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Assessment of Groundwater Quality using Statistical Techniques of Balasore District of Odisha, India

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Abstract : *Geochemical studies of groundwater have been carried out in Balasore district of Odisha state. The analyses of water samples of the district reveals the physicochemical parameters of the district. The physicochemical parameters studied are p^H, Total alkalinity, TDS, EC, TH, Ca^{++}, Mg^{++}, Na^+, K^+, Cl^-, HCO_3^-, etc. The results are examined with reference to the drinking water quality standards as per BIS (I.S. 10500:2012) and WHO. The physiography and geological setting of the district is highly conducive for rich ground water resource. Industrialization, urbanization and inputs from modern agriculture result depletion of ground water quality. The main focus of this study is to evaluate groundwater quality through correlation coefficient and regression analysis. Most of the parameters are more or less correlated with each other. In some pockets of the district fluoride and iron are problems. In coastal track salinity is a problem. The ground water of the district is safe for domestic and irrigation use. Thus, proper awareness as well as policy decision is required to get contaminant free groundwater for a sustainable use.*

Key words: *Physicochemical parameters of water, Depletion of ground water, Sustainable water use.*

Introduction

Geochemistry of groundwater is an important factor determining its use for domestic, irrigation and industrial purposes. The degradation of groundwater quality generally occurs due to natural processes and other anthropogenic influences. The increased knowledge of geochemical processes that control groundwater chemical composition could lead to improve the understanding of hydrogeochemical systems in such areas. Such understandings like rock–water interactions, aquifer lithology, dissolution and residence time of groundwater may be helpful to improve the groundwater quality and management (Hem 1985). However, the over exploitation of groundwater for agricultural and other anthropogenic purposes were clubbed with frequent failure of monsoon and will lead to contamination of groundwater. A number of studies on groundwater quality with respect to drinking and irrigation purposes have been carried out in different parts of India (Sunitha et al. 2005; Subba Rao 2006; Giridharan et al. 2008; Das et al.2010; Krishna Kumar et al. 2011; Sarath Prasanth et al. 2012). The chief root of water supply for domestic requirements in town, rural and urban fringe of India is groundwater (Shroff et al., 2015). Das et al., 2020). More than

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33% of all groundwater sources are unfit for human consumption. Groundwater is the most reliable water resource for the survivals of human beings. It is widely used for drinking, irrigation, and various industrial purposes over the world, (Delgado et al. 2010; Varis 2014). Water, being one of the most valuable and important resources on earth, it needs to be utilized properly for the healthy, sustainable and progressive economic growth of any region, but the wholesomeness of surface as well as groundwater has been deteriorated because of both natural and man-made actions (Uddin et al., 2021). Understanding the status and suitability of groundwater quality is the first step of sustainable water resources management. Human activity and natural environmental change are two major driving forces for the variations of regional hydrology and water resources (Li 2014). With the rapid development of economy and swift growth of world population, the impacts of human activities on the environment, especially on water resources, are inevitably intensifying. The modification of landforms for developmental activities have significant impacts on hydrological cycles, ecological diversity and water resources (Li et al. 2014a). According to WHO water quality standards, Groundwater parameters should have within their permissible limits, exceeding these limits leads to the beginning of undesirable changes in the ecosystem. Monitoring is also important because they provide important information about the nature of pollution and the type of remedial measures for the management of water pollution (Mustapha and Garba, 2015).

Various statistical concepts were used for better understanding of water quality parameters (Isaaks and Srivastav, 1989 and Kumar and Ahmed, 2003). A simple systematic method based on statistical correlation was developed using the mathematical relationship to compare parameters of water quality (Joshi et al., 2009). It would be an interesting solution for establishing relationship between parameters than the traditional chemical analysis method. The equations developed for regression analysis can be strongly used for parameters with important correlation coefficients to estimate the concentration of certain other dominant components (Saikrishna et al., 2020).

Study Area

Balasore district is located on the northern coast of Odisha with geographical area of 3806 sq.km. and is divided in to 12 Community Development Blocks. The district is located between latitude 21° 04′ North to 21° 58′ North and longitude between 86° 16′ East to 87° 29′ East. The district has 5 towns. As per 2011 census total population of the district was 23,20,529 and population density of 610/sq.km. Annual maximum temperature is 45p C and minimum temperature 9p C. The district experiences monsoon climate with normal annual rainfall of 1592mm out of which 85% is received during south west monsoon season. The month of July and August receives heaviest rainfall. The land elevation varies from the mean sea level in the east to 600 metres above mean in the north and west. The major part of the district covering more than 75% of the geographical area is having elevation between 2-10 metres above mean sea level. The district is well drained by rivers, important rivers are the Budhabalanga and the Subarnarekha. Hydrogeomorphological features of Balasore district are mainly attributed to fluviomarine, erosional, denudational and depositional processes. Four main types of soil groups are found in the districts are Alfisols, Aridisols, Entisols and Ultisols. The major parts of the district are underlain by Tertiary and quaternary alluviums including recent alluvium. The north western part of the district is underlain by the Archaeo-Proterozoic Granites and Granite Gneisses with minor Pegmatites and vein Quartz. The district is endowed with vast arable lands (61.11%) and one of the most agriculturally developed districts of Odisha. Though the district is primarily agrarian, there are a number of large scale industries and factories in and around the Balasore town. Apart from these, there are a number of small and medium scale agro-based industries including sea food packaging industries in the areas proximity to the Bay of Bengal. Other industries are PVC pipes, Insulated cable, Pharmaceuticals, Latex product manufacturing, Polymer based manufacturing and stonequeries. The district is potentially vulnerable to natural disasters like cyclone, flood, drought and tsunami (Fig.1).

Data base and Methodology

Database

The department of water resources, Govt. of Odisha and Central Ground Board are the most extensive hydrogeochmical data base in Odisha. The proposed research includes micro level hydrogeological data acquisition supported by geophysical and hydro chemical investigations supplemented with ground water exploration down to the depths of 200 meters, including quality monitoring (intensive inventory of wells). This study is based on water sample analysis together with the utilization of existing geological and hydrogeological information.For the assessment of ground water quality, water sample from open/dugwell collected for phreatic aquifer and for fracture zone aquifer water sample collected from EW/OW constructed for exploration. Hydrological and Hydro meteorological studies, Infiltration Tests, Geophysical Surveys, Water Quality Analysis, GIS data integration and analysis. Since the area is difficult to access in all the seasons through drilling rigs, a bulk of the area was covered under Geophysical investigation, mainly through close spaced vertical electrical soundings (VES). Not only Schlumberger configuration but Werner and Pole Dipole & Dipole Dipole method too was utilized. Wherever there was space constraint, Half Schlumberger method was utilized. Objective behind VES was to accurately demarcate the Fresh Saline interface on a geographic plane. However, because of the inherent salinity problem, individual geoelectrical layer wise interpretation could not be obtained beyond 30 metres depth. For ascertaining ground water quality, water samples were collected from the existing network of National Hydrographs Network Monitoring Stations [Aquifer – I (Phreatic)] and also from the Tube wells [Aquifer II & III] during the pre monsoon season and analyzed in the Regional Chemical Laboratory using the Standard Analytical Protocols of APHA. In addition to this, a number of chemical data of Rural Water Supply & Sanitation of Department of Rural Development, Govt. of Odisha, available in website of the Department of Drinking Water Supply, Govt. of Odisha too was collected and collated. These data were used to interpret the chemical characteristics of the Aquifer(s) concerned. In general, it was found that the Water Quality of the Phreatic Aquifer are potable and conforms to the BIS: 10500 standards for drinking water. However, in the Deeper

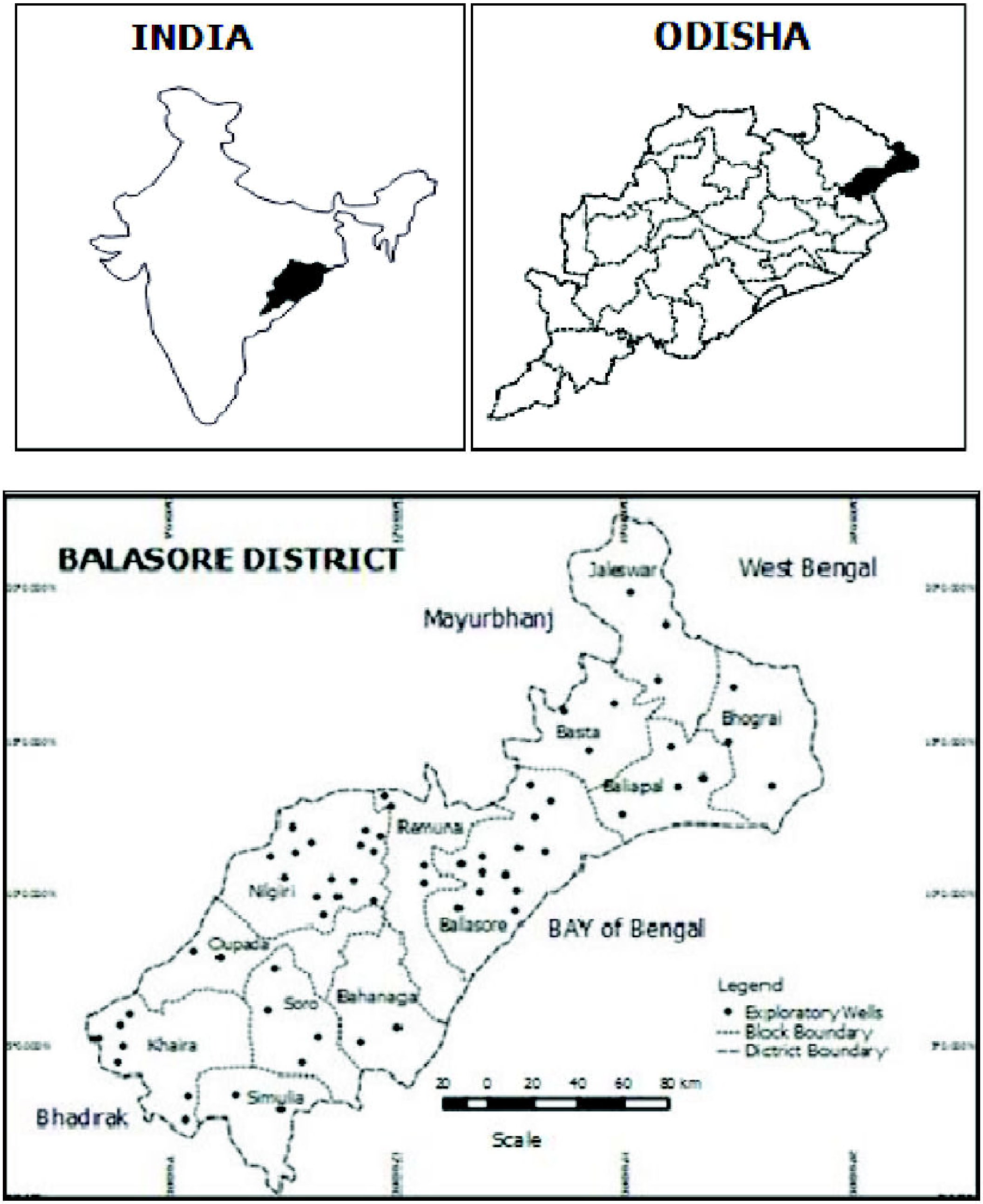

Fig.1 Location of the Balasore district

Aquifers (Aquifer II & III), there are some quality related issues. Data available from other agencies like Directorate of Ground Water Development, Rural Water Supply & Sanitation, Public Health Engineering Department, Soil Conservation Directorate, Directorate of Minor Irrigation, Department of Water Resources, Office of the Special Relief Commissioner, Department of Agriculture & Food Production, Directorate of Livestock & Animal Husbandry, India Meteorological Department were compiled to check for any further data gaps. The data so obtained was converted into digital form with geographic attributes to transform it into a GIS database.

The pH and EC values were determined in situ with the help of a portable pH-meter and EC-meter whereas other constituents were determined in the laboratory by using different volumetric methods, Flame photometer (Systonics-128), Spectrophotometer (Shimadzu, UV-1201). The PTEs analysis was carried out by using an Atomic Absorption Spectrophotometer (GBC-Avanta).

The water quality study of the district is studied based on twelve physiochemical parameters namely pH, total dissolved solid (TDS), total hardness, total alkalinity, electrical conductivity, Ca^{++}, Na^{+}, K^{+}, Mg^{++}, Cl^{-}, CO_3^{-}, HCO_3^{-}. Physicochemical parameters of pre-6 monsoon season of 78 sample points of 2019 were collected from twelve blocks of the districts.

Methodology

The Karl Pearson Correlation coefficient was computed for measuring the bivariate linear relationship of the above twelve variables. The multivariate linear relationship was studied taking total hardness, total alkalinity and total dissolved solid as dependent variable and other physicochemical parameters as independent variables. The independent variables were decided on the basis of study of correlation matrix. The variables having strong and moderate correlation with the dependent variables were considered as the predictor. The classification of correlation coefficient was strong for $r>0.60$ or $r< -0.60$; moderate for r lying within 0.40-0.60 or (–)0.40 to (-) 0.60; weak for r lying within 0.20-0.40 or (-)0.20- (-)0.40. For $r < 0.20$ and >(-)0.20 is considered as no correlation (Saleem et al., 2012). The predictors used in the regression model for different dependent variables are as follows.

Total Hardness (Dependent): Independent variables- EC, TDS, TA, Calcium (Ca^{++}), Magnesium (Mg^{++}), Potassium (K^{+}), Chloride (Cl^{-}), Bicarbonate ($HCO3^{-}$).

Total Alkalinity (Dependent): Independent variables- EC, TDS, hardness, Calcium (Ca^{++}), Magnesium (Mg^{++}), Bicarbonate (HCO3-).

Total Dissolved Solid (Dependent): Independent variables- EC,TH, TA, Calcium (Ca++), Magnesium (Mg^{++}), Chloride (Cl-), Bicarbonate (HCO3-).

Step wise forward linear regression analysis was under taken. Descriptive statistics such as minimum, maximum, mean, standard deviation (SD), median, quartiles were computed for each of the variables The statistical analysis for the study was done using SPSS IBM Statistics 24.0.

Objective of the study

The aims of the present study are (1) to assess the groundwater quality for drinking and irrigation purposes, (2) to analyze the main factors influencing groundwater quality in the area, and (3) to provide local decision makers some measures for the management of groundwater in the area. This study will be helpful in local groundwater management and may also be potentially important for the protection and governance of groundwater in many other parts of the world that face similar situations. Therefore, a simple and breakneck method for systematic assessment and monitoring of groundwater quality becomes crucial in order to examine the usefulness of water for drinking and to adopt suitable measures for its safeguard.

Geological and hydrogeological features

Geologically, the major parts of the District is underlain by the Quaternary to Holocene (recent) unconsolidated Alluvial formations, with the Pre Cambrian to Proterozoic rock of the Singhbhum Granites or its equivalent, serving as basements in most of the cases and in some places, the Tertiary Limestones serves as the basement. Some of the Older Alluvial Formations (mostly of fluvial nature) are often lateritized at the top. Ground water occurs under water table in shallow aquifers and under semi confined to confined condition in deeper aquifers. Hydrogeologically all the formations encountered in the district can be broadly divided in to three sub groups viz.1-Crystalline,2-Sedimentary formations and 3-Laterites.The occurrence of fresh water aquifers in coastal tract of Balasore is restricted by two important factors (i) Occurrence of hard rocks in the western side and (ii)Salinity hazard problems in the eastern part. The district is underlain by thick alluvial deposits and is endowed with huge ground water resource potential. The agrarian development of the district is boosted by tapping this enormous groundwater resources through dug well, shallow and filter point tube well and medium deep tube well. The present stage of ground water development is 53.29% leaving vast scope for ground water development in the district. Ground water irrigation practices can insure increased agricultural production by enhancing the area irrigated. Apart from irrigation, drinking water scarcity can also be mitigated through judicious utilization of ground water. With the first agricultural development, rapid ground water decline during rabi season in February –May has been noted in some blocks. The over exploitation may lead to saline water ingress in coastal track of the district. In the coastal tract within a width range of 5 to 10kms from the coast, the saline water is above the fresh ground water. Due to wide variation of hydrogeological setup in the district, the occurrence and distribution of aquifers are non- uniform and also their yielding capacity. All the 12 blocks are classified as safe ground water. Major ground water related issues are 1. Presence of ground water troughs in both pre & post monsoon season in Deeper Aquifers in the three areas: Basta-Baliapal, Balasore-Chandipur and Soro-Anantapur sectors. 2. Presence of inherent saline affected areas along the coast line in the Kalyani- Chandipur- Chandeneswar tract spanning the Balsaore, Baliapal and Bhogarai sector and 3. Presence of Iron and Fluoride above permissible limits in certain part of the district. Ground water level in the district during the pre-monsoon season remains within 6-8 metres below ground level. During the post-monsoon season, the depth of the water level remains within 4-6 metres below ground level (Fig.2&3).

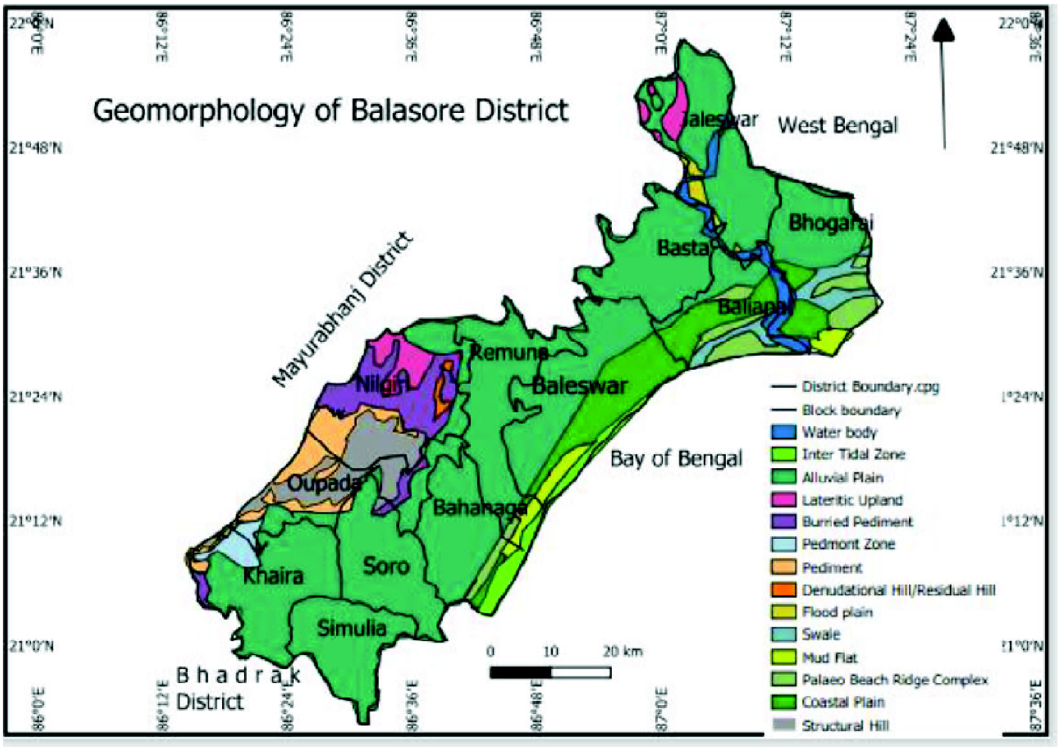

Fig.2 Geomorphology of Balasore District

Results and Discussion

The quality of groundwater in Balasore district is usually suitable for domestic, industrial and irrigation use in mostcases, barring some zones of inland iron and fluoride and salinity of coastal areas with seawater ingress. Groundwater ismostly free from arsenic, iron or fluoride pollution. The quality of urban groundwater has become degraded inall small and large cities. Within city limits, groundwater ishighly polluted due to several sources of pollution such asleaking sewers, septic tanks of toilets, and chemical spills. Knowledge of the existing nature, magnitude, andsources of the various pollution loads is a prerequisite toassess the groundwater quality.

The quality of groundwater varies widely depending on the physiographic set up as well as geologicalformation.The water from shallow aquifers of inland areasis fresher in comparison to the waterfromcoastal alluvial tract.The quality of water in deeper aquifers, like shallow aquifers, is governed by the physiographic as well as geological set up. The water from deeper aquifers is also fresher in inland areas than that of coastal area. The chemical characteristics of water from deeper depth are more or less similar to the water of shallow aquifers occurring under same hydrogeological set up. The occurrence of pollutantsin deeper aquifer water is also restricted in minor pockets. It is important to note that the concentration of pollutants like nitrate in water is less in deeper aquifers than that of shallowaquifers.

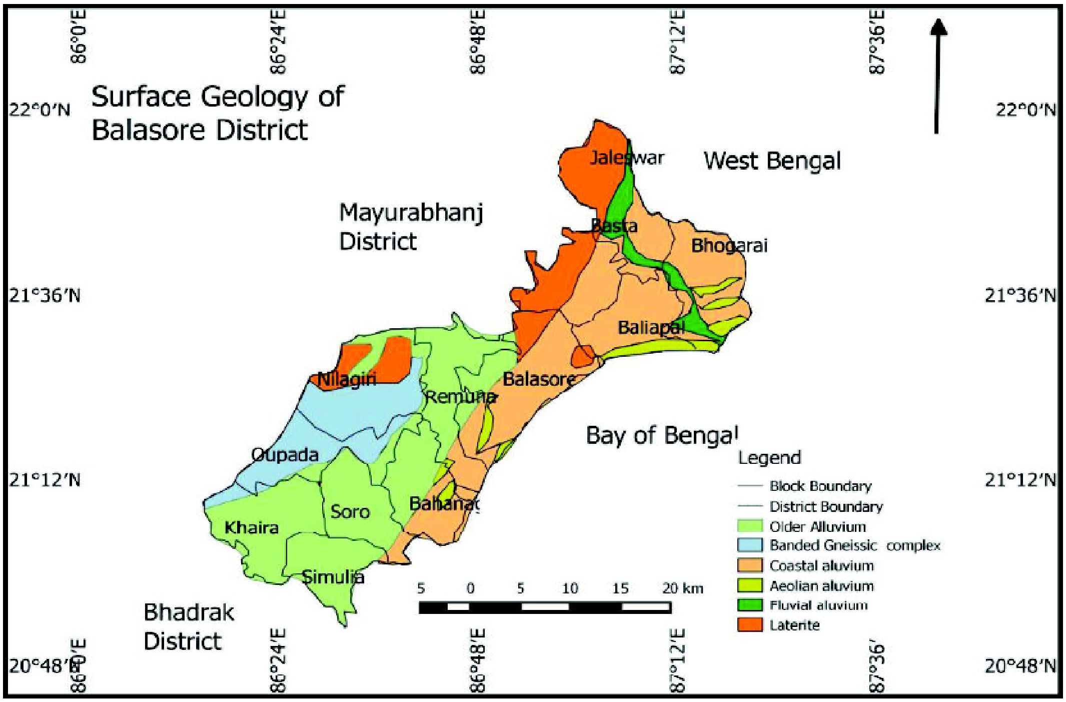

Fig.3 Surface Geology of Balasore district

The physiochemical analysis of the ground water quality of Balasore district has been compared with the Water Quality Index (WQI) of WHO.

pH– It is one of the most important operational water quality. Water in a pure state has a neutral pH which shows concentration hydrogen ion in the water. Generally, elevated pH (alkaline waters) does not impact human health, but it can alter the taste of the water and it shows a close association with ionic constituents of the water (Wagh et al. 2016a, b).The physiochemical parameter P^H of groundwater samples of Balasore district was ranges from 7.92- 8.53with average of 8.34 against World Health Organization (WHO) standard 2011 of 6.5-8.5. Lowest pH of 7.92 is in Nilgiri block and highest 8.53 in Basta block. Both blocks have granite andlaterite rock formations. Average pH of the district varies from 8.24 in Baliapal block to 8.41 in Balasore Block. This indicates that all the groundwater samples have pH value above the most desirable limit.

The mean ± SD (8.34 ± 0.13) and median (IQR) [8.37 (8.32 – 8.42)] have very high values. Groundwater quality of the district is mostly alkaline in nature. High pH in Balasore and Baliapal blocks are due to the impact of industrial pollution of the ground water.All biochemical reactions are vulnerable to pH changes (Rao et al. 1993). The most groundwater has been found to be alkaline in nature, suggesting that bicarbonate is dominant over carbonate ions, influencing the pH of most water (Laar et al. 2011). The presence of hard water minerals and the release of agricultural waste water can lead to factors influencing alkalinity (Dinka 2014). The spatial irregularity is observed in the P^H may be influenced by saturation and dilution phenomenon .

Electrical conductivity-The Electrical conductivity (EC) is a measure of total salt content of water based on the flow of electrical current through the sample. The higher the salt content, greater will be the flow of electrical current. EC value of groundwater may be an approximate index of total content of dissolved substance in water and it depends open the temperature, concentration and type of ions present (Hem, 1985). EC can be classified as type I, if the augment of salts are low i.e. EC < 1,500 μmhos/cm., if the EC = 1,500 μmhos/cm, it is type II and if the salts are higher i.e. EC> 1,500 μmhos/cm/ it is type III. The electrical conductivity of the district ranges from 103-787 (μmhos/cm)and mean at 25°C against the most desirable limit 1500 μmhos/cm. Mean EC is 423.49 (μmhos/cm).Lowest EC 103 μmhos/cm is in Bahanaga block and highest 787 in Soroblock. The mean lowest EC is 325 (μmhos/cm) in Simulia block and highest mean is 487 (μmhos/cm) in Remuna block. The mean ±SD423.49 ± 173.36 and the median 388.00(285.50-559.75) are well below the most desirable limit. Higher EC content is due to proximity to the coast. Lower EC content of the study area indicates that lower salt content in the groundwater and falls under Classification type I of EC. From the above classification, almost all the values of EC are within the type I, i.e. low enrichment of salts (Prasanth*et al.,* 2012).

TDS-The TDS mainly comprises of inorganic salts and small amounts of organic matter that are dissolved in water. The principal constituents are usually calcium, magnesium, sodium and potassium and anions of carbonate, bicarbonate, chloride and sulphate. Thetotal dissolved solids (TDS) are an important parameter fordrinking water quality and irrigation suitability due to thecontained ionic constituents (Davies and DeWiest 1966). According to the BIS, the ideal TDS for drinking water is below 500 mg/l and the maximum permissible limit is 2000 mg/l. According to WHO specification, TDS values of water up to 500 mg/l is the highest desirable limit and allowable limit is 1500. The TDS has a wide range in the study area of 68.0-532.0 mg/l, with a mean concentration of 289.67 mg/1. Lowest TDS observed is 68 in Bahanaga block. Lowest mean TDS of the district is 227.5 in Simulia block and highest 331.86 in Remuna block. The TDS variations are due to the climatic condition, lithology, and local agricultural and anthropogenic practices. Very few centres have TDS slightly higher than the maximum desirable limit. Half of the centres have TDS value below 273 mg/l (Median), 3/4th of the centres have TDS lower than 379.0 mg/l. Only two centres have TDS more than 500 are in Jaleswar block 532 and Soro block 526. The mean ±SD (289.67 ± 116.14) and median (IQR) [273.00(191.75-379.00)]. Based on TD Sclassification, majority of the samplesare under desirable for drinking and irrigation purpose. This indicated that TDS value among majority sample centres are quite lower than the highest desirable limit.

Total alkalinity- Alkalinity of water is due to the geology of the area and the percolation of rain and surface water along with the dissolved carbon dioxide of the atmosphere. Rain water is naturally acidic, which tends to dissolve some minerals more easily. Alkalinity increase is an indication of increase in concentration of carbonates and bicarbonates of sodium and magnesium may be through sea water. Total alkalinity as CaCO3 (mg/l) in the study area is in the range of 20.0-255.0 mg/l. Lowest alkalinity and highest alkalinity were in Bahanaga block. Lowest mean alkalinity of 57.5 found in Oupada and highest of 142.50 in Balasore block. The mean (115.26 ± 54.51 mg/l) and median values [107.50 (72.50-165.0)] are within the most desirable limit of WHO Drinking Water Quality standards i.e. 200 mg/l. Beyond this limit test of water become unpleasant. In absence of alternate water source alkalinity up to 600 gm/l is permissible. Only in 3 out of 78 cases the alkalinity crosses the most desirable limit.

Total Hardness (TH)-Total hardness is an important parameter of water forits use in domestic sector. It arises due to the presence of calcium andmagnesium. In general, hard waters originate in areas where the topsoil is thick and limestone formations are present (Arumugam 2010). The total hardness in water is derived from the solution of carbon dioxide released by bacterial action in the soil, in percolating rain water. Low TH condition develops and led to the dissolution of insoluble carbonates in the soil and in limestone formations to convert them in to soluble bicarbonates. Impurities in limestone such as sulphates, chlorides and silicates, become exposed to the solvent action of water as carbonates are dissolved so that they also pass in to solution. Water hardness has no known adverse effect, however some evidence indicates its role in heart disease. Hard water is unsuitable for domestic use and it is a measure of the Ca^{2+} and Mg^{2+} content and is expressed in equivalent. of calcium carbonate. hardness of water (temporary or permanent is by the inhibition of soap action in water due to the precipitation of Ca^{2+} and Mg^{2+} salts such as carbonates, sulphates and chlorides. Temporary hardness is mainly due to the presence of calcium chloride and get removed when water boils. Permanent hardness is caused by the presence of Ca^{2+} and Mg^{2+} which get removed by ion exchangeprocesses,Hardness of water limits its use for industrial purposes, causing scaling of pots, boilers and irrigation pipes and may cause health problems to humans, like kidney failure. In the study area hardness ranges from 20 to 225 mg/l whichis within the permissible limits. Lowest hardness in Balasore block and highest hardness in Soroblock. The general acceptance level of hardness is 300gm/l although WHO has set an allowable limit of 600gm/l. Average total hardness varies from 117.50 to 185.00 mg/l. Oupada block has lowest hardness, Balasore and Soro block has highest total hardness. The mean ±SD(155.71 ± 64.04) and median values 140.00(105.00-202.50). The groundwater of the entire study area lies within the desirable limit of WHO standards 300 mg/l.

Ca++ - Calcium is the fifth abundant natural element that is dissolved from soils, rocks and the essential component responsible for the hardness of water. Geological sources, agricultural waste and industrial waste could be used to generate calcium in drinking water (Deshpande 2011). Acceptable limit of calcium in drinking water is 75mg/l (200mg/l in case of no other alternative source) (BIS 2012). Calcium and Magnesium are the most abundant elements in nature and also found in surface and groundwater. Ca^{++} concentration varies within the range of 8.0-90.0 mg/l. Lowest calcium concentration in Balasore city and highest concentration in Soro block. Average calcium concentration in blocks vary from 25.25mg/l in Basta block to 45.5 mg/l in Soroblock. The mean ±SD (31.49 ± 16.05)/l and median values [27.0 (20.0-44.0)] are within the WHO drinking water desirable limit i.e. 75mg/l. 3/4th of the centres have Ca^{++} lower than 44.0 mg/l. Hence the water can be used for drinking water .Calcium ion is necessary for proper mineralization of bones and bone strength. Osteoporosis, defective teeth, nephrolithiasis (kidney stone), rickets, hypertension and stroke, etc., can result from inadequate calcium intake (Faruqi 2002).

Mg++-Generally calcium and magnesium maintain a state of equilibrium in most ground water (Hem 1985).The prime sources of magnesium (Mg^{2+}) in the natural water are several rock types, sewage and industrial wastes (Deshpande 2011). Higher magnesium levels in drinking water can trigger unwanted drinking water tastes that cause laxative effects. Mg^{++} values range between 1.22-41.31mg/l. Lowest magnesium of 1.22 mg/l in Bahanaga block and highest 41.31 mg/l in Balasore block. Average lowest magnesium of 7.3 mg/l in Oupada block and highest 26.93 in Balasore block. The mean ±SD (18.71 ± 9.98) and median values [17.01(11.85-25.52)].The acceptable limit of magnesium in drinking water is considered as 30mg/l, though 100mg/l is also used in case of no other alternative source(BIS,2012) these values are within the most desirable limit of WHO standards. For drinking purposes, the necessary permissible limit of magnesium in groundwater is 150 mg/L (WHO 2011). Magnesium helps in maintaining normal nerve and muscle system and helps bones remain strong. It also helps in regulatingglucose levels in blood and aids in the production of energy and protein. Deficiency of magnesium in the human diet might lead to anxiety, fatigue or anorexia

Sodium-Sodium is present in most of the natural water as it ranks 6th among natural elements in order of abundance. Sodium helps in regulating blood pressure levels in the human body. Sodium is an important ion used for the classification of irrigation water due to its reaction with soil, which reduces its permeability. Hence, air and water circulation is restricted during wet conditions and such soils become usually hard when dry (Saleh et al. 1999). Sodium is usually expressed in terms of percent sodium or soluble sodium percentage. The concentration of sodium varies between 7.0-78.0 mg/l and the mean ±SD values is 24.44 ± 12.22 and the median value is 22.20 mg/l. 3/4th of the stations have Na^{+} value lower than 27.60 mg/l.

Potasium- Potassium is a naturally occurring element. The concentration of K+ is observed in the range of 2.30- 18.0 mg/l and mean ±SD value is 6.81 ± 3.16. In ½ of the study area, K+ are found lower than 6.15 mg/l. 3/4th of the studied area values are lower than 8.03 mg/l.

Chloride- High chloride concentration in certain area can be derived from different sources such as weathering, rock, soil leaching, domestic, urban, industrial effluents, dry environment

(Sarath Prashanth et al. 2012; Subba Rao et al. 2017). Residual water inpores of granites may contain chloride (Shand 1952). The high concentration of chloride gives a salty taste to water, which is unfit for drinking and irrigation, can cause physiological harm. Usually, water with a high chloride content has an unpleasant taste and may be dangerous for certain agricultural purposes. When ingested in higher concentrations, higher chlorides cause laxative effects in humans (Sunitha et al. 2019). Chloride ion combines with sodium and forms sodium chloride. In this study the concentration of chloride varies from 3.55-92.17 mg/l. Lowest and highest concentration of chloride found in Bhogarai block. Relatively lower concentration of chloride is found in the study area. Average chloride concentration 33.67 mb/l, highest 51.41 mg/l in Soro block and lowest 15.36 mg/l in Balasore block. The mean ±SD (32.63 ± 22.87) and the median [30.14(10.64-46.97)] values are also within the standard values of WHO. As per WHO (2011) Cl^- has standard limit of 200 mg/L -500mg/l for drinking water (WHO 1990; BIS 2012).

HCO3-Bicarbonate originates from the reaction of ground water with CO2 in soil or air or due to the action of CO2 upon the basic materials of the soil and granitic rock. The value of HCO3- ranges between 24.40-305.00 mg/l.It has a mean ±SD value 134.12 ± 65.75. 3/4th of bicarbonate values of the studied areas are lower than 190.63 mg/l.Average concentration is

Table .1 Descriptive statistics of physio-chemical parameters of ground water samples of Balasore district(N=78)

Variables	Mean ± SD	Median(IQR)	Range (Min. - Max.)	WHO Standard Value (Most desirable limit)
pH	8.34 ± 0.13	8.37(8.32-8.42)	(7.92-8.53)	6.5-8.5
EC (¼mhos/cm)	423.49 ± 173.36	388.00(285.50-559.75)	(103.00-787.00)	1500 (¼mhos/cm)
TDS (mg/l)	289.67 ± 116.14	273.00(191.75-379.00)	(68.00-532.00)	500 in mg/l
Total Alkalinity (mg/l)	115.26 ± 54.51	107.50(72.50-165.00)	(20.00-255.00)	200 in mg/l
Total Hardness (mg/l)	155.71 ± 64.04	140.00(105.00-202.50)	(45.00-345.00)	100 in mg/l
Ca^{++} (mg/l)	31.49 ± 16.05	27.00(20.00-44.00)	(8.00-90.00)	75 in mg/l
Mg^{++} (mg/l)	18.71 ± 9.98	17.01(11.85-25.52)	(1.22-41.31)	50 in mg/l
Na^+ (mg/l)	24.44 ± 12.22	22.20(18.64-27.60)	(7.00-78.00)	-
K^+ (mg/l)	6.81 ± 3.16	6.15(4.68-8.03)	(2.30-18.00)	-
Cl^- (mg/l)	32.63 ± 22.87	30.14(10.64-46.97)	(3.55-92.17)	200 mg/l
CO_3^- (mg/l)	8.15 ± 4.32	6.00(6.00-7.50)	(6.00-24.00)	-
HCO_3^- (mg/l)	134.12 ± 65.75	122.00(83.88-190.63)	(24.40-305.00)	-

Source: Computed by the author

130.17mg/l. lowest value of bicarbonate of 67.10 mg/l in Oupada block and highest of 165.72 in Balasore block. Carbonate values varies between 3.55-92.17 mg/l. Its mean ±SD value is 8.15 ± 4.32. No standard limits have been provided by the Bureau of Indian Standards for level of carbonate in drinking water (Table.1).

Composite index of the ground water quality

The ground water quality of the district is within permissible limit except in the coastal part salinity is a problem. The composite index of rankings of the parameters of the ground water quality of the district at the block level is analysed to know the standard of ground water. It shows that Oupada and Simulia blocks have very good ground water quality. These blocks are in the western part of the district. Good ground water in Bahanaga, Basta and Nilgiri blocks. Bahanaga and Basta blocks are in the western part of the district where as Nilgiri in eastern part of the district. Moderate quality ground water in Soro, Khaira, Bhogarai, Remunaand Baliapal blocks. Bhogarai and Baliapal blocks are in the eastern part of the district where as Soro, Remuna and Khaira blocks are in the western part of the district. Low quality ground water in Balasore and Jaleswar blocks (Table. 2 & Fig.4).

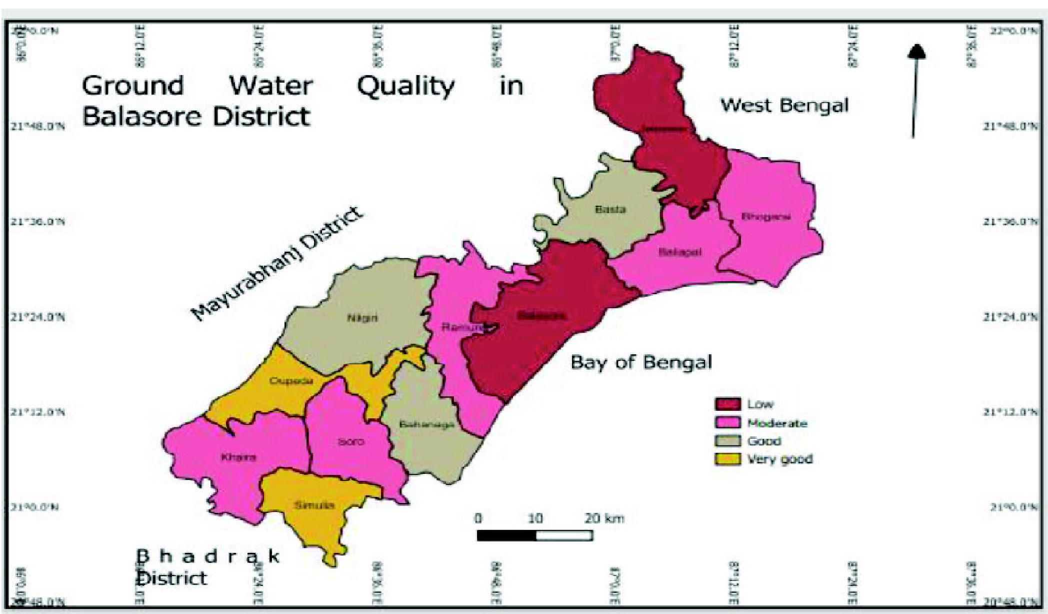

Fig.4 Ground water quality in Balasore district

Correlation Analysis:

Twelve physicochemical variables are subjected to correlation analysis and the result is furnished in the correlation matrix at Table-2. The pH has weak correlation with two variables

Table-2. Quality of ground water in Balasore district 2019

Sl. No.	C.D.Block	P^H	Electrical Conduc-tivity [µmhos/cm]_Gen	Total TDS gm/1	Phen Alk, as $CaCO_3$ [mg/L]	Total Alkalnity, as $CaCO_3$ [mg/L]	Total Hardness Total $CaCO_3$, [mg/L]	Hradness Ca, as $CaCO_3$, [mg/L]	Calcium, [mg/L]_Major ion	Magnesium, [mg/L]_Major ion	Chloride, [mg/L]_Major ion	Sulphate, [mg/L]_Major ion	Carbonate, [mg/L]_Major ion	Bicarbo-nate, [mg/L]_Major ion
1	Bahanaga	8.35	406.67	273	5.83	120.83	138.33	74.17	29.67	15.60	21.27	33.6	7.00	140.30
2	Balasore City	8.36	386.69	257.92	6.54	100.00	131.15	67.31	29.92	15.52	27.55	11.45	7.84	114.02
3	Balasore	8.41	421.17	291.33	6.67	142.50	185.00	74.17	29.67	26.93	15.36	0	8	165.72
4	Baliapal	8.24	388.75	274	6.67	121.88	168.13	86.88	34.75	19.75	21.27	33.6	9	144.11
5	Basta	8.39	436.88	299.38	6.88	112.50	147.50	63.13	25.25	20.50	40.77	0	8.25	128.86
6	Bhogarai	8.35	465.57	326.57.	5	113.57	165.00	80.00	32.00	20.64	41.53	0	6.00	132.46
7	Jaleswar	8.37	473.88	327.75	5	124.38	170.63	77.50	31.00	22.63	45.20	0	6.00	145.34
8	Khaira	8.27	447.00	305.25	5	121.25	158.75	73.75	29.50	20.65	31.91	0	6.00	141.43
9	Nilgiri	8.25	357.00	250.67	3.33	130.00	165.00	101.67	40.67	15.40	15.37	0	4.00	154.53
10	Oupada	8.27	348.50	245	2.5	57.5	117.50	87.50	35.00	7.3	46.07	0	6.00	67.10
11	Remuna	8.34	487.00	331.86	5	125.00	154.29	85.00	34.00	16.81	37.48	0	6.00	146.40
12	Simulia	8.36	325	227.5	5	75.00	135.00	85.00	34.00	12.15	42.55	0	6.00	85.40
13	Soro	8.26	442.00	299.45	3.75	107.50	185.00	113.75	45.5	17.33	51.41	0	4.50	126.58

Source:Computed by the author

Calcium and Magnesium ion. With the remaining 10 variables the correlation was insignificant. EC has strong correlation with 5 variables (TDS, TH, Total alkalinity, Mg^{++}. HCO_3^-) and moderate correlation with 2 variable (Ca^{++} and Cl^-). TDS has a strong correlation with 5 variables (EC, TH, Total alkalinity, Mg^{++}. HCO_3^-.)and moderate correlation with Ca^{++}, Cl^-. Total alkalinity has a strong correlation with 5 variables (EC, TDS, TH, Mg^{++}. HCO_3^-) and a moderate correlation with Ca^{++}. Total Hardness has a strong correlation with 6 variables (EC, TDS, Total Alkalinity, Ca^{++}, Mg^{++}. HCO_3^-) and a weak correlation with Cl^-. Calcium has a strong correlation with one variable (TH) and a moderate correlation with 4 variables (EC, TH, Total alkalinity, HCO_3^-) and a weak correlation with CO_3^-. Magnesium has a strong correlation with 5 variables (EC, TH, Total alkalinity, TDS, HCO3-) and a weak correlation with pH and Ca^{++}. Chloride has a moderate correlation with EC and TDS and a weak correlation with TH and Ca^{++}. Bicarbonate has a strong correlation with 5 variables (EC, TDS, Total alkalinity, TH, Mg^{++}) and a moderate correlation with Ca^{++} (Table.3,Fig.5,6,7,8,9,10&11)

Table 3 Karl Pearson's Correlation analysis of physicochemical parameters of ground water samples of Balasore district of Odisha (N=78)

Variables	pH	EC	TDS	Total Alkaline	Total Hardness	Ca^{++}	Mg^{++}	Na^{++}	K^+	Cl^-	CO_3^-	HCO_3^-
pH	1											
EC	0.087	1										
TDS	0.067	0.993**	1									
Total Alkaline	0.181	0.830**	0.833**	1								
Total Hardness	-0.090	0.774**	0.799**	.839**	1							
Ca++	-0.387**	.498**	0.522**	.476**	0.783**	1						
Mg++	0.238*	.720**	0.737**	.843**	0.794**	.244*	1					
Na++	0.045	0.033	0.026	0.132	0.066	0.039	0.065	1				
K+	0.127	-0.179	-0.191	-0.191	-0.223*	-0.195	-0.157	-0.085	1			
Cl-	-0.078	.521**	.515**	0.081	0.260*	0.308**	0.104	0.006	-0.164	1		
CO_3^-	0.081	0.029	0.012	0.044	-0.198	-0.325**	0.008	-0.08	0.003	-0.108	1	
HCO_3^-	0.131	0.826**	.832**	.997**	0.860**	0.518**	.835**	0.133	-0.199	0.087	0.004	1

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

Source: Computed by the author

Regression Analysis:

Backward linear regression analysis was done for TDS with 7 independent variables namely

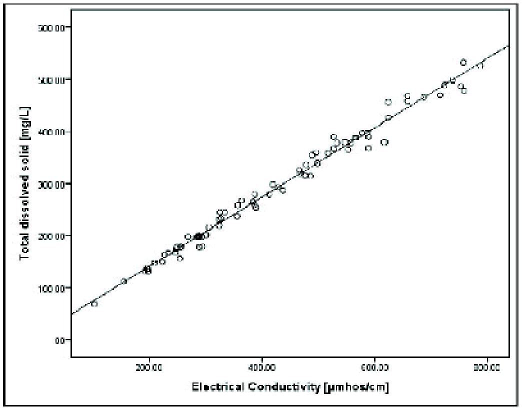

Fig.5 Scatter plot of TDS with EC

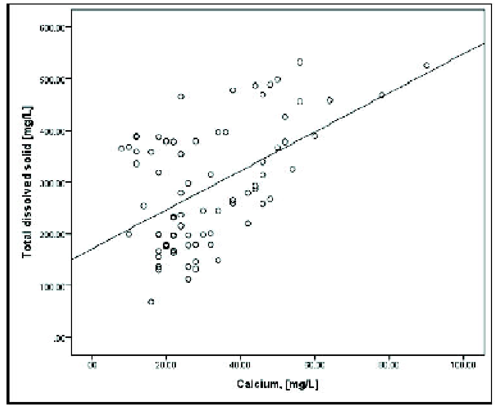

Fig.6 Scatter plot of TDS Vs Ca++

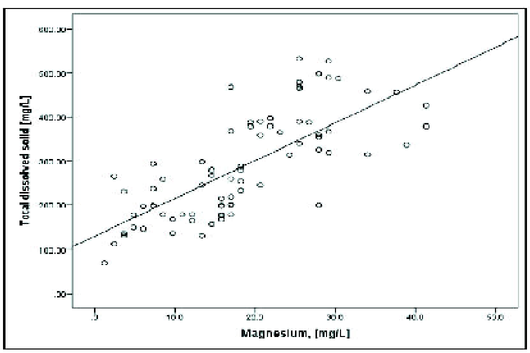

Fig-7 Scatter plot of TDS Vs Mg^{++}

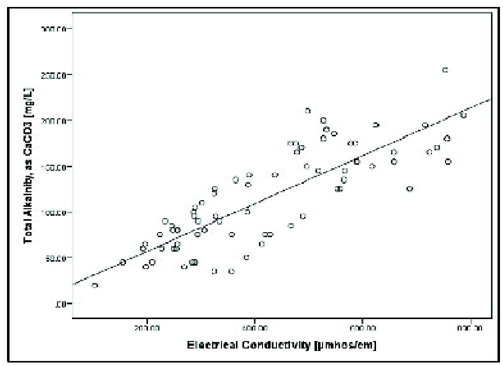

Fig-8 Scatter plot of TA Vs EC

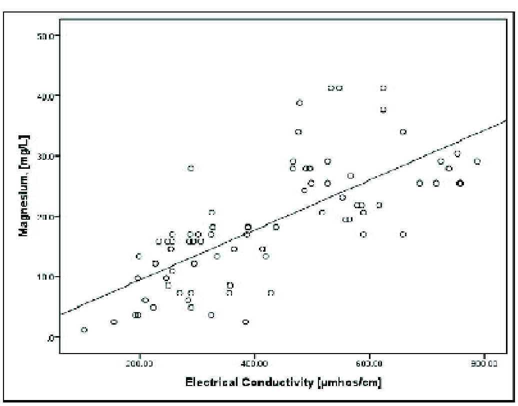

Fig-9 Scatter plot of EC Vs Mg^{++}

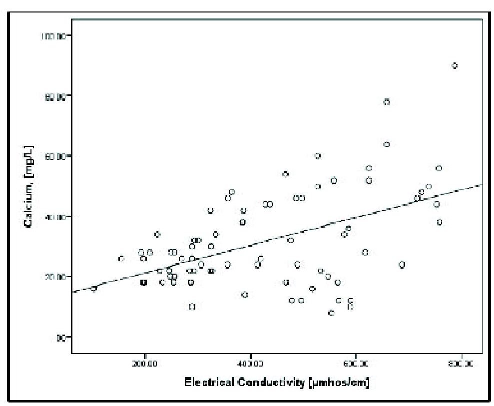

Fig-10 Scatter plot of EC Vs Ca^{++}

EC, Total Hardness, Total alkalinity, Calcium, Magnesium, Chloride and bicarbonate. The backward regression was continued up to step-4 and the final variable included in the regression model were EC, Calcium and Magnesium ion with significant regression coefficient ($p<0.05$). The regression model has a coefficient of determination (R2) =0.989.The implied EC, Calcium and Magnesium ions of the groundwater explained 98.9% of the variations in the TDS in the groundwater. The regression model is as follows.

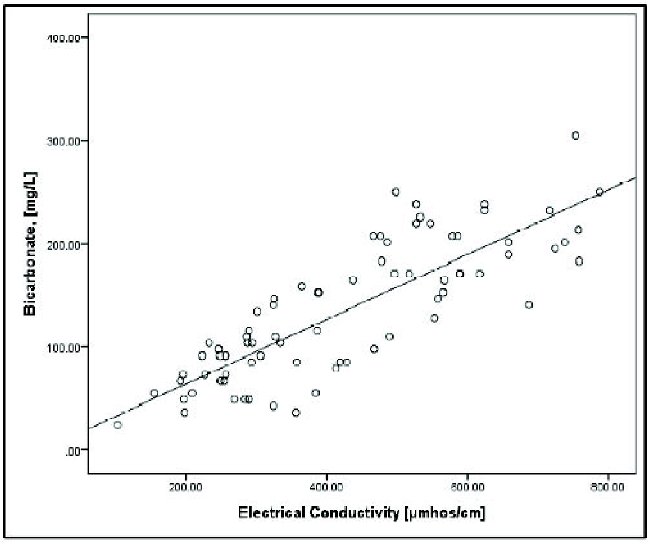

Fig 11. Scatter plot of EC Vs HCO_3

Y (TDS) = 3.312 + 0.624 EC + 0.317 Ca^{++} + 0.642 Mg^{++}.

The regression model implied that unit change in the EC value can affect 0.624 change in the TDS value keeping the values of other two variable constant. Unit change in the Ca^{++} value will affect 0.317 change in the TDS value keeping the other variables constant. Unit change in the Mg^{++} value will affect 0.642 change in the TDS value, keeping other variables constant.

Similarly backward linear regression analysis was done for total alkalinity with 6 independent variables namely EC, TDS, Total Hardness, Calcium, Magnesium and bicarbonate. The backward regression was continued up to step-2 and the final variable included in the regression model were TDS, Ca^{++} and HCO_3^- with significant regression coefficient ($p<0.05$). The regression model has a coefficient of determination (R^2) = 0.997. The implied TDS, Ca^{++} and HCO_3^- of the groundwater explained 99.7% of the variations in the total alkalinity in the groundwater. The regression model is as follows.

Y (Total Alkalinity) = 5.985 + 0.014 TDS -0.2Ca^{++} + 0.832 HCO_3^-.

Table.4 Linear Regression analysis for TDS and Total Alkaline (N=78)

Dependent variables	Step	Independent variables	Coefficients B	SE	R^2	p' value
TDS	1	(Constant)	6.124	4.984	0.990	0.223
		EC (µmhos/cm)	0.640	0.026		0.000
		Total Alkalinity (mg/l)	-0.643	0.502		0.204
		Ca^{++} (mg/l)	0.256	0.155		0.103
		Mg^{++} (mg/l)	0.892	0.284		0.002
		Cl- (mg/l)	-0.001	0.110		0.994
		HCO_3^- (mg/l)	0.460	0.418		0.275
	2	(Constant)	6.121	4.936	0.990	0.219
		EC (µmhos/cm)	0.640	0.015		0.000
		Total Alkalinity (mg/l)	-0.642	0.493		0.197
		Ca^{++} (mg/l)	0.256	0.151		0.096
		Mg^{++} (mg/l)	0.892	0.280		0.002
		HCO_3^- (mg/l)	0.460	0.415		0.271
	3	(Constant)	2.756	3.898	0.990	0.482
		EC (µmhos/cm)	0.635	0.015		0.000
		Total Alkalinity (mg/l)	-0.100	0.063		0.113
		Ca^{++} (mg/l)	0.374	0.108		0.001
		Mg^{++} (mg/l)	0.942	0.277		0.001
	4	(Constant)	3.312	3.924	0.989	0.401
		EC (µmhos/cm)	0.624	0.013		0.000
		Ca^{++} (mg/l)	0.317	0.103		0.003
		Mg^{++} (mg/l)	0.642	0.206		0.003
Total Alkalinity (mg/l)	1	(Constant)	6.119	0.951	0.997	0.000
		TDS (mg/l)	0.015	0.005		0.008
		Ca^{++} (mg/l)	-0.209	0.028		0.000
		Mg^{++} (mg/l)	-0.053	0.068		0.440
		HCO_3^- (mg/l)	0.838	0.012		0.000
	2	(Constant)	5.985	0.932	0.997	0.000
		TDS (mg/l)	0.014	0.005		0.011
		Ca^{++} (mg/l)	-0.2	0.025		0.000
		HCO_3^- (mg/l)	0.832	0.009		0.000

Source: Computed by the author

The regression model implied that unit change in the TDS value can affect 0.014 change in the total alkalinity value keeping the values of other two variable constant. Unit change in the Ca^{++} value will affect -0.2 change in the total alkalinity value keeping the other variables constant. Unit change in the HCO_3^- value will affect 0.832 change in the TDS value keeping other variables constant (Table.4).

Conclusion

The western part of the district is underlain by hard rock formation and is also associated with patchy occurrence of fluoride in some of the habitation. Iron infestation is common in the alluvial areas bordering the laterite cappings. There are also inherent salinity problems in the blocks bordering the Bay of Bengal.The water of inland areas is fit for most type of crops but in coastal areas slightly salt tolerant crops can grow. The quality of water in deeper aquifers, like shallow aquifers, is governed by the physiographic as well as geological set up. The water from deeper aquifers is also fresher in inland areas than that of coastal area. The chemical characteristics of water from deeper aquifers are more or less similar to the water of shallow aquifers occurring under same hydrogeological set up. Industrialization, urbanization and use of chemical fertilizers in agriculture contaminate the ground water. The occurrence of pollutants in deeper aquifer water is also restricted in minor pockets. It is important to note that the concentration of pollutants like nitrate in water is less in deeper aquifers than that of the shallow aquifers. Electrical conductivity in all the sample points are within the type I, i.e. low enrichment of salts. TDS value among majority sample centres are quite lower than the highest desirable limit. Only in 3 out of 78 cases the alkalinity crosses the most desirable limit. Total Hardness of groundwater of the entire study area exceeds the most desirable limit but lies within the maximum allowable limit of drinking water quality standards. Total hardness can be considered as an issue in the area. Calcium and Magnesium values are within the most desirable limit. The concentration of sodium in the ground water was found to be as per the Indian standard. Relatively lower concentration of chloride is found in the study area. Correlation matrix shows high degree of linear associations among the pairs of variables. The pH has weak correlation with two variables. Calcium and Magnesium ion has no correlation with the rest of the studied variables. EC, TDS, total alkalinity, total hardness, magnesium and HCO_3^- has a strong correlation with 5 to 6 of the variables and a moderate level of correlation with 2 numbers of variables. Ca^{++} has strong correlation with one variable and moderate correlation with 4 variables. Variables like Na^+, K^+, Cl^-, CO_3^- do not have strong correlation with any of the variables and have moderate to weak correlation with very fewer number of variables. Linear Regression analysis found significant regression model for two quality indicators like TDS and total alkalinity. The TDS had three predictor variables like EC, Ca^{++} and Mg^{++} that explains 98.9% of the variations. Total Alkalinity has three predictor variables like TDS, Ca^{++} and HCO_3^- that explains 99.7% of the variations. The composite index of the quality of ground water shows very good in Oupada and Simulia blocks and low quality in Balasore and Jaleswar blocks.

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