaluate the success of management actions, long-term observation is essential. Previous research may not have enough spatial resolution to fully capture the local changes in Khordha District's groundwater quality. High-resolution geographical assessments, particularly in regions with varying land use patterns and hydrogeological environments, may offer insightful information about the heterogeneity of groundwater quality. Certain studies could concentrate on a small number of water quality metrics, possibly ignoring additional pollutants or signs of deteriorating water quality. A more comprehensive understanding of the dynamics of groundwater quality could be obtained through a thorough study that considers physical, chemical, and biological characteristics. It's possible that research hasn't done enough to address how human activities like industrialisation, urbanisation, and agriculture affect groundwater quality. By combining hydrological studies with information on land use and socioeconomic variables, it may be possible to clarify the causes of groundwater pollution and develop sustainable water management strategies. Research on risk assessment techniques and focused management approaches to lessen groundwater pollution in Khordha District might be lacking. Predictive models, risk maps, and decision-support systems could be developed to aid in resource allocation and action prioritisation. Research may not have sufficiently considered how climate change can affect Khordha District's groundwater quality. Subsequent investigations may examine the potential effects of alterations in temperature patterns, precipitation patterns, and hydrological dynamics on groundwater recharge rates, pollutant transport pathways, and the resilience of water quality. The significance of community involvement and capacity building in groundwater quality monitoring and management programmes may go unnoticed in research. Engaging local stakeholders in participatory ways could improve data collecting, knowledge sharing, and community empowerment in addressing water quality issues.

2.2 Hydrogeological scenario of study area

About 11.9% of the wells have a pre-monsoon depth to water level between 10 and 20 m, while 52.9% have a depth between 5 and 10 m. The depth to water level in roughly 23.5% of the wells is between 2 and 5 m, while in about 11.8% of the wells, it is less than 2 m. The sources of groundwater availability in the study area depends on the numbers of open well (dug well), deep tube well, medium tube well (bore well) and shallow tube wells present in that area. The source also depends on water received from rivers. Some of the major Mahanadi distributaries are the rivers Kuakhai, Bhargabi, Kushabhadra, and Daya. The tributaries of the Mahanadi are the Ran and the Kalijiri. The southern parts of the area are drained by the Sulia, Kharia, and Kusumi streams. Rainfall, seepage from canals, return flow from applied irrigation, and seepage from tanks and ponds are the main sources of replenishment for ground water. In the district, government bore wells equipped with hand pumps and privately dug wells are the primary methods of extracting ground water for home consumption. The dynamic ground water resource of Khurda district has been estimated using data related to a variety of parameters, including rainfall, water level fluctuations, specific yield, ground water abstraction structures for various utilities, irrigation, and other data recorded and/or collected by CGWB, SE region and GWS & I, Government of Orissa, and other state government agencies. Based on guidelines suggested by the Ground Water Estimation Committee (G.E.C., 1997), the availability of ground water resources has been estimated block by block. The Khurda district's total annual dynamic ground water resource is estimated to be 47618 hectare metres. Based on the estimated yearly demand, 5001 acre metres of utilisable groundwater are set aside for home and industrial use each year 2025. With a gross annual draft of 14141 hectare metres for all uses, there is still 29874 hectare metres of ground water available for future expansion for irrigation. It has been determined that the district's average groundwater development stage is currently only 29.7%. In the Bhubaneswar block, the ground water development stage ranges from a maximum of 48.7% to a minimum of 18.56% in the Banapur block.

In the fractured formations of the research area, ground water is found in weathered residue under unconfined conditions and in fractures at deeper levels under semi-confined to confined conditions. Depending on the type of rock, weathered residue can range in thickness from insignificant to 35–40 m. In Charnockites and Anothosites, the weathered zone thickness is at its lowest, but in Khondalites, it is at its highest. These worn areas provide a shallow aquifer, which is an unconfined source of ground water. In granitic rocks, the average yield of a dug well is 20 to 22 m³ per day, and the maximum production is 36 to 40 m³ per day. The yield in other hard rocks is limited to 25 m³ per day, with an average of 12 to 15 m³ per day. The sandstones that make up the majority of the Athagarh formation's aquifer system are found at both shallow and deeper depths. Shale primarily forms pheratic aquifers, which have a finite amount of potential. The upper, lateritized portion of the weathered zone is up to 5–6 m, while the lower portion stretches down to 12–15 m. In the weathered zone, the average yield of wells that have been sunk is between 20 and 25 m³ per day. At deeper cracks, the yield typically ranges from 7 to 10 lps.

2.3 Climate & rainfall

The district experiences three distinct seasons a year—winter, summer, and rainy season—due to its tropical monsoon environment. With an average daily maximum temperature of 38 °C, May is the hottest month while December is the coldest, with an average daily high temperature of 15.7 °C. The annual average rainfall is 1436.1 mm, whereas the normal annual rainfall is 1449.1 mm. In Bhubaneswar, the relative humidity ranges from 48 to 85%. In the district, the average monthly potential evapotranspiration values vary from 57 mm in January to 284 mm in May.

2.4 Geological and hydrological status

The hydrological setting and groundwater occurrence of a location are generally determined by its geological and geomorphic configuration. The below figures i.e., Figs. 2, 3, 4, 5, 6 and 7 shows the slope, aspect, land use land cover, curvature, distance to stream and contour maps of the study area respectively.

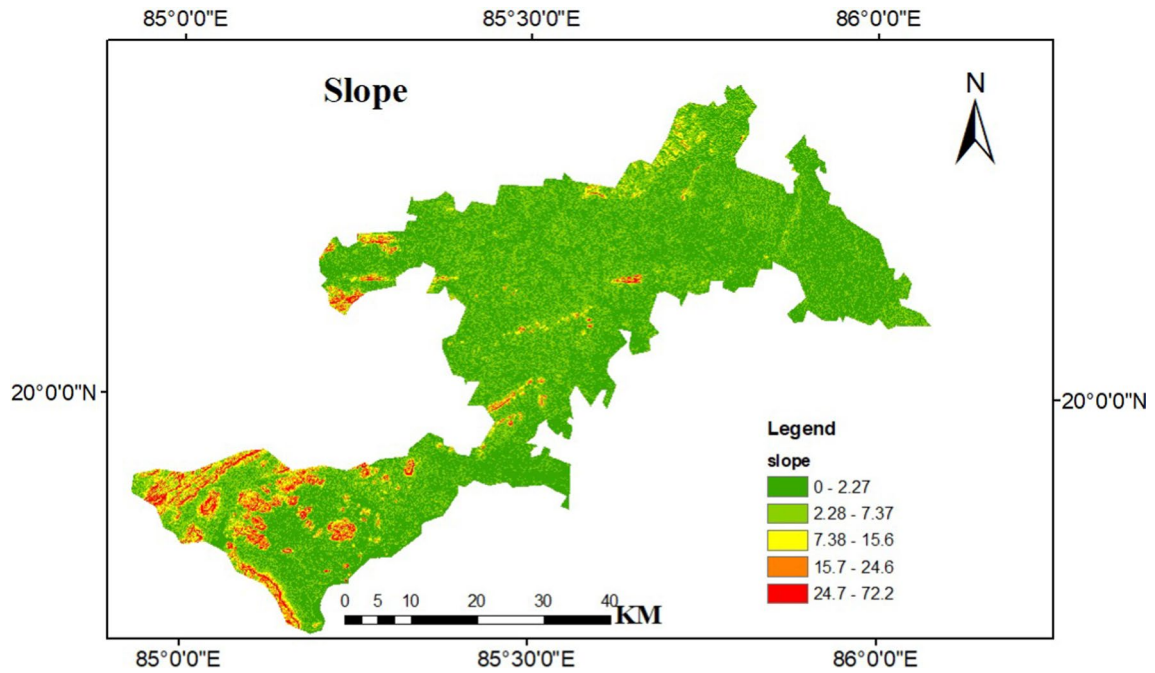


Fig. 2 Slope map of study area

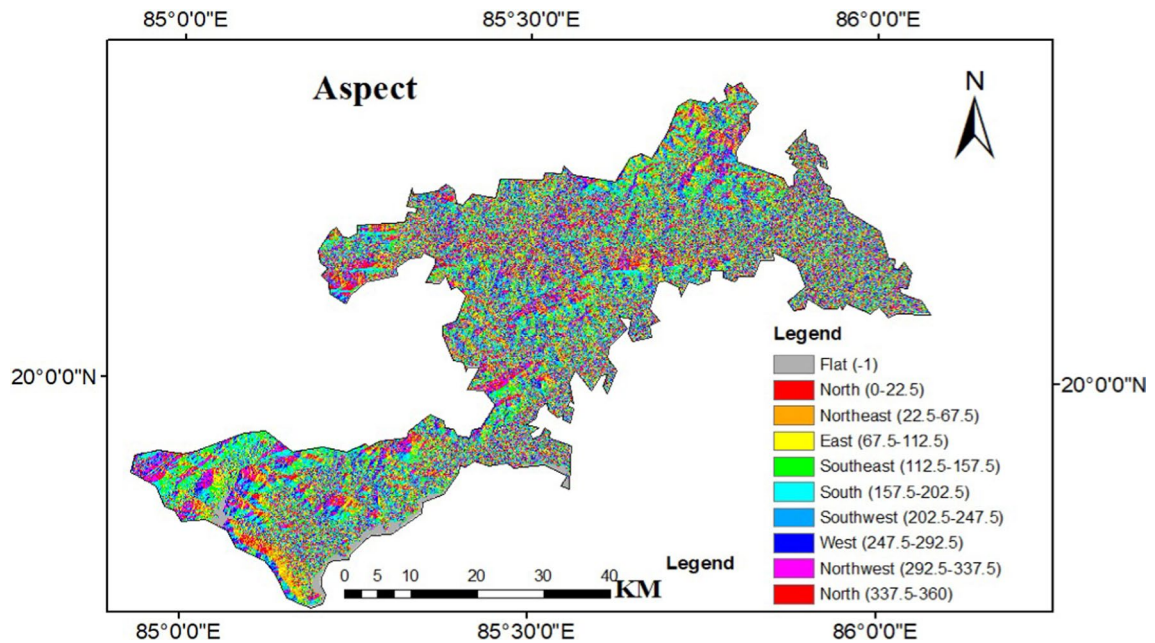


Fig. 3 Aspect map of study area

3 Methodology

Using tube-wells, ground water samples are taken in polythene bottles for 49 designated places of the Khordha district during the pre-monsoon and post-monsoon seasons.

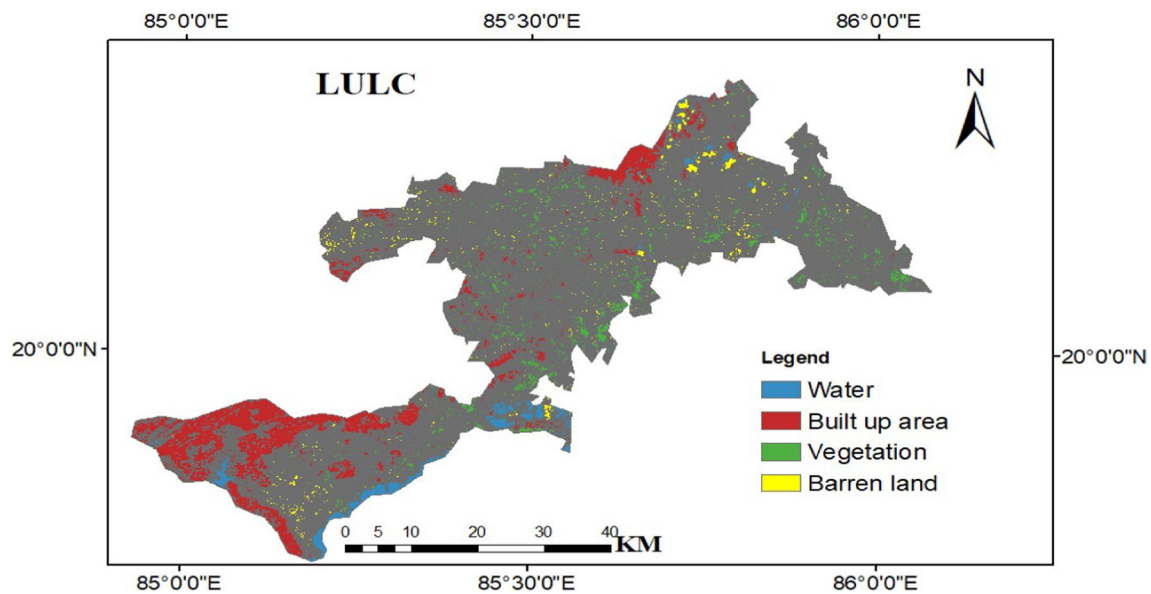


Fig. 4 Land use land cover map of study area

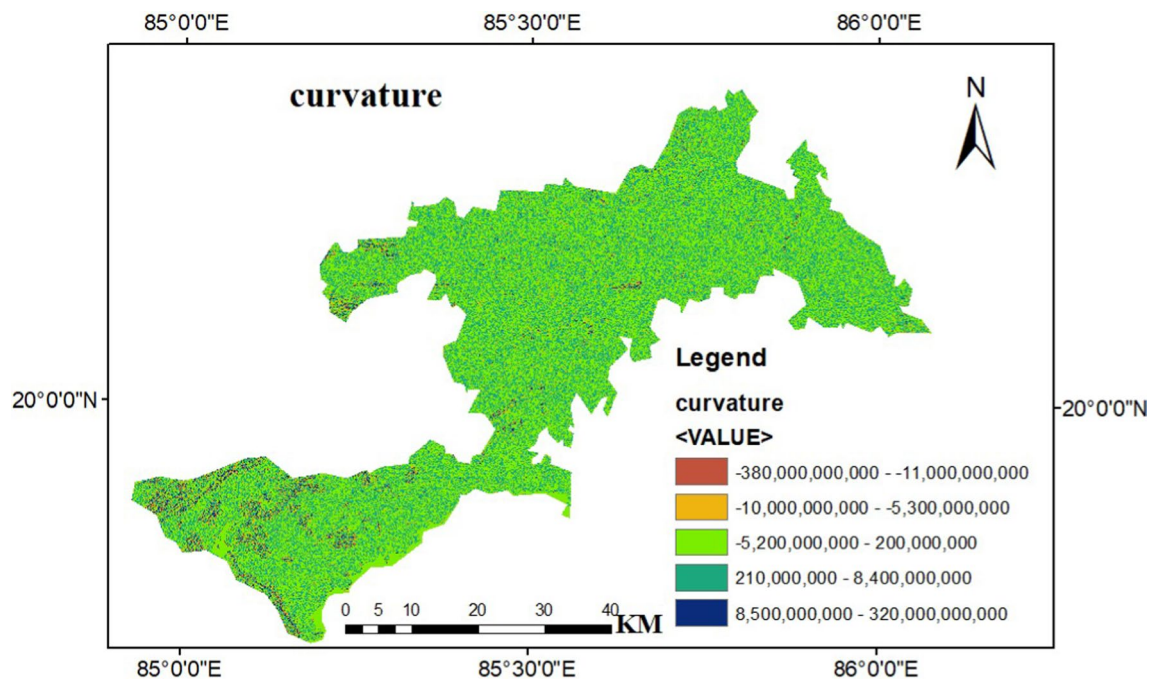


Fig. 5 Curvature map of study area

3.1 Determination of physical parameters

The physical parameters such as pH, TDS (total dissolved solids), (EC) Electrical Conductivity, Temperature, Salinity, DO (Dissolved Oxygen) are measured by the using an instrument called AP-7000 Aquaprobe. In order to minimise the impacts of bio-fouling, which is frequent in longer deployments, the AP-7000 Aquaprobe is built for long-term deployment. It does this by using a central cleaning mechanism to maintain the fitted sensors clean. It has six user-configurable auxiliary sockets that allow the probe to be equipped with multiple specialised sensors. The AP-7000 can measure up to 17 different parameters simultaneously. It was determined on spot locations.

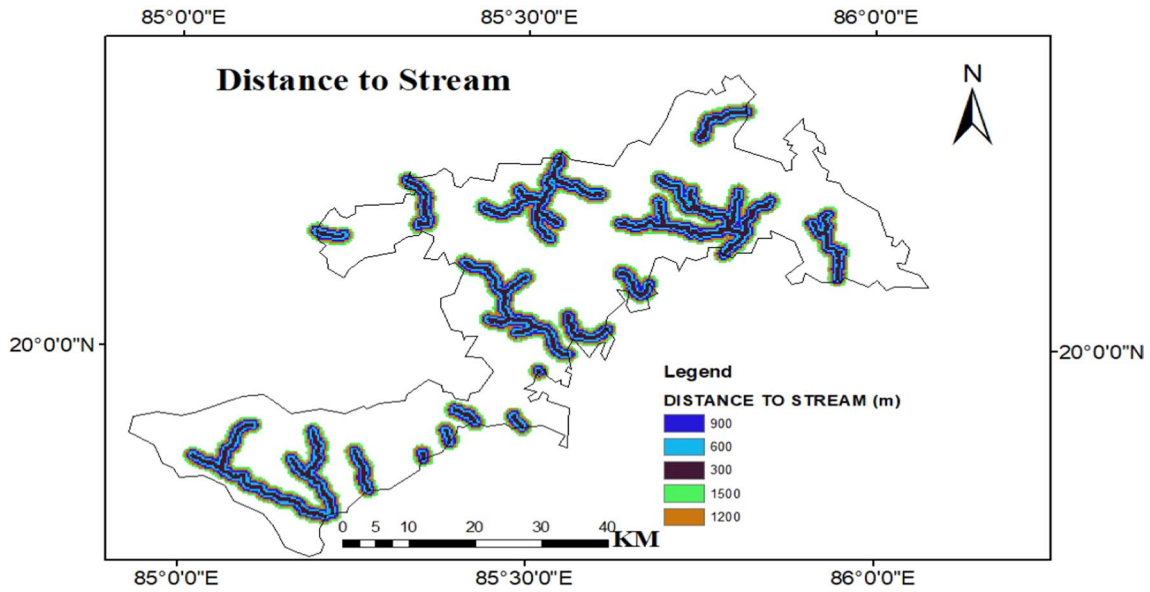


Fig. 6 Distance to stream map of study area

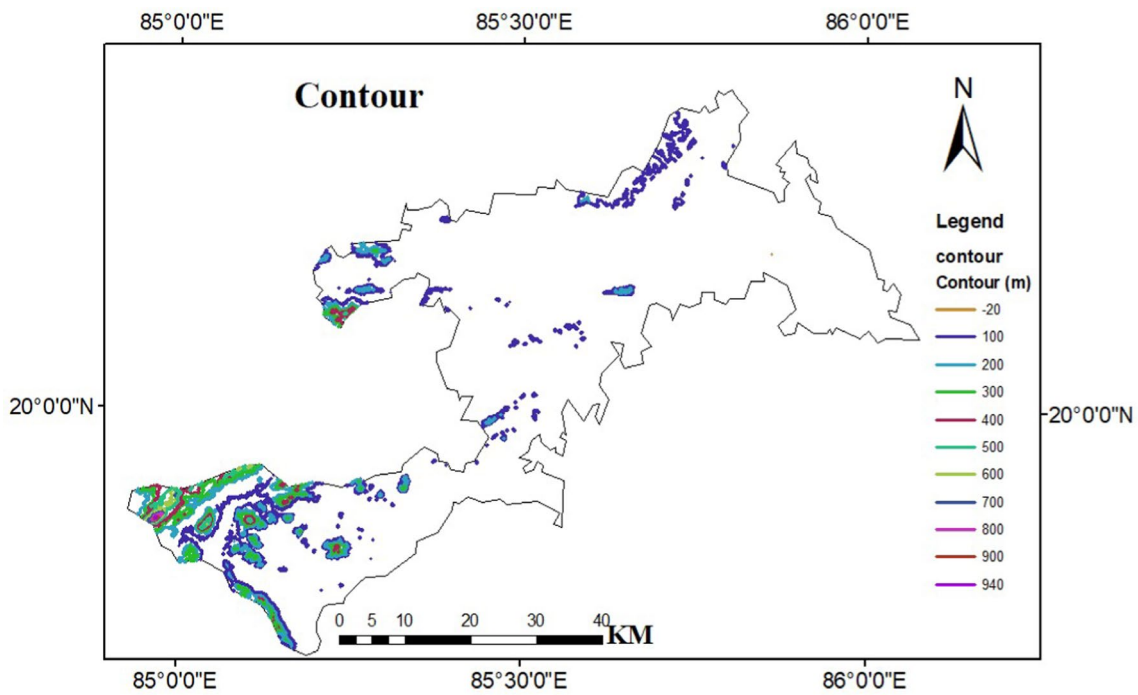


Fig. 7 Contour map of study area

3.2 Determination of Alkalinity

First 50 ml of water sample collected is taken in a beaker. Then methyl orange indicator is added to the sample which turns the sample into orange colour. Then 2N H_2SO_4 is taken in a burette. Titration is then done where drops of H_2SO_4 is added to the sample which turns the orange colour of the sample to pink colour. Then the Initial Burette readings and the Final Burette readings are noted for each sample and alkalinity is calculated in mg/l of $CaCO_3$.

3.3 Determination of total hardness

First 50 ml of water sample collected is taken in a beaker. Then Murexide indicator which is red in colour available in powder form is added to the sample which turns the sample into wine red colour. Then a little amount of Buffer is added to the beaker with the help of glass rod. Then 0.01 M EDTA is added to the beaker drop wise by using a burette which turns the wine red colour to blue colour and the initial and final burette readings are noted for each sample and total hardness is calculated in mg/l.

3.4 Determination of calcium hardness

First 50 ml of water sample collected was taken in a beaker. Then Murexide indicator, which is red available in powder form, was added to the sample turning the sample into wine red colour. Then a little amount of 1 M NaOH was added to the beaker with the help of a glass rod. Then 0.01 M EDTA was added to the beaker drop wise by using a burette which turned the wine red blue. The initial and final burette readings were noted for each sample, and calcium hardness was calculated in mg/l.

3.5 Determination of magnesium hardness

Magnesium hardness is determined by subtracting calcium hardness to total hardness.

3.6 Determination of chloride

0.2395 gm of AgNO_3 was first added to 100 ml of distilled water. Then 5 gm of $\text{K}_2\text{Cr}_2\text{O}_4$ added to a little amount of distilled water and kept for at least 12 h. 50 ml of water sample is taken in a beaker. Then 2 ml of potassium chromate indicator which is yellow in colour is added to the sample which turns the sample into yellow colour. Then 50 ml of double distilled water is added to the sample and is then thoroughly mixed. Then silver nitrate solution is added to the beaker drop-wise by using a burette which turns the yellow colour of the sample into peach colour and the initial and final burette readings are noted for each sample and chloride is calculated in mg/l.

3.7 Determination of fluoride

In a conical flask filled with 1000 millilitres of double-distilled water, 0.221 grammes of anhydrous sodium fluoride (NaF) was used to dissolve the first stock of fluoride. Standard Fluoride Solution is then diluted. 0.958 gm SPADNS (red coloured powder) solution was then added to 500 ml of double distilled water and kept in the dark place away from sunlight. 0.133 gm of zirconyl chloride octahydrate ($\text{ZrOCl}_2 \cdot 0.8\text{H}_2\text{O}$) was added in 25 ml double distilled water in a conical flask also 350 ml of concentration of HCl was added to it. Then water is added. Equal volumes of Zirconyl Acid Reagent and SPADNS solution were mixed up in a conical flask and kept in the dark place away from sunlight. When testing is to be done SPADNS reagent is taken out from the dark place, and then some amount of it has to be taken in a beaker as per requirement of the testing. After that, the total amount of fluoride was calculated using Perkin Elmer Lambda 25 U.V. ray spectro-photo meter. First the wavelength of spectro-photo meter was fixed at 550–580 nm, and absorbance was found. Then 10 ml of sample collected was mixed with 2 ml of SPADNS reagent in a beaker. The mixture was then added to the cuvette, placed in the UV gamma machine, and absorbance was calculated. The first two procedures were repeated for each sample collected.

3.8 Determination of nitrate

0.7218 gm of potassium nitrate (KNO_3) was dissolved in 1000 ml of double distilled water in a conical flask. Then 2 ml of chloroform was added to it and properly mixed. 100 ml of stock nitrate solution to 1000 ml double distilled water was then diluted in another conical flask and then 2 ml of chloroform is added to it and properly mixed. Fixing the wavelength at 220–275 nm in Perkin Elmer Lambda 25 UV ray spectro-photo meter, absorbance is found. Then 10 ml of

sample collected is mixed with 2 ml of 0.1N HCL in a beaker and is thoroughly mixed. Then the mixture is added to the cuvette and placed in the UV gamma spectro-photo meter and absorbance is calculated. The first two procedures are repeated for each samples collected.

3.9 Determination of phosphate

First 219.5 mg anhydrous KH_2PO_4 (Potassium Phosphate) was dissolved in double distilled water and diluted upto 1000 ml. Then 50 ml of stock phosphate solution was diluted to 1000 ml. Then 2.5 gm of $((NH_4)_2MoO_4$ (Ammonium Molybdate) was dissolved in 17.5 ml of water in a beaker. 28 ml of conc. H_2SO_4 was then added to 40 ml of water in another beaker. Then the contents of two beakers were mixed to form an ammonium molybdate solution. Stannous chloride reagent I and stannous chloride reagent II were then prepared. After that the total amount of phosphate was calculated using Perkin Elmer Lambda 25 U.V. ray spectro-photo meter. First the wavelength of spectro-photo meter was fixed at 550–580 nm, and absorbance was found. 10 ml of sample collected was mixed with 10 drops of ammonium molybdate and 2 drops of Stannous Chloride Reagent II in a beaker and was mixed properly so that the colour of the mixture changes to blue.

Table 1 Unit weights and agencies recommended by Drinking Water Standards (All values except pH and Electrical Conductivity are in mg/L)

SI No	Parameters	Standards	Recommended agency
1	Ph	6.5–8.5	ICMR/BIS
2	Electrical conductivity	300	ICMR
3	Total dissolved solids	500	ICMR/BIS
4	Flouride	1–1.5	WHO
5	Total Alkalinity	120	ICMR
6	Ca	75	ICMR/BIS
7	Mg	30	ICMR/BIS
8	Cl	250	ICMR
9	Total hardness	300	ICMR/BIS
10	Nitrate	45	ICMR/BIS

Table 2 Correlation Matrix of parameters during post-monsoon season of 2022

	Temp (°C)	pH	TDS (ppm)	EC (µS/cm)	Salinity (ppm or psu)	DO	Nitrate	TA	TH	Ca Hardness	Mg Hardness	Flouride	Chloride	Phosphate
Temp (°C)	1													
pH	-0.15008	1												
TDS (ppm)	-0.03182	-0.32923	1											
EC (µS/cm)	0.020759	-0.31396	0.982032	1										
Salinity (ppm)	0.012078	-0.26802	0.839636	0.856466	1									
DO	0.299997	-0.02757	-0.14465	-0.16496	-0.1634	1								
Nitrate	-0.13346	0.053674	0.55941	0.530196	0.398359	0.250459	1							
TA	-0.20893	-0.2633	0.757	0.719794	0.723753	-0.22849	0.258663	1						
TH	0.120785	-0.30669	0.621117	0.665602	0.659556	-0.17053	0.249506	0.510178	1					
Ca Hardness	0.279641	-0.14639	0.420573	0.498551	0.507016	-0.32648	-0.07016	0.279774	0.740899	1				
Mg Hardness	0.087757	-0.31849	0.624399	0.660879	0.652818	-0.13573	0.290899	0.524063	0.993521	0.65978	1			
Flouride	0.038118	-0.18528	-0.18748	-0.22946	-0.158	0.003143	-0.31986	-0.20849	-0.17821	-0.09043	-0.18375	1		
Chloride	0.037751	-0.21124	0.890004	0.913604	0.679942	0.017423	0.622557	0.511509	0.489202	0.347813	0.488868	-0.18092	1	
Phosphate	-0.0815	0.094915	-0.01758	-0.04871	-0.03482	0.280824	-0.01837	0.105055	-0.17039	-0.27532	-0.14392	-0.30387	-0.03448	1

Table 3 Correlation Matrix of parameters during pre-monsoon season of 2023

	Temp (°C)	pH	TDS (ppm)	EC (µS/cm)	Salinity (ppm or psu)	DO	Nitrate	TA	TH	Ca Hardness	Mg Hardness	Flouride	Chloride	Phosphate
Temp (°C)	1													
pH	0.257574	1												
TDS (ppm)	-0.03026	0.206256	1											
EC (µS/cm)	-0.0325	0.203569	0.997541	1										
Salinity (ppm)	-0.08574	0.157215	0.957264	0.959056	1									
DO	0.290284	-0.18309	-0.14933	-0.13674	-0.18311	1								
Nitrate	-0.10082	-0.28628	0.54115	0.54522	0.511351	0.279779	1							
TA	-0.22989	0.216747	0.789783	0.789939	0.779356	-0.19533	0.28073	1						
TH	0.036196	0.302584	0.78718	0.786966	0.823225	-0.21052	0.252633	0.645796	1					
Ca Hardness	0.147133	0.303296	0.623551	0.617188	0.665172	-0.2801	0.053481	0.452001	0.923719	1				
Mg Hardness	-0.00703	0.290417	0.8178	0.81989	0.850428	-0.17677	0.317183	0.693315	0.98971	0.859403	1			
Flouride	-0.05545	0.124763	-0.28457	-0.2868	-0.25274	-0.09511	-0.30249	-0.24254	-0.29908	-0.29064	-0.29055	1		
Chloride	0.028363	-0.02274	0.907535	0.910442	0.892338	-0.07203	0.579554	0.593302	0.77078	0.659182	0.782543	-0.32298	1	
Phosphate	-0.1438	-0.12172	0.240162	0.251964	0.289304	0.06389	0.205925	0.208856	0.061762	-0.05791	0.104152	0.042415	0.227251	1

The mixture was then added to the cuvette, placed in the U.V. gamma machine, and absorbance was calculated. The first two procedures were repeated for each samples collected (Table 1).

3.10 Data analysis

In present research, correlation matrixes of the parameters were calculated below in Table 2 and 3 for post and pre monsoon seasons of 2022 and 2023, respectively. Most common coefficient r , produced by Data Analysis Tool Pak-Excel Building, a Karl Pearson correlation matrix is utilised to measure linear relationships amid parameters. One of the most effective ways to estimate the degree of connection between the many variables taken into consideration in this study is through correlation analysis. As a result, a correlation matrix that shows the strength of a linear relationship between any two parameters was computed. It is measured as a coefficient (R) by degree of correlation. R-value is utilised for identifying highly interrelated and correlated water quality parameters that might affect water quality of that area.

3.11 Spatial analysis by geographic information system (GIS)

A GIS is a commanding tool utilised for spatial analysis and computerized mapping. It provides functionality for capturing, storing, analyzing, querying, and displaying output geographic information. Present work utilizes ArcGIS Desktop 10.3, latest type of popular GIS software developed by ESRI. Two topographical maps of scale 1:50,000 having numbers F45T12 and F45T15 covering the study areas Khordha district respectively are collected from Geographical Survey of India, Bhubaneswar, Odisha. Then the topographical maps consisting of the location of the ground water samples are scanned.

The scanned copies of the maps are then added to the GIS screen by using GIS software. After being added georeferencing of the maps is done to the area coordinates. After referencing all maps, on-screen digitization was done for creating point and section maps of various geographical objects. Digitization of sample positions as points were conducted and associated to an attribute table which includes seasonal concentration of chemical data. Due to more convenience of metric coordinates in analysis of spatial data in comparison to geographical lat/long coordinates, geographical coordinates were transformed into metric coordinates utilising Universal Transverse Mercator (UTM) projection.

3.12 Spatial distribution of parameters

Spatial analyses of different physical and chemical parameters were carried out utilising ArcGIS 10.3 software. As digitization is done by using point shapefile, interpolation of digitized points is required. Interpolation method is used so that the estimation of attribute values of positions which are inside range of accessible data utilising known data values can be determined. Here, in this project work, three different types of interpolation methods are used. For interpolating data spatially and estimating values amid measurements, an Inverse Distance Weighted Interpolation is used.

Before imposing the interpolation methods to draw maps, positions of sample stations were introduced as point layers into GIS software. Every sample point was allocated by a number and kept in point attribute table. For each sampling station attribution data file contain values of all physical and chemical parameters in distinct columns. Geo-database was utilised for generating spatial distribution maps of analysed water quality constraints like temperature, salinity, calcium hardness, fluoride, phosphate by using these three interpolation methods, and then the results were given.

3.12.1 Inverse distance weighted interpolation

It is utilised when a set of points is compact enough for capturing variation in degree of local surface necessary for analysis. It expressly assumes that objects that are closer together are more similar than objects that are farther away. All data points are utilised in interpolation procedure. The value of a node is computed by average weighted summation of all points. Then spatial distribution maps of different water quality parameters were generated using **IDW**. Spatial distribution data of all parameters was then transferred to raster utilising export tool in ArcMap for allowing reclassification.

3.12.2 Spline method of interpolation

It is the process by which geostatistical tools estimate values by minimising the total curvature of the surface through a function. As a result, the input locations are precisely traversed by a smooth surface. In theory, it's similar to bending a rubber

sheet to fit between the points while reducing the surface's overall curvature. The tension kind of spline, which often produces smoother surfaces but increases computation time, is employed in this project.

3.12.3 Kriging method of interpolation

This is an additional geo-statistical tool technique that relies on statistical models incorporating auto-correlation, or the statistical correlations between the observed points. This method makes the assumption that there is a spatial correlation reflected in the direction or distance between sample locations, which can be utilised to explain surface variance. This approach enables geo-statistical algorithms to give a prediction surface and a metric indicating the degree of certainty or accuracy of the predictions. The underlying premise of the Kriging approach is that surface variation can be explained by a spatial correlation reflected in the direction or distance between sample points.

3.13 Development of the groundwater quality index (GQI)

WQI is a single score that is produced by taking into account several significant water quality parameters. The process of determining the quality of water involves integrating the individual effects of each parameter in the appropriate proportion. Several researchers have generally estimated WQI in three phases (Water programme, 2007, Ramkrishnaiah et al., 2009). In this case, a distinct method of weighing was taken into consideration in order to pinpoint and emphasize the location-specific causes of water contamination. In order to determine each parameter's relative importance in the overall quality of water suitable for drinking, a weight (w_i) was first allocated based on the percentage of samples that met the standards' allowable limit.

Numerous nations developed the Water Quality Index (WQI) using their national standards. Horton (1965) proposed the first Water Quality Index (WQI) to be used in evaluating the total water quality. Cude 2001 enhances knowledge of water quality concerns by combining intricate data and producing a score that evaluates the suitability of the water's quality for a range of applications. In 2003, Sargaonkar and Deshpande created an overall pollution index for surface water based on a broad classification scheme in the Indian context, and they defined quality in terms of its physical, chemical, and biological properties. Boyacioglu created the Universal Water Quality Index (UWQI) in 2007 in order to offer a more straightforward approach to characterising the surface water quality that is utilised as a source of drinking water. Although hydrogeology and groundwater movement have a direct or indirect impact on water quality, the majority of WQI recommendations were based on physical, chemical, and biological factors. The quality of the groundwater is contaminated by the mobile elements through either surface or subterranean flow. In this study, eight significant factors were selected to calculate the water quality index. The World Health Organisation (WHO, 1993), Bureau of Indian Standards (BIS, 1991), Indian Council for Medical Research (ICMR), and American Public Health Association (APHA, 1994) have all proposed drinking water quality criteria, which have been used to calculate the WQI. The water body's WQI was determined using the weighted arithmetic index approach (Brown et al., 1972). Further, quality rating or sub index, (q_n) was calculated using the following expression.

$$q_n = 100 \frac{[V_n - V_{io}]}{[S_n - V_{io}]} \quad (1)$$

(Let there be n water quality parameters. The quality rating, or sub index, q_n , for the n th parameter is a number that indicates how this parameter's relative value in the contaminated water compares to the standard allowable value.)

where, q_n = Quality rating for the n th Water quality parameter.

V_n = Estimated value of the n th parameter at a given sampling station.

S_n = Standard permissible value of the n th parameter.

V_{io} = Ideal value of n th parameter in pure water.

(i.e., 0 for all other parameters except the parameter pH and Dissolved oxygen (7.0 and 14.6 mg/L respectively).

Unit weight was calculated by a value inversely proportional to the recommended standard value S_n of the corresponding parameter;

$$W_n = \frac{K}{S_n} \quad (2)$$

where, W_n = unit weight for the n th parameters.

S_n = Standard value for n th parameters.

K = Constant for proportionality.

Table 4 Water Quality Index (WQI) and status of water quality (Chatterji and Raziuddin 2002)

Water quality index level	Water quality status
0–25	Excellent water quality
26–50	Good water quality
51–75	Poor water quality
76–100	Very Poor water quality
> 100	Unsuitable for drinking

The overall Water Quality Index was calculated by aggregating the quality rating with the unit weight linearly. WQI can be calculated by following formula Table 4.

$$WQI = \frac{\sum q_n W_n}{\sum W_n} \quad (3)$$

4 Results and discussion

Results of the water quality parameters of 49 sampling areas of Khordha district from September 2022 to April 2023 are given in the below Table 5 and 6, and the correlation matrix of the mentioned parameters is shown in the below Tables 3, 5 and 6 separately for post-monsoon season of 2022 and pre-monsoon season 2023 respectively.

4.1 Temperature

The temperature of water samples ranges from maximum 19.14 °C at Gangeswarpur to 14.46 °C at Hanspal during post-monsoon season of 2022 while it varies from 33.1 °C at Gangeswarpur to 28.1 °C at Hanspal during pre-monsoon season of 2023 as shown in the below Fig. 8 and Fig. 9. From the correlation matrix, temperature has a strong positive relationship with EC, salinity, DO, TH, calcium hardness, magnesium hardness, chloride and fluoride. Still, a strong negative relationship is found between temperature and pH, TDS, TA, nitrate and phosphate during post-monsoon season, as shown in above Table 3. During pre-monsoon season, a strong positive relationship is found between temperature and pH, DO, TH, calcium hardness and chloride while temperature has a strong negative relationship with salinity, magnesium hardness, TDS, TA, EC, nitrate, fluoride, and phosphate as shown in above Table 5 and 6.

The spatial distribution of temperature is done by the help of IDW interpolation by using Arc GIS 10.3 as shown in Fig. 10 during post-monsoon 2022 and Fig. 11 during pre-monsoon 2023.

4.2 Salinity

Salinity varied from maximum 1.92 ppm at Baradibi to a minimum 0.5 ppm at Haripur during post-monsoon of 2022, while salinity ranged from a maximum 1.07 ppm at Baradibi to a minimum 0.01 ppm at Dalua during pre-monsoon season of 2023, as shown below in Fig. 12 and Fig. 13. From the correlation matrix, salinity has a strong positive relationship with temperature, TDS, EC, nitrate, TA, TH, calcium hardness, magnesium hardness and chloride but a strong negative relationship with pH, DO, fluoride and phosphate during post-monsoon season, as shown in Table 3. During pre-monsoon season, salinity has a strong positive relationship with pH, TDS, EC, nitrate, TA, TH, calcium hardness, magnesium hardness, chloride and phosphate, while a strong negative relationship with temperature, DO and fluoride as shown in Table 5 and 6.

The spatial distribution of salinity is done with the help of IDW interpolation by using Arc GIS 10.3 as shown in Fig. 14 during post-monsoon 2022 and Fig. 15 during pre-monsoon 2023.

4.3 pH

The pH varied from maximum 7.98 at Radhakantapur to minimum 6.14 at Taradei Bhajagarh during post-monsoon season in 2022 while the pH varied from maximum 7.27 at Adalabad and Niranjapur to minimum 5.45 at Andharua during pre-monsoon season in 2023 as shown below in the Fig. 16 and Fig. 17. From the correlation matrix, pH has a

Table 5 The results obtained from the deretmination of various parameters of the water quality using Aquameter and by titration

location	Coordinate	Colour	Odour	Pre-monsoon		pH	TDS	EC	DO	TA	TH	Mg hardness	Chloride	Nitrate
				Temp (°C)	Salinity (ppm)									
Dihasahi	N20°21.44' E85°53.78'	Colour less	Odour less	29.6	0.09	6.41	190	290	1.56	120	90.78	67.056	29.13	5.198
Tiranapada	N20°18.37' E85°54.97'	Colour less	Odour less	29	0.33	6.7	506	779	1.65	240	205.0	166.57	109.5	4.127
Hanspal	N20°18.91' E85°52.80'	Colour less	Odour less	28.1	0.64	6.97	876	1350	4.12	600	199.9	193.37	97.45	10.37
Kesara	N20°16.59' E85°52.44'	Colour less	Odour less	30.4	0.11	6.88	222	346	3.2	200	163.2	113.29	18.08	0.067
Dianpatana	N20°14.38' E85°56.23'	Colour less	Odour less	30	0.12	6.32	304	432	1.65	220	159.1	115.76	29.13	0.089
Kiajori	N20°12.50' E85°56.83'	Colour less	Odour less	30	0.15	6.54	190	245	2.01	245	132.6	85.153	24.11	0.098
Poljhari	N20°12.21' E85°58.23'	Colour less	Odour less	29.9	0.17	6.87	223	341	2.73	186	153	101.46	26.18	0.475
Amanakud	N20°09.14' E86°02.10'	Colour less	Odour less	29.1	0.12	6.53	156	234	1.53	203	173.4	123.49	6.530	0.27
Bhagabati- parha	N20°19.47' E85°42.15'	Colour less	Odour less	29.3	0.15	6.44	100	201	2.96	167	146.8	105.15	2.511	0.07
Panda sahi	N20°06.81' E85°59.19'	Colour less	Odour less	29.5	0.18	6.48	123	244	1.39	144	185.6	131.64	9.041	0.179
Sidhakutila	N20°08.99' E85°60.58'	Colour less	Odour less	29.5	0.13	6.52	111	210	3.62	191	177.4	129.21	23.10	-0.06
Pala sahi	N21°13.87' E86°45.96'	Colour less	Odour less	29.1	0.15	6.3	156	263	2.16	160	161.1	124.34	27.12	0.452
Pratapsashan	N20°12.93' E85°52.24'	Colour less	Odour less	30.1	0.08	6.98	155	240	1.25	160	98.94	61.798	11.08	0.087
Danaparha	N20°09.23' E85°55.71'	Pale yellow	Odour less	29.8	0.1	6.62	199	308	0.96	220	102	71.73	21.09	0.359
Adalabad	N20°08.65' E85°54.12'	Colour less	Odour less	29.4	0.06	7.27	114	175	1.22	120	60.18	40.138	11.08	0.112
Chandaka	N20°22.05' E85°45.98'	Colour less	Odour less	29.6	0.03	5.67	62	96	5.98	120	32.64	19.968	16.05	0.958
Dalua	N20°21.91' E85°43.69'	Colour less	Odour less	29.8	0.01	5.92	55	86	5.46	123	27.54	17.723	15.06	2.698
Andharua	N20°19.53' E85°46.27'	Colour less	Odour less	28.9	0.02	5.45	46	71	6.18	120	15.3	11.618	11.08	5.037
Khandagiri	N20°15.71' E85°47.13'	Pale yellow	Odour less	30.2	0.41	5.96	633	975	5.96	180	173.4	132.49	246.1	13.97
Jalimunda sahi	N20°20.21' E85°49.31'	Colour less	Odour less	29.8	0.15	6.3	295	455	1.3	226	132.6	87.19	54.26	1.833
Railway colony	N20°18.82' E85°48.61'	Colour less	Odour less	29.5	0.12	6.25	293	450	1.2	242	108.1	71.308	46.76	0.659
Ganga Nagar	N20°15.77' E85°49.26'	Colour less	Odour less	29.7	0.14	6.23	296	457	1.1	240	120.3	79.86	56.89	6.298

Table 5 (continued)

location	Coordinate	Colour	Odour	Pre-monsoon		Ca hardness	Flouride	Phosphate	pH	TDS	EC	DO	TA	TH	Mg hardness	Chloride	Nitrate
				Temp (°C)	Salinity (ppm)												
Dihapur	N20°12.56' E85°49.92'	Pale yellow	Odour less	30.4	0.57	75.668	1.257	0.6259	6.94	776	1194	2.66	440	225.4	149.75	181.8	2.605
Gangeswar-pur	N20°10.21' E85°49.59'	Colour less	Odour less	33.1	0.12	55.626	1.3382	0.427	7.26	254	390	6.06	120	180.5	124.9	20.59	0.069
Niranjanpur	N20°10.26' E85°45.59'	Colour less	Odour less	31.1	0.11	53.172	1.977	0.0396	7.27	256	399	5.3	130	170.6	116.9	33.88	0.05
Brahmakun-dala	N20°11.85' E85°46.85'	Colour less	Odour less	30.1	0.13	71.578	1.794	0.1009	7.13	251	392	6.03	173	216.2	144.66	24.17	0.064
Jatani	N20°10.22' E85°42.35'	Colour less	Odour less	29.5	0.13	51.94	-0.308	0.1759	6.83	267	349	2.31	227	173.4	121.46	13.56	0.088
Chhelda	N20°12.16' E85°42.69'	Colour less	Odour less	30	0.15	53.1726	-6.941	0.3786	6.51	234	375	2.42	254	150.9	97.787	23.17	0.157
Pitapalli	N20°12.18' E85°39.68'	Pale yellow	Odour less	29.1	0.12	58.0808	1.0882	0.2009	6.87	242	373	2.27	250	201.9	143.79	22.17	0.064
Mahul	N20°14.10' E85°38.14'	Colour less	Odour less	28.7	0.18	58.8988	-4.757	0.1869	6.91	301	451	2.53	166	165.2	106.34	31.14	0.076
Madhupur	N20°14.30' E85°38.76'	Colour less	Odour less	29.1	0.15	54.8086	1.1102	0.2396	6.52	97	111	2.53	144	173.4	118.59	7.071	-0.09
Nuapartha	N20°14.92' E85°35.06'	Colour less	Odour less	30	0.18	53.1726	0.4558	0.2147	6.78	184	207	1.63	137	148.9	95.747	16.77	0.079
Jaymangala	N20°12.45' E85°32.82'	Colour less	Odour less	31.1	0.17	67.897	1.4926	0.3729	6.59	239	324	1.45	142	185.6	117.74	29.19	0.074
Jagulipatna	N20°11.87'E85°34.46'	Colour less	Odour less	30.1	0.12	51.945	1.4558	0.4045	6.39	198	299	2.13	136	153	101.05	24.6	0.1791
Dalaiput	N20°08.48'E85°35.95'	Colour less	Odour less	29.1	0.1	48.266	1.3161	0.2498	6.49	217	336	1.62	130	142.8	94.536	58.77	-0.47
Porapartha	N20°08.53'E85°39.94'	Pale yellow	Odour less	28.6	0.06	49.904	1.0294	0.089	6.06	119	185	5.66	276	193.8	143.89	14.57	0.79638
Dalaka	N20°05.92'E85°31.97'	Colour less	Odour less	29.3	0.11	42.5388	1.5225	0.6899	6.99	219	338	1.93	300	182.8	140.09	18.87	0.03529
Radhakanta-pur	N20°09.22'E85°31.89'	Colour less	Odour less	30.1	0.13	50.094	1.7088	0.1376	6.73	305	476	2.1	332	187.8	137.86	60.98	0.07194
Badapokha-ria	N19°58.67'E85°28.96'	Colour less	Odour less	32.3	0.12	56.4476	-7.088	0.0198	6.52	247	371	5.3	160	178.5	122.05	51.27	3.93809
Nirakarpur	N19°59.51'E85°31.97'	Colour less	Odour less	29.8	0.1	12.6796	1.727	0.0159	5.87	202	312	1.62	60	46.92	34.244	63.29	4.7583
Kamaguru	N20°00.17'E85°26.08'	Colour less	Odour less	29	0.09	44.992	0.5735	0.1419	6.38	281	357	1.42	228	148.9	103.98	35.68	1.0909
Taradei	N19°55.92'E85°25.43'	Colour less	Odour less	30.1	0.07	35.584	-7.787	0.1708	7.14	165	257	3.56	178	147.9	112.36	21.39	2.71538
Bhajangarh	N19°55.92'E85°25.43'	Colour less	Odour less	32.1	0.13	40.083	-2.197	0.0535	7.1	274	423	5.14	240	171.6	131.27	42.19	0.73846
Dadhibha-manapur	N19°55.92'E85°25.43'	Colour less	Odour less	29.7	0.06	21.269	1.025	0.3408	6.98	315	493	6.1	120	86.7	65.431	56.79	0.7963
Barhapari	N20°16.88'E85°23.23'	Colour less	Odour less	29.8	0.06	25.359	1.8455	0.4899	6.3	117	180	6.56	170	71.4	46.041	28.18	2.9475
Gopinathpur	N19°50.11'E85°21.00'	Pale yellow	Odour less	30	0.06	19.632	-12.38	0.5129	6.12	113	175	7.37	240	75.48	55.848	19.88	-0.0899
Gainartha	N19°49.50'E85°18.77'	Colour less	Odour less	31.4	0.04	9.8164	1.897	0.4585	6.16	76	117	5.6	80	57.12	47.306	28.18	0.1276
Haripur	N19°48.14'E85°15.15'	Pale yellow	Odour less	29.9	1.07	180.788	-12.88	0.6388	6.62	1380	2124	0.65	570	681.6	500.57	480.4	7.7036

Table 5 (continued)

location	Coordinate	Colour	Odour	Pre-monsoon		Ca hardness	Flouride	Phosphate	pH	TDS	EC	DO	TA	TH	Mg hardness	Chloride	Nitrate
				Temp (°C)	Salinity (ppm)												
Kurumijhar	N19°52.01'E85°19.43'	Colour less	Odour less	29.8	0.24	59.716	-15.25	0.254	6.28	368	561	7.87	160	238.8	178.96	97.44	14.5063

Table 6 The results obtained from the deretmination of various parameters of the water quality using Aquameter and by titration

location	Coordinate	Colour	Odour	Post-monsoon		Ca hardness	Flouride	Phosphate	pH	TDS	EC	DO	TH		Mg hardness	Chloride	Nitrate
				Temp (°C)	Salinity (ppm)								TA	TA			
Dihasahi	N20°21.44' E85°53.78'	Colour less	Odour less	15.16	0.52	11.56	1.24	0.47	8	175	250	1.24	111	63.86	52.3	17.29	5.36
Tiranapada	N20°18.37' E85°54.97'	Colour less	Odour less	15	0.64	17.35	1.11	0.28	6.1	478	786	1.33	232	171.6	154.29	77.32	4.62
Hanspal	N20°18.91' E85°52.80'	Colour less	Odour less	14.46	1.42	2.84	0.0042	0.3	6.4	745	1020	4.08	600	146.2	143.44	69.87	10.51
Kesara	N20°16.59' E85°52.44'	Colour less	Odour less	16.7	0.51	23.84	1.07	0.0045	6.3	197	296	3.04	200	121.7	97.92	12.68	0.42
Dianpatana	N20°14.38' E85°56.23'	Colour less	Odour less	16	0.73	20.547	1.11	0.0067	7.8	286	427	1.48	210	118.4	97.903	17.35	0.69
Kiajori	N20°12.50' E85°56.83'	Colour less	Odour less	16	0.57	21.152	1.42	0.0079	8.01	175	263	1.91	231	78.12	56.968	16.25	0.35
Poljhari	N20°12.21' E85°58.23'	Colour less	Odour less	15.7	0.69	25.15	1.02	0.05	6.34	221	332	2.51	167	114.6	89.5	16.82	0.456
Amanakud	N20°09.14' E86°02.10'	Colour less	Odour less	15.4	0.73	24.35	1.24	0.03	8.03	137	234	1.33	201	106.5	82.2	5.41	0.452
Bhagabati- partha	N20°19.47' E85°42.15'	Colour less	Odour less	15.9	0.57	20.14	1.24	0.006	8.02	91	200	2.54	154	48.62	28.48	0.17	0.245
Panda sahi	N20°06.81' E85°59.19'	Colour less	Odour less	15.7	0.82	26.15	1.11	0.29	8.1	111	239	1.27	138	124.8	98.7	6.58	0.572
Sidhakutila	N20°08.99' E85°60.58'	Colour less	Odour less	15.7	0.78	21.64	1.21	0.012	8.1	101	201	3.52	178	116.5	94.91	15.94	0.09
Pala sahi	N21°13.87' E86°45.96'	Colour less	Odour less	15.4	0.57	18.44	1.36	0.081	7.9	127	259	2.04	149	105.5	87.12	15.73	0.69
Pratapsashan	N20°12.93' E85°52.24'	Colour less	Odour less	16.2	0.54	16.25	1.26	0.087	6.31	147	236	1.17	149	31.55	15.3	7.67	0.34
Danapartha	N20°09.23' E85°55.71'	Pale yellow	Odour less	15.6	0.57	15.84	1.17	0.0056	6.1	174	306	0.84	210	47.65	31.81	15.31	0.56
Adalabad	N20°08.65' E85°54.12'	Colour less	Odour less	15.2	0.51	11.16	1.52	0.097	6.17	109	164	1.12	111	24.75	13.59	7.67	0.79
Chandaka	N20°22.05' E85°45.98'	Colour less	Odour less	15.16	0.53	5.12	0.21	0.56	7.24	45	92	5.96	111	15.94	10.82	9.25	0.95
Dalua	N20°21.91' E85°43.69'	Colour less	Odour less	15.6	0.54	2.65	0.41	0.12	7.56	52	79	5.42	115	11.82	9.17	8.78	3.1
Andharua	N20°19.53' E85°46.27'	Colour less	Odour less	15.46	0.51	0.954	0.21	0.071	7.14	41	69	6.1	111	6.94	5.986	7.67	5.37
Khandagiri	N20°15.71' E85°47.13'	Pale yellow	Odour less	16.5	0.78	21.554	1.05	0.069	7.54	597	962	5.82	156	106.5	84.996	160.8	13.76
Jalimunda sahi	N20°20.21' E85°49.31'	Colour less	Odour less	15.6	0.57	23.14	-12.6	0.006	7.87	247	448	1.1	205	85.65	62.51	33.95	2.45
Railway colony	N20°18.82' E85°48.61'	Colour less	Odour less	15.7	0.73	18.44	-5.72	0.07	7.89	236	449	1.01	214	78.62	60.18	32.82	0.98
Ganga Nagar	N20°15.77' E85°49.26'	Colour less	Odour less	15.5	0.63	20.45	-11.52	0.052	7.81	244	457	1.1	232	96.84	76.39	33.85	6.95

Table 6 (continued)

location	Coordinate	Colour	Odour	Post-monsoon		Ca hardness	Flouride	Phosphate	pH	TDS	EC	DO	TH		Mg hardness	Chloride	Nitrate
				Temp (°C)	Salinity (ppm)								TA	TA			
Dihapur	N20°12.56' E85°49.92'	Pale yellow	Odour less	16.7	1.12	37.21	1.17	0.17	6.31	641	1175	2.25	412	164.8	127.64	137.6	2.89
Gangeswar-pur	N20°10.21' E85°49.59'	Colour less	Odour less	19.14	0.73	26.14	1.29	0.13	6.01	209	389	5.92	111	124.9	98.81	16.92	0.42
Niranjanpur	N20°10.26' E85°45.59'	Colour less	Odour less	17.67	0.51	25.11	1.43	0.0091	6.1	231	362	5.01	116	111.4	86.35	19.27	0.86
Brahmakun-dala	N20°11.85' E85°46.85'	Colour less	Odour less	16.17	0.78	36.84	1.42	0.0035	6	229	385	5.96	127	185.6	148.79	16.85	0.25
Jatani	N20°10.22' E85°42.35'	Colour less	Odour less	15.7	0.78	26.81	0.014	0.061	6.3	225	332	2.01	204	106.5	79.74	9.82	0.37
Chhelda	N20°12.16' E85°42.69'	Colour less	Odour less	16	0.57	27.51	-1.84	0.14	8	196	361	2.19	231	126.8	99.34	15.96	0.68
Pitapalli	N20°12.18' E85°39.68'	Pale yellow	Odour less	15.4	0.73	28.64	1.08	0.061	6.4	239	375	2.07	225	175.9	147.3	15.32	0.48
Mahul	N20°14.10' E85°38.14'	Colour less	Odour less	15.47	0.82	28.47	0.052	0.051	6.42	278	436	2.13	147	105.9	77.47	18.64	0.29
Madhupur	N20°14.30' E85°38.76'	Colour less	Odour less	15.4	0.57	25.17	1.11	0.063	8.07	65	126	2.14	138	106.5	81.38	4.92	0.01
Nuapatha	N20°14.92' E85°35.06'	Colour less	Odour less	16	0.82	25.84	0.26	0.061	6.0	97	211	1.43	114	87.65	61.81	9.24	0.35
Jaymangala	N20°12.45' E85°32.82'	Colour less	Odour less	17.67	0.69	33.56	1.17	0.142	8.03	191	312	1.27	115	124.8	91.29	17.64	0.67
Jagulipatna	N20°11.87'E85°34.46'	Colour less	Odour less	16.17	0.73	25.56	1.17	0.15	7.8	114	286	2.07	105	118.9	93.38	15.96	0.36
Dalaiput	N20°08.48'E85°35.95'	Colour less	Odour less	15.4	0.57	24.94	1.29	0.062	8.1	194	324	1.38	116	96.45	71.51	33.95	0.01
Porapartha	N20°08.53'E85°39.94'	Pale yellow	Odour less	15.24	0.51	24.94	1.014	0.0054	7.6	94	168	5.43	227	127.9	103	6.82	0.98
Dalaka	N20°05.92'E85°31.97'	Colour less	Odour less	15.62	0.51	21.96	1.28	0.069	6.3	181	341	1.64	300	146.7	124.31	9.46	0.24
Radhakanta-pur	N20°09.22'E85°31.89'	Colour less	Odour less	16.17	0.78	25.71	1.36	0.041	6.1	284	476	1.98	304	149.28	123.57	45.96	0.56
Badapokha-ria	N19°58.67'E85°28.96'	Colour less	Odour less	18.62	0.73	27.64	-3.84	0.0031	8.1	196	369	5.14	127	136.9	109.15	35.34	4.12
Nirakarapur	N19°59.51'E85°31.97'	Colour less	Odour less	15.6	0.57	6.84	1.35	0.0052	7.4	180	321	1.47	32	16.34	9.5	34.21	4.96
Kamaguru	N20°00.17'E85°26.08'	Colour less	Odour less	15.02	0.52	21.25	0.24	0.014	7.85	197	339	1.29	204	87.65	66.4	20.27	1.42
Taradei	N19°55.92'E85°25.43'	Colour less	Odour less	16.17	0.53	16.94	-3.28	0.05	6.1	114	235	3.39	107	258.6	241.22	15.07	2.95
Bhajangarh	N19°55.92'E85°25.43'	Colour less	Odour less	18.16	0.78	20.84	0.065	0.0085	6.04	192	432	5.07	213	115.8	95.03	30.36	0.96
Dadhibamanapur	N19°55.92'E85°25.43'	Colour less	Odour less	15.67	0.51	11.84	1.02	0.061	6.4	281	489	5.96	111	47.67	35.83	91.25	0.82
Barhapari	N20°16.88'E85°23.23'	Colour less	Odour less	15.6	0.51	12.86	1.36	0.13	7.8	105	176	632	106	32.84	19.98	16.94	3
Gopinathpur	N19°50.11'E85°21.00'	Pale yellow	Odour less	16	0.51	7.67	-8.76	2.11	7.6	124	161	7.12	232	33.47	25.8	7.41	0.01
Gainartha	N19°49.50'E85°18.77'	Colour less	Odour less	17.24	0.5	2.85	1.42	0.14	7.62	56	113	5.84	54	21.48	18.63	16.94	0.76
Haripur	N19°48.14'E85°15.15'	Pale yellow	Odour less	15.92	1.92	51.67	-6.21	0.17	6.1	1040	1983	0.42	504	351.8	300.17	190.6	7.94

Table 6 (continued)

location	Coordinate	Colour	Odour	Post-monsoon		Ca hardness	Flouride	Phosphate	pH	TDS	EC	DO	TA	TH	Mg hardness	Chloride	Nitrate
				Temp (°C)	Salinity (ppm)												
Kurumijhar	N19°52.01'E85°19.43'	Colour less	Odour less	15.6	0.79	26.17	-5.87	0.07	7.65	287	541	7.23	127	184.7	158.1	62.45	14.64

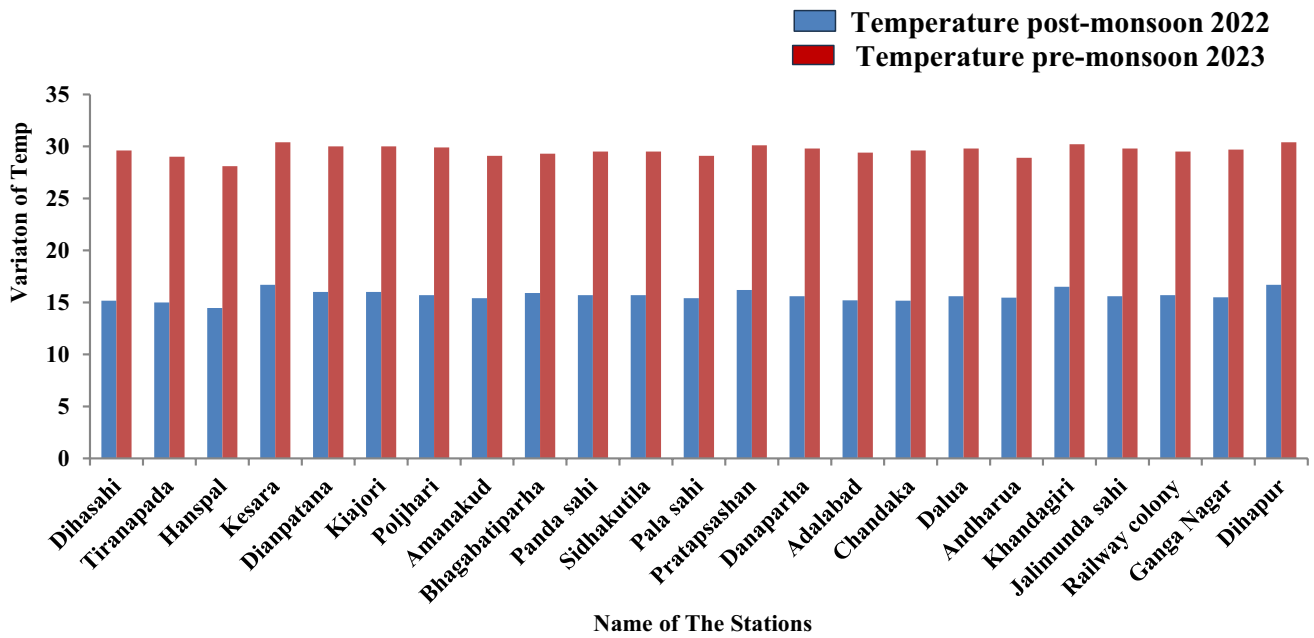


Fig. 8 Distribution of temperature from Dihasahi to Dihapur

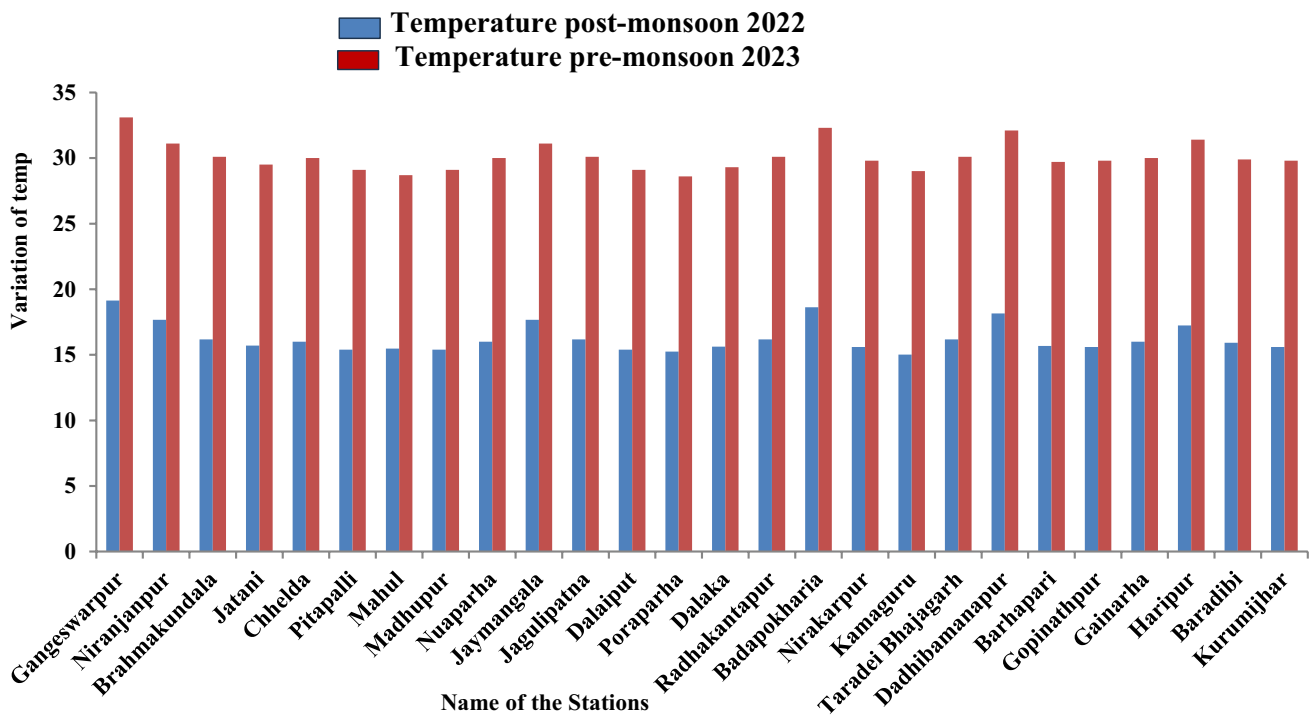


Fig. 9 Distribution of temperature from Gangeswarpur to Kurumijhar

strong positive relationship with nitrate and phosphate but a strong negative relationship with temperature, TDS, EC, salinity, DO, TA, TH, calcium hardness, magnesium hardness, chloride and fluoride during post-monsoon season, as shown in Table 3. During pre-monsoon season, pH has a strong positive relationship with temperature, TDS, EC, salinity, TA, TH, calcium hardness, magnesium hardness and fluoride while a strong negative relationship with DO, nitrate, chloride and phosphate as shown in Table 5 and 6.

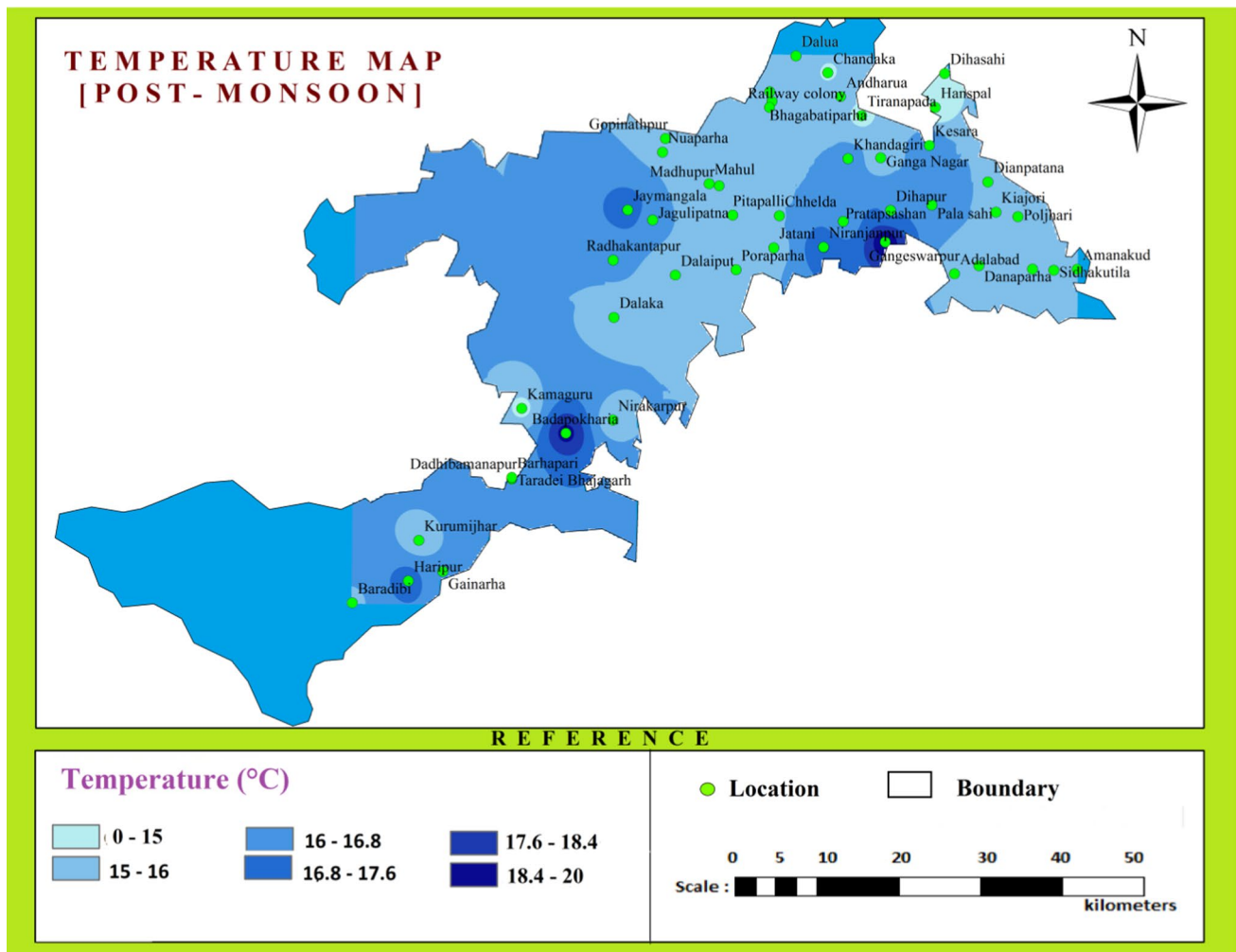


Fig. 10 Spatial distribution of temperature during post-monsoon 2022

The spatial distribution of pH is done by the help of IDW interpolation by using Arc GIS 10.3 as shown in Fig. 18 during post-monsoon 2022 and Fig. 19 during pre-monsoon 2023.

4.4 Total dissolved solids

The Total Dissolved Solids varied from maximum 786 ppm at Baradibi, 744 ppm at Hanspal, 597 ppm at Khandagiri and 594 ppm at Dihapur to minimum 41 ppm at Andharua and 45 ppm at Chandaka during post-monsoon season in 2022, where as it varies from maximum 1380 ppm at Baradibi, 876 ppm at Hanspal, 776 ppm at Dihapur, 633 ppm at Khandagiri and 506 ppm at Tiranpada to minimum 46 ppm at andharua, 55 ppm at Dalua and 62 ppm at Chandaka during pre-monsoon season in 2023 as shown below in Fig. 20 and Fig. 21. From the correlation matrix, TDS has a strong positive relationship with EC, salinity, nitrate, TA, TH, calcium hardness, magnesium hardness and chloride but a strong negative relationship with temperature, pH, DO, fluoride and phosphate during post-monsoon season, as shown in Table 3. During pre-monsoon season, TDS has a strong positive relationship with withpH, EC, salinity, nitrate, TA, TH, calcium hardness, magnesium hardness, chloride and phosphate while a strong negative relationship with temperature, DO and fluoride as shown in Table 5 and 6.

The spatial distribution of Total Dissolved Solids is done by the help of Kriging interpolation by using Arc GIS 10.3 as shown in Fig. 22 during post-monsoon 2022 and Fig. 23 during pre-monsoon 2023.

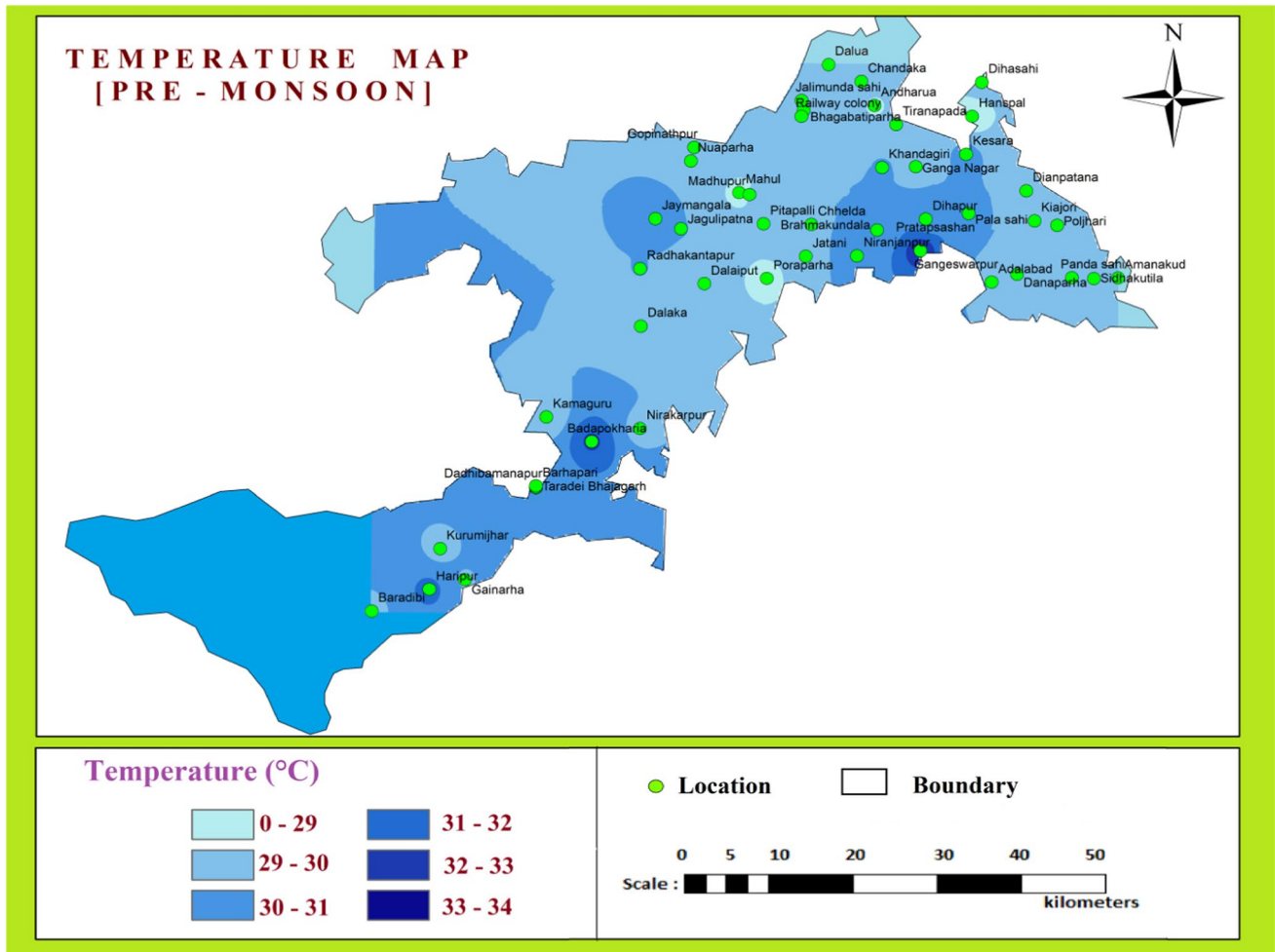


Fig. 11 Spatial distribution of temperature during pre-monsoon 2023

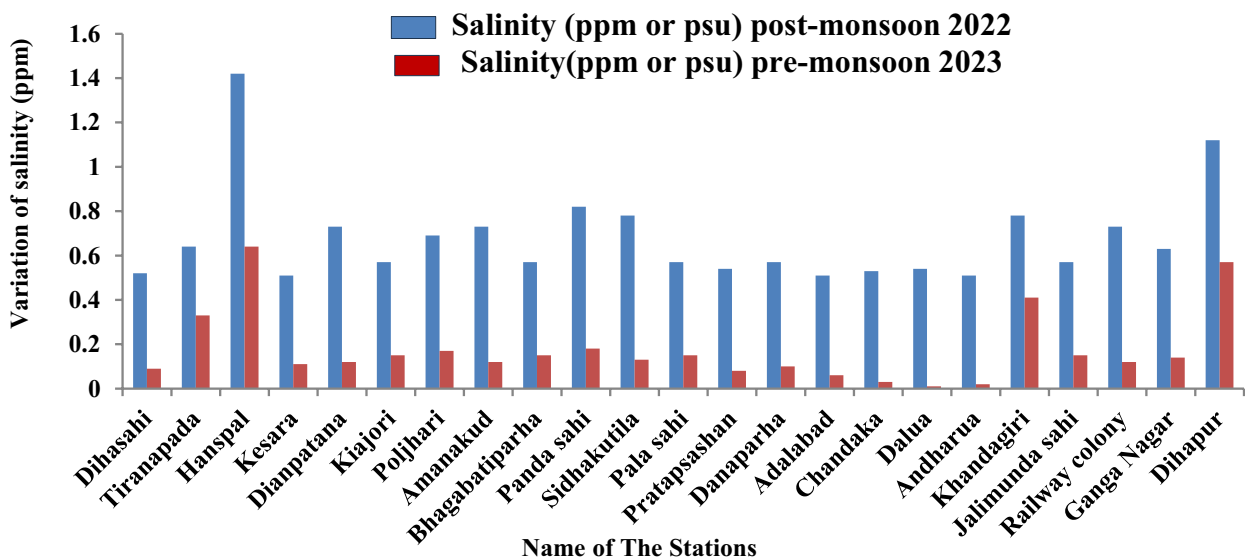


Fig. 12 Distribution of Salinity from Dihasahi to Dihapur

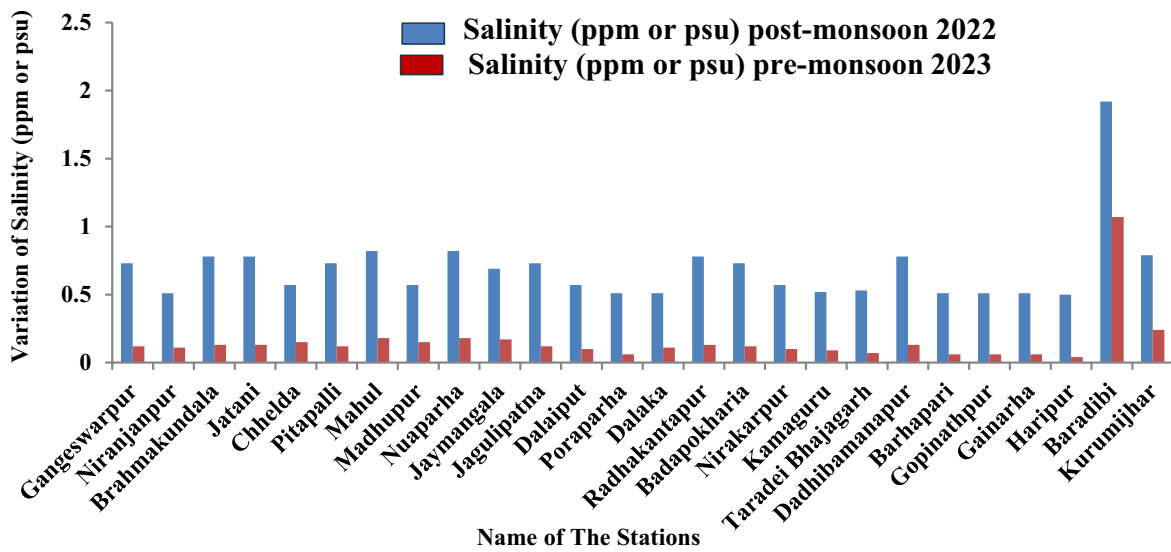


Fig. 13 Distribution of Salinity from Gangeswarpur to Kurumijhar

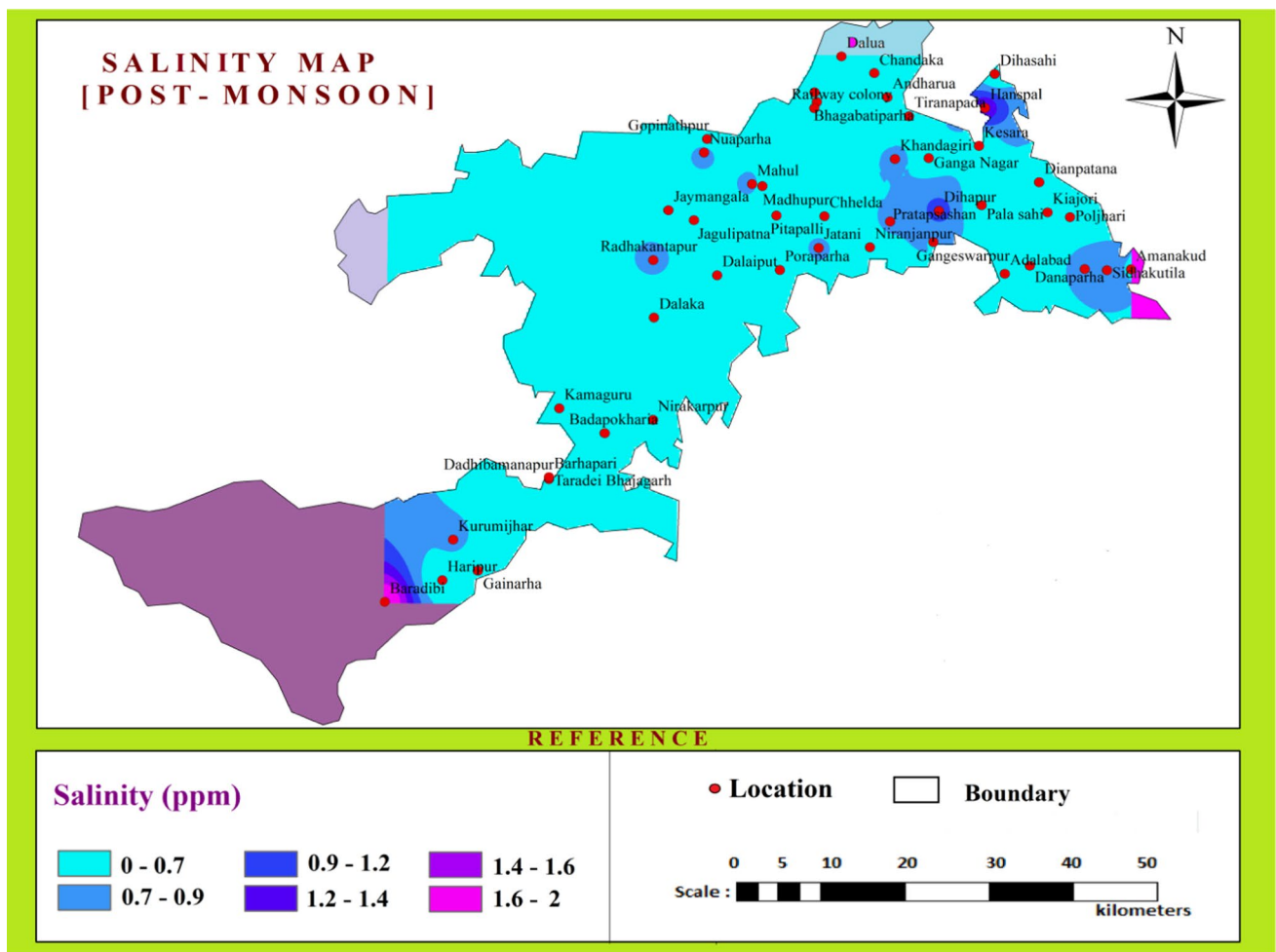


Fig. 14 Spatial distribution of salinity during post-monsoon 2022

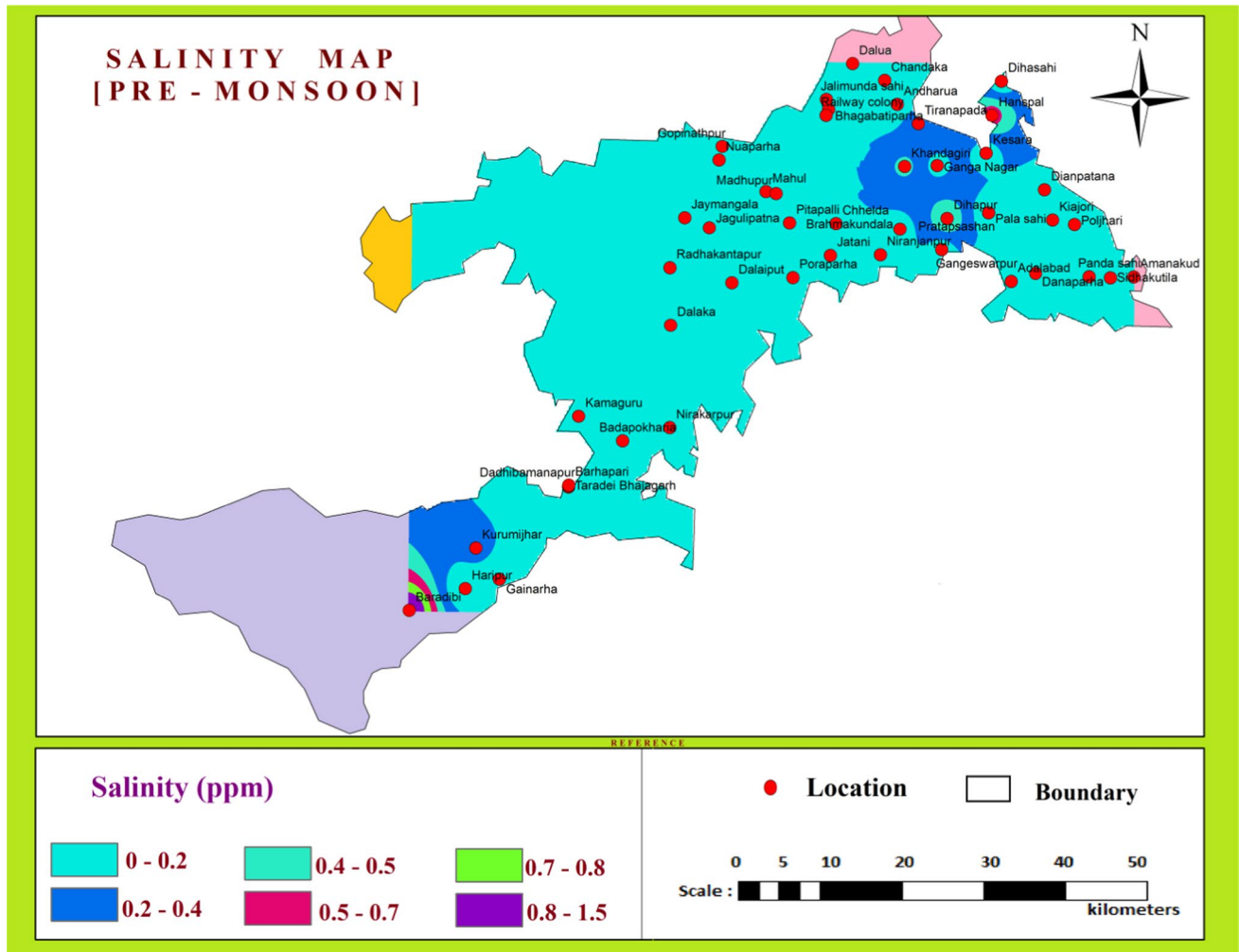


Fig. 15 Spatial distribution of salinity during pre-monsoon 2023

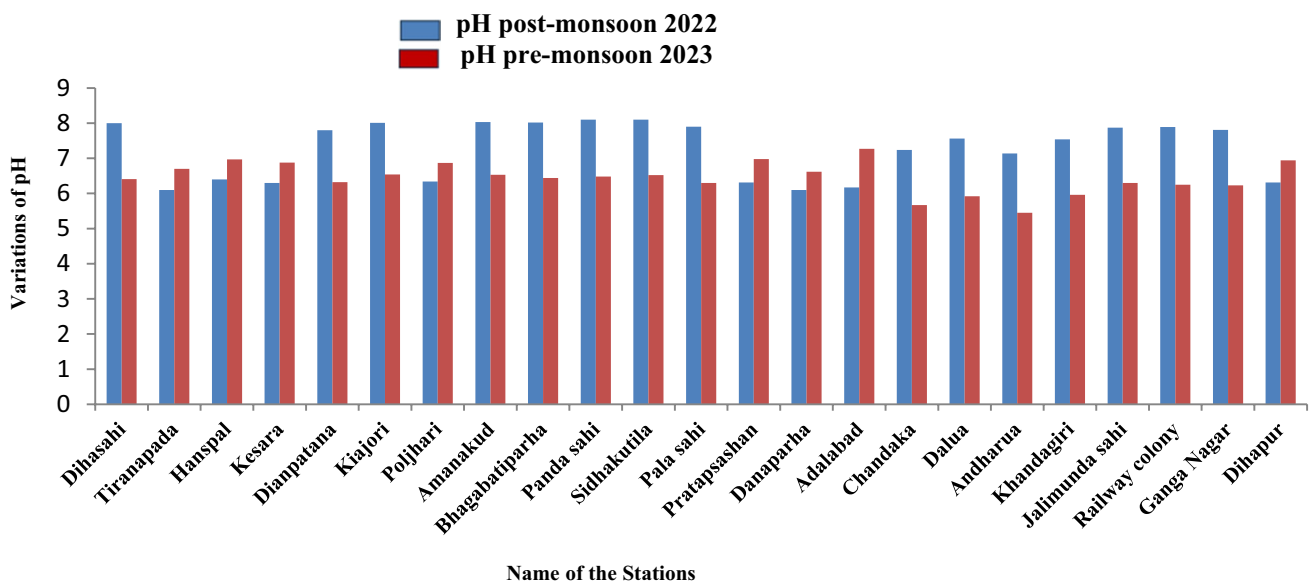


Fig. 16 Distribution of pH from Dihasahi to Dihapur

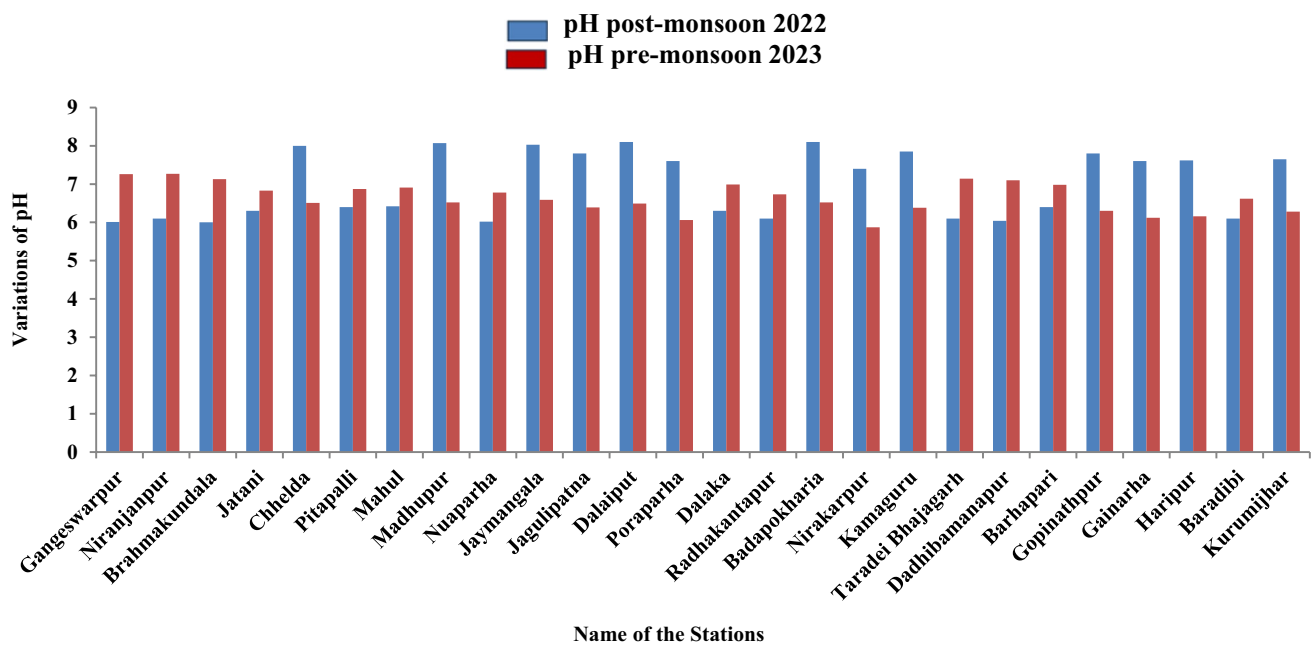


Fig. 17 Distribution of pH from Gangeswarpur to Kurumijhar

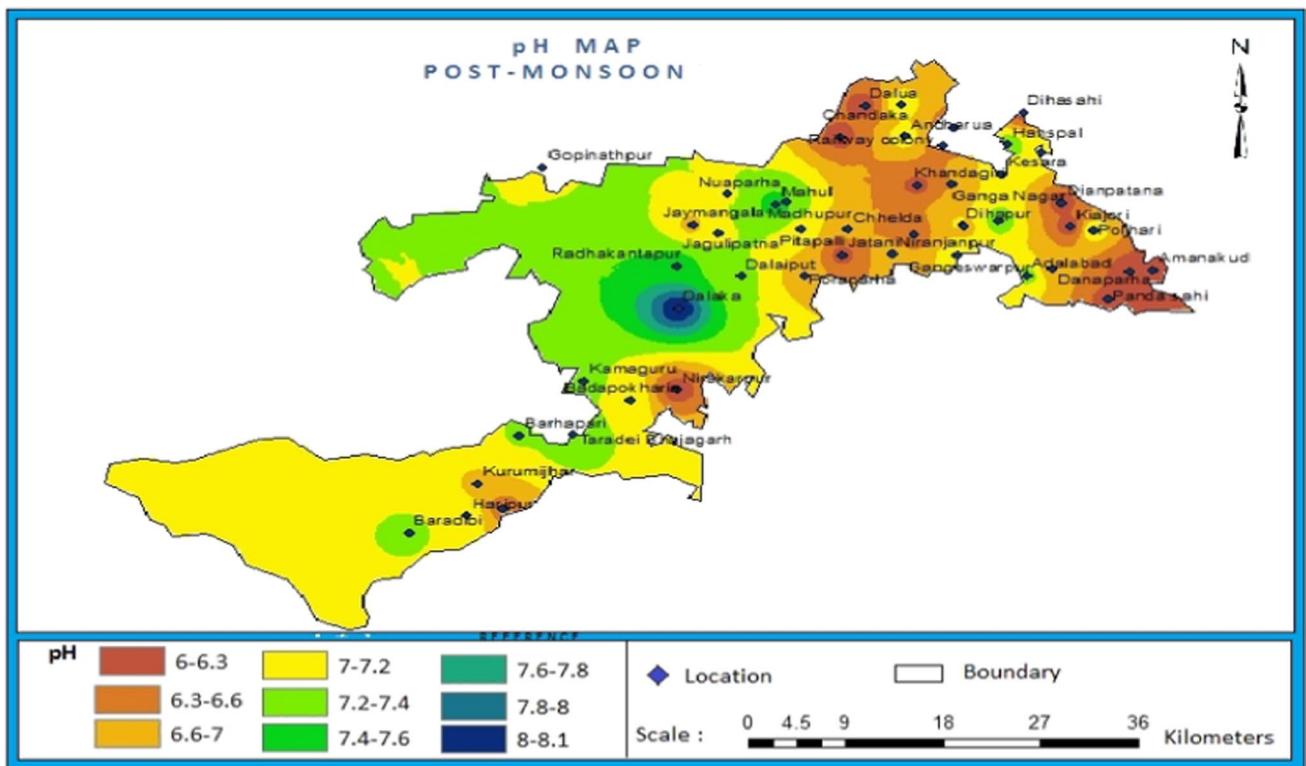


Fig. 18 Spatial distribution of pH during post-monsoon 2022

4.5 Conductance

The Conductance varied from maximum 1983 $\mu\text{S}/\text{cm}$ at Baradibi to minimum 69 $\mu\text{S}/\text{cm}$ at Andharua during post-monsoon season of 2022, where as the Conductance varied from maximum 2124 $\mu\text{S}/\text{cm}$ at Baradibi to minimum

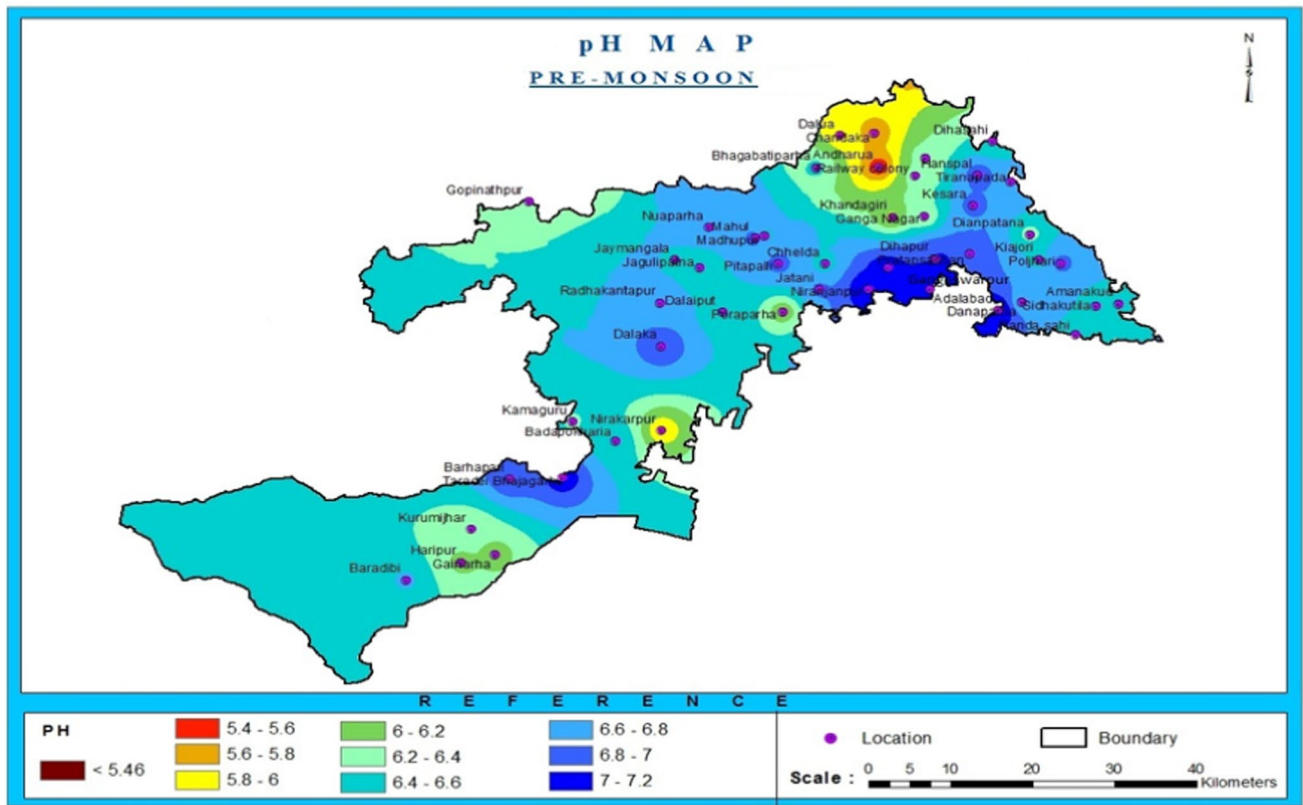


Fig. 19 Spatial distribution of pH during pre-monsoon 2023

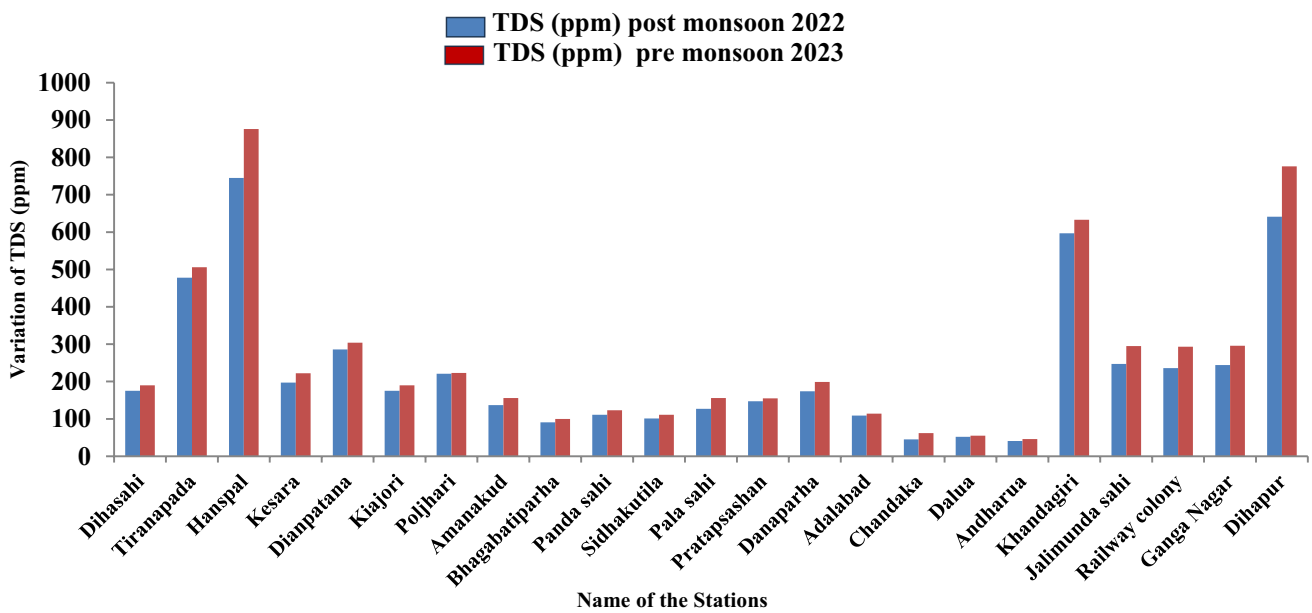


Fig. 20 Distribution of TDS from Dihasahi to Dihapur

71 $\mu\text{S}/\text{cm}$ at Andharua during pre-monsoon season of 2023 as shown below in Fig. 24 and Fig. 25. From the correlation matrix, EC has a strong positive relationship with temperature, TDS, salinity, nitrate, TA, TH, calcium hardness, magnesium hardness and chloride but a strong negative relationship with pH, DO, fluoride and phosphate during post-monsoon season, as shown in Table 3. During pre-monsoon season EC has a strong positive relationship with

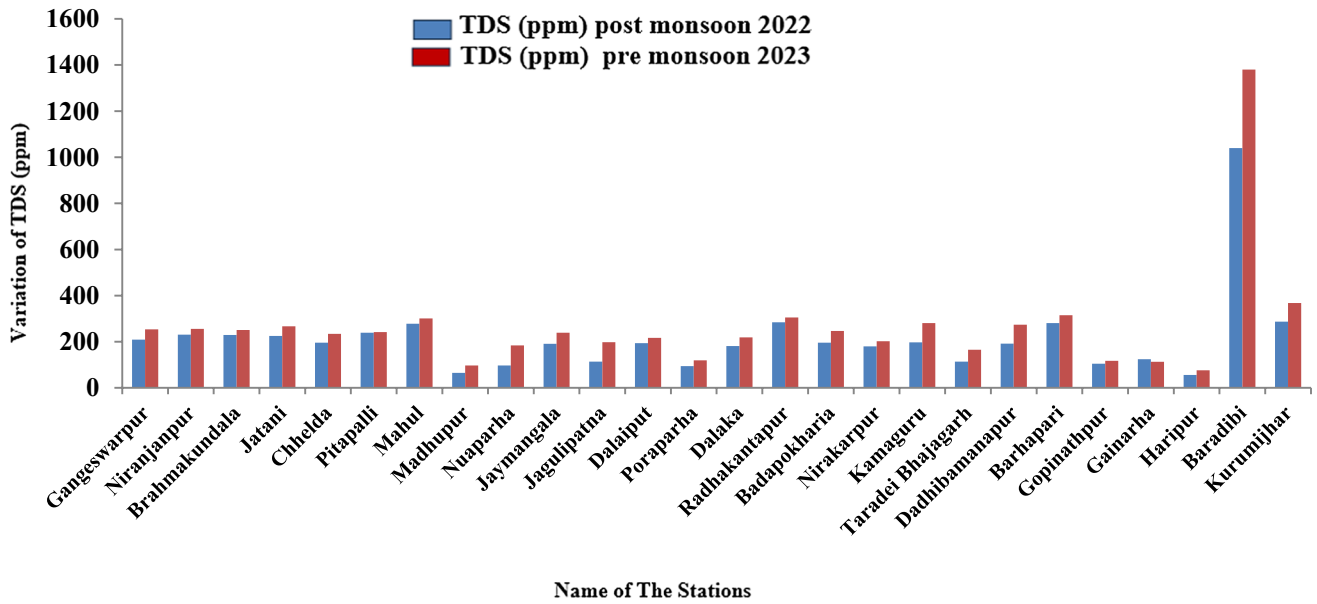


Fig. 21 Distribution of TDS from Gangeswarpur to Kurumijhar

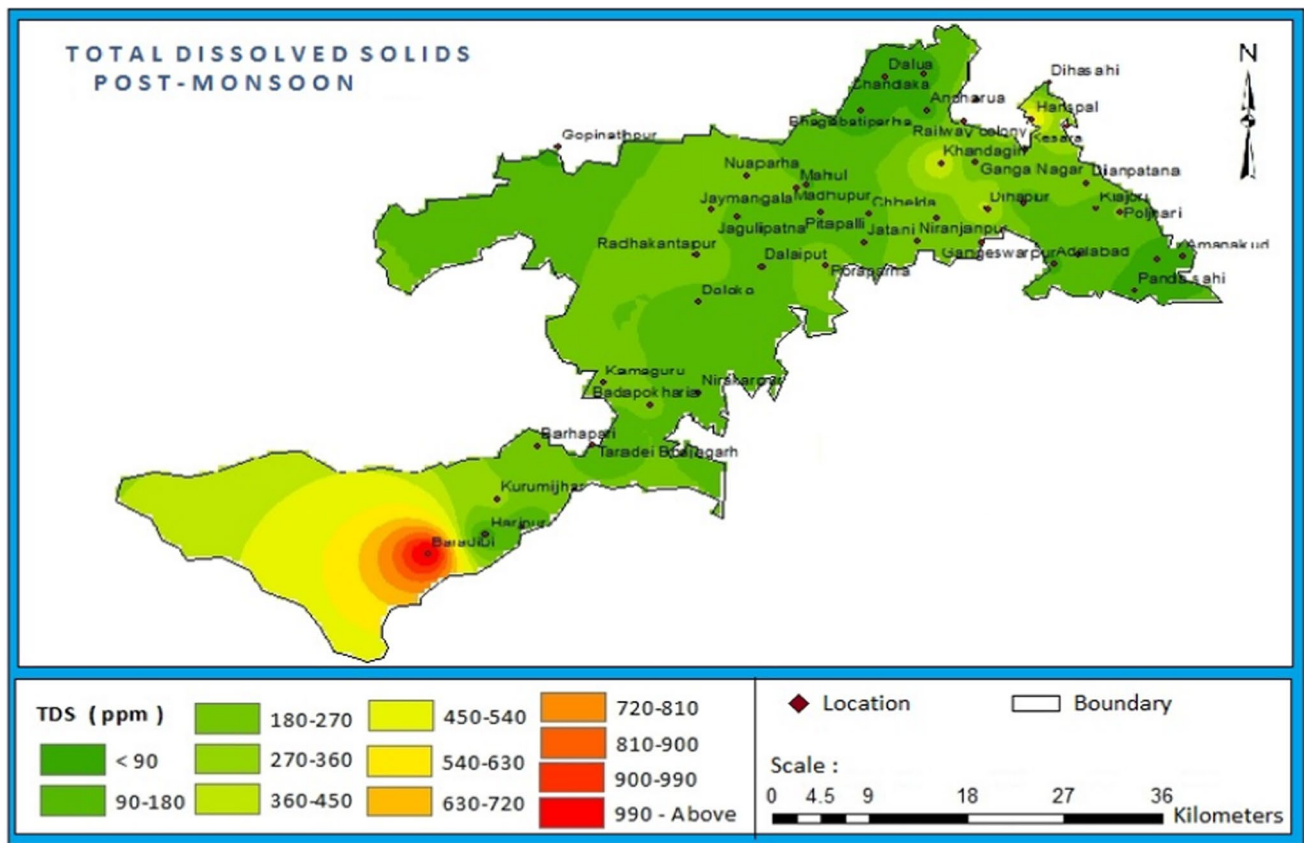


Fig. 22 Spatial distribution of TDS during post-monsoon 2022

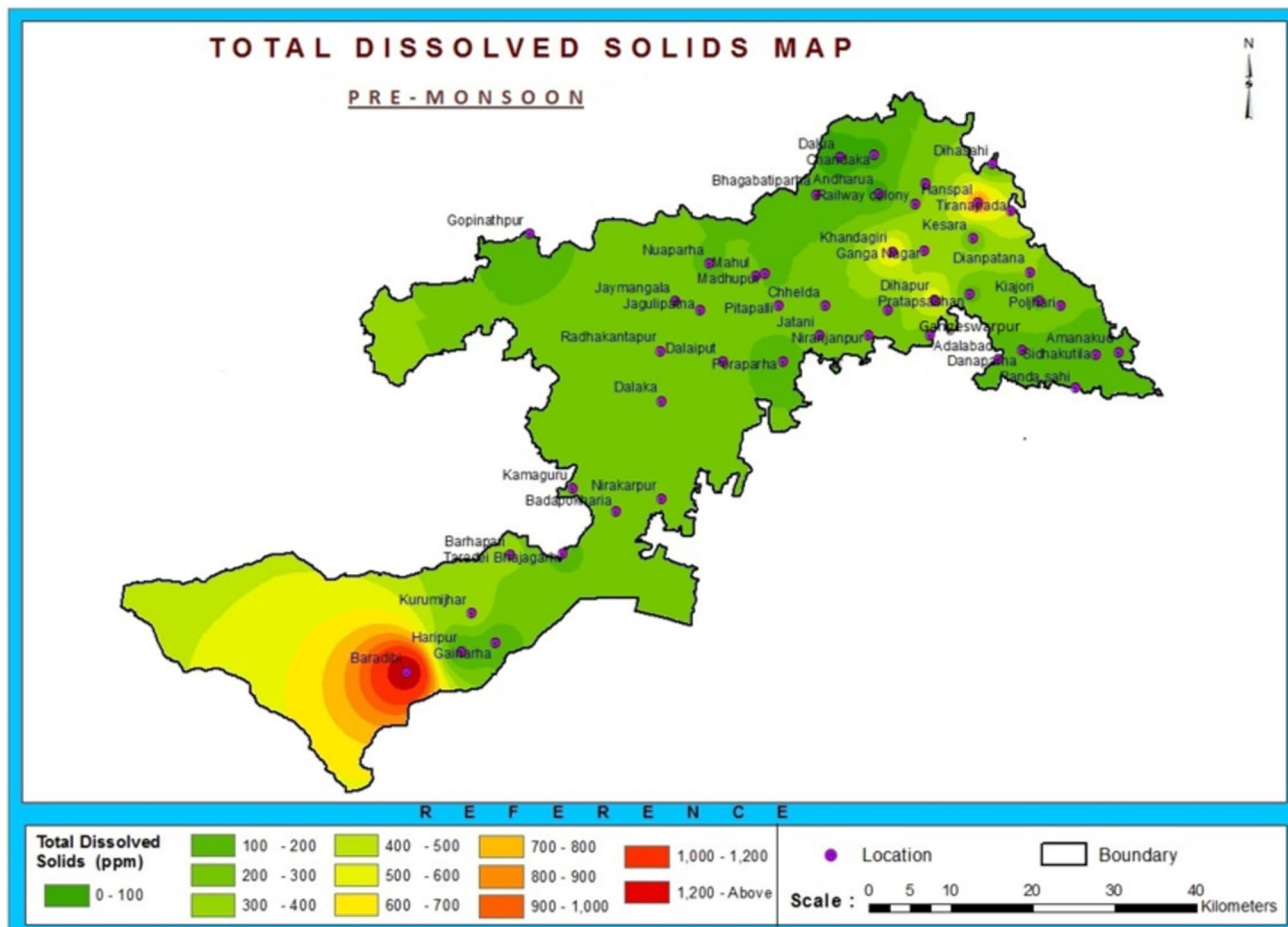


Fig. 23 Spatial distribution of TDS during pre-monsoon 2023

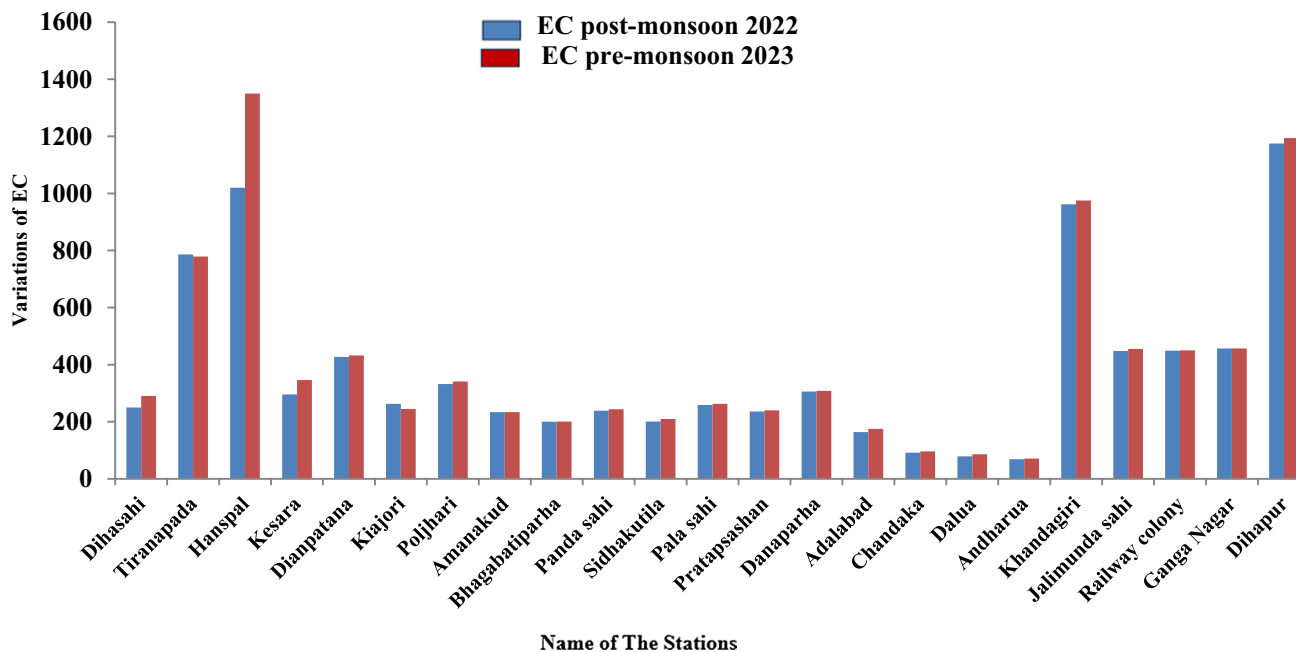


Fig. 24 Distribution of EC from Dihasaki to Dihapur

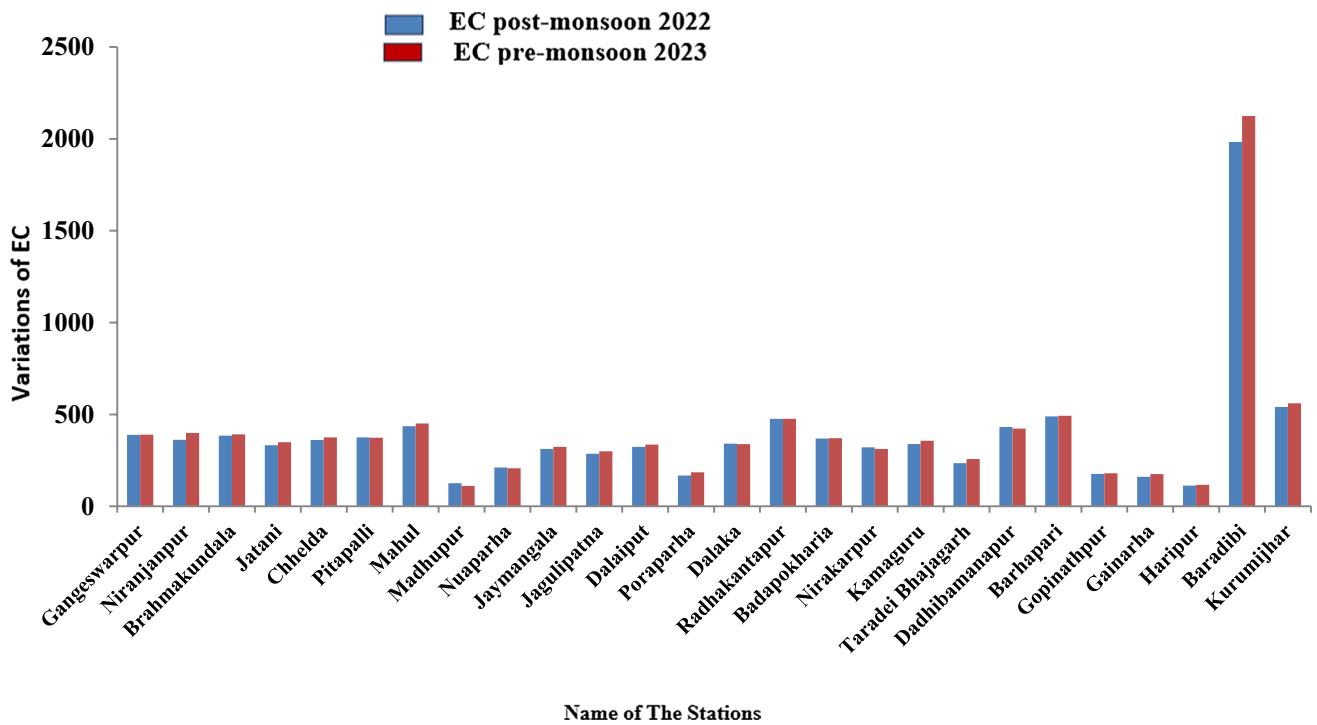


Fig. 25 Distribution of EC from Gangeswarpur to Kurumijhar

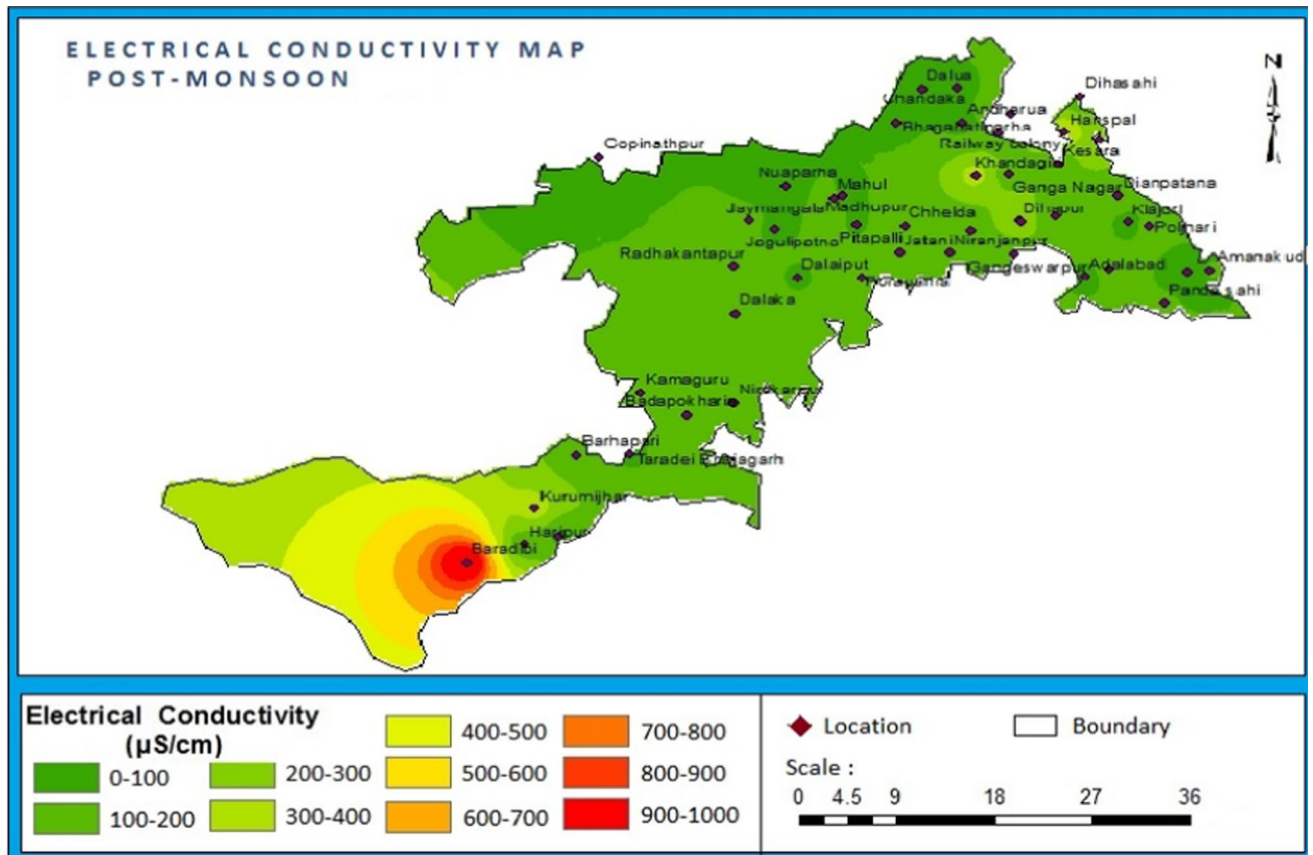


Fig. 26 Spatial distribution of EC during post-monsoon 2022

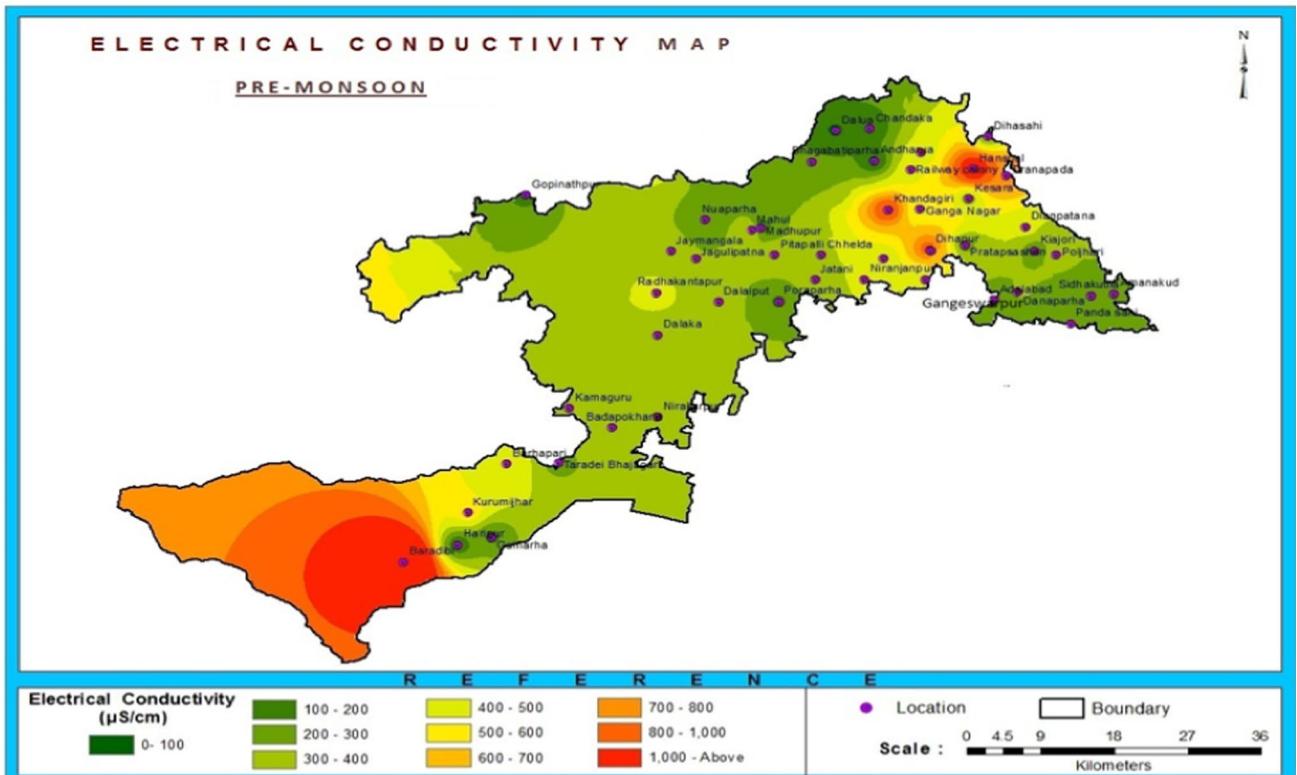


Fig. 27 Spatial distribution of EC during pre-monsoon 2023

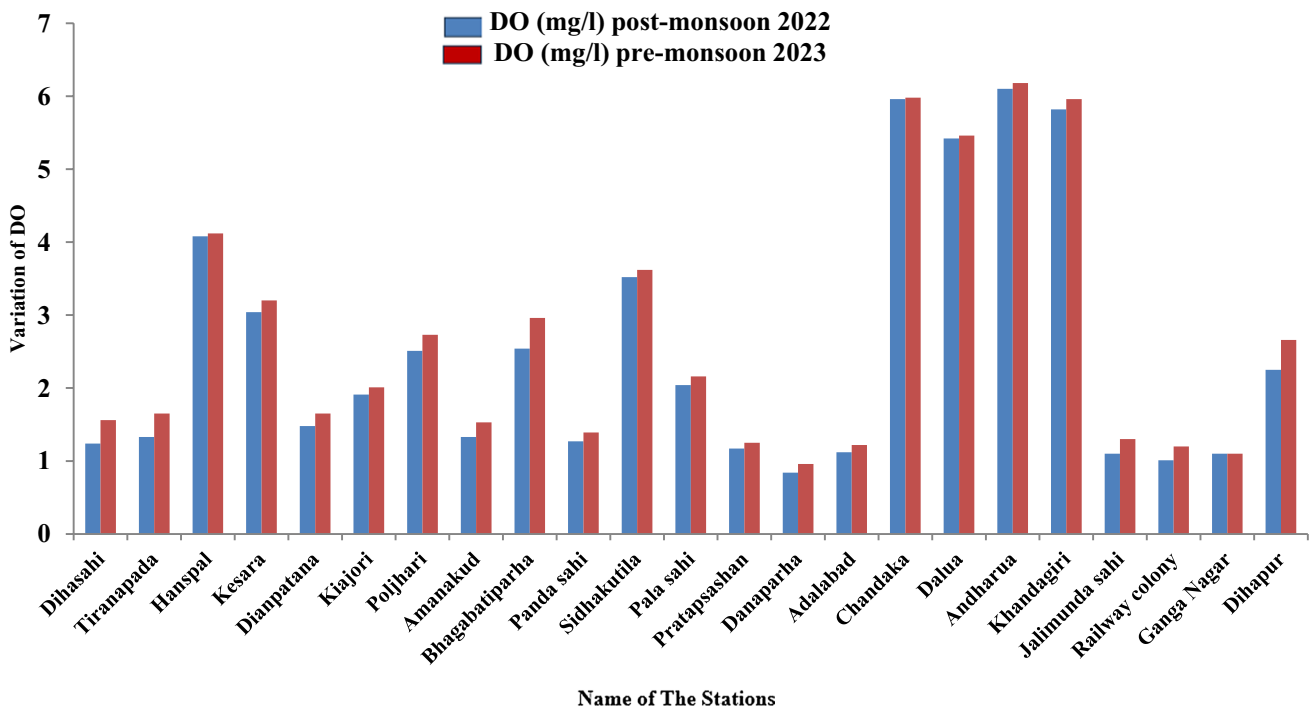


Fig. 28 Distribution of DO from Dihasahi to Dihapur

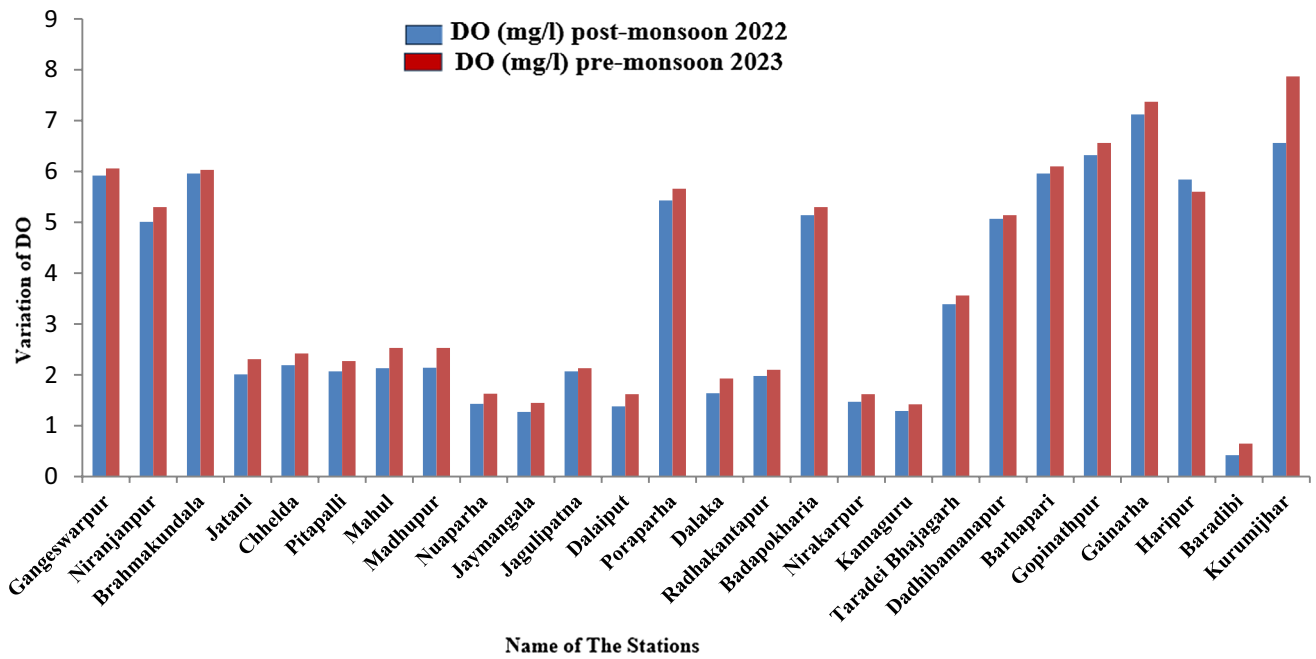


Fig. 29 Distribution of DO from Gangeswarpur to Kurumijhar

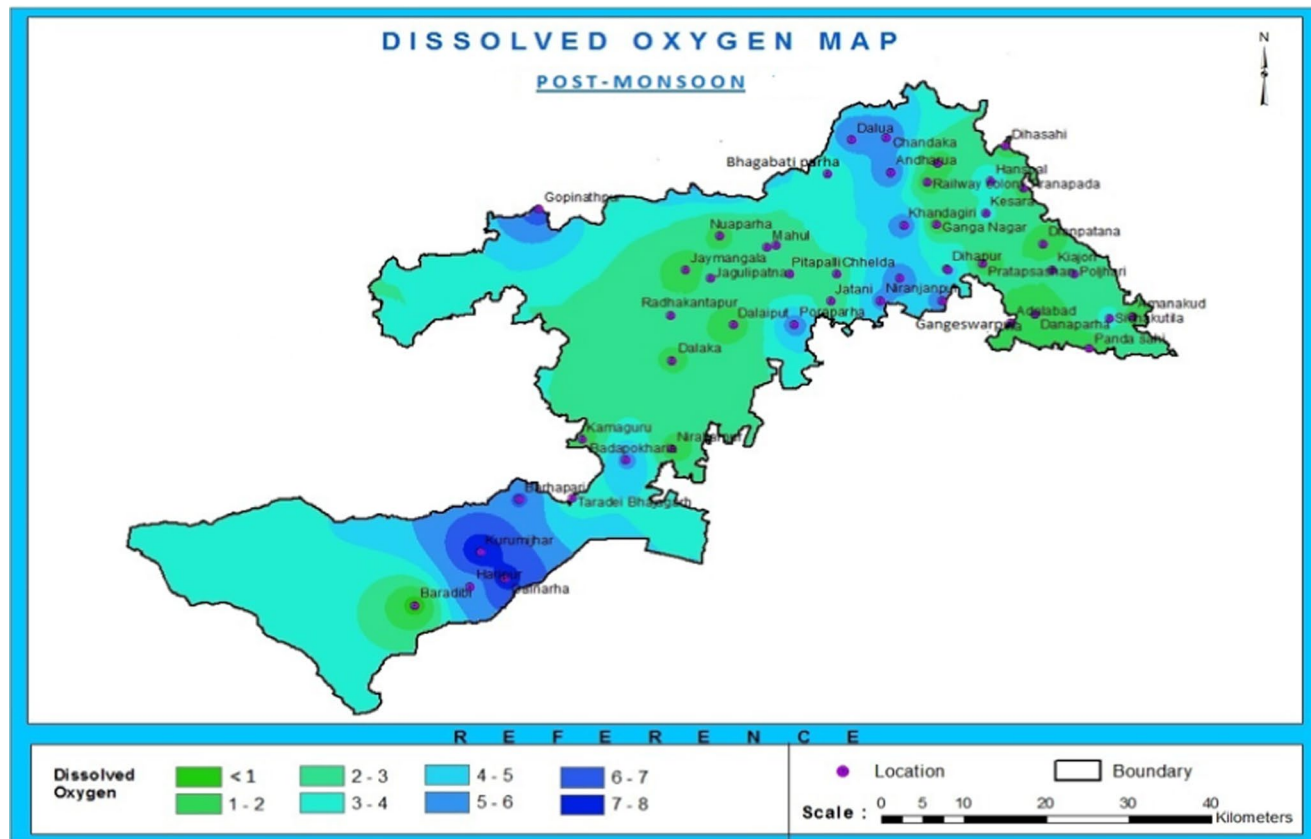


Fig. 30 Spatial distribution of DO during post-monsoon 2022

with pH, TDS, salinity, nitrate, TA, TH, calcium hardness, magnesium hardness, chloride and phosphate while a strong negative relationship with temperature, DO and fluoride as shown in Table 5 and 6.

The spatial distribution of Electrical Conductivity is done by the help of Spline interpolation by using Arc GIS 10.3 as shown in Fig. 26 during post-monsoon 2022 and Fig. 27 during pre-monsoon 2023.

4.6 Dissolved oxygen (D.O)

The D.O value ranged from maximum 6.27 mg/l at Gopinathpur to minimum of 0.42 mg/l at Baradibi during post-monsoon of 2022 where as maximum 7.87 mg/l at Kurumijhar to minimum 0.65 mg/l at Baradibi during pre-monsoon season of 2023 as shown below in Fig. 28 and Fig. 29. From the correlation matrix, DO has a strong positive relationship with temperature, nitrate, fluoride, chloride and phosphate but a strong negative relationship with pH, TDS, EC, salinity, TA, TH, calcium hardness and magnesium hardness during post-monsoon season, as shown in Table 3. During pre-monsoon season DO has a strong positive relationship with phosphate, nitrate and temperature while a strong negative relationship with pH, TDS, salinity, EC, TA, TH, calcium hardness, magnesium hardness, chloride and fluoride as shown in Table 5 and 6.

The spatial distribution of D.O is done by the help of IDW interpolation by using Arc GIS 10.3 as shown in Fig. 30 during post-monsoon 2022 and Fig. 31 during pre-monsoon 2023.

4.7 Alkalinity

The Alkalinity varied from maximum 546 mg/l of CaCO_3 at Hanspal to minimum 32 mg/l of CaCO_3 at Nirakarpur during post-monsoon season of 2022 where as it varies from maximum 600 mg/l of CaCO_3 at Hanspal and 570 mg/l of CaCO_3 at Baradibi to minimum 60 mg/l of CaCO_3 at Nirakarpur and 80 mg/l of CaCO_3 at Haripur during pre-monsoon season of 2023 as shown below in Fig. 32 and Fig. 33. From the correlation matrix, alkalinity has a strong positive relationship with TDS, salinity, EC, TH, calcium hardness, magnesium hardness, nitrate, chloride and phosphate but a strong negative

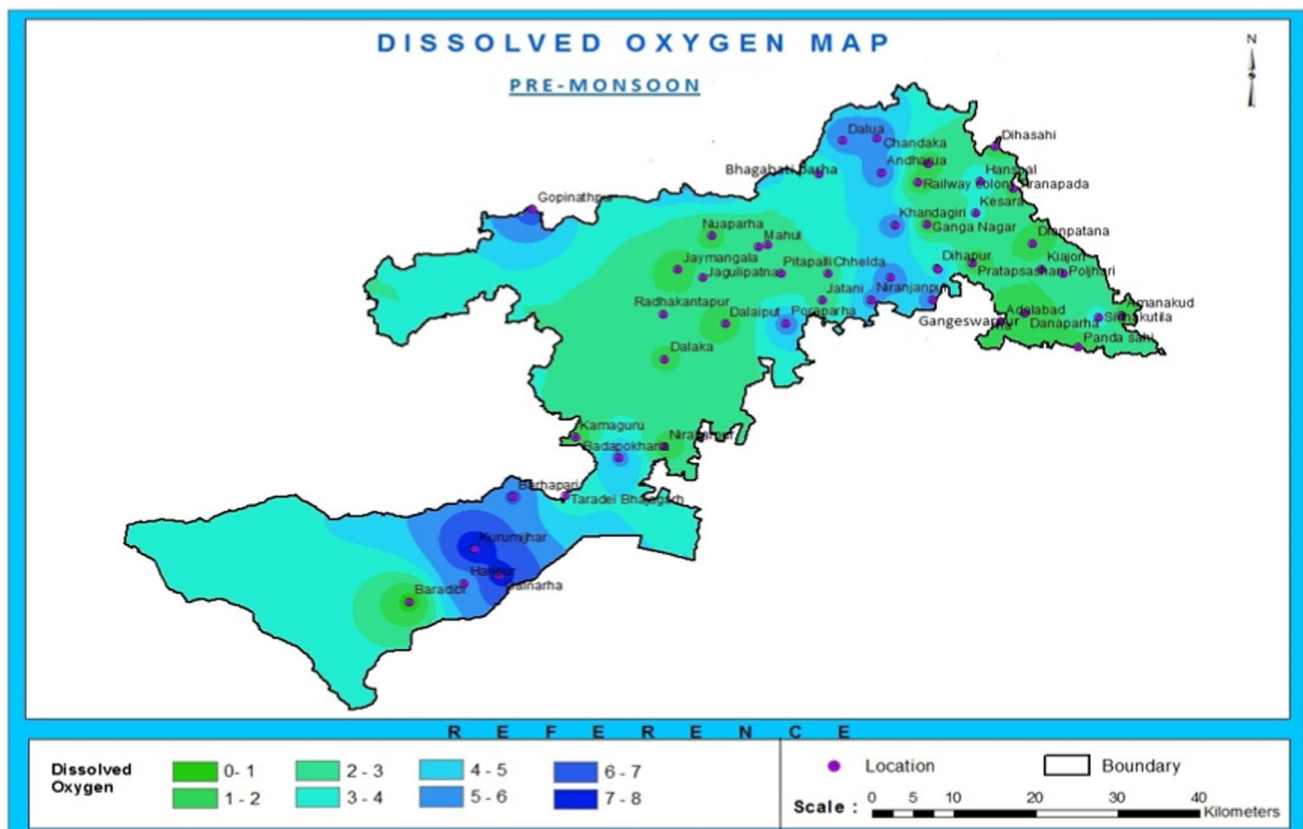


Fig. 31 Spatial distribution of DO during pre-monsoon 2023

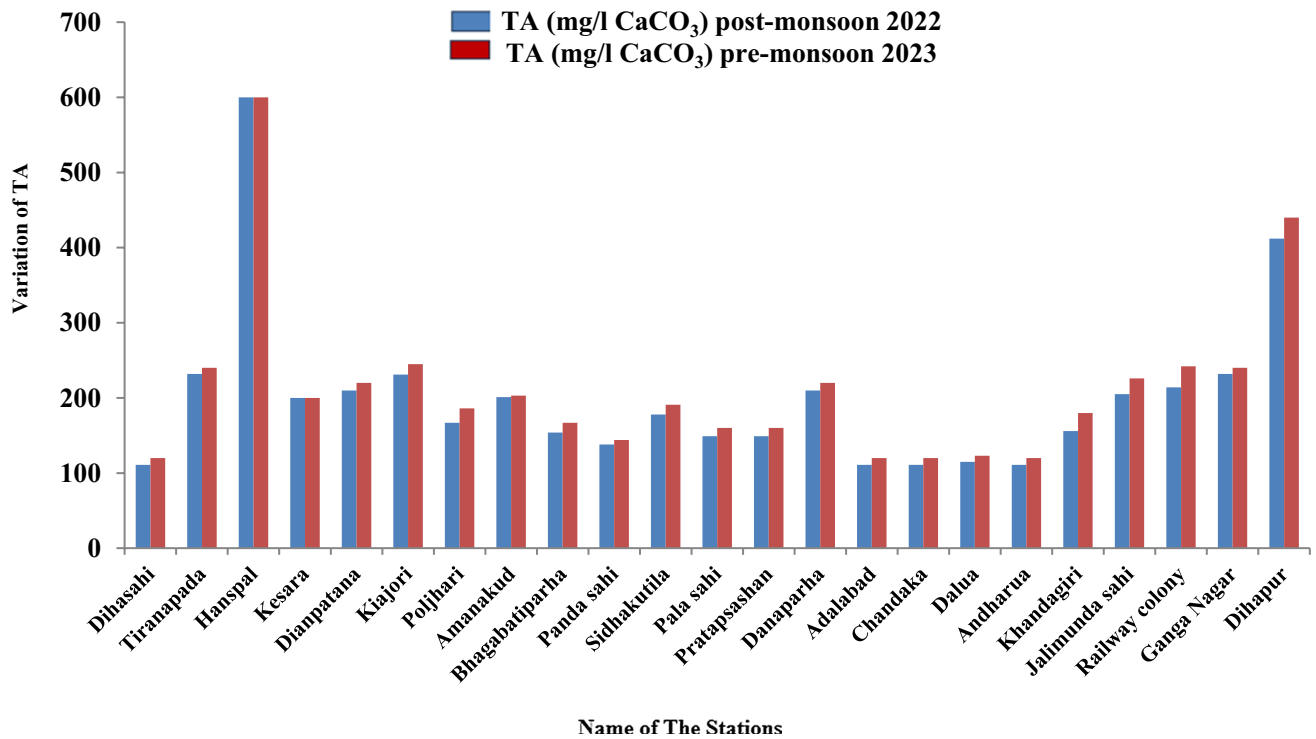


Fig. 32 Distribution of TA from Dihasahi to Dihapur

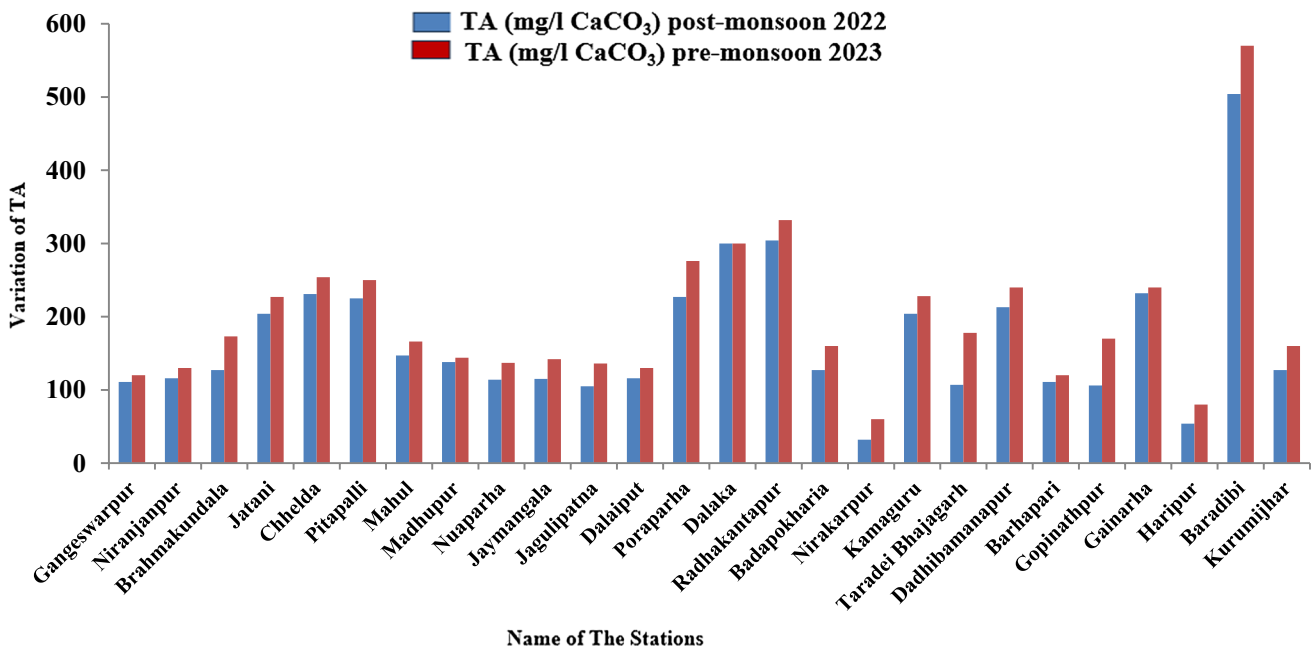


Fig. 33 Distribution of TA from Gangeswarpur to Kurumijhar

relationship with temperature, pH, DO and fluoride during post-monsoon season, as shown in Table 3. During pre-monsoon season alkalinity has a strong positive relationship with pH, EC, TDS, salinity, nitrate, TH, calcium hardness, magnesium hardness, chloride and phosphate while a strong negative relationship with temperature, DO and fluoride as shown in Table 5 and 6.

The spatial distribution of Total Alkalinity is done by the help of Spline interpolation by using Arc GIS 10.3 as shown in Fig. 34 during post-monsoon 2022 and Fig. 35 during pre-monsoon 2023.

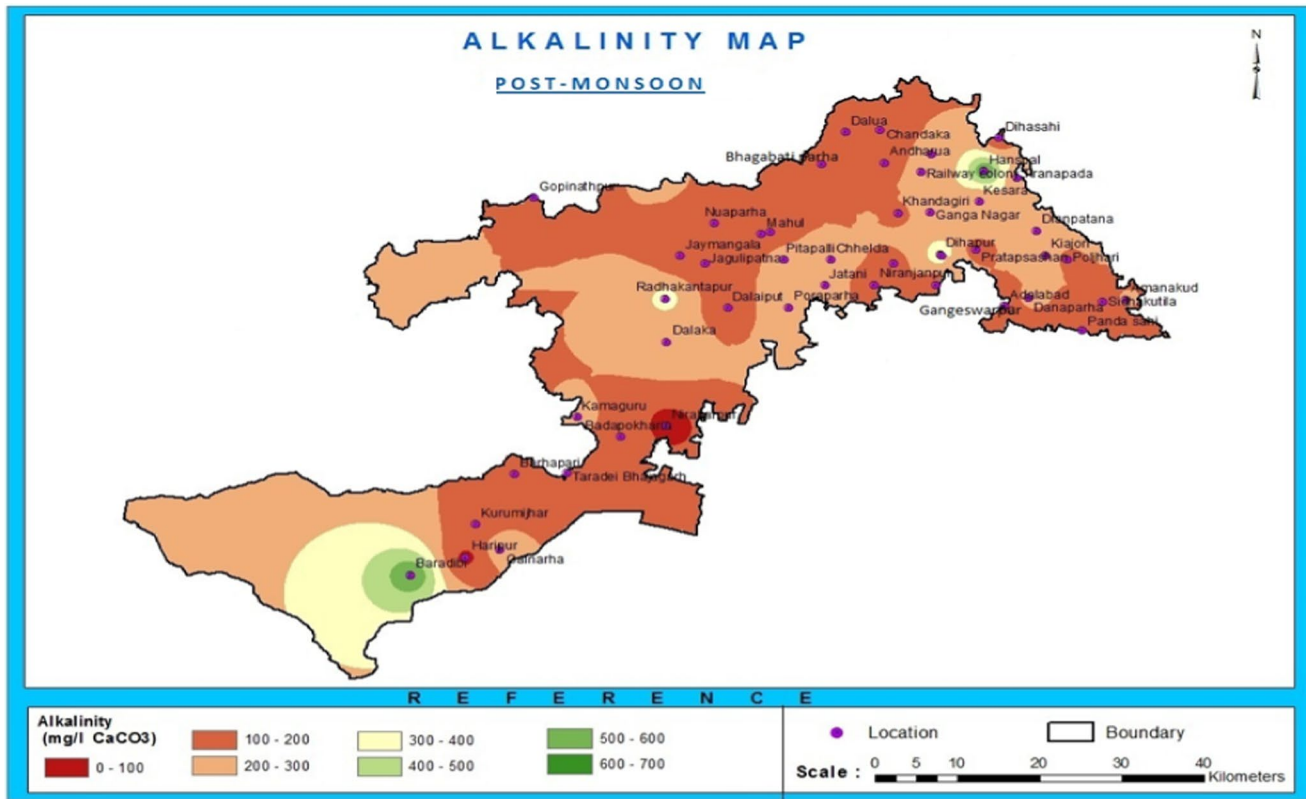


Fig. 34 Spatial distribution of Alkalinity during post-monsoon 2022

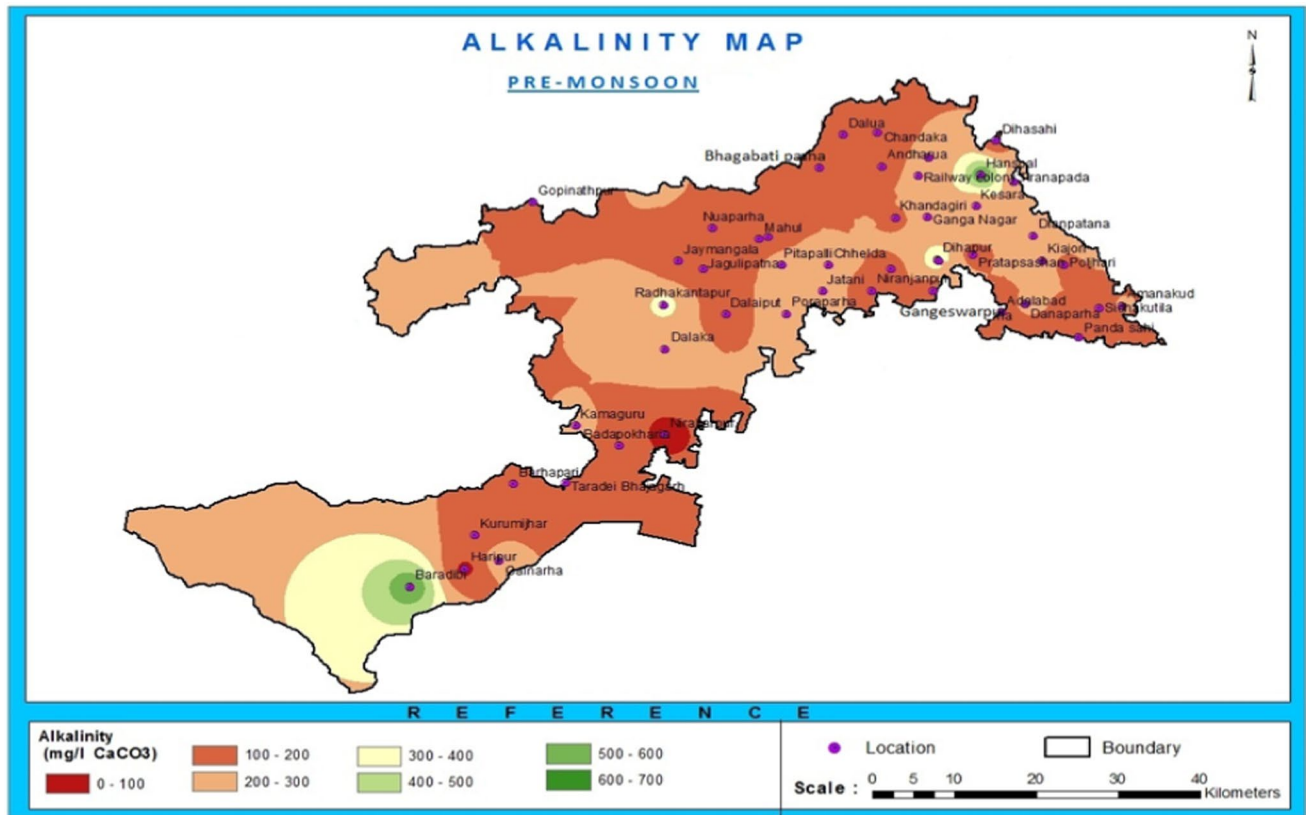


Fig. 35 Spatial distribution of Alkalinity during pre-monsoon 2023

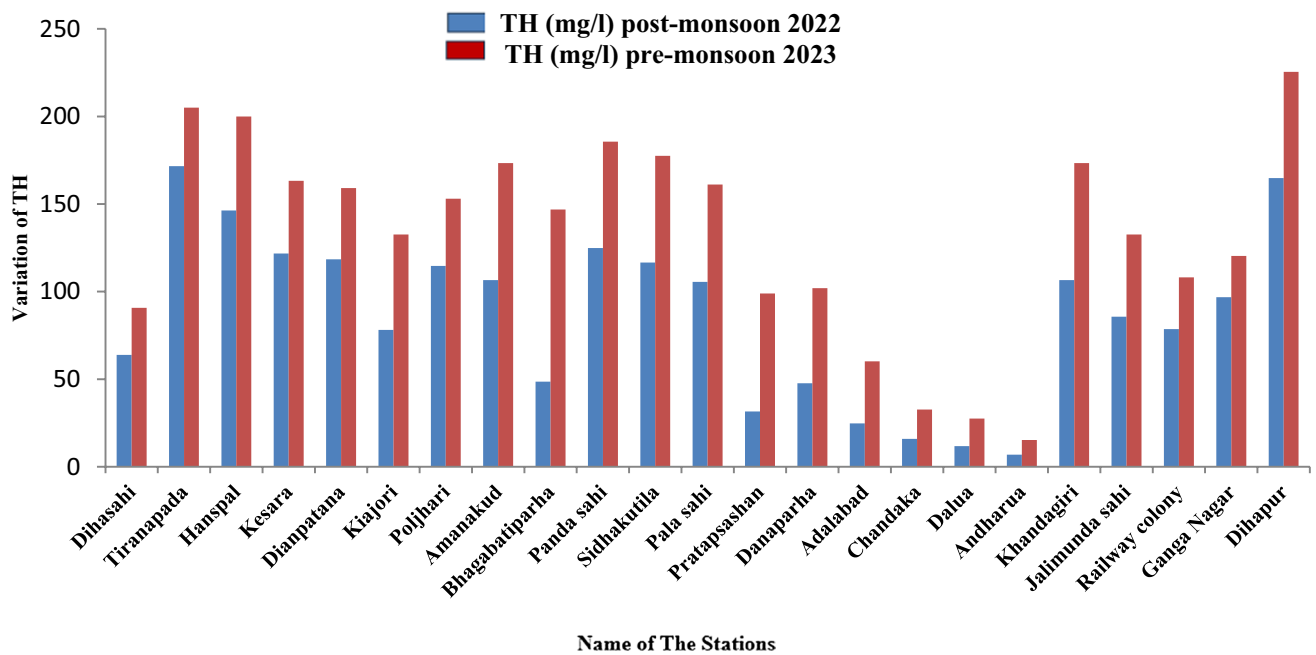


Fig. 36 Distribution of TH from Dihasahi to Dihapur

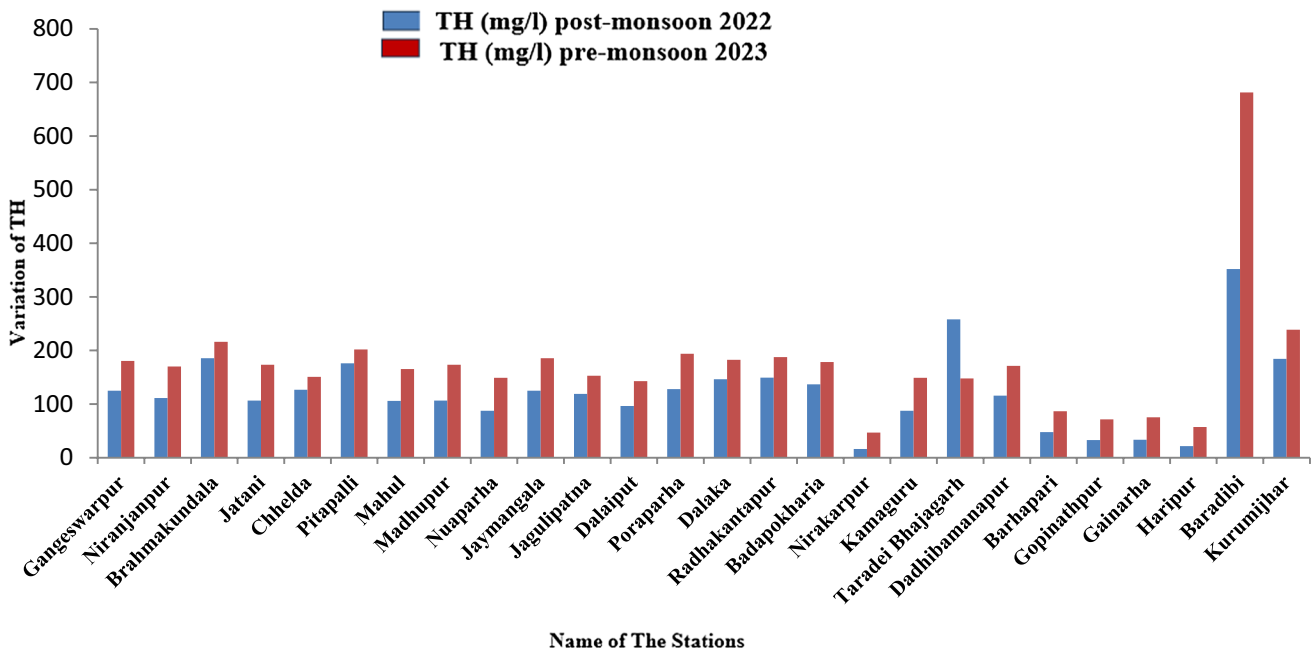


Fig. 37 Distribution of TH from Gangeswarpur to Kurumijhar

4.8 Total hardness

The Total Hardness varied from maximum 351.84 mg/l at Baradibi to minimum 6.94 mg/l at Andharua during post-monsoon season of 2022 whereas it ranges from maximum 681.36 mg/l at Baradibi to minimum 15.3 mg/l at Andharua during pre-monsoon season of 2023 as shown below in Fig. 36 and Fig. 37. From the correlation matrix, TH has a strong positive relationship with temperature, TDS, EC, salinity, nitrate, TA, calcium hardness, magnesium hardness and chloride but a strong negative relationship with pH, DO, fluoride and phosphate during post-monsoon season,

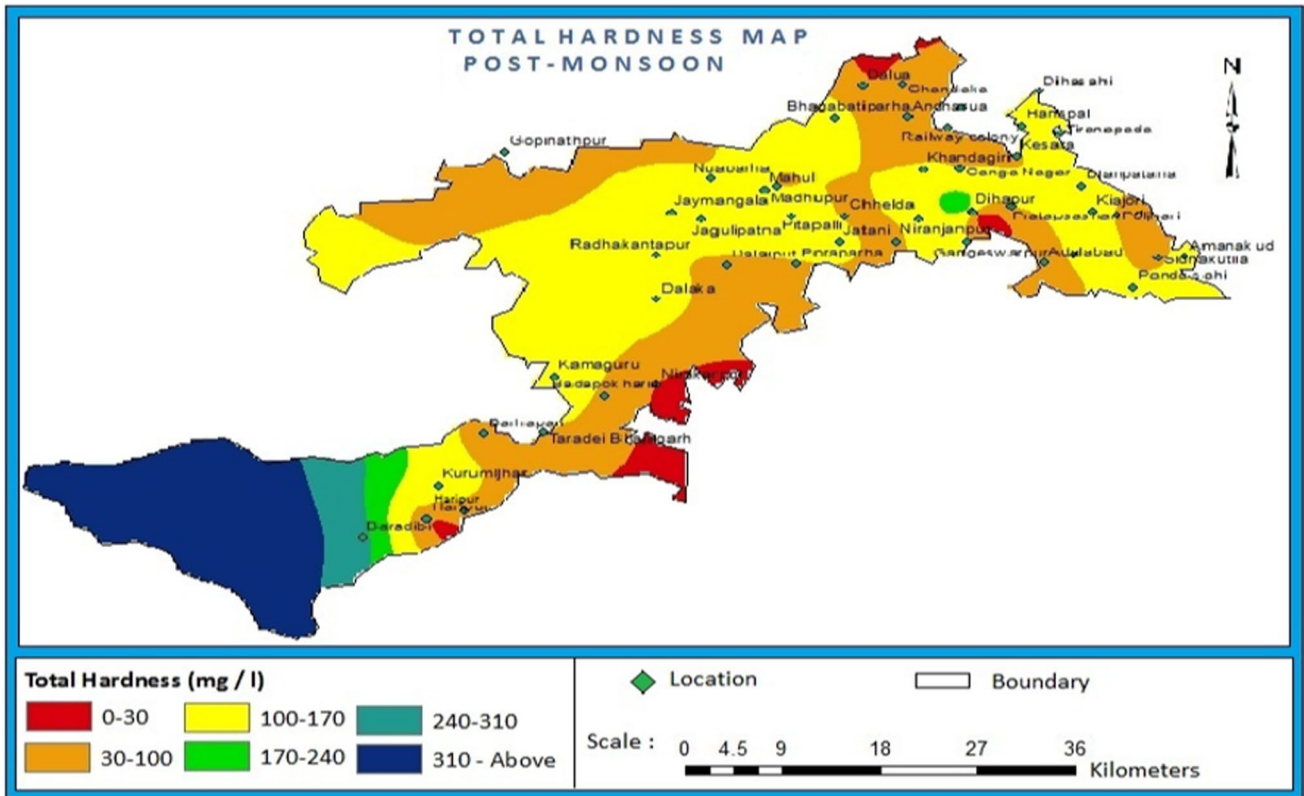


Fig. 38 Spatial distribution of TH during post-monsoon 2022

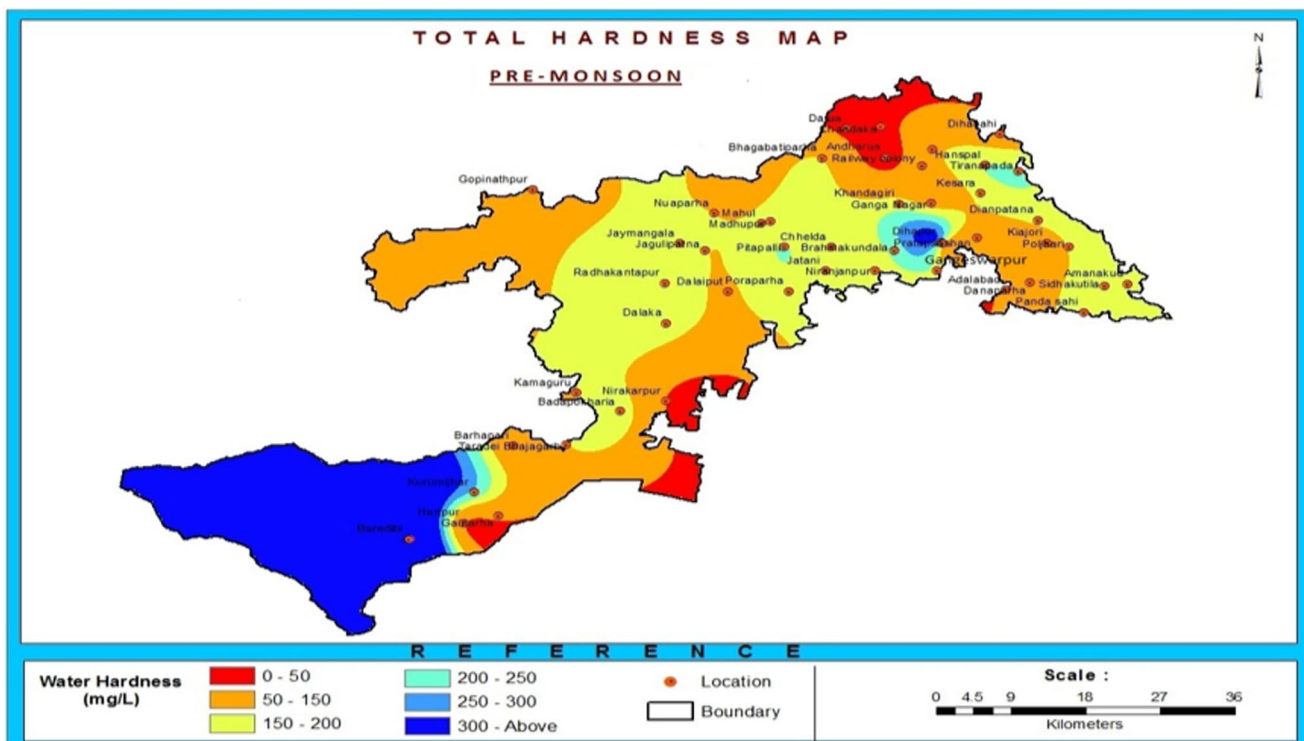


Fig. 39 Spatial distribution of TH during pre-monsoon 2023

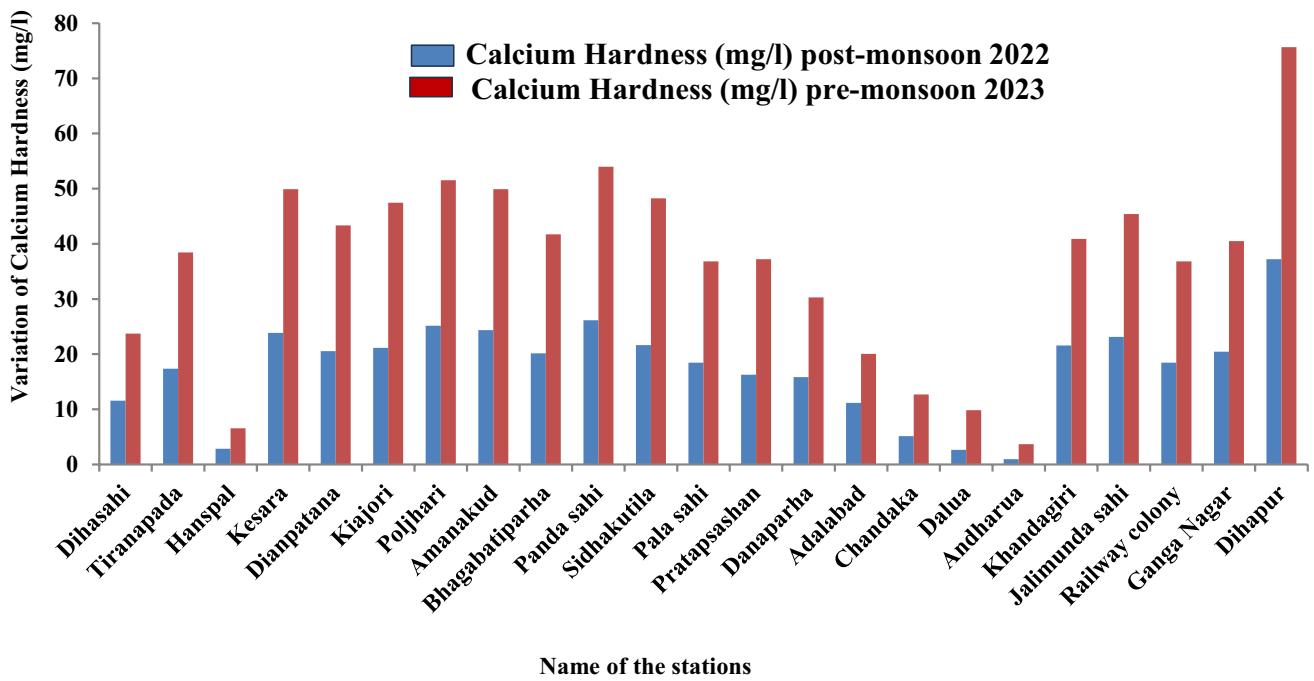


Fig. 40 Distribution of Calcium Hardness from Dihasahi to Dihapur

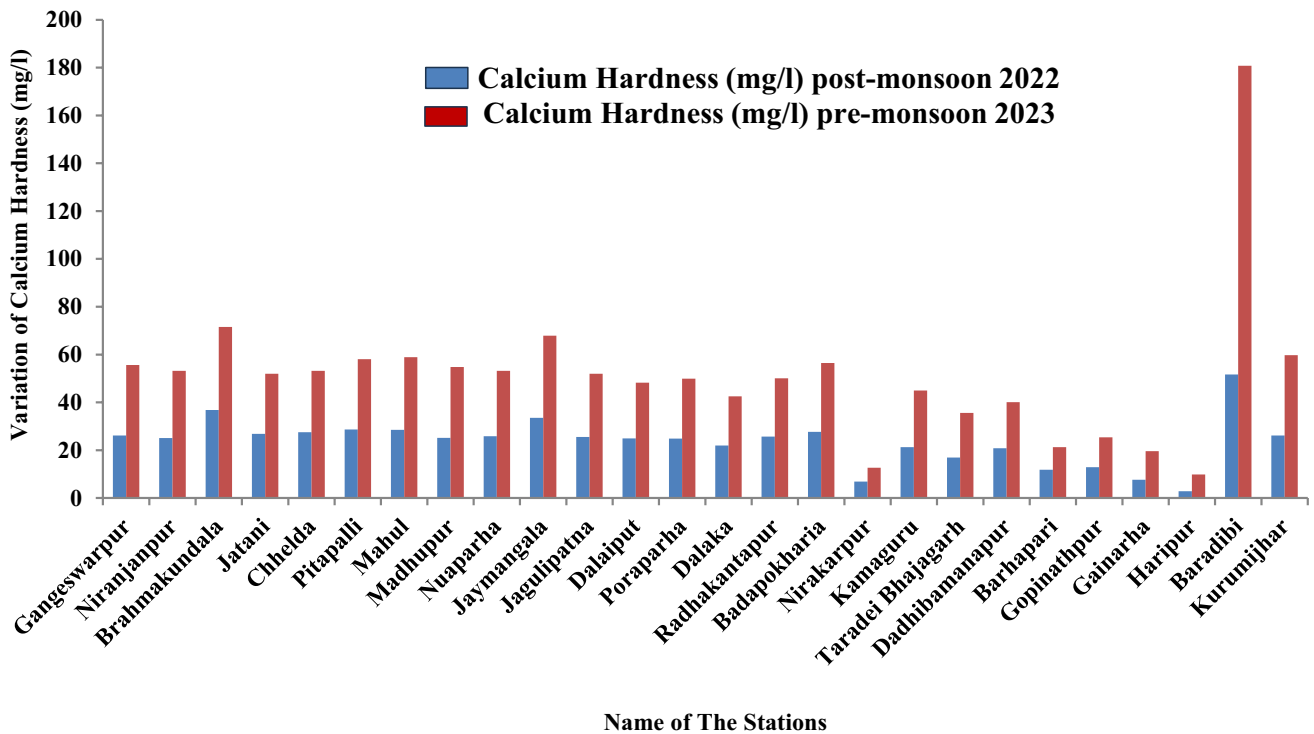


Fig. 41 Distribution of Calcium Hardness from Gangeswarpur to Kurumijhar

as shown in Table 3. During pre-monsoon season TH has a strong positive relationship with pH, temperature, TDS, EC, salinity, nitrate, TA, calcium hardness, magnesium hardness, chloride and phosphate while a strong negative relationship with DO and fluoride as shown in Table 5 and 6.

The spatial distribution of Total Hardness is done by the help of Kriging interpolation by using Arc GIS 10.3 as shown in Fig. 38 during post-monsoon 2022 and Fig. 39 during pre-monsoon 2023.

4.9 Calcium hardness

The Calcium hardness varied from maximum 51.67 mg/l at Baradibi and 37.21 mg/l at Dihapur to minimum 2.65 mg/l at Dalua, 2.84 mg/l at Hanspal, and 2.85 mg/l at Haripur during Post-monsoon season in 2022. In contrast, it varies from a maximum of 180.78 mg/l at Baradibi, 75.668 mg/l at Dihapur and 71.578 mg/l at Brahmakundala to a minimum of 3.68 mg/l at the same time Andharua and 6.54 mg/l at Hanspal mg/l at during pre-monsoon season in 2023 as shown below in Fig. 40 and Fig. 41. From the correlation matrix, calcium hardness has a strong positive relationship with temperature, salinity, EC, TDS, TA, TH, magnesium hardness and chloride. Still, it has a strong negative relationship with pH, DO, nitrate, fluoride and phosphateduring the post-monsoon season, as shown in above Table 3. During pre-monsoon season, calcium hardness has a strong positive relationship with pH, temperature, salinity, EC, TDS, TA, nitrate, TH, magnesium hardness and chloride. Still, it has a strong negative relationship with DO, fluoride and phosphate as shown in above Table 5 and 6.

The spatial distribution of Calcium Hardness is done with the help of IDW interpolation by using Arc GIS 10.3 as shown in Fig. 42 during post-monsoon 2022 and Fig. 43 during pre-monsoon 2023.

4.10 Magnesium hardness

The Magnesium hardness varied from maximum 300.17 mg/l at Baradibi and 241.22 mg/l at TaradeiBhajagarh to minimum 9.17 mg/l at Dalua and 9.5 mg/l at Nirakarpur during post-monsoon season in 2022, where as it varies from maximum 500.57 mg/l at Baradibi to minimum 11.62 mg/l at Andharua during pre-monsoon season in 2023 as shown below in Fig. 44 and Fig. 45. From the correlation matrix, magnesium hardness has a strong positive relationship with temperature, EC, salinity, TDS, TA, TH, calcium hardness, nitrate and chloride. Still, it has a strong negative relationship with pH, DO, fluoride and phosphate during the post-monsoon season, as shown in above Table 3. During pre-monsoon season, magnesium hardness has a strong positive relationship with pH, EC, salinity, TDS, TA, TH, calcium hardness,

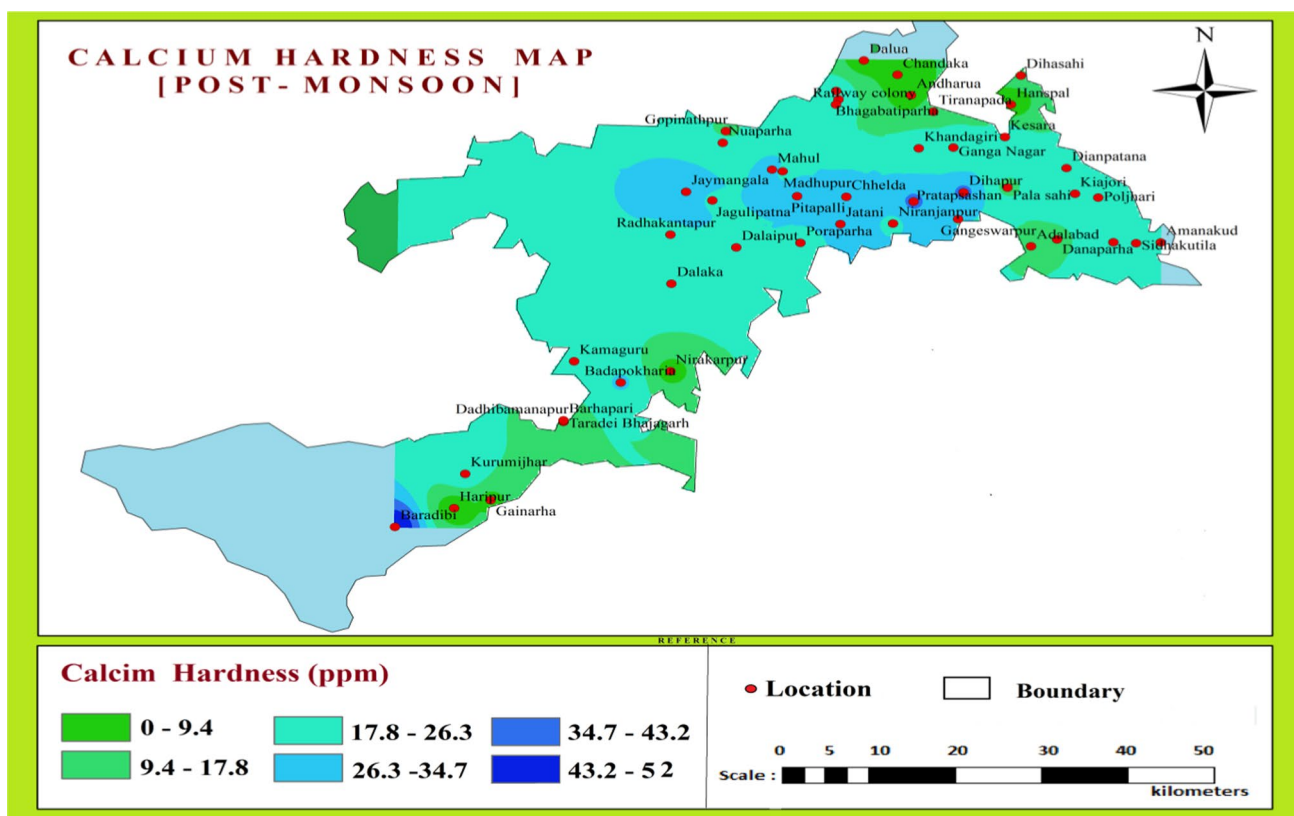


Fig. 42 Spatial distribution of Calcium Hardness during post-monsoon 2022

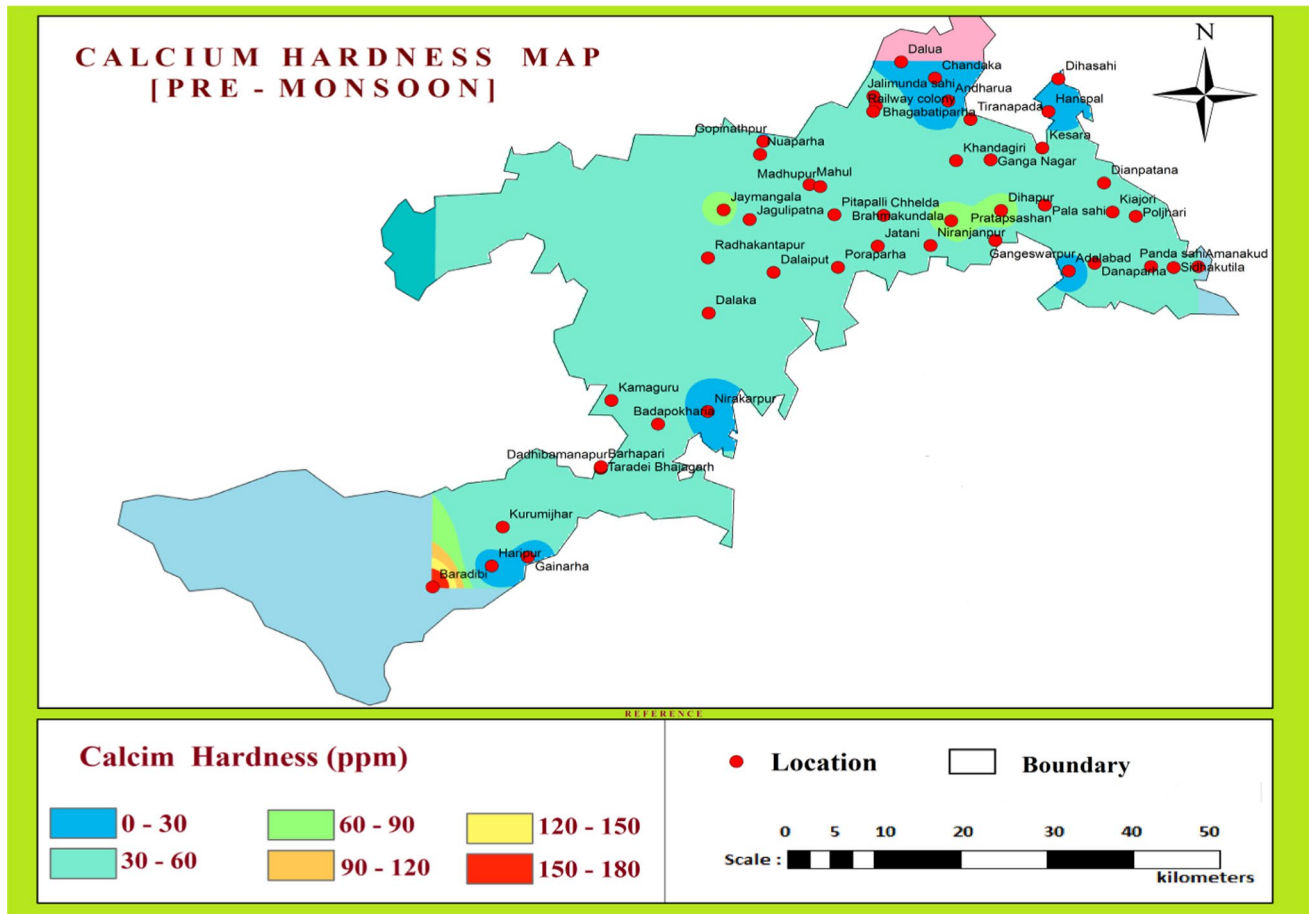


Fig. 43 Spatial distribution of Calcium Hardness during pre-monsoon 2023

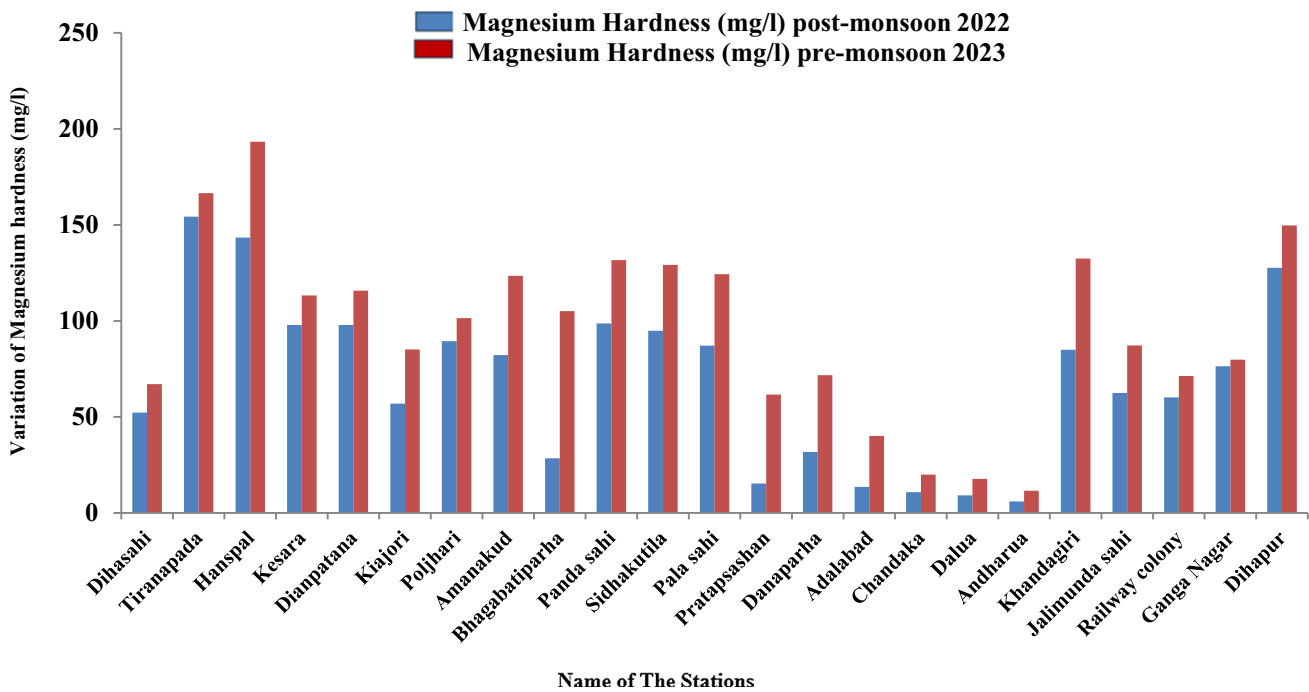


Fig. 44 Distribution of Magnesium hardness from Dihasahi to Dihapur

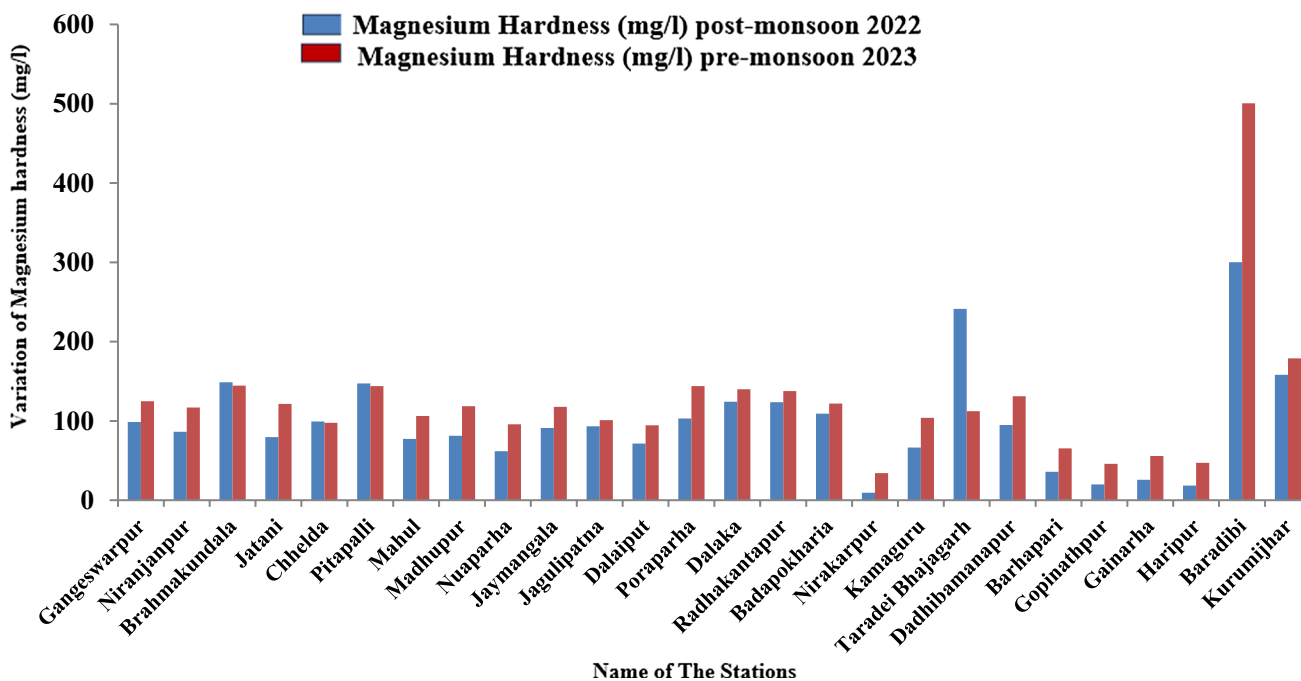


Fig. 45 Distribution of Magnesium hardness from Gangeswarpur to Kurumijhar

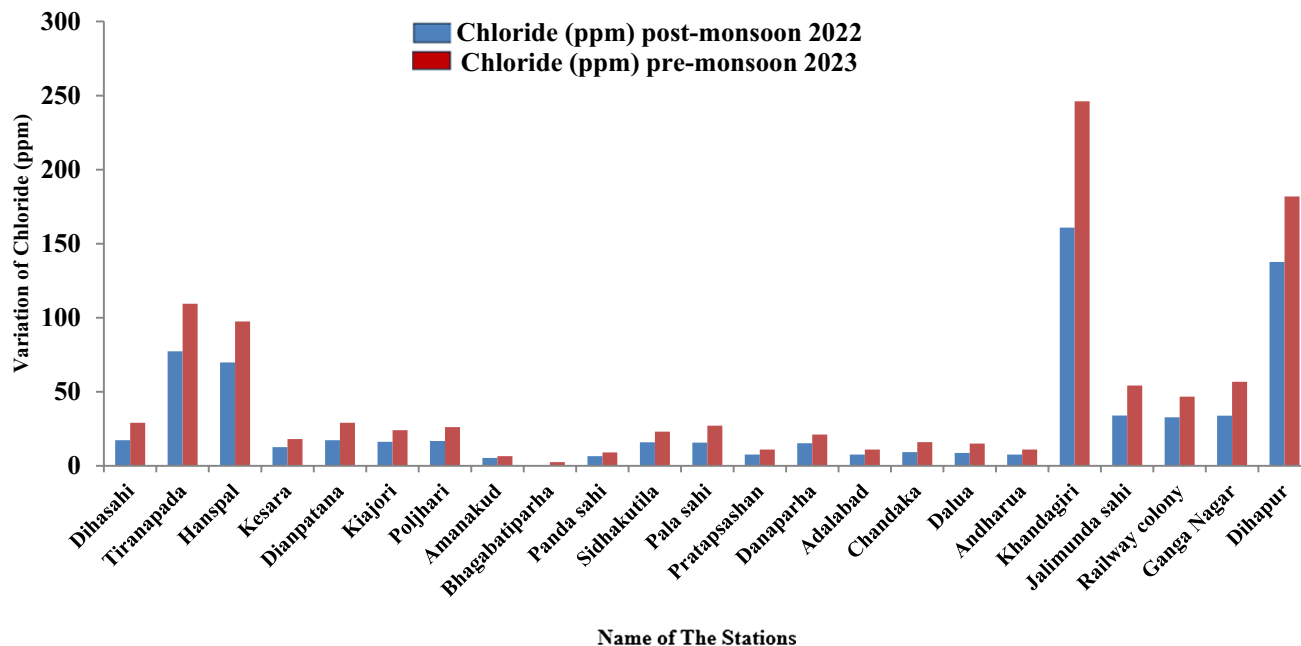


Fig. 46 Distribution of chloride from Dihasahi to Dihapur

nitrate, chloride and phosphate. Still, it has a strong negative relationship with temperature, DO and fluoride, as shown in above Table 5 and 6.

4.11 Chloride

The Chloride varied from maximum 190.46 ppm at Baradibi and 160.84 ppm at Khandagiri to minimum 0.17 ppm at Bhagabatiparha during post-monsoon season in 2022 where as it varies from maximum 480.22 ppm at Baradibi to minimum 2.51 ppm at Bhagabatiparhaduring pre-monsoon season in 2023 as shown below in Fig. 46 and Fig. 47.. From

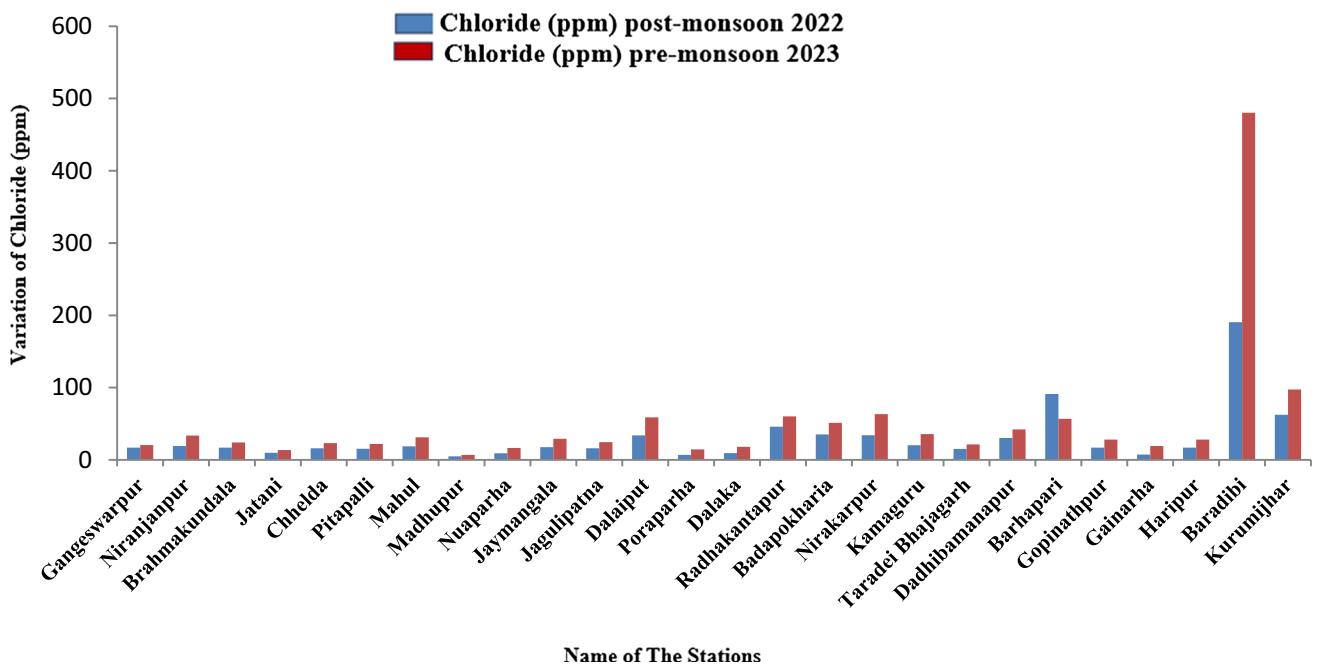


Fig. 47 Distribution of chloride from Gangeswarpur to Kurumijhar

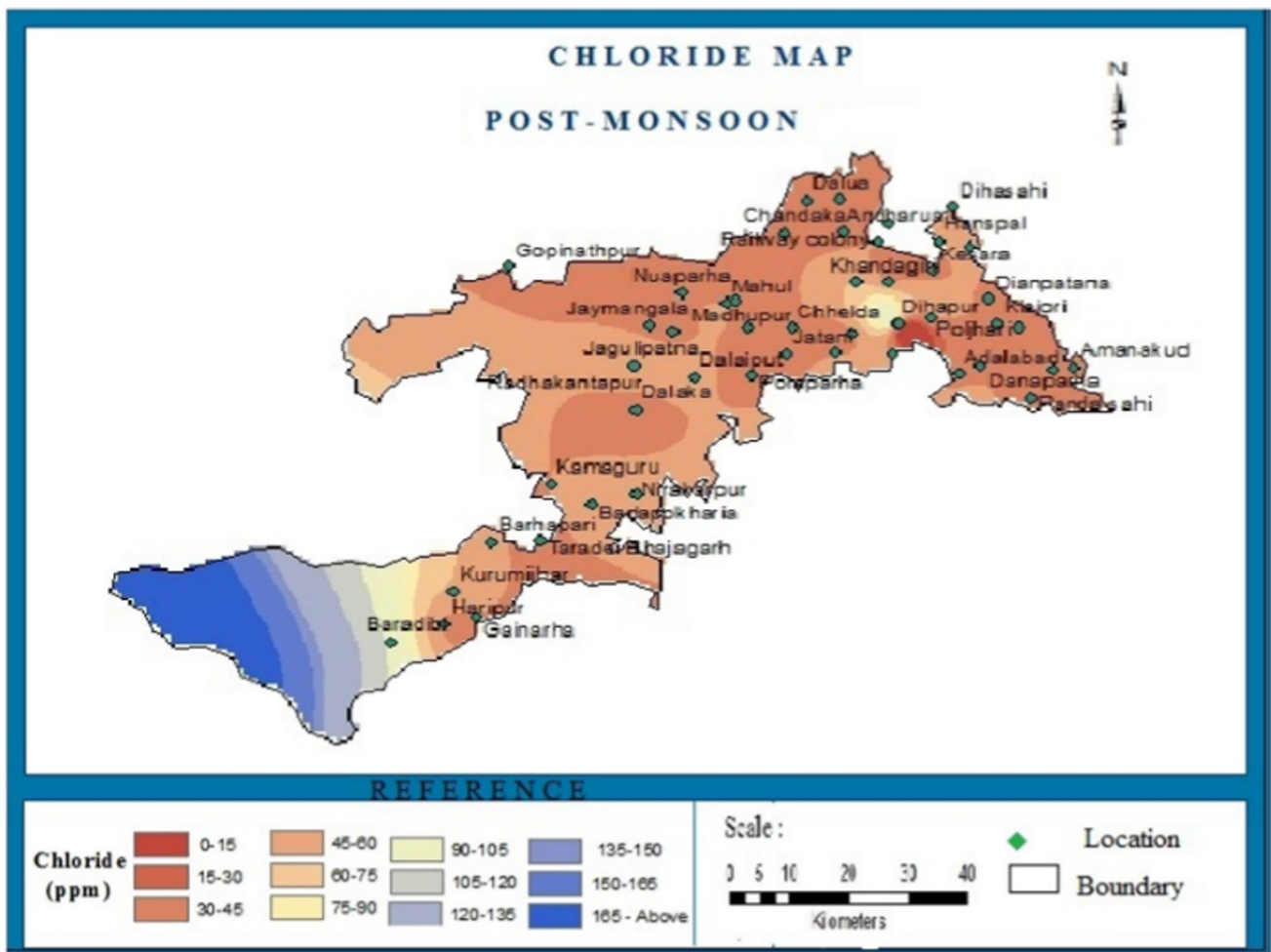


Fig. 48 Spatial distribution of Chloride during post-monsoon 2022

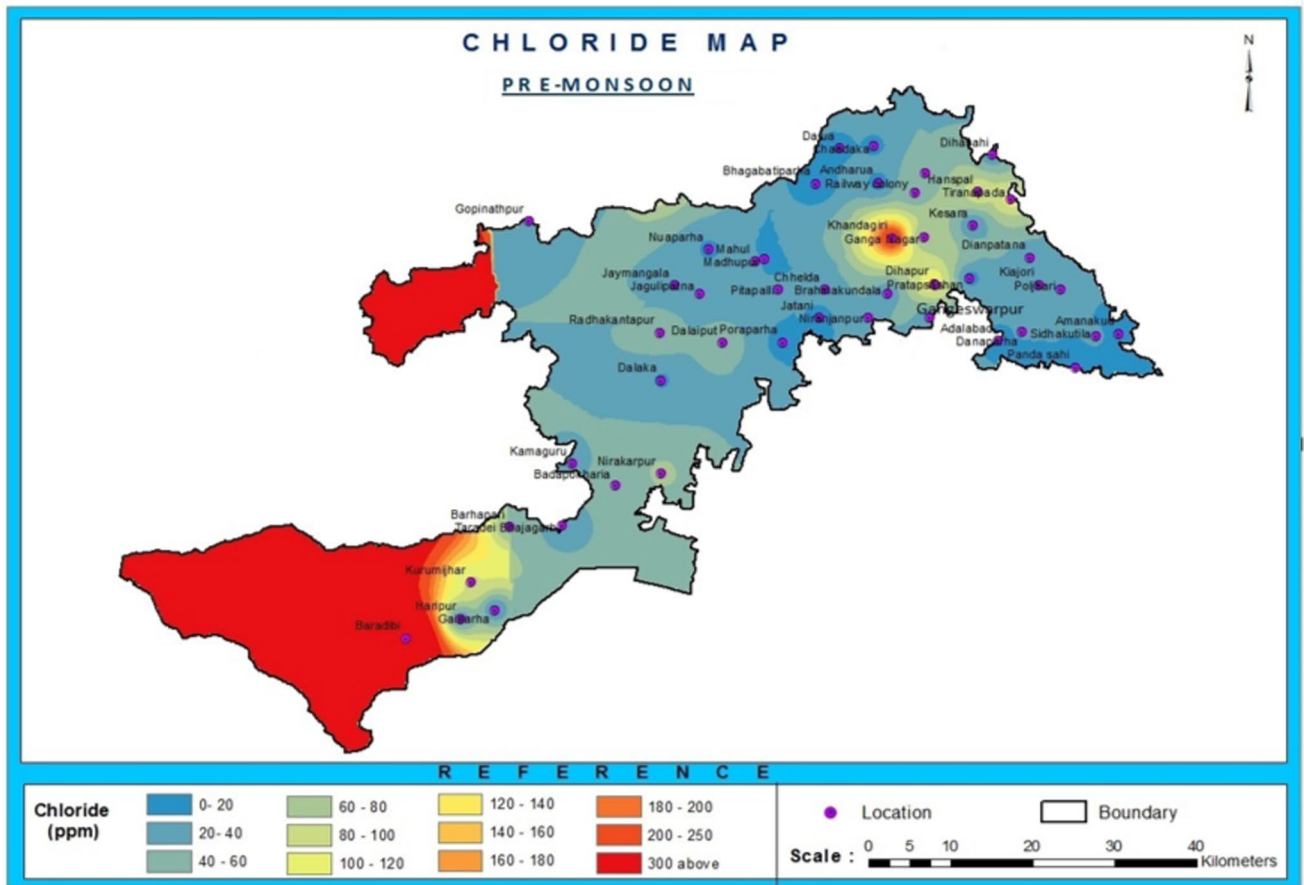


Fig. 49 Spatial distribution of Chloride during pre-monsoon 2023

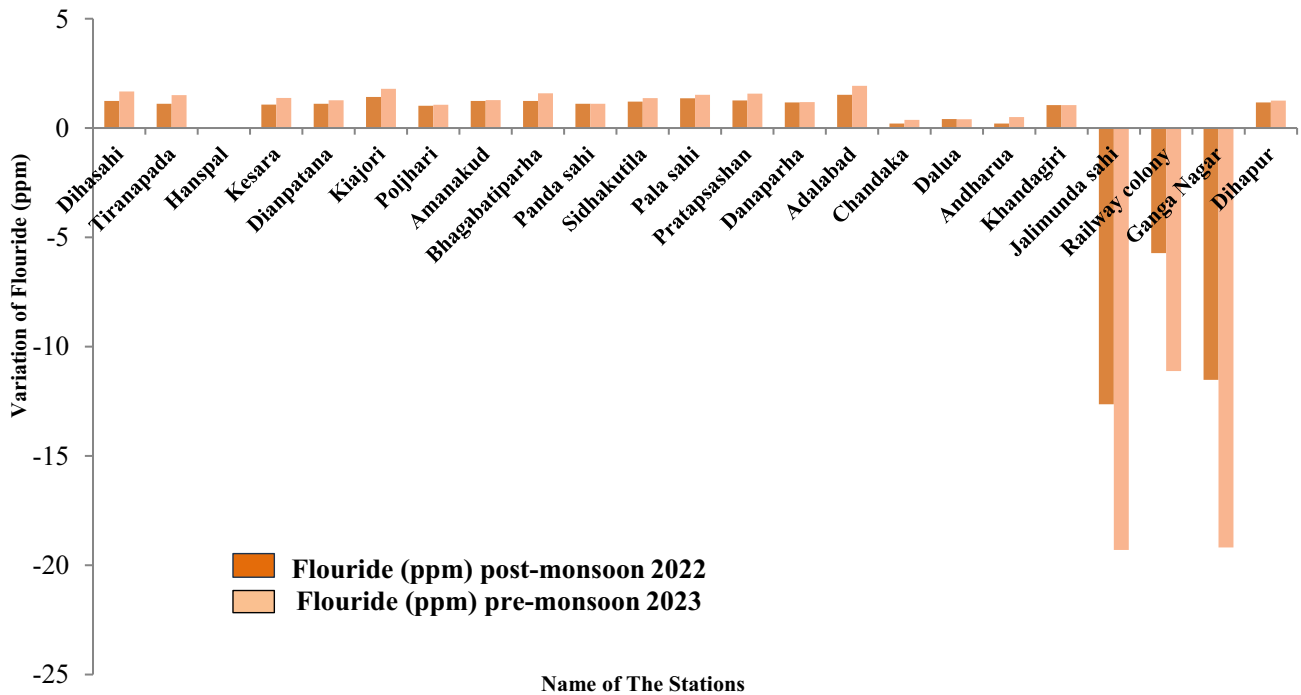


Fig. 50 Distribution of flouride from Dihasahi to Dihapur

the correlation matrix, chloride has a strong positive relationship with temperature, TDS, EC, salinity, DO, TA, TH, calcium hardness, magnesium hardness and nitrate and has a strong negative relationship with pH, fluoride and phosphate during the post-monsoon season, as shown in above Table 3. During pre-monsoon season, chloride has a strong positive relationship with temperature, TDS, EC, salinity, TA, TH, calcium hardness, magnesium hardness, nitrate and phosphate and has a strong negative relationship with pH, fluoride and DO as shown in above Table 5 and 6.

The spatial distribution of Chloride is done by the help of Kriging interpolation by using Arc GIS 10.3 as shown in Fig. 48 during post-monsoon 2022 and Fig. 49 during pre-monsoon 2023.

4.12 Fluoride

Fluoride varied from maximum 1.52 ppm at Adalabad to minimum-12.64 ppm at JalimundaSahi during post-monsoon season of 2022 while it ranges from maximum 1.3382 ppm at Adalabad and 1.977 ppm at Niranjanpur to minimum-19.301 ppm at JalimundaSahi and-19.1911 ppm at Ganga Nagar during pre-monsoon season of 2023 as shown below in Fig. 50 and Fig. 51. In this research work, most of the samples contains less amount of fluoride content. The correlation matrix shows that fluoride has a strong positive relationship with temperature and DO & strong negative relationship with pH, EC, TDS, salinity, TA, TH, calcium hardness, magnesium hardness, nitrate, phosphate and chloride during post-monsoon season, as shown in Table 3. During pre-monsoon season, fluoride has a strong positive relationship with pH and phosphate while a strong negative relationship with temperature, DO, EC, TDS, salinity, TA, TH, calcium hardness, magnesium hardness, nitrate, chloride as shown in Table 5 and 6.

The spatial distribution of fluoride is done with the help of IDW interpolation during post-monsoon 2022 as shown in Fig. 52 and during pre-monsoon 2023 as shown in Fig. 53 by using Arc GIS 10.3.

4.13 Phosphate

Phosphate varied from maximum 0.56 ppm at Chandaka to a minimum 0.0031 ppm at Badapokharia and 0.0035 ppm at Brahmakundala during post-monsoon season of 2022, while it ranges from maximum 1.021626 ppm at Chandaka to a minimum 0.00892 ppm at Dianpatana during pre-monsoon season of 2023, as shown in Fig. 54 and Fig. 55. From the correlation matrix, phosphate has a very strong positive relationship with pH, DO and TA. Still, it has a very strong negative relationship with temperature, calcium, hardness magnesium hardness, salinity, nitrate, phosphate, TDS, TH, EC,

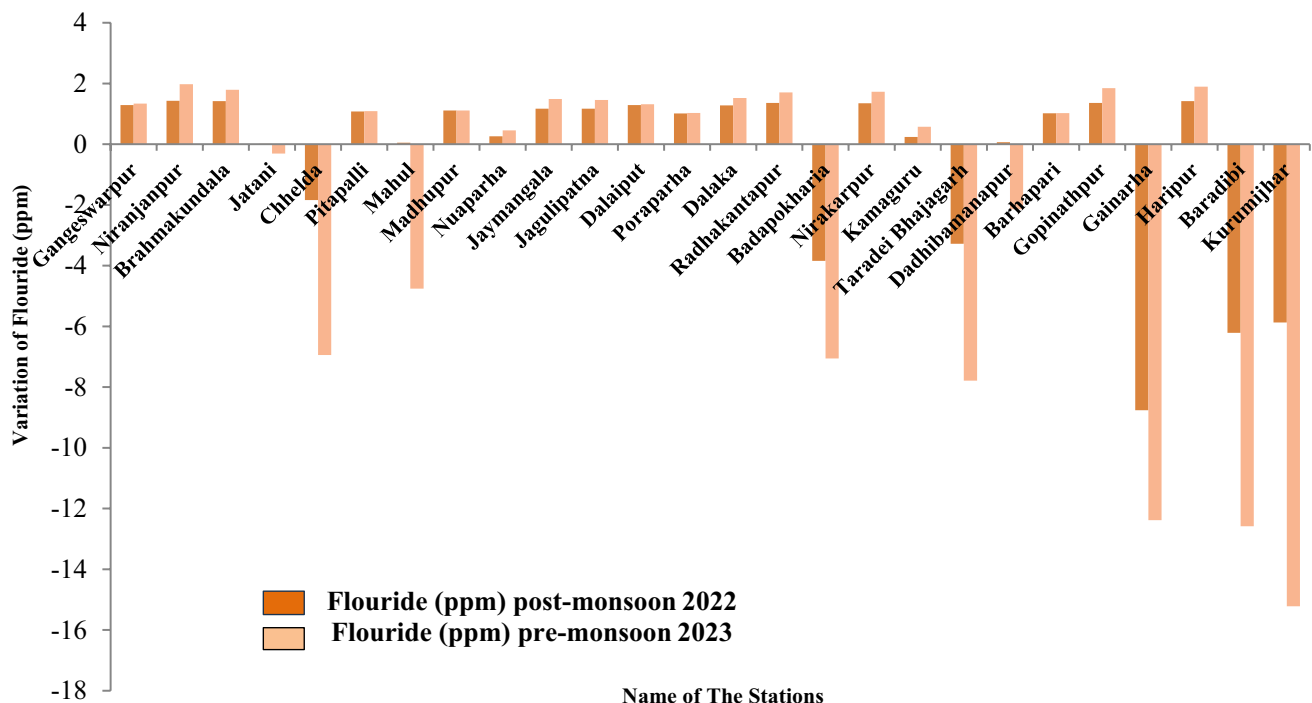


Fig. 51 Distribution of fluoride from Gangeswarpur to Kurumijhar

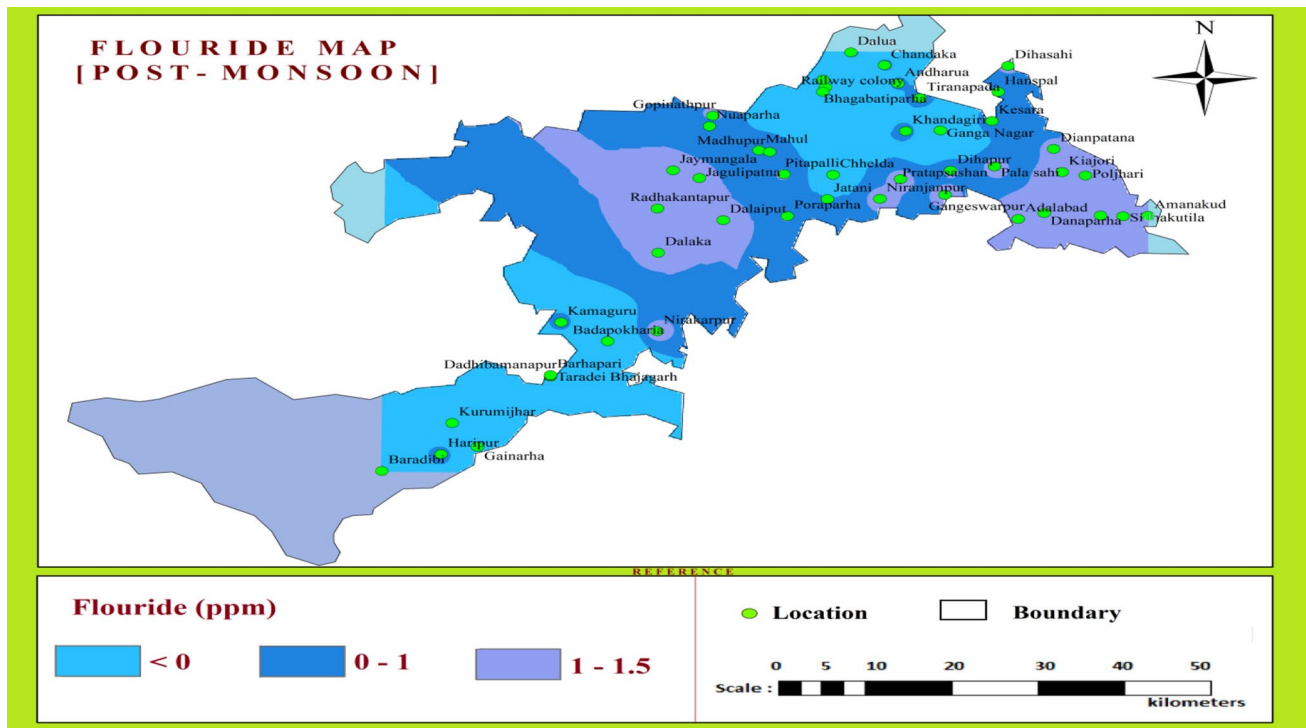


Fig. 52 Spatial distribution of Fluoride during post-monsoon 2022

chloride and fluoride during post-monsoon season, as shown in Table 3. During pre-monsoon season, phosphate has a strong positive relationship with salinity, TDS, EC, DO, nitrate, TA, TH, calcium hardness, magnesium hardness, phosphate, chloride and fluoride while it has a strong negative relationship with temperature, pH and calcium hardness, as shown in Table 5 and 6.

The spatial distribution of fluoride is done by the help of IDW interpolation during post-monsoon 2022 as shown in Fig. 56 and during pre-monsoon 2023 as shown in Fig. 57 by using Arc GIS 10.3.

4.14 Nitrate

The Nitrate varied from maximum 14.64 ppm at Kurumijhar, 13.76 ppm at Khandagiri and 10.51 ppm at Hanspal to minimum 0.0095 ppm at Sidhakutilla, 0.01 ppm at Madhupur, 0.01 ppm at Dalaiput and 0.01 ppm at Gainarha during post-monsoon season in 2022, where as it varies from maximum 14.50 ppm at Kurumijhar and 10.32 ppm at Hanspal to minimum -0.0642 ppm at Sidhakutilla, -0.00859 ppm at Madhupur, -0.04705 ppm at Dalaiput and -0.08959 at Gainarha during pre-monsoon in 2023 as shown below in Fig. 58 and Fig. 59. From the correlation matrix, nitrate has a very strong positive relationship with pH, TDS, salinity, DO, TH, nitrate, magnesium hardness, chloride and TA. Still, it has a very strong negative relationship with temperature, calcium hardness, phosphate and fluoride during post-monsoon season, as shown in Table 3. During pre-monsoon season, nitrate has a strong positive relationship with salinity, TDS, EC, DO, TA, TH, calcium hardness, magnesium hardness, phosphate and chloride while it has a strong negative relationship with temperature, pH and fluoride as shown in Table 5 and 6.

The spatial distribution of Nitrate is done by the help of Spline interpolation by using Arc GIS 10.3 as shown in Fig. 60 during post-monsoon 2022 and Fig. 61 during pre-monsoon 2023.

4.15 Ground water quality index

Using the weighted arithmetic water quality index, the GWQI was calculated. In this project work, it is evaluated that rating for WQI, in some of the areas is of very excellent quality during post-monsoon 2022 and pre-monsoon 2023. It is also found out that some of the areas of Khordha contain groundwater which is unsuitable for drinking, so further research should be carried out in those areas where the water is unsuitable for drinking as shown below in Fig. 62 and Fig. 63.

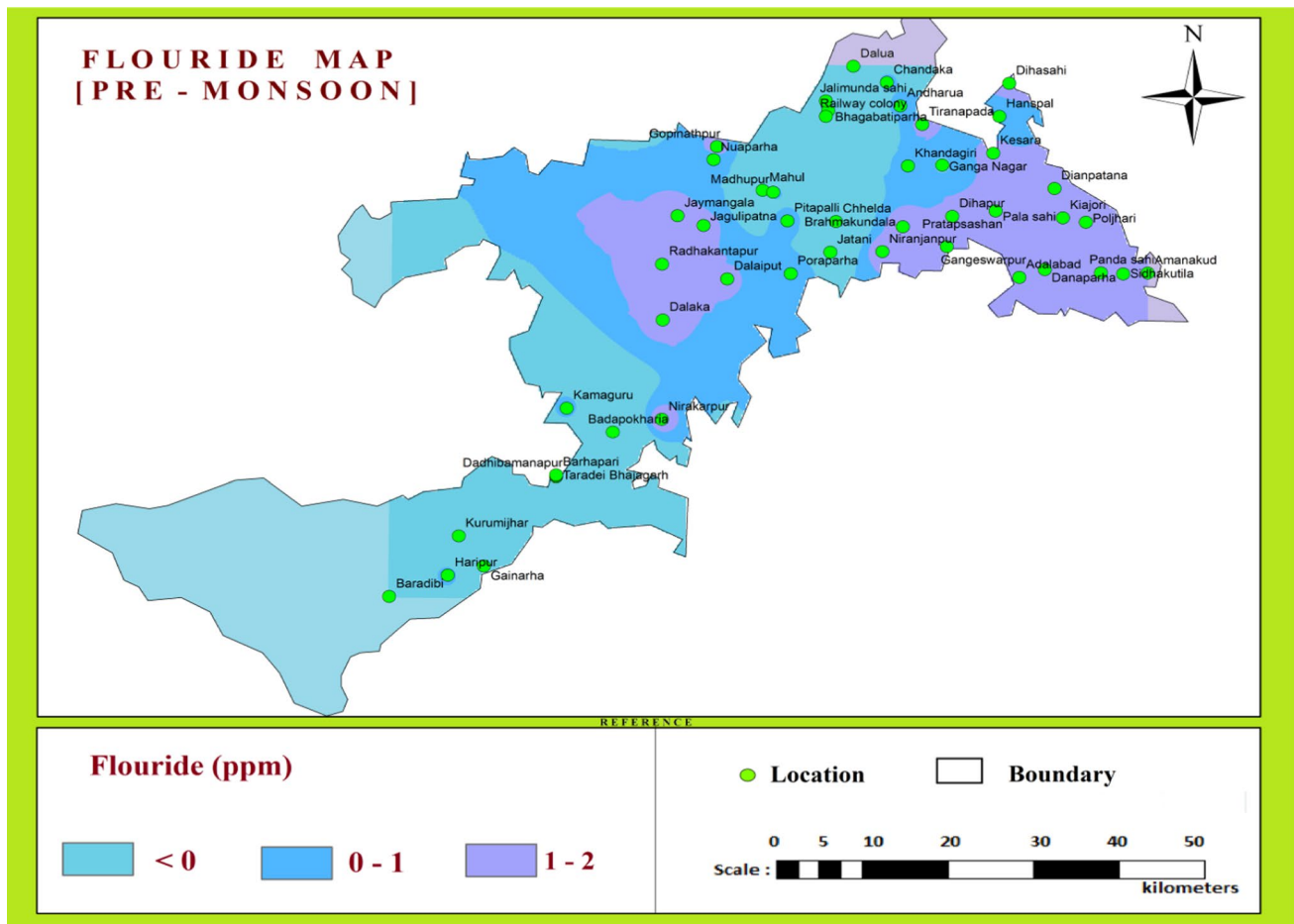


Fig. 53 Spatial distribution of Flouride during pre-monsoon 2023

The spatial distribution of GWQI is done with the help of IDW interpolation by using Arc GIS 10.3 as shown in Fig. 64 during post-monsoon 2022 and Fig. 65 during pre-monsoon 2023 Table 7.

5 Discussion

Globally, the most important groundwater resources have come under a large risk because of extreme increase in inhabitants, current land-use applications (industrial and agricultural), and water supply demands that cause danger to both the quantity and quality of water. Therefore, assessment and monitoring of groundwater quality are significant to guarantee sustainable safe usage of these resources for different purposes. On the other hand, defining the condition of water quality is challenging because of spatial changeability of numerous pollutants and broad variety of indices (physical, biological and chemical). These indicators provide an approach to review the conditions of water quality in such a way that it can be undoubtedly transferred to all the audiences. It can assist to appreciate if the quality of groundwater body possesses a possible danger to different usages of water, cross-check and balance aquifer susceptibility assessment, and specify success in remediation and protection efforts. Areas where quality of groundwater is low can then be targeted for more thorough analysis. This proposed work can offer a comparative assessment regarding variability of groundwater quality on basis of usually accessible groundwater quality data. Based on widely accessible groundwater quality data (e.g., major anions and cations), the suggested groundwater quality index can, in general, offer a relative assessment of the variability of water quality. Nonetheless, the issue of groundwater quality in any location may always be addressed by incorporating particularly significant water quality indicators for the surrounding ecosystem. Additionally, an impartial and objective depiction of the total groundwater quality is made possible by choosing the best possible combination of the relevant parameters that determine how variable the quality of the groundwater is. Groundwater quality is a problem

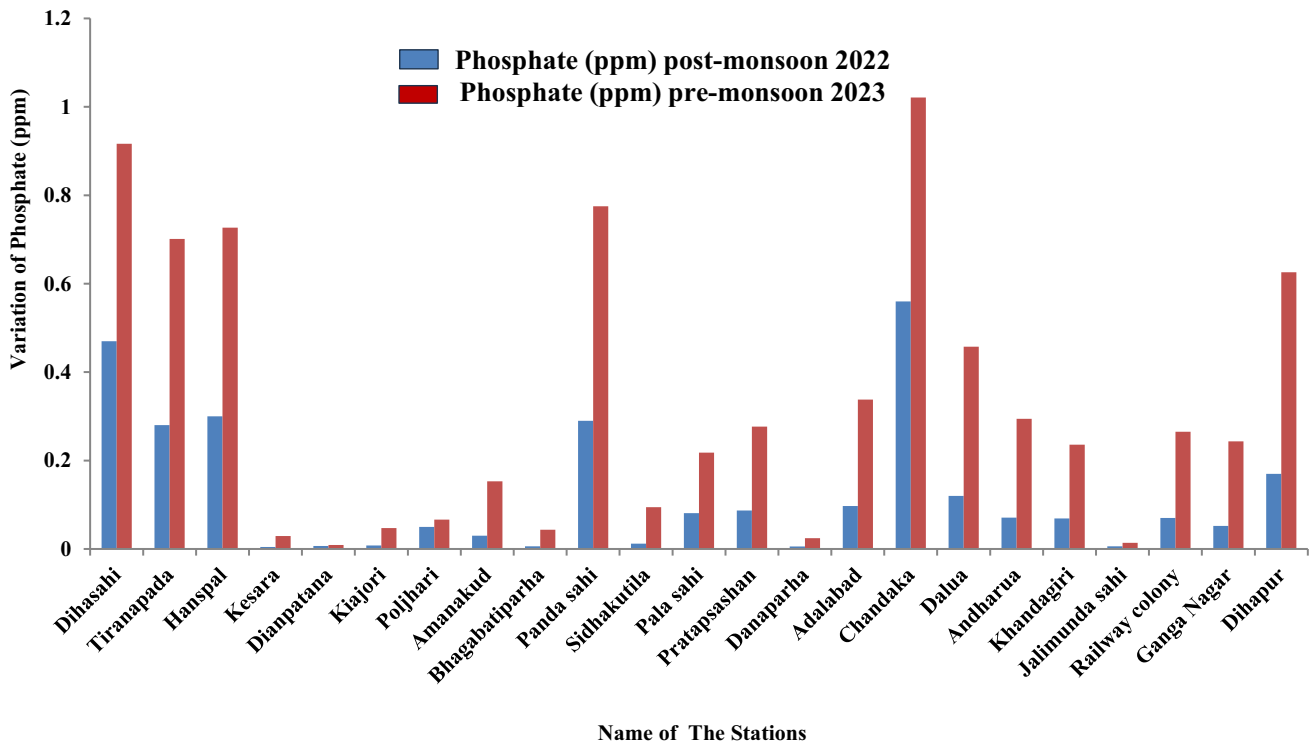


Fig. 54 Distribution of phosphate from Dihasahi to Dihapur

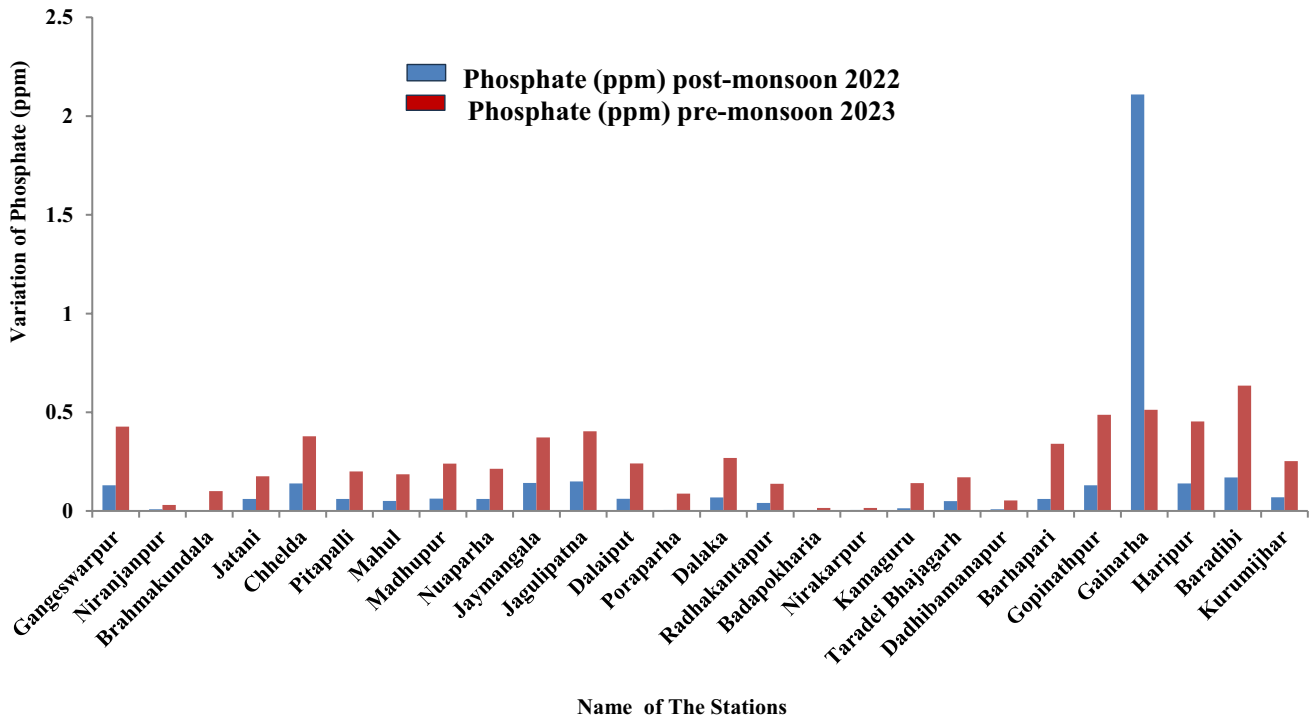


Fig. 55 Distribution of phosphate from Gangeswarpur to Kurumijhar

that can be solved for any place by incorporating particularly important water quality indices for the local ecosystem. Furthermore, an impartial and objective assessment of the overall groundwater quality is possible by selecting the best combination of available parameters that show variations in groundwater quality.

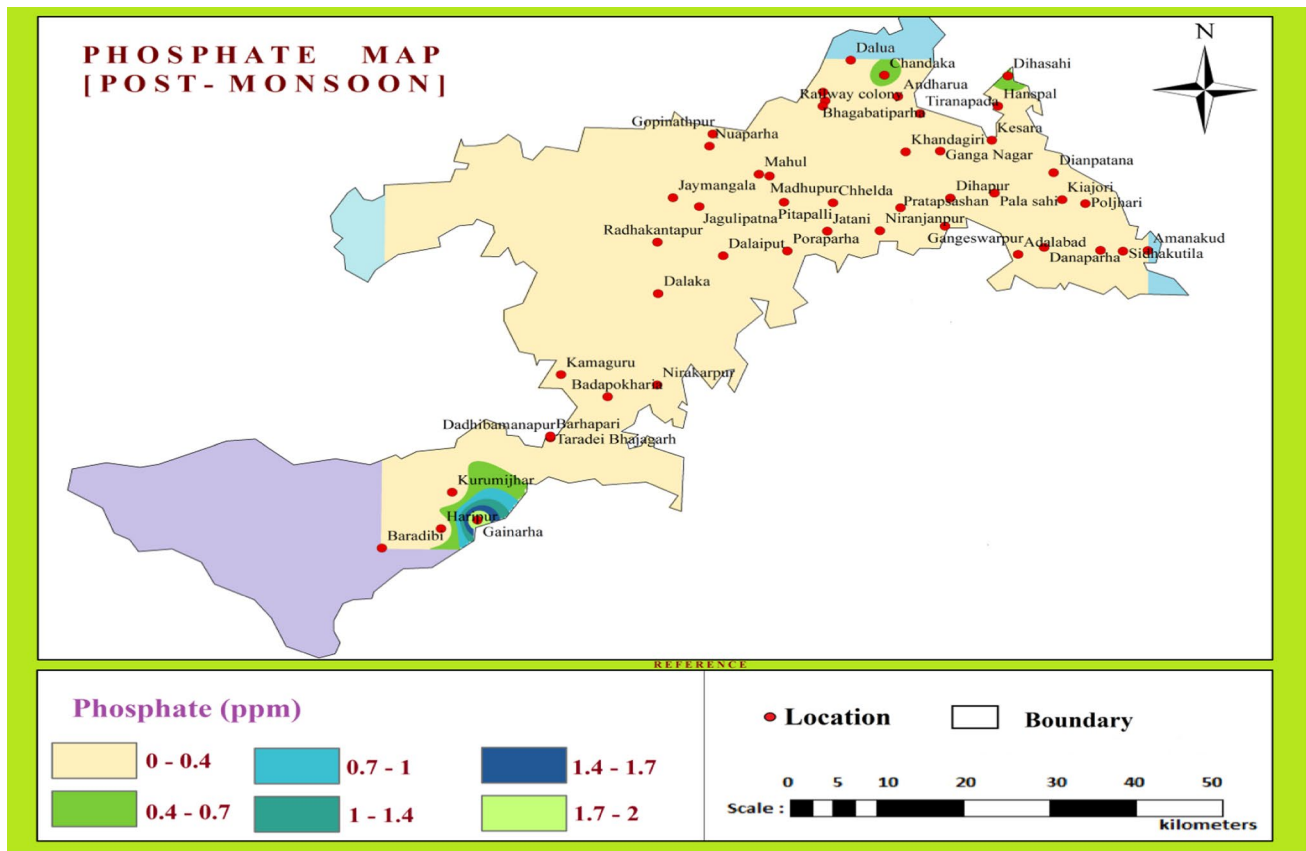


Fig. 56 Spatial distribution of Phosphate during post-monsoon 2022

5.1 Implications of poor groundwater quality on public health

Since groundwater is an essential supply of drinking water for millions of people globally, poor groundwater quality can have a substantial impact on public health. Heavy metals, nitrates, pesticides, and pathogens including bacteria and viruses are just a few of the contaminants that contaminated groundwater may include. Drinking water tainted with these compounds can cause a variety of health issues, such as neurological disorders, cancer, and gastrointestinal ailments. Groundwater is frequently the main source of drinking water in many places, particularly in rural and poor nations. Communities may not have access to clean, safe drinking water when this water is contaminated, which increases their risk of contracting waterborne illnesses. Some demographics are more susceptible to the negative health impacts of contaminated groundwater than others, including children, pregnant women, the elderly, and people with weakened immune systems. Prolonged exposure to pollutants in groundwater can have long-term health implications, such as impaired organ function, reproductive difficulties, delayed child development, and an elevated risk of cancer. Even while they might not show up right away, these effects can have a big impact over time. Low-income and minority communities are among the marginalised groups who are frequently disproportionately impacted by poor groundwater quality. Exacerbating already existing health disparities, these communities may be more prone to rely on groundwater for drinking water and may not have the resources to manage contamination issues.

5.2 Detailed analysis of how seasonal variations impact groundwater quality

In groundwater, temperature can affect a number of chemical and biological activities. Elevated temperatures have the ability to quicken chemical processes, which could lead to a greater dissolving of impurities or minerals in the water. High temperatures can also have an impact on microbial activity, which can change how quickly organic matter breaks down and how quickly some bacteria proliferate. The concentration of dissolved salts in water, mostly sodium chloride (table

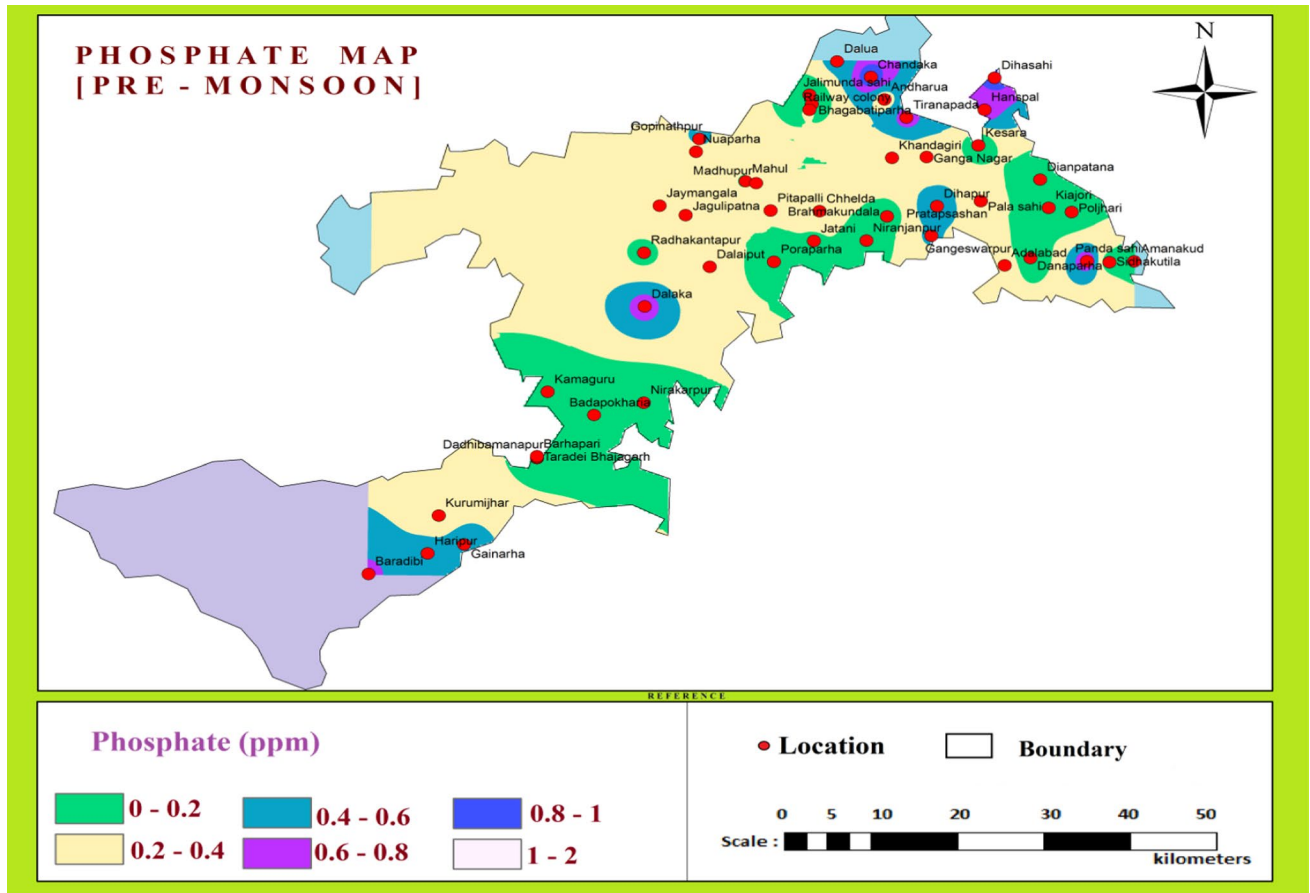


Fig. 57 Spatial distribution of Phosphate during pre-monsoon 2023

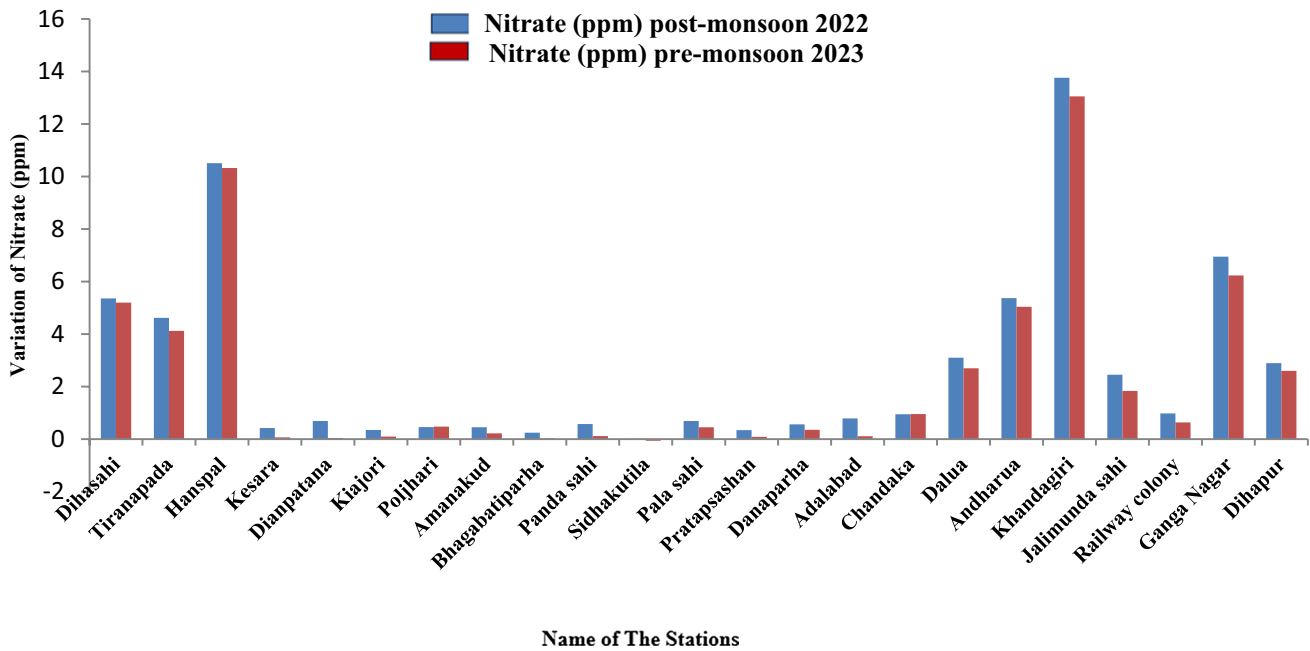


Fig. 58 Distribution of nitrate from Dihasahi to Dihapur

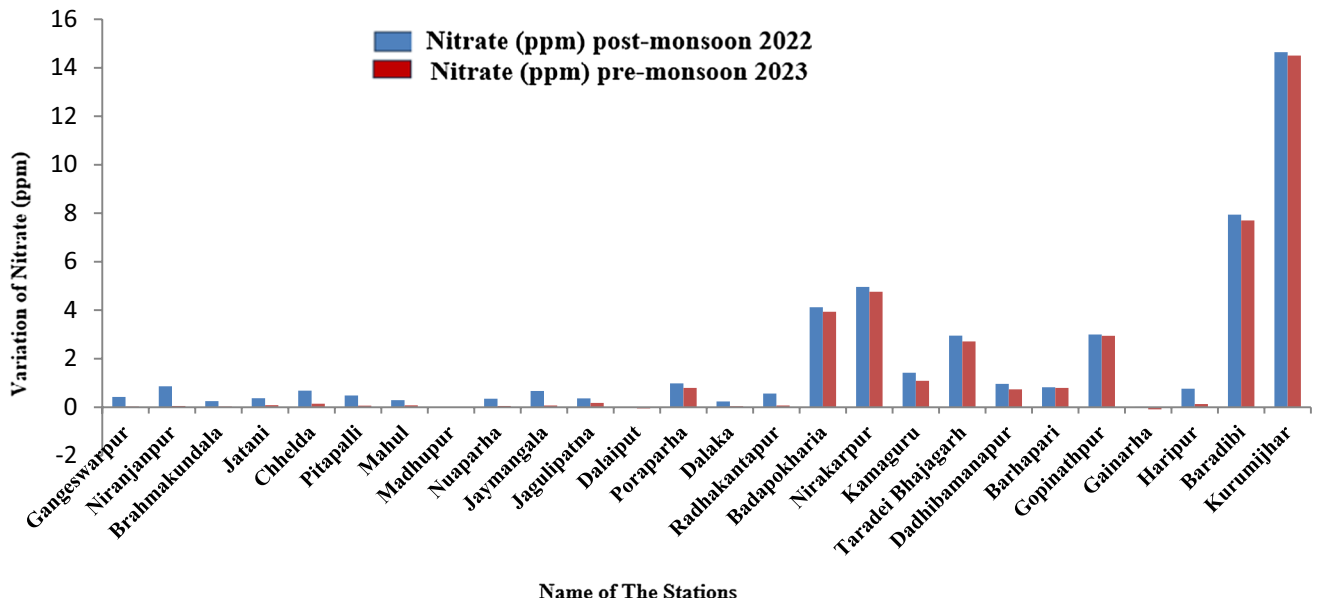


Fig. 59 Distribution of nitrate from Gangeswarpur to Kurumijhar

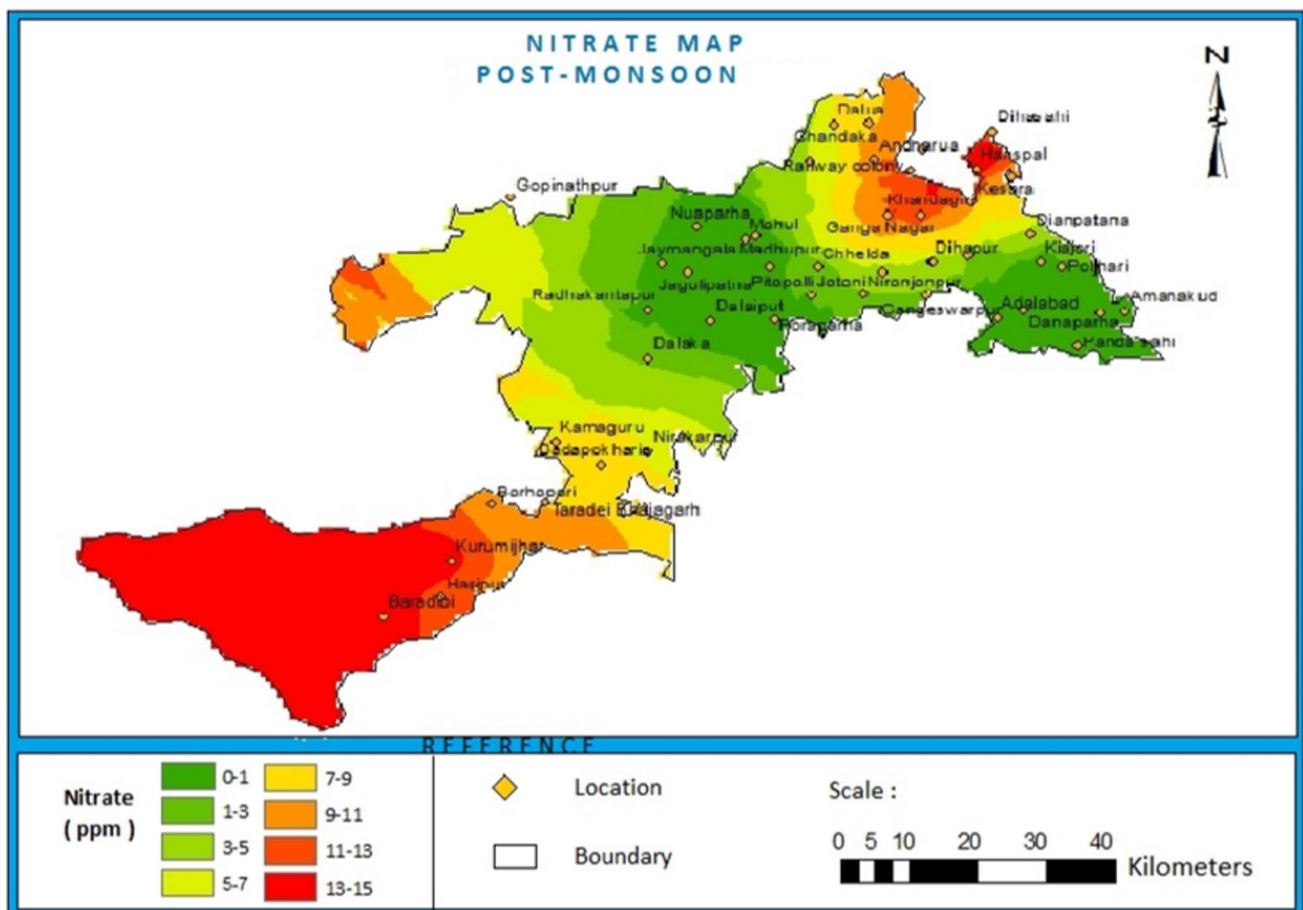


Fig. 60 Spatial distribution of Nitrate during post-monsoon 2022

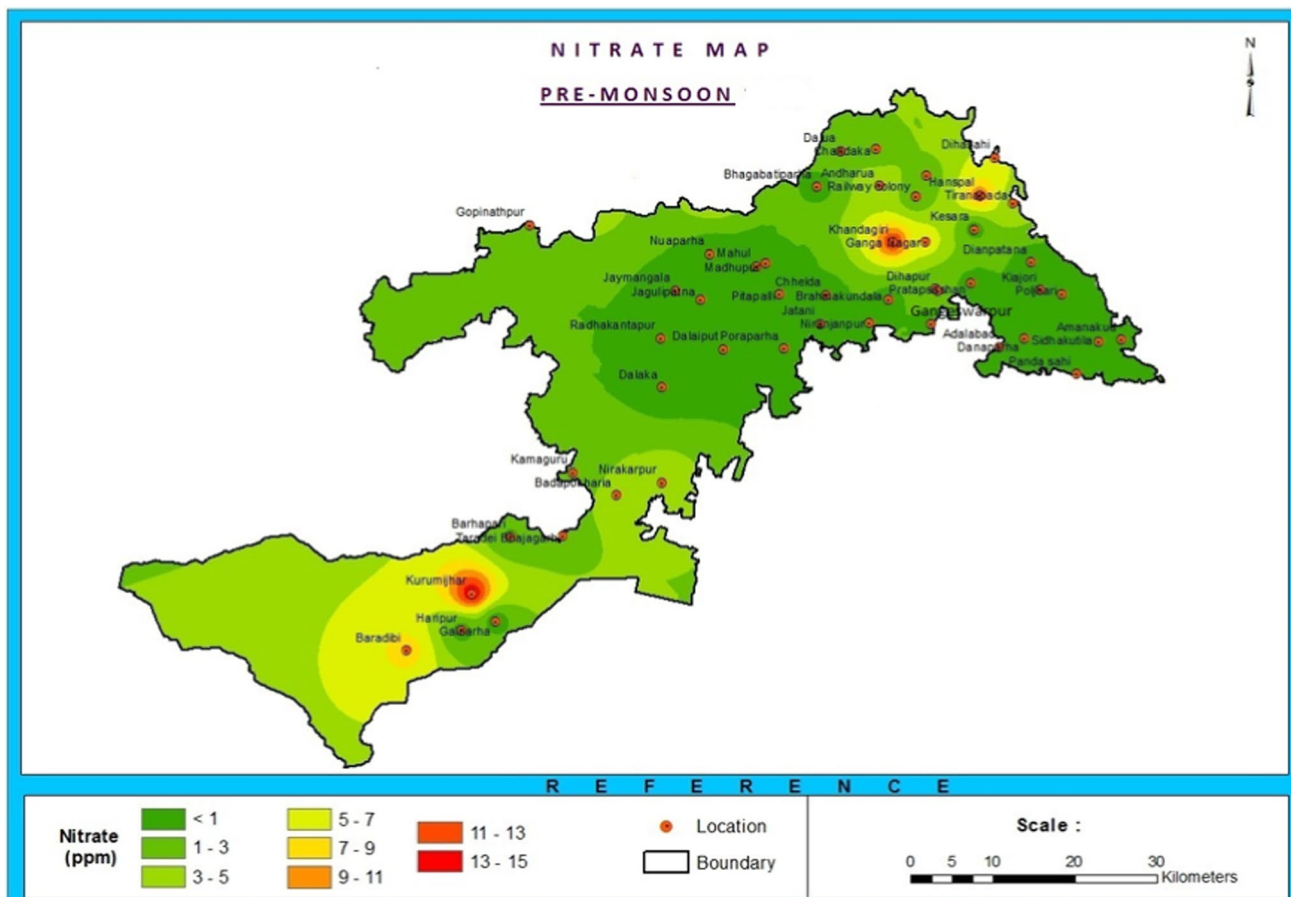


Fig. 61 Spatial distribution of Nitrate during pre-monsoon 2023

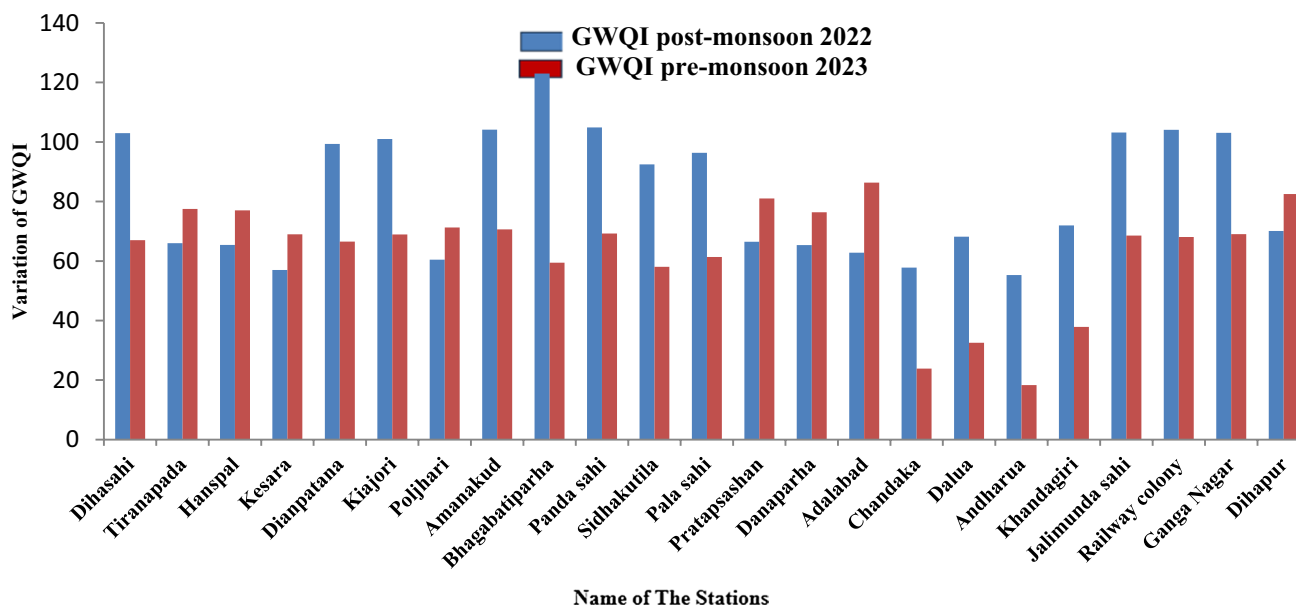


Fig. 62 Distribution of WQI from Dihasahi to Dihapur

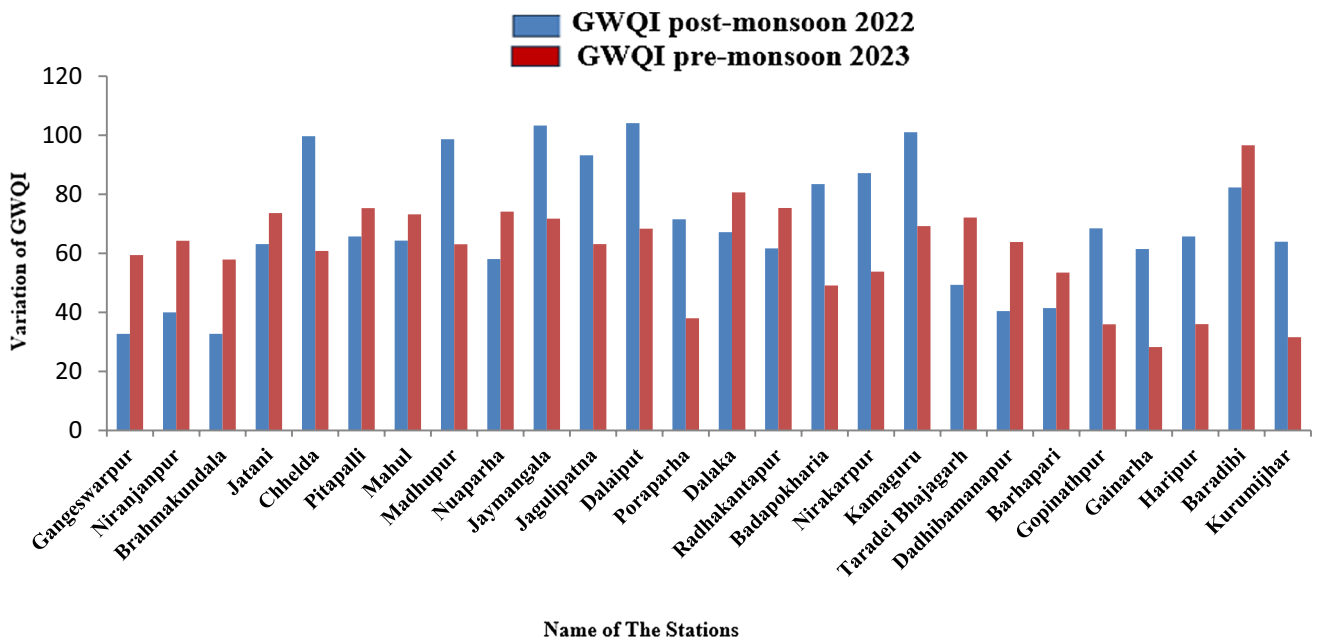


Fig. 63 Distribution of WQI from Gangeswarpur to Kurumijhar

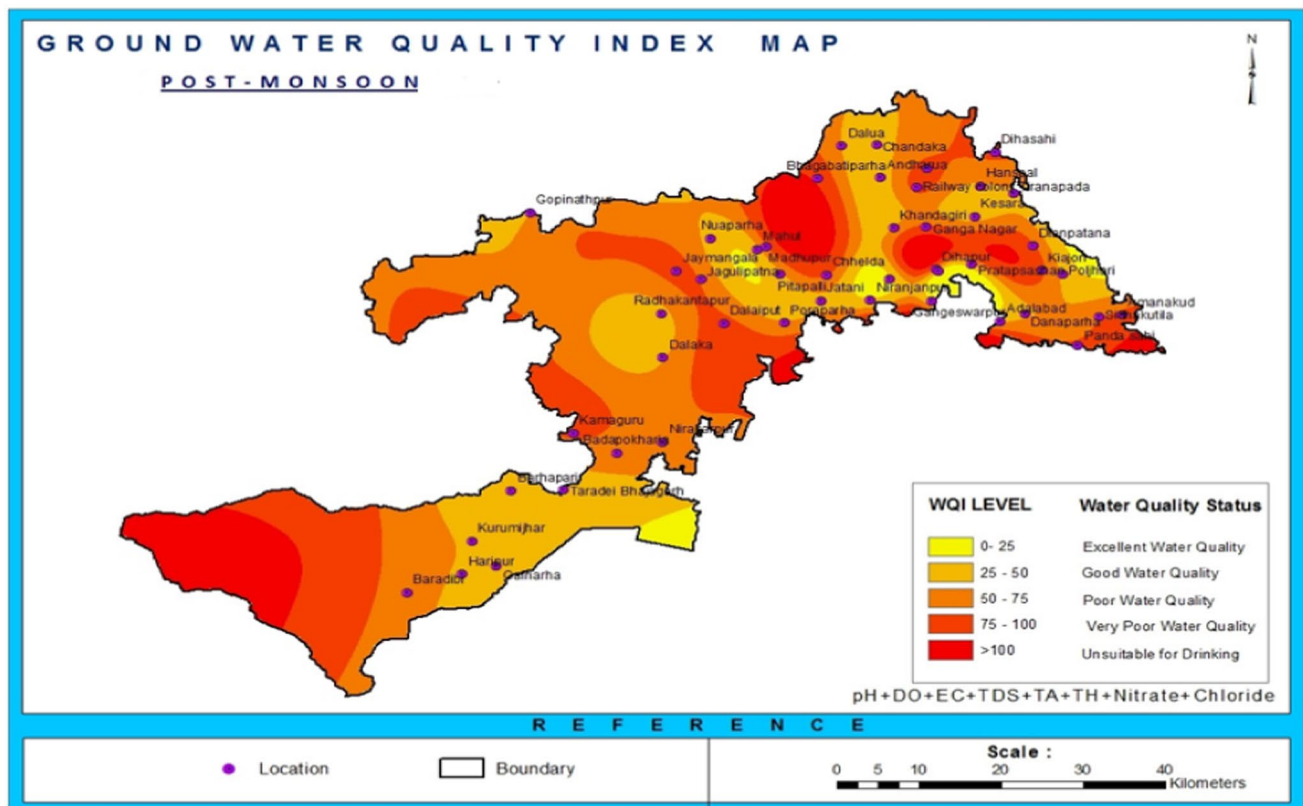


Fig. 64 Spatial distribution of GWQI during post-monsoon 2022

salt) but also possibly include sulphate and magnesium ions, is referred to as salinity. Because high salinity has a negative impact on soil fertility and human health, it can make water unfit for drinking or irrigation. Salinity can affect how water tastes and whether or not it is suitable for use in industrial processes. The concentration of calcium ions (Ca_{2+}) in water is measured by calcium hardness. Excessive calcium hardness can cause appliances and pipelines to build scale, which

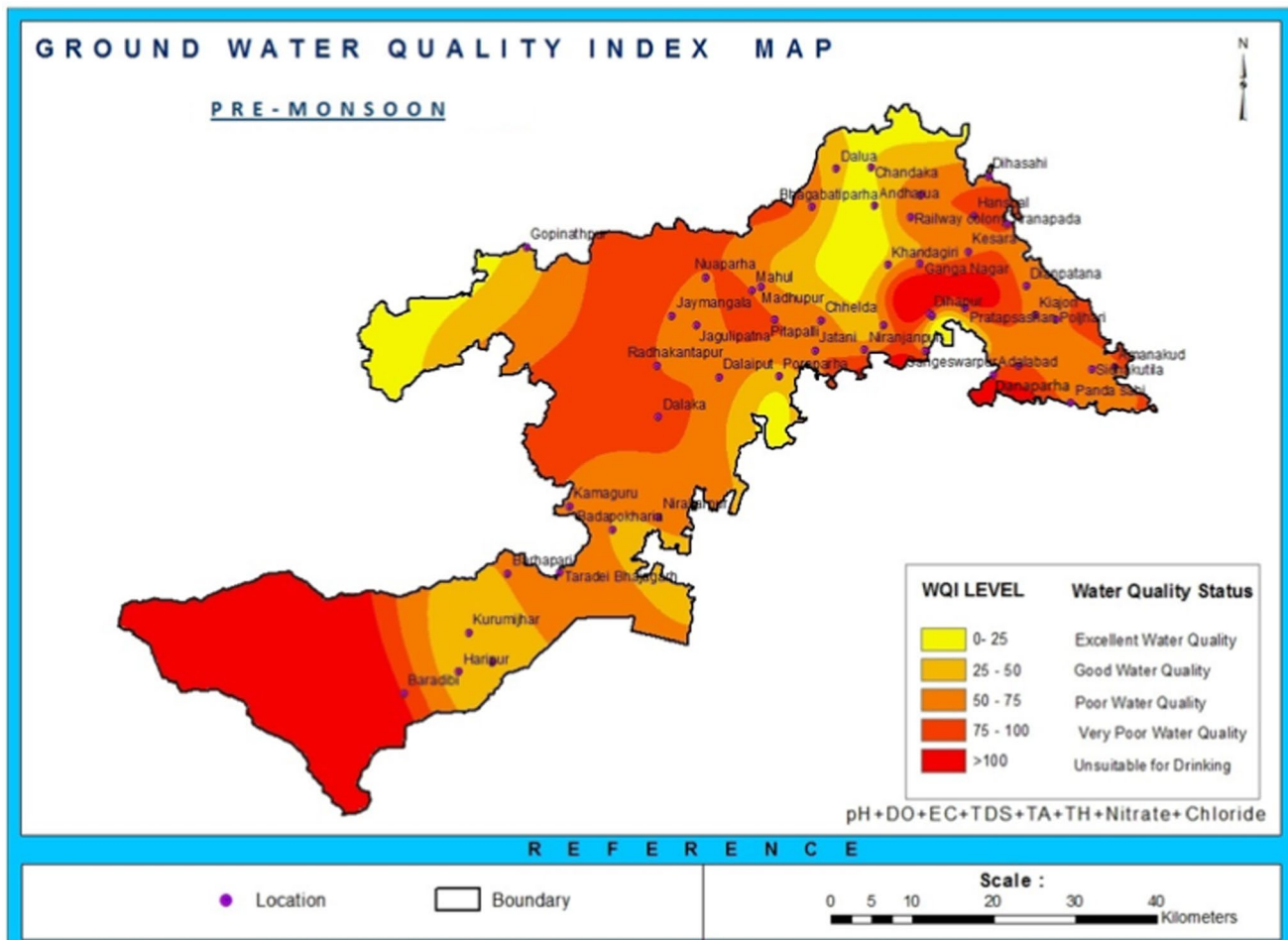


Fig. 65 Spatial distribution of GWQI during pre-monsoon2023

shortens the appliances' lifespan and efficiency. Furthermore, the lathering power of soap can be impacted by calcium hardness, which can influence cleaning procedures. Although fluoride is naturally found in groundwater, it can also be added by humans through practices like fluoridating water or conducting industrial processes. Although phosphate is a nutrient that is necessary for plant growth, too much of it can cause eutrophication, which is a condition in which too much plant growth lowers the oxygen content of water bodies, endangering aquatic life. Algal blooms, which can create poisons dangerous to human health and aquatic ecosystems, can also be caused by phosphorus. When fluoride levels are right, tooth decay can be avoided, which is good for dental health. On the other hand, a high fluoride diet can cause skeletal or dental fluorosis, which can result in abnormalities of the bones or tooth mottling. The ability of water to neutralise acids is measured by its alkalinity. It is mostly produced by carbonate, hydroxide, and bicarbonate ions that have dissolved. Stable aquatic ecosystems depend on the ability of high alkalinity levels to buffer against pH variations and slow down abrupt increases in acidity. On the other hand, overly high alkalinity could be a sign of contamination from industrial discharge or agricultural runoff, which would affect the quality of the water. On a logarithmic scale from 0 to 14, pH represents the acidity or basicity of water, with 7 representing neutrality. The pH of groundwater affects the solubility of certain minerals and compounds. pH extremes can damage aquatic life and reduce the effectiveness of water treatment systems. Due to its ability to assist fish and other creatures' respiration, DO is essential for maintaining aquatic life. bad DO levels in groundwater may be a sign of bad water quality and restricted aquatic species habitat appropriateness. DO concentrations can be impacted by variables like temperature, water flow dynamics, and organic pollutants. Seasonal fluctuations can impact DO levels through modified rates of oxygen exchange with the environment and microbial activity. Examples of these variations include higher temperatures and changing precipitation patterns. The amount of dissolved calcium and magnesium ions in water is referred to as its hardness. High levels of hardness can create scaling in pipes and appliances, lowering their lifespan and efficiency, but they are not directly detrimental to

Table 7 The results obtained from the determination of rating for WQI

Name of the location	GPS coordinate	Source	Year	Season	WQI	Interferences
Dihasaki	N20°21.44' E85°53.78'	Tube Well	2022	Post-monsoon	102.979	Unsuitable for drinking
			2023	Pre-monsoon	67.0925	Poor water quality
Tiranapada	N20°18.37' E85°54.97'	Tube Well	2022	Post-monsoon	66	Poor water quality
			2023	Pre-monsoon	77.5635	Poor water quality
Hanspal	N20°18.91' E85°52.80'	Tube Well	2022	Post-monsoon	65.43	Poor water quality
			2023	Pre-monsoon	77.0575	Poor water quality
Kesara	N20°16.59' E85°52.44'	Tube Well	2022	Post-monsoon	57.01	Poor water quality
			2023	Pre-monsoon	68.9776	Poor water quality
Dianpatana	N20°14.38' E85°56.23'	Tube Well	2022	Post-monsoon	99.35	Very poor water quality
			2023	Pre-monsoon	66.5863	Poor water quality
Kiajori	N20°12.50' E85°56.83'	Tube Well	2022	Post-monsoon	101.03	Unsuitable for drinking
			2023	Pre-monsoon	68.979	Poor water quality
Poljhari	N20°12.21' E85°58.23'	Tube Well	2022	Post-monsoon	60.45	Poor water quality
			2023	Pre-monsoon	71.254	Poor water quality
Amanakud	N20°09.14' E86°02.10'	Tube Well	2022	Post-monsoon	104.15	Unsuitable for drinking
			2023	Pre-monsoon	70.6599	Poor water quality
Bhagabatiparha	N20°19.47' E85°42.15'	Tube Well	2022	Post-monsoon	123	Unsuitable for drinking
			2023	Pre-monsoon	59.4644	Poor water quality
Panda sahi	N20°06.81' E85°59.19'	Tube Well	2022	Post-monsoon	104.87	Unsuitable for drinking
			2023	Pre-monsoon	69.2753	Poor water quality
Sidhakutila	N20°08.99' E85°60.58'	Tube Well	2022	Post-monsoon	92.46	Very poor water quality
			2023	Pre-monsoon	58.0658	Poor water quality
Pala sahi	N21°13.87' E86°45.96'	Tube Well	2022	Post-monsoon	96.37	Very poor water quality
			2023	Pre-monsoon	61.375	Poor water quality
Pratapsashan	N20°12.93' E85°52.24'	Tube Well	2022	Post-monsoon	66.5	Poor water quality
			2023	Pre-monsoon	81.01322	Very poor water quality
Danaparha	N20°09.23' E85°55.71'	Tube Well	2022	Post-monsoon	65.37	Poor water quality
			2023	Pre-monsoon	76.798	Very poor water quality
Adalabad	N20°08.65' E85°54.12'	Tube Well	2022	Post-monsoon	62.79	Poor water quality
			2023	Pre-monsoon	86.3547	Very poor water quality
Chandaka	N20°22.05' E85°45.98'	Tube Well	2022	Post-monsoon	57.79	Poor water quality
			2023	Pre-monsoon	23.86371	Excellent water quality
Dalua	N20°21.91' E85°43.69'	Tube Well	2022	Post-monsoon	68.18	Poor water quality
			2023	Pre-monsoon	32.5488	Good water quality
Andharua	N20°19.53' E85°46.27'	Tube Well	2022	Post-monsoon	55.31	Poor water quality
			2023	Pre-monsoon	18.31861	Excellent water quality
Khandagiri	N20°15.71' E85°47.13'	Tube Well	2022	Post-monsoon	71.98	Poor water quality
			2023	Pre-monsoon	37.8843	Good water quality
Jalimundasahi	N20°20.21' E85°49.31'	Tube Well	2022	Post-monsoon	103.2	Unsuitable for drinking
			2023	Pre-monsoon	68.576	Poor water quality
Railway colony	N20°18.82' E85°48.61'	Tube Well	2022	Post-monsoon	104.09	Unsuitable for drinking
			2023	Pre-monsoon	68.0855	Poor water quality
Ganga Nagar	N20°15.77' E85°49.26'	Tube Well	2022	Post-monsoon	103.09	Unsuitable for drinking
			2023	Pre-monsoon	69.0624	Poor water quality
Dihapur	N20°12.56' E85°49.92'	Tube Well	2022	Post-monsoon	70.1	Poor water quality
			2023	Pre-monsoon	82.988	Very poor water quality
Gangeswarpur	N20°10.21' E85°49.59'	Tube Well	2022	Post-monsoon	32.7	Good water quality
			2023	Pre-monsoon	59.469	Poor water quality
Niranjanpur	N20°10.26' E85°45.59'	Tube Well	2022	Post-monsoon	39.97	Good water quality
			2023	Pre-monsoon	64.266	Poor water quality

Table 7 (continued)

Name of the location	GPS coordinate	Source	Year	Season	WQI	Interferences
Brahmakundala	N20°11.85' E85°46.85'	Tube Well	2022	Post-monsoon	32.73	Good water quality
			2023	Pre-monsoon	57.979	Poor water quality
Jatani	N20°10.22' E85°42.35'	Tube Well	2022	Post-monsoon	63.11	Poor water quality
			2023	Pre-monsoon	73.624	Poor water quality
Chhelda	N20°12.16' E85°42.69'	Tube Well	2022	Post-monsoon	99.71	Very poor water quality
			2023	Pre-monsoon	60.8078	Poor water quality
Pitapalli	N20°12.18' E85°39.68'	Tube Well	2022	Post-monsoon	65.74	Poor water quality
			2023	Pre-monsoon	75.3355	Poor water quality
Mahul	N20°14.10' E85°38.14'	Tube Well	2022	Post-monsoon	64.34	Poor water quality
			2023	Pre-monsoon	73.1964	Poor water quality
Madhupur	N20°14.30' E85°38.76'	Tube Well	2022	Post-monsoon	98.66	Very poor water quality
			2023	Pre-monsoon	63.088	Poor water quality
Nuaparha	N20°14.92' E85°35.06'	Tube Well	2022	Post-monsoon	58.07	Poor water quality
			2023	Pre-monsoon	74.1358	Poor water quality
Jaymangala	N20°12.45' E85°32.82'	Tube Well	2022	Post-monsoon	103.29	Unsuitable for drinking
			2023	Pre-monsoon	71.7376	Poor water quality
Jagulipatna	N20°11.87' E85°34.46'	Tube Well	2022	Post-monsoon	93.24	Very poor water quality
			2023	Pre-monsoon	63.122	Poor water quality
Dalaiput	N20°08.48'E85°35.95'	Tube Well	2022	Post-monsoon	104.12	Unsuitable for drinking
			2023	Pre-monsoon	68.348	Poor water quality
Poraparha	N20°08.53'E85°39.94'	Tube Well	2022	Post-monsoon	71.53	Poor water quality
			2023	Pre-monsoon	37.9916	Good water quality
Dalaka	N20°05.92'E85°31.97'	Tube Well	2022	Post-monsoon	67.18	Poor water quality
			2023	Pre-monsoon	80.65345	Very poor water quality
Radhakantapur	N20°09.22'E85°31.89'	Tube Well	2022	Post-monsoon	61.69	Poor water quality
			2023	Pre-monsoon	75.3683	Very poor water quality
Badapokharia	N19°58.67'E85°28.96'	Tube Well	2022	Post-monsoon	83.46	Very poor water quality
			2023	Pre-monsoon	49.09	Good water quality
Nirakarpur	N19°59.51'E85°31.97'	Tube Well	2022	Post-monsoon	87.19	Very poor water quality
			2023	Pre-monsoon	53.8546	Poor water quality
Kamaguru	N20°00.17'E85°26.08'	Tube Well	2022	Post-monsoon	101.06	Unsuitable for drinking
			2023	Pre-monsoon	69.0824	Poor water quality
TaradeiBhajagarh	N19°55.92'E85°25.43'	Tube Well	2022	Post-monsoon	49.35	Good water quality
			2023	Pre-monsoon	72.1161	Poor water quality
Dadhibamanapur	N19°55.92'E85°25.43'	Tube Well	2022	Post-monsoon	40.44	Good water quality
			2023	Pre-monsoon	63.8469	Poor water quality
Barhapari	N19°55.92'E85°25.43'	Tube Well	2022	Post-monsoon	41.47	Good water quality
			2023	Pre-monsoon	53.455	Poor water quality
Gopinathpur	N20°16.88'E85°23.23'	Tube Well	2022	Post-monsoon	68.47	Poor water quality
			2023	Pre-monsoon	35.9273	Good water quality
Gainarha	N19°50.11'E85°21.00'	Tube Well	2022	Post-monsoon	61.46	Poor water quality
			2023	Pre-monsoon	28.2243	Good water quality
Haripur	N19°49.50'E85°18.77'	Tube Well	2022	Post-monsoon	65.74	Poor water quality
			2023	Pre-monsoon	36.0286	Good water quality
Baradibi	N19°48.14'E85°15.15'	Tube Well	2022	Post-monsoon	82.31	Very poor water quality
			2023	Pre-monsoon	96.6288	Very poor water quality
Kurumijhar	N19°52.01'E85°19.43'	Tube Well	2022	Post-monsoon	63.95	Poor water quality
			2023	Pre-monsoon	31.5924	Good water quality

human health. Furthermore, hardness might influence how well some water treatment methods work, such as soap usage in households and industrial operations. Common sources of groundwater pollution include septic tanks, animal faeces, and fertilisers used in agriculture. Because high nitrate levels can result in methemoglobinemia, sometimes known as "blue baby syndrome," they offer health hazards, particularly to unborn children and expectant mothers. Furthermore, nitrate pollution can cause surface waters to become eutrophic, which can result in algal blooms and the deterioration of ecosystems. Concentrations of chloride in groundwater can come from man-made activities like applying road salt and industrial effluent, or they might come from natural sources like geological formations. High amounts of chloride can be a sign of pollution and make the water unsafe to consume or use for irrigation because of its salty flavour and possible health risks. Further more, when chloride is utilised for irrigation, it can damage infrastructure and degrade soil quality. The term TDS refers to the total concentration of dissolved ions in water, which includes salts, minerals, and organic materials. The taste, appearance, and usability of water for different uses can all be impacted by high TDS levels. TDS is produced by industrial discharge, agricultural runoff, and the natural weathering of rocks. Droughts and excessive rains are examples of seasonal fluctuations that might affect TDS levels by changing the rates of groundwater recharging and the dilution processes involved. The primary factor affecting water's electrical conductivity, as measured by EC, is the concentration of dissolved ions in the water. Elevated TDS levels are frequently correlated with high EC readings, which denote low water quality. Measurements of EC are frequently employed as a stand-in for TDS and are useful in determining the salinity, pollution, and appropriateness of groundwater for various applications. Seasonal variations in temperature, precipitation, and land use can have a substantial impact on groundwater quality. Increased runoff from cities, industrial locations, and agricultural fields during the rainy season can contaminate groundwater reservoirs. On the other hand, dry seasons may result in reduced groundwater recharge, which could cause concentration effects—a situation in which contaminants are concentrated greater in the remaining water. Variations in the seasons can also affect biological activity, which includes the breakdown of organic materials and affects dissolved oxygen and nutrient levels in water.

5.3 Long-term trends in groundwater quality to suggest possible future changes

Long-term trends in groundwater quality can be predicted by taking into account a number of variables, including population expansion, land use changes, climate change, and technological improvements. Changes in precipitation patterns might impact groundwater recharge rates and water availability due to climate change. Increased groundwater contamination can result from urbanisation and agricultural growth introducing pollutants including pesticides, fertilisers, and industrial chemicals. Water quality indicators like turbidity and sedimentation can be impacted by deforestation and soil erosion, which can also have an impact on groundwater recharge rates and sediment transport. The need for groundwater resources for industrial, agricultural, and drinking water supply will increase as the population grows. When groundwater resources are overused, aquifers may be depleted and become more susceptible to contamination because of a decreased capacity for dilution. Technological developments in water treatment could provide ways to reduce pollution and enhance the quality of groundwater. Monitoring tools like sensor networks and remote sensing can give current information on groundwater quality and point up new problems. Mitigating future degradation of groundwater quality can be achieved by strengthening legislation and enforcement mechanisms to regulate pollution releases and encourage sustainable groundwater management. Groundwater quality can be long-term preserved and improved by implementing land use planning policies, groundwater monitoring programmes, and sustainable water resource management techniques. Better management of water resources and a decrease in pollution from individual and community activities can result from raising public knowledge of the issue and encouraging participation in groundwater protection initiatives. A culture of responsible water management can be fostered by education campaigns on pollution avoidance, sustainable water use practices, and conservation of water.

6 Conclusion

This research is to understand the groundwater quality of Khordha district and pictorially represent it using GIS. Assessment of groundwater quality with reference to physical and chemical characteristics was carried out in 49 areas of Khordha district of Odisha. For this purpose, groundwater sample collection and analysis were done once in two months, i.e., September & October during post-monsoon season of 2022 and March & April during pre-monsoon season of 2023. The study includes assessment of groundwater quality using 14 parameters. Groundwater of the study area covering

Khordha district was mostly alkaline during post-monsoon and slightly acidic during pre-monsoon season. With respect to major anions, the groundwater is generally suitable for domestic purposes except for a few locations where the concentration of nitrate or fluoride exceeds the permissible limit of WHO standards. Groundwater is also suitable for irrigation purposes for several locations except for a few locations where salinity is high. From the research work, it is also found out that the colour of groundwater is pale yellow in some of the areas such as Khandagiri, Dihapur, Pitapalli, Poraparha, Gainarha and Baradibi. It is also found out that the water sample collected contains undesirable elements which may lead to epidemic. Moreover, GIS makes the groundwater quality maps into an easily understandable format. The groundwater quality index found in this paper is useful to know the qualities of water in the present study area. This study can be very helpful to the farmers, builders, researchers, etc. Farmers, in sense that they, can predict the quality of groundwater of the surrounding areas by knowing the amount of cations or anions present in the study areas and are aware of doing any agricultural activities in those areas. Likewise, in the case of builders, they can assume the type of soil present in the neighbouring areas of the study area by knowing the quality of groundwater flowing through the soil. Then, they can predict the foundation of building to be built. Also, in the case of scientists or researchers, they will benefit by knowing the amount of cations or anions present in the study areas. Then, they could predict the presence of the parameters in the surrounding areas by doing further research. Therefore, the study of characteristics of this groundwater sample recommends that assessment of water quality parameters and water quality management practices should be periodically carried out for protecting ground water resources.

Author contribution Chinmayee Biswakalyani-Software, Validation, Writing, Editing, Data curation, Sandeep Samantaray-Supervision, Deba Prakash Satpathy-Writing – review & editing, Data curation, Conceptualization, Methodology.

Funding Not Applicable.

Data availability <http://cgwb.gov.in/>

Declarations

Competing interests The authors declare no competing interests.

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