DISSERTATION REPORT
ON
GROUNDWATER INVESTIGATION IN THE COASTAL PARTS OF ODISHA

SUBMITTED
BY

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SUBMITTED IN:- MAY,2017

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I, hereby, certify that the report entitled **"GROUNDWATER INVESTIGATION IN THE COASTAL PARTS OF ODISHA"** in partial fulfilment of the requirement for the degree of **MASTER OF SCIENCE** in **CENTRE FORENVIRONMENTAL SCIENCES, CENTRAL UNIVERSITY OF JHARKHAND**, during the period of **January 2017** to **May 2017**, is an authentic record of my own work under the supervision of **Dr. Bhaskar Singh**, Assistant Professor, Central University of Jharkhand and **Dr M.S. Rao**, Scientist 'E', Hydrology Investigation Division, National Institute of Hydrology (NIH), Roorkee (Uttarakhand).

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This dissertation entitled"Groundwater investigation in the coastal parts of Odisha" submitted by Miss Priya Mukherjee, Centre for Environmental Sciences, Central University of Jharkhand, Ranchi as a part of the Master programme, is an original work and has not been submitted so far in part or in full, for any other degree or diploma of any University or Institution.

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ABSTRACT

Groundwater, the unseen part of the hydrological cycle is the most widely used source of drinking water in India. About 85 percent of India's rural water requirements and 50 percent of the urban necessity is met by groundwater. But in the vicinity of sea, groundwater is often beset with salinity hazard. Intensive groundwater extraction from aquifer reduces freshwater outflow to sea, lowering the water table and causing saltwater intrusion. The saltwater intrusion can be identified using geo-electrical, geochemical, isotopic and groundwater modelling studies.

The topic of the report "Groundwater investigation in the coastal parts of Odisha" is taken to investigate the condition of freshwater present in the coastal aquifers of Odisha; to check is the water used by local people in the proximity of the sea is not intrude by salinity.

The purpose of this study is to elucidate the chemical and isotopic changes in groundwater samples to compare its quality from the WHO and BIS standards to know its safety for drinking and irrigation taking Odisha as the study area.

The state of Odisha covers an geographical area of 1, 55, 707 sq.km and a coastline of 480.40 km. Agriculture is the main economy of the state. Orissa is one of the India's largest rice producer state contributing about one-tenth of country's total rice production. But the principle problem that Odisha agriculture faces is the shortage of water in many areas although it is endowed with a rainfall of 1502mm.

The drought-flood-cyclone syndrome and tidal incursion have restricted the availability of uncontaminated surface water round the year. This along with the ever increasing demand of water for drinking and irrigation for the high population density has led to the increase in use of groundwater as a sustainable source of freshwater. Hence the management of the coastal aquifers of this area for maintaining the hydro-chemical balance between freshwater and saltwater and ensuring protection of the aquifers is important. These necessitate a through periodic investigation of groundwater for the proper understanding of coastal groundwater regime of the area.

Salinization is the major problem in coastal areas degrading freshwater quality and availability. Hence the monitoring and identification of the origin of salinity is important in both water management and its remediation. Isotopic techniques are mainly used for

identifying the source of water. The stable isotopes of oxygen and hydrogen are used for the study of the groundwater samples. Dual inlet isotope mass spectrometer instrument is used for this examination.

The anionici.e fluoride, chloride, nitrate, nitrite, sulphate as well as cationic i.e sodium, ammonium, potassium, magnesium and calcium concentration in the groundwater and seawater samples of Odisha's different parts are investigated using Ion-Chromatography (Dionex ICS 5000).

Moreover electrical conductivity, temperature, pH and radon were also calculated. All these parameters are analysed and interpreted in the report.

The areas unsafe for drinking and irrigation are demarcated and the areas prone to salinity hazard are also identified. Moreover a zoning of the sampling sites is done to check the water condition of the sampled areas.

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LIST OF ABBREVIATIONS

°C	- Degree Celcius
µL	- microlitre
‰	- Permille
□^{18}O	- Oxygen -18
^{222}Rn	- Radon -222
BCM	- Billions cubic meter
BEX	- Base exchange indices
BIS	- Bureau Of Indian Standards
Ca^{2+}	-Calcium
CGWB	- Central Ground Water Board
Cl^{-}	- Chloride
CWC	- Central Water Commission
□D	- Deuterium
°E	- degree east
EC	- Electrical Conductivity
F^{-}	-Fluoride
FAO	- Food and agriculture Organisation
GIS	- Geographic Information System
HP	- Hand pump
K^{+}	-Potassium
Km	- kilometres

KR - Kelly's ratio

LW - Lagoon water

m - meters

meq/l- miliequivalents per litre

mg/l- milligram per litre

Mg^{2+} - Magnesium

mha- million hectare

mL - mili-litre

mm - mili-meter

n.a. - not analysed

Na^{+} - Sodium

°N - degree north

NASA - National Aeronautics And Space Association

ND - not detected

NH_4^{+} -Ammonium

NO_2^{-} - Nitrite

NO_3^{-} -Nitrate

pCi/l- pico Curie per litre

ppm- parts per million

psi - pounds per square inch

SAR - Sodium adsorption ratio

SGD - Submarine Groundwater Discharge

SO_4^{2-} -Sulphate

sq. km - square kilometers

SW - Sea water

SWI - Salt water intrusion

UNESCO - United Nation Educational and Scientific Organisation

USGS - United States Geology Survey

WHO - World Health Organisation

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CHAPTER-1

GENERAL INTRODUCTION

1.1 INTRODUCTION

Groundwater, the unseen part of the hydrological cycle is the most widely used source of drinking water in India. About 85 percent of India's rural water requirements and 50 percent of the urban necessity is met by groundwater. But in the vicinity of sea, groundwater is often beset with salinity hazard. Intensive groundwater extraction from aquifer reduces freshwater outflow to sea, lowering the water table and causing saltwater intrusion. The saltwater intrusion can be identified using geo-electrical, geochemical, isotopic studies.

The coastal areas are heavily urbanized and therefore require an adequate and sustained yield of freshwater which is fit to meet for various purposes. The increased use of groundwater in coastal areas disproportion the existing dynamic balance between freshwater and seawater leading to intrusion of sea water.

There are different types of pollutants that can be found in groundwater, such as nitrate, heavy metals and saltwater. Intrusion is a common problem in coastal aquifers. Contamination of groundwater due to salinity intrusion into coastal aquifers has become a major problem for coastal communities. Therefore, understanding of seawater intrusion is required for the management of coastal water resources.

Groundwater levels in the aquifers are exhausted faster than they can recharge. This is directly connected to the position of the interface and regulate the amount of saltwater that can intrude into the freshwater aquifer system. Contamination of freshwater bodies caused by saltwater intrusion is a global issue, affecting water quality, vegetation and soil conditions along coastal area. Seawater intrusion occurs in coastal freshwater aquifers when both the saltwater and freshwater of different densities allow the ocean water to intrude into the groundwater aquifer. Salinity intrusion in coastal aquifers has traditionally been dependant upon the observation wells and collection of water samples. In some areas due to over-exploitation of groundwater, decline in water levels have resulted in insufficiency of water supply and intrusion of saline water in coastal aquifers had also been observed.

Hence, as the world's population is growing at an alarming rate, fresh water supplies are constantly getting depleted, bringing with it issues like saltwater intrusion and increasing the importance of public awareness of the issues, groundwater monitoring, management, and conservation.

1.2 HYDROLOGICAL CYCLE

The cyclic flow of water from earth's surface (oceans, rivers etc) to the atmosphere and again back to the earth via rain sustaining the various life processes is known as the hydrological cycle or water cycle. The balance is always maintained in hydrological cycle i.e the amount of water coming in the form of rain is always equal to the amount of water evapo-transpired by the earth's system. Hence there is no net gain or loss of energy and the energy is always conserved fulfilling the law of thermodynamics. Although it a very complex system which passes through all the three stages i.e solid, liquid and gas during its cyclic flow.

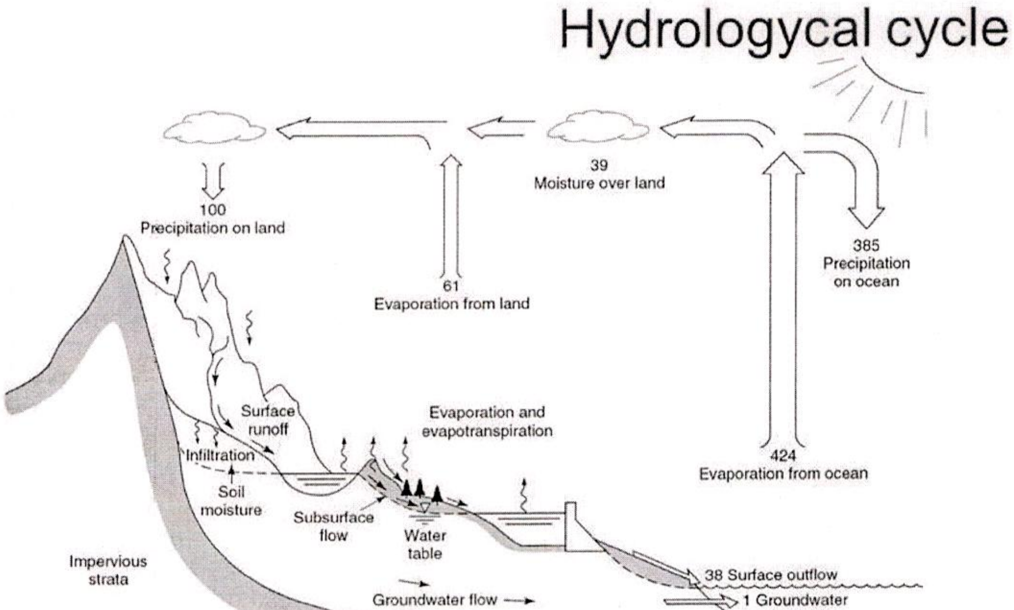


Fig1.1:- Hydrological cycle diagram showing its various components and its contribution in the cyclic flow (Source:-chow et.al, Applied hydrology, McGraw Hill, 1988).

The hydrological cycle process quantitatively can be explained with the help of the given fig.1.1. (chow et.al,1988).It is seen that 100 units of precipitation occurs on land surface(I_L) and 385 units are precipitated onto the oceans(I_O) which would be total 485 units precipitation occurs on earth i.e input (I) can be taken as 485 units. A part of the land precipitated water moves via surface run-off to the rivers, lakes and ultimately to the oceans. Another part of it is infiltrated into the ground and becomes a part of groundwater flow which also end its journey into the ocean. The plants and trees also take up the water from the ground-level and hence water is transpired from them as output. The total water evapo-transpired by soil (Os) and vegetation (Ov) as output is equal to 61 units.38 units of water makes its way into the oceans as surface outflow and 1 unit of water as groundwater outflow is also returned to the ocean. The ocean returns about 424 units of water into the atmosphere by evaporation as output (Oo).

Total Input (I) =100 units (I_L) + 385 units (I_O)
=485 units
Total Output (O) = (Os+Ov)+Oo
=61 units+424 units
=485 units
Therefore Input =Output
i.e, I=O
Hence the cycle or the balance is maintained.

Table1.1-Hydrological Processes Data On An Annual Scale

PROCESS	**VOLUME OF WATER**(in cubic km)
1.Evaporation from world's oceans	449,500
2.Evapo-transpiration from soil and plants	70,600
3.Precipitation on oceans	403,500
4.Precipitation on land	116,500
5.Surface run-off to oceans	45,900
6. Total Human consumption for agriculture, industry and water supply	9100

(Source:- original data from NASA, Journal of climate,2015)

1.3 GROUNDWATER

Groundwater -the unseen part of the hydrological cycle is the most widely used source of drinking water .The water occurring underground beneath the earth's surface in the pores, crakes and crevices between soil and rocks is called groundwater. It is an important natural resource contributing to the health and economy. A part of the incoming water in form of precipitation infiltrates into ground and reaches a saturated zone in the subsurface. This saturated groundwater can slowly move downwards and ultimately gets discharged into the lakes, streams and oceans.

Earth is considered as a blue planet about 70 percent of the earth's surface is water covered. However 97 percent of this total available water is saline and freshwater is only 3 percent. Out of this 3 percent water, 77 percent is trapped in glaciers and snow and 11 percent is considered to be found at a depth of 800m below ground. About 11 percent of water is available as extractable groundwater and 1 percent of freshwater is found surface water (CGWB, manual on artificial recharge, Sept 2007).

Groundwater occurs in various zones. The first zone is called the soil-water zone which extends from the soil surface to the root zone. Below it lie intermediate vadose zone. The third zone is known as the capillary zone and all these three zones together form the unsaturated zone or the zone of aeration. Water table is marked at the lower limit of the capillary zone marking the boundary between the unsaturated and saturated zone(Basic Ground-Water Hydrology by Ralph C. Heath, 1983) as given in fig1.2. below.

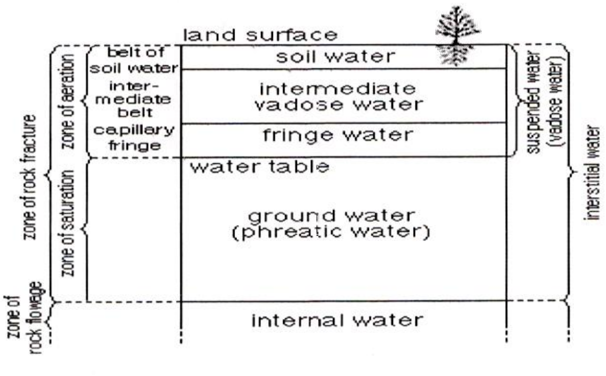


Fig 1.2.:-Groundwater and its various zones (Source:-KGS, Geology, Marshall country geohyrology, after O.E. Meinzer, 1923).

1.3.1 TYPES OF GEOLOGICAL FORMATIONS RELATED TO GROUNDWATER

i) **Aquifer:-** An aquifer is a sub-surface reservoir composed of geologic units that are sodden with water. The word *aquifer* comes from the Latin word *aqua* (water) and *ferre* (to bear or carry). Aquifers provide two important functions: a) they transmit groundwater from areas of recharge to areas of discharge, and b) they provide a storage medium for sealable quantities of groundwater. Aquifer can be further divided into two types:

   A. **Unconfined Aquifer:-** An unconfined aquifer is one in which the aquifer rests on an impervious formation whose upper boundary is patented by the water table.

   B. **Confined Aquifer:-** An confined aquifer is circumscribed by impervious formations both above and below and groundwater occurs under pressure greater than that of the atmospheric pressure therefore also called as artesian or pressure aquifer.

ii) **Aquiclude:-** An aquiclude is a saturated but relatively hermetic material that does not allow water infiltration best example being clay.

iii) **Aquitard:-** An aquitard is saturated but poorly layer that does not yield water freely to wells and impedes groundwater movement example sandy clay.

iv) **Aquifuge:-** An aquifuge is a relatively impenetrable formation that neither contains nor transmits water example hard granite.

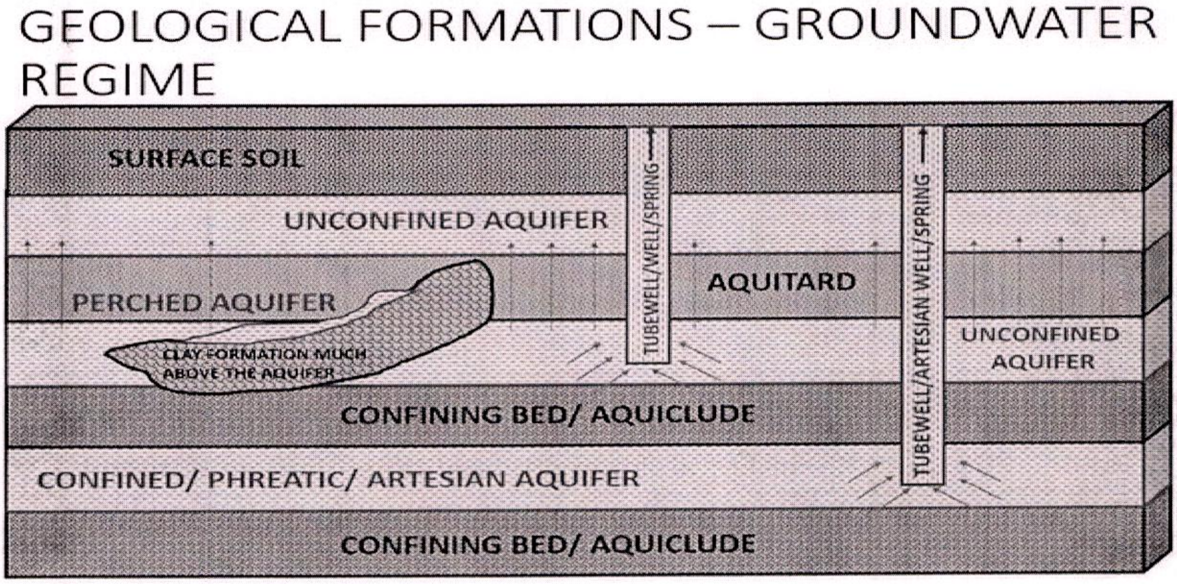


Fig1.3:-Geological formation groundwater regime (Source:-Quora, LakshmiKanthan MuraliKrishnan, 2017).

1.3.2 IMPORTANCE OF GROUNDWATER

Mankind have always known the presence and significance of groundwater. It is ubiquitous and embraced as fresh. It can be considered as a vast hidden resource which is always in motion starting its journey from the area of recharge to their destination the discharge areas. It sustains life on earth by providing water and minerals to plants- the producers of the ecosystem. Moreover it serves as a baseline flow for rivers and streams and hence supports a variety of ecosystems.

Groundwater is the source of water for more than 85 percent of India's rural domestic requirements, 50 percent urban requirements and more than 50 percent irrigation requirements (CGWB, manual on artificial recharge, Sept 2007).

Groundwater plays a sustainable role in water supply and ecosystem functioning. Worldwide, 2.5 billion people depend solely on groundwater resources to satisfy their basic daily water needs, and hundreds of millions of farmers rely on groundwater to sustain their livelihoods and contribute to the food security of so many others (UNESCO, 2012). Groundwater reportedly provides drinking water to at least 50% of the global population and accounts for 43% of all water used for irrigation (FAO, 2010).

The ever increasing necessity for water to support the food and drinking water requirement of the growing population along with urbanisation and industrialisation have restricted the availability of surface water and has increased the load on groundwater. As a result the groundwater is extensively exploited as a sustainable source of freshwater.

Table-1.2-Quantitative Estimate Of Groundwater And Its Uses

1.	Total Replenishable Ground Water Resources	431 BCM
2.	Ground Water Resources Available for Irrigation	396.6 BCM
3.	Ground Water Potential Available for Domestic, Industrial And Other Purposes	71 BCM (approx.)
4.	Irrigation Potential from Ground Water	64 M ha

(Source:- CWC, Annual report, 2013-14)

1.3.3 GROUNWATER RECHARGE AND ITS FLOW

Groundwater recharge can be defined as the process of movement of water inside the soil layers through infiltration as base-flow or interflow under the influence of gravity making its path to the saturated zone. Groundwater enters the soil in the vadose zone and passes through the unsaturated zone and finally enters the phreatic zone or the aquifers. The source of groundwater recharge can be natural or anthropogenic. The natural recharge of groundwater occurs through rivers, lakes or through other aquifers and the human induced recharge occurs through the canals, sewers, over irrigation in gardens etc.

The route that the groundwater imitate from the area of recharge to the area of discharge is known as groundwater flow path. Various hydro-geological factors like climate, geology, landform and biotic factors affect the recharge process in different ways.

The decoding of the origin and movement of groundwater is important before proceeding to the utilisation of groundwater. Henry Darcy, a French hydraulic engineer studied the movement of water through sand and gave a relation now known as Darcy's Law. This law governs the flow of groundwater in most alluvial and sedimentary formations.

The figure 1.3 shows the whole hydrological cycle along with the recharge and flow of groundwater. The water in the form of precipitation reaches the earth's surface where it infiltrates and becomes a part of groundwater. This groundwater can then be pumped out for human consumption or can become a part of groundwater flow which ultimately discharges to surface water bodies or oceans from where it can again evaporate, condense and precipitate out as rain continuing the cycle.

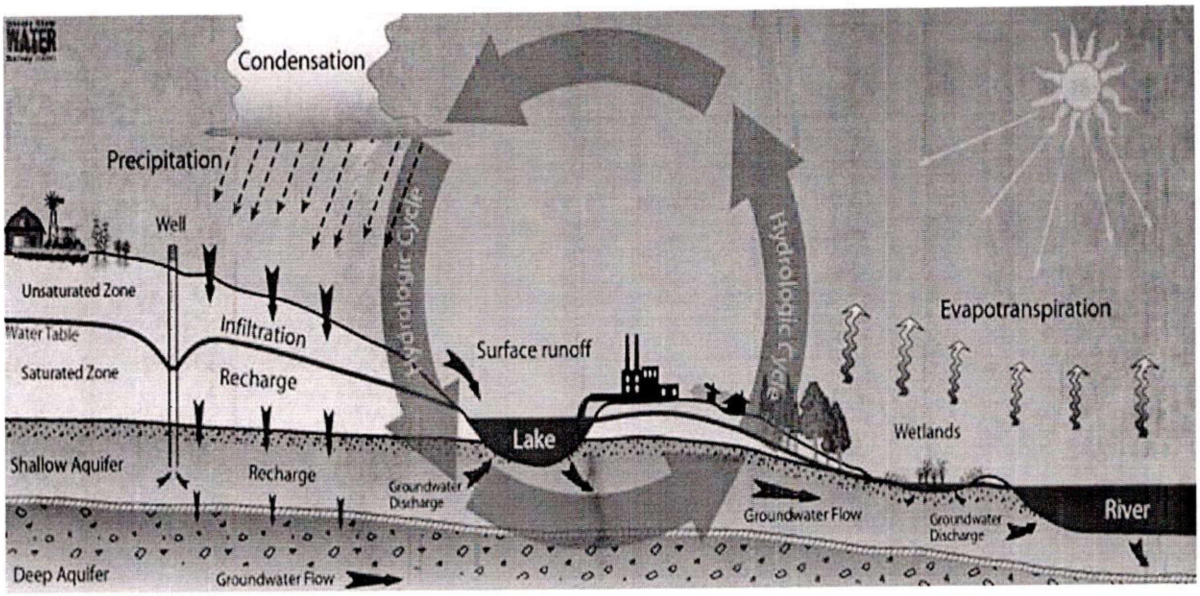


Fig1.4.:-Groundwater recharge and its flow directions(Source:-Esri, Making groundwater recharge and discharge maps in one day. An arc-GIS 9.2application for water resource research, by Yu-Feng-Lin et al.)

1.4 INTERACTION BETWEEN SURFACE WATER AND GROUNDWATER

The surface water and groundwater are connected to each other through the hydrological cycle. Groundwater can contribute to the base-flow of surface water or the surface water can recharge groundwater depending upon the hydraulic condition. Most of the surface water exists in solid state in glaciers and permanent ice. Only a small part of surface water occurs in streams, rivers, lakes and wetlands. The solid surface water can join the groundwater table through snowmelt and run-off. The surface water occurring in rivers, lakes etc. can exchange water masses with groundwater by either loosing water in case where the water level of surface water are higher than the water level of ground or by gaining water in case where the groundwater level is higher as compared to that of surface water. But the quality and motion of groundwater and surface water vary greatly and hence can leading to modification of physical, chemical and biological properties of water in the system. The surface water can transport heavy loads of nutrients and dissolved chemicals with their water to the aquifers. Moreover the groundwater also contains many dissolved chemicals through the solubility of rocks which they can transport to surface water. Hence the exchange of water between the systems causes a change in water quality.

1.5 COASTLINE AND COASTAL ZONE

The coast is a unique environment where land, sea and atmosphere combine, communicate and interplay continuously influencing a strip of spatial zone defined as coastal zone. Although there is no common definition to coastline or coastal zone as it is difficult to place a limit mark around it. An accepted definition is “the part of the land affected by its proximity to the sea, and that part of the sea affected by its proximity to the land as the extent to which man's land-based activities have a measurable influence on water chemistry and marine ecology” (US Commission on Marine Science, Engineering and Resources, 1969). The line that forms the boundary between land and sea is denoted as coastline. They form the most potent ecosystems due to the influence of both nature and anthropogenic activities but still are one of the most prolific habitats. A large part of the global human population now lives in coastal areas: estimates range from 20.6 per cent within 30 km of the sea to 37 per cent in the nearest 100 km to the coast (Cohen et al., 1997; Gommes et al., 1998; Nicholls and Small, 2002). In addition, a considerable portion of global economic wealth is generated in coastal zones (Turner et al., 1996). The coastal areas accrue various economic benefits along with various non-use values as shown in fig1.4.

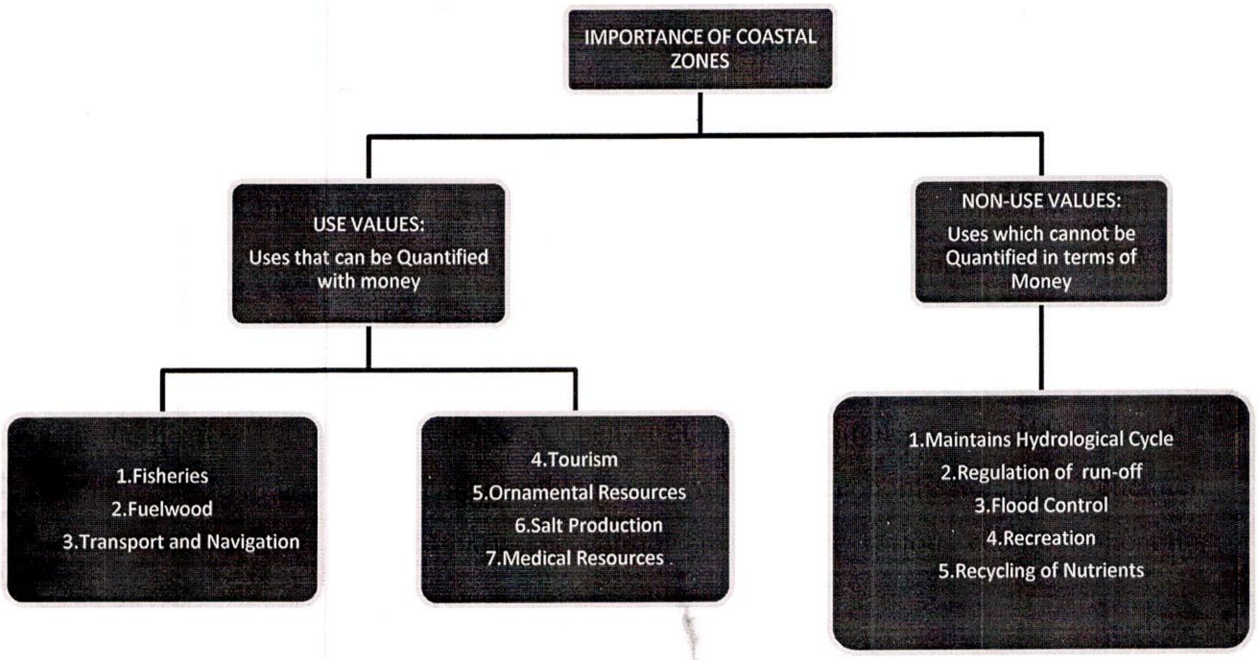


Fig1.5.:-Tabular summary of importance of Coastal zones

1.6 DIFFERNCE BETWEEN SEAWATER AND GROUNDWATER

SEAWATER	**GROUNDWATER**
Seawater covers almost 71%of the earth's surface. Moreover seawater comes under surface water body.	Groundwater, part of freshwater occupies less than 1% of the earth's area. Groundwater is a part of underground water occurring in aquifers.
Seawater contains high salinity content mainly due to presence of sodium chloride. Hence it is not suitable for drinking as drinking salt water can drain water from the body and can cause dehydration.	Groundwater can have some salinity but mostly the content is very low i.e less than 1%. Hence it is a major source of drinking and irrigation water.
Seawater has high buoyancy.	Groundwater lacks the buoyancy of seawater.
The electrical conductivity of seawater is more than that of groundwater.	The electrical conductivity of groundwater is less as compared to seawater.
Seawater has a density higher than that of groundwater mainly because of presence of sodium chloride.	Groundwater has a density lower than that of seawater.
The boiling point of seawater is higher than groundwater.	The boiling point of groundwater is lower than seawater.
The freezing point of seawater is lower than groundwater.	The freezing point of groundwater is higher than seawater.

1.7 SEAWATER –GROUNDWATER INTERACTION

Of all the sources of freshwater, groundwater constitutes about 90% of world's readily available freshwater (Boswinkel, 2000). Groundwater is also widely used, for instance, for drinking water supply and irrigation in food production (Zekster and Everett, 2004). Apart from these groundwater is also an essential component of the hydrological cycle. Hence is an important source of water to rivers, ponds, lakes, wetlands etc. and sustains various ecosystems. Moreover, some field investigations indicate groundwater as a surprisingly important source of water and solute input to coastal waters (Lewis, 1987; Moore, 1996; Kim et al., 2003). According to Church (1996), these scientific findings challenge our understanding of coastal and oceanic chemical mass balance and ecosystem functioning. On the one hand, the seaward flow of fresh groundwater to coastal waters may carry land-generated pollutants, which constitute a serious threat to coastal ecosystems, in addition to limit the available fresh groundwater resources. On the other hand, the quality and availability of these fresh groundwater resources in coastal areas are also threatened by seawater intrusion from the seaside (Bear et al., 1999; Paper III).These interaction helps to maintain the hydrological cycle as groundwater and seawater are both the component of hydrological cycle and hence interact with each other to complete the cycle. Moreover the exchange between the bodies is important for nutrient input and ocean productivity (McCoy, C.A., D.R. Corbett, 2009).Groundwater and seawater interaction in coastal areas is influenced by density difference, which cause a invisible interface i.e the zone of dispersion between them as shown in fig1.5.

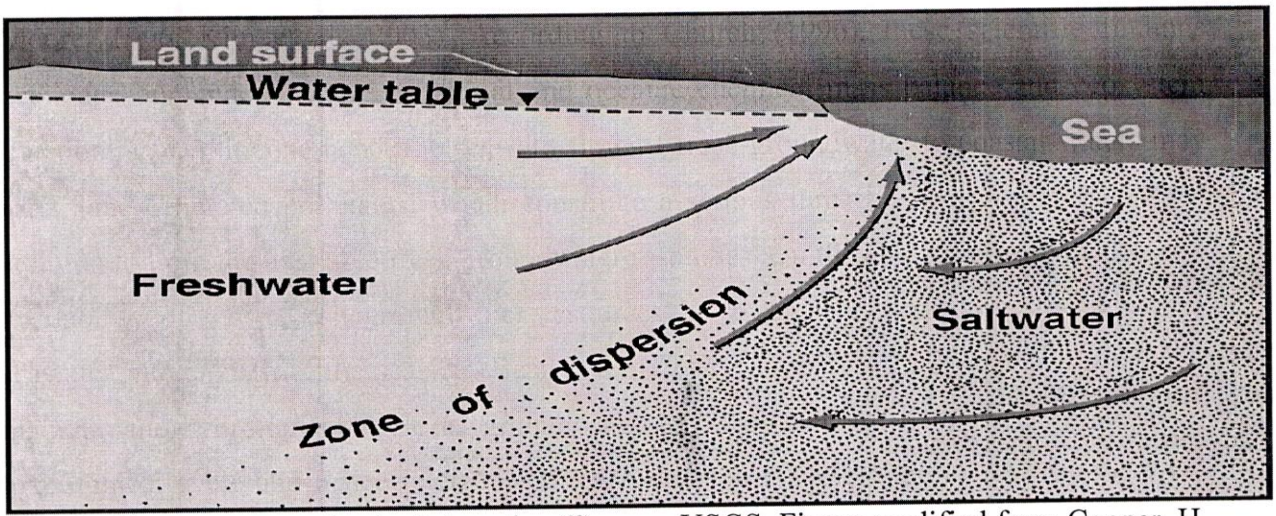


Fig1.6.:-Seawater-groundwater interaction.(Source:-USGS, Figure modified from Cooper, H. H., 1964, A hypothesis concerning the dynamic balance of fresh water and salt water in a coastal aquifer: U.S. Geological Survey Water-Supply Paper 1613-C, p. 1-12)

1.7.1 FACTORS INFLUENCING SEAWATER-GROUNDWATER INTERACTION

Generally, under natural conditions groundwater in seaside aquifers moves seaward and prevents the seawater from intruding inland and hence preserve the interface between freshwater and seawater. But to satisfy the high populace demand of coastal areas the aquifers in coastal zones are in high proximity of brininess. The various factors influencing the seawater-groundwater interactions are:-

- Unrestricted groundwater pumping in coastal aquifers can change the interface between sea-water and groundwater as in heavily exploited aquifers the amount of withdrawal often exceeds recharge and hence the seawater is drawn towards the aquifer changing the interface.
- Climatic variables such as precipitation, surface run-off and temperature can have an affect on seawater groundwater interaction as with lower precipitation amount and higher temperatures the recharge rate will be less with increased evaporation and hence can change the interface (Ranjan, 2007).
- The rising level of carbon-dioxide due to pollution can also lead to change in interface inland as due to increasing concentration of carbon-dioxide surface temperature rises and cause an increase in evaporation rate affecting recharge of freshwater in coastal aquifers.
- Another factor that affects the interaction is land use planning and management. If certain wells are dependant on coastal aquifers to satisfy the demands for agriculture, industrial use, drinking water and residential use then recharge rate of the aquifer must be able to cope up. The over-pumping of the aquifers can cause a zone of depression to move inland and reduce freshwater availability.
- Climate change and sea level rise can also affect the seawater-groundwater interaction as sea level rise can contaminate groundwater supplies due to landward and upward movement of sea-water in coastal aquifers by changing the elevation of the freshwater-saltwater interface.

1.8 SEAWATER INTRUSION

Seawater intrusion is a natural process, by which seawater displaces and mixes with the fresh groundwater in coastal aquifers due to the density difference existing between waters of different salinities (Carmen Prieto, 2005). It can be caused either by decrease in groundwater level or an increase in seawater level. When groundwater is withdrawn more than the amount being recharged then saltwater intrusion takes place. The saltwater intrusion changes the interface between freshwater and seawater that is the area where seawater and freshwater meets and forms a hydrological barrier. The interface in this case moves inland and makes fresh groundwater saline. Some authors have used the term saltwater encroachment to refer to lateral movement of saltwater within an aquifer and the term saltwater intrusion to refer to vertical movement of saltwater. Another term that has been used to describe a specific type of vertical saltwater intrusion is saltwater upconing, which refers to the movement of saltwater from a deeper saltwater zone upward into the freshwater zone in response to pumping at a well or well field (Reilly and Goodman, 1987). The Baden Ghyben-Herzberg relationship states that for every foot (h) of groundwater above sea level there are forty feet of fresh water below sea level (H). When we pump out fresh water rapidly, we lower the height of the freshwater in the aquifer forming a cone of depression. The salt water rises 40 feet for every 1 foot of freshwater depression and forms a cone of ascension as shown in figure 1.7. Seawater may eventually enter a well that was once pumping fresh water, making it unusable.

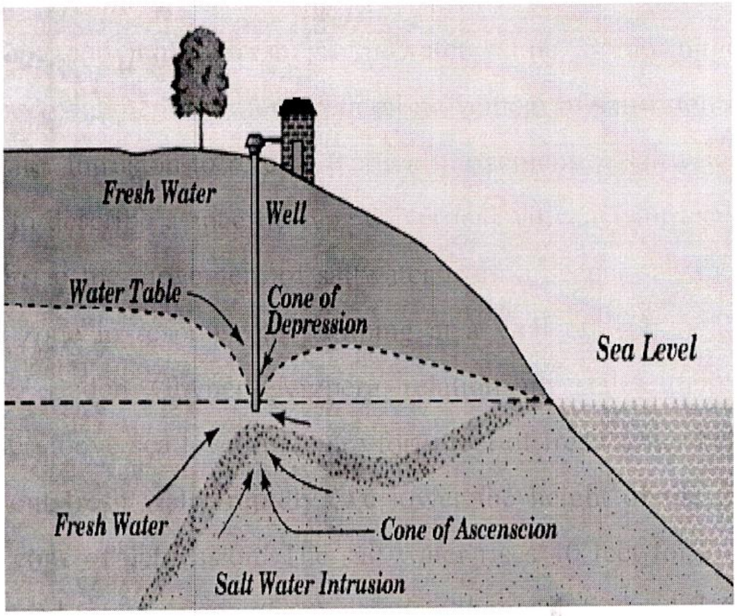


Fig1.7.:-Saltwater intrusion in coastal Aquifers (Source:-Lenntech, Saltwater intrusion in groundwater).

1.9 SUBMARINE GROUNDWATER DISCHARGE

Sub-marine groundwater discharge is a process in coastal areas. The release of groundwater directly seaward is called sub-marine groundwater discharge. The study of submarine groundwater discharge (SGD) considers the water flow from aquifer, representing an input into the ocean. Though recognized by hydrologists for many years (e.g. Kohout, 1966), SGD drew little attention from the oceanographic community until relatively recently (Burnett, 1999) mainly because of difficulty in measuring this attribute. Submarine groundwater recharge could be very significant per unit length of coastline as an outflow process, because the length of coastline where submarine groundwater discharge occurs is very great, and will occur whether or not rivers are present. As submarine groundwater discharge is a ubiquitous process and hence it can impact coastal oceans and can impel ecosystem change. The term SGD refers all direct discharge of sub-surface fluids across land-ocean interface. The SGD rate is defined as (Makoto Taniguchi et.al., 2008):-

$$\text{SGD}=\text{SFGD}+\text{RSGD} \qquad (1)$$

Where, SFGD=Submarine fresh groundwater discharge

And, RSGD=Recirculated saline groundwater discharge

RSGD=RSGD□+ RSGD□+ RSGD□ (2)

Where,

RSGD□= re-circulated water due to wave-setup

RSGD□= re-circulated water due to tidal driven oscillation

RSGD□= re-circulated water due to convection

Figure 1.8 explains the term SGD by showing all discharges of sub-surface fluids along the land ocean interface. All the SGD driving forces like convection, hydraulic head, tidal pumping and wave set up flow movement are shown with the figure from aquifers and ocean.

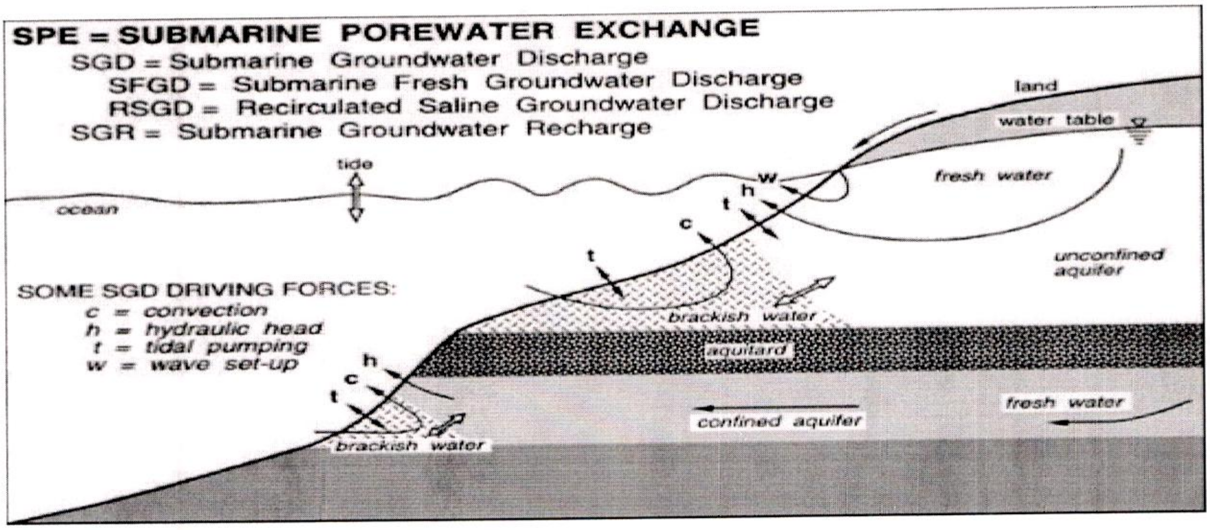


Fig1.8.:- Showing Submarine groundwater discharge process(Source:-Investigation of submarine groundwater discharge by Makoto Taniguch et.al, 2002).

1.10 LITERATURE REVIEW:-

Significant studies have been carried out on groundwater investigation both in India and across the globe. The literature review of the report is sub-divided into three parts and presented below:

1.10.1 Review of literature on groundwater and its quality investigation

Todd, in the year 1980 gave that groundwater is the primary source of water for human activities such as agriculture, industry and domestic drinking water especially in regions with limited annual precipitation. Groundwater resources provide a reliable drought buffer in large regions of the world given by Calow et. al. in 1997. Knowledge of hydrochemistry of groundwater is a vital tool for assessing its quality and understanding its suitability for various needs (Oniawa et. al, 1999). Burke and Moench in 2000 explained the socio-economic dependency on groundwater.

Groundwater is considered to be less vulnerable than surface sources and can therefore help to stabilize agricultural populations and reduce the need for farmers to migrate when drought threatens agricultural livelihoods (Moench, 2002). The ability to access groundwater plays a major role in reducing risk and increasing incomes (Moench, 2003), especially when other modes of irrigation are absent.

Morris et al. in 2003 stated that water stored in the ground beneath our feet is invisible and so its depletion and degradation due to contamination can proceed unnoticed, unlike our rivers, lakes and reservoirs, where drying up or pollution rapidly becomes obvious and is reported.

Harter, 2003 stated that since most groundwater is colourless, odourless and without specific taste, we are typically more concerned with its chemical qualities.

Subramani et.al (2005) investigated the groundwater quality and its suitability for drinking purpose in Tamil Nadu, India. They also compared quality results of groundwater with the maximum limits suggested by World Health Organization (WHO) as well as classifying the underground water resources. Subramani et. al. also reported occurrence of high concentration of sulphate that could cause laxative effect on human system.

Indian population is still dependent completely on saturated surface or Groundwater resources (Kumar et al.2005).

1.10.2 Review of literature on saltwater intrusion in coastal aquifers.

Groundwater quality assessment is important for sustaining various human activities but in the vicinity of the sea i.e mainly in the coastal aquifers groundwater is often beset with salinity hazard. The first and oldest physical formulations of saltwater intrusion were made by W. Baydon-Ghyben (1888, 1889) and A. Herzberg (1901) and referred as the Ghyben-Herzberg formulation. They first established the relationship between freshwater-saltwater along seacoast in late 1800's. Although the relationship was developed for static equilibrium conditions it soon became clear that apart from hydraulic gradient, density variations between seawater and freshwater were important. Subsequently Hubbert in 1940 improved this relation to evolve the concept of sharp interface between seawater and freshwater.

Reilly and Goodman in 1985 have made a comprehensive review of various studies relating to saltwater intrusion. A brief summary of the study is presented below.

During the early 1940's the problem of saltwater intrusion was observed and several field studies were done in United states, Netherland, Israel etc. Many of the field studies showed the importance of the geologic framework and variations in permeability characteristics. Lusczynski and Swarzenski (1960, 1962) documented a staggered interface due to the multi-aquifer groundwater system on Long island, New York. They also documented multiple saltwater wedges in the same aquifer that apparently are caused by variations in the permeability characteristics of the system.

Glover (1959) developed a formula to describe he saltwater-freshwater 'sharp' interface in a coastal aquifer using potential theory. Cooper (1959) developed the hypotheses of hydro-dynamic dispersion to explain the mixing and associated perpetual circulation of seawater observed in various field investigations. Bear and others (1964, 1974) also contributed to the quantification and understanding of the saltwater-freshwater dynamics using Hele-Shaw model. Henry (1959) developed some solutions for delivering the sharp interface under various conditions and also made the first attempt to quantitatively determine the effects of dispersion and density dependant flow on saltwater encroachment in coastal aquifers (Henry,1964) by investing 2D hypothetical cross-section.

Later advances in understanding saltwater-freshwater relationship have occurred with the development of numerical models. Numerical models using sharp interface approach assume freshwater and saltwater as two immiscible fluids. The interface is obtained by solving the coupled partial differential equations governing the two fluids flow. The miscible fluids or the solute transport approach is more general and close to reality, in which saline and freshwater mix producing a continuous variation in concentration.

Ginsberg and Levanton in 1976 concluded that, industrialization, ground water extraction and recharge, uses of water in coastal areas certainly has relation with interface movement. Seawater intrusion occurs mainly on account of saltwater transport by advection and hydro-dynamic dispersion (Nowroozi et al. 1999).

Charbeneau, in 2000 concluded that intrusion of saltwater is the most common contamination occurrence in coastal aquifers.

Saltwater intrusion is a natural process, and bound to occur but it becomes an environmental problem when excessive pumping of fresh water from an aquifer takes place (Soni and Pujari, 2010).

Several research studies on seawater intrusion in coastal aquifers were carried out in various parts of the world making use of geochemical indicators (Custodio and Bruggeman 1987; McCaffrey et al. 1987; Gonfiantini and Aragu´as 1988; Todd 1989; FAO report 1997; Jones et al. 1999; Moujabber et al. 2004, 2006; Appelo and Postma 2005; Slama et al. 2010). Sukhija et al. (1996) used the inorganic water chemistry as a tool to differentiate the current and palaeo-salinities in coastal part of Cauvery basin, India. Desai et al. (1979) studied the sources of salinity and geochemical evolution of seawater in coastal aquifers in part of Gujarat, India. Similarly isotopes of $\delta^{18}O$ and $\delta^{2}H$ were used to understand the mixing of seawater with the groundwater by many researchers (Gaye 2001; Aragu´as 2003; Kim et al. 2003a, b; Faye et al. 2005; Chen and Jiao 2007; Korfali and Jurdi 2010; Nwankwoala and Udom 2011).

Several geochemical criteria can be used to identify the origin of salinity in coastal aquifers (Bear et.al., 1999):Cl concentration, Cl/Br ratios, Na/Cl ratios, Ca/(HCO_3 +SO_4) ratios.

Zeynel Demire (2010) studied the influence of seawater on a coastal aquifer in an International protected area, Goksu delta Turkey. The salinity and EC measurements and the thematic maps indicate that the origin of groundwater salinity in Goksu delta is due to seawater intrusion which resulted from intensive pumping.

1.10.3 Review of literature on saltwater intrusion and groundwater investigation in Odisha

Report on the "Development of coastal areas affected by salinity" by National Committee On The Development Of Backward Areas in 1981, Government of India found that the salt affected coastal districts are Balasore, Cuttack, Puri and Ganjam.

Radhakrishna in the year 2001 in the paper "Saline freshwater interface structure in Mahanadi delta region, Orissa, India" found that aquifers in the northern sector of the basin and within the framework of Birupa and Mahanadi are characterized by an interface depth range that varies between 40 and 280 m below ground level (bgl) with brackish water on the top underlain by freshwater aquifers. The aquifers in the southern sector within the framework of Khatjori/ Devi and Koyakhai/ Daya/ Kushbhadra/ Bhargavi are characterized by an interface depth range that varies from 10 to 120□m with freshwater aquifers near the surface underlain by saline, brackish water aquifers.

S.Das and K.J Anandha Kumar in 2005 in the paper "Management of Groundwater in Coastal Orissa, India" found that the development in the area is primarily constrained by salinity hazards. Over development in the vicinity of the sea runs the risk of seawater ingress. High concentration of iron, fluoride, nitrate, sulphate or other undesirable chemicals in groundwater, though of sporadic occurrence also affects the groundwater quality.

Dileep K.Panda and A. Kumar in 2011 in their paper "Evaluation of an over-used coastal aquifer (Orissa, India) using statistical approaches" studied an over-exploited aquifer in Balasore, India and found that the lower and upper limit of the 95% confidence interval derived from the 1000 bootstrap samples indicated substantial decline in groundwater levels and in the irrigated area.

P.P.Das et. al in the year 2016 in the paper titled "Hydro-geo-chemical evolution and potability evaluation of saline contaminated coastal aquifer system Rajnagar, Odisha, India: A geospatial perspective" conducted a hydro-geo-chemical study across the coastal aquifer system of Rajnagar block, Kendrapara districts, Odisha, India. Analysis of the sub-surface water samples portrays an alkali dominated water type during pre-monsoon season. However the aquifer system displays an even distribution of strong and weak acids for both monsoonal regimes. The extensive occurrence of salinity hazards, sodium hazards and magnesium hazards across the terrain makes the groundwater unsafe for domestic and agriculture.

The Central Groundwater Board year book of Odisha provides the whole executive summary of Odisha along with groundwater status. To monitor the effect caused by indiscriminate use of this precious resource on groundwater regime, Central Ground Water Board, South Eastern Region, Bhubaneswar has established about 1323 National Hydrograph Network Stations (NHNS) (open / dug wells) and 137 purpose built piezometres under Hydrology Project in the state of Orissa. The water levels are being monitored four times a year. Besides, to study the change in chemical quality of groundwater in time and space, the water samples from these NHNS are being collected once a year (Pre-monsoon) and analysed in the Water Quality Laboratory of the Region. The data of both water level and chemical analysis are being stored in computers using industry standard Relational Database

Management System (RDBMS) like Oracle and MS SQL Server. The CGWB Report of 2013-14 is taken into consideration in the report.

1.11 OBJECTIVE OF THE STUDY

The purpose of this study is to elucidate the chemical and isotopic changes in groundwater samples. With the analysis of chemical and isotope values of the samples the following objectives would be drawn:

i) To compare its quality from the WHO and BIS standards to know its safety for drinking.

ii) To study the suitability of groundwater for irrigation purposes.

iii) To identify the places that may be affected by saltwater intrusion.

iv) Spatial variation in hydro-geo-chemical quality of groundwater in Odisha.

CHAPTER -2

STUDY AREA

2.1 INTRODUCTION

India has a vast coastline of about 7500 km of which Odisha covers an area of 480.4 km. The State of Odisha spreads over an area of 1,55,707 sq. km and is bounded between 17°49□ to 22°34□ North latitude and 81°24□ to 87°29□ East longitude. The Odisha coast is depositional and formed by the Mahanadi, Brahmani and Baitarani delta. The State comprises of 3 revenue divisions, 30 districts, 58 subdivisions and 314 community development blocks. The total population of the state as per 2011 census is 419.73 lakhs, out of which the rural population is 349.70 lakhs and the urban population is 70.03 lakhs. The hydrology, geology and physic-chemical feature of the area is discussed in this chapter with special emphasis on the coastal districts of Odisha(CGWB Report, Orissa, 2013).

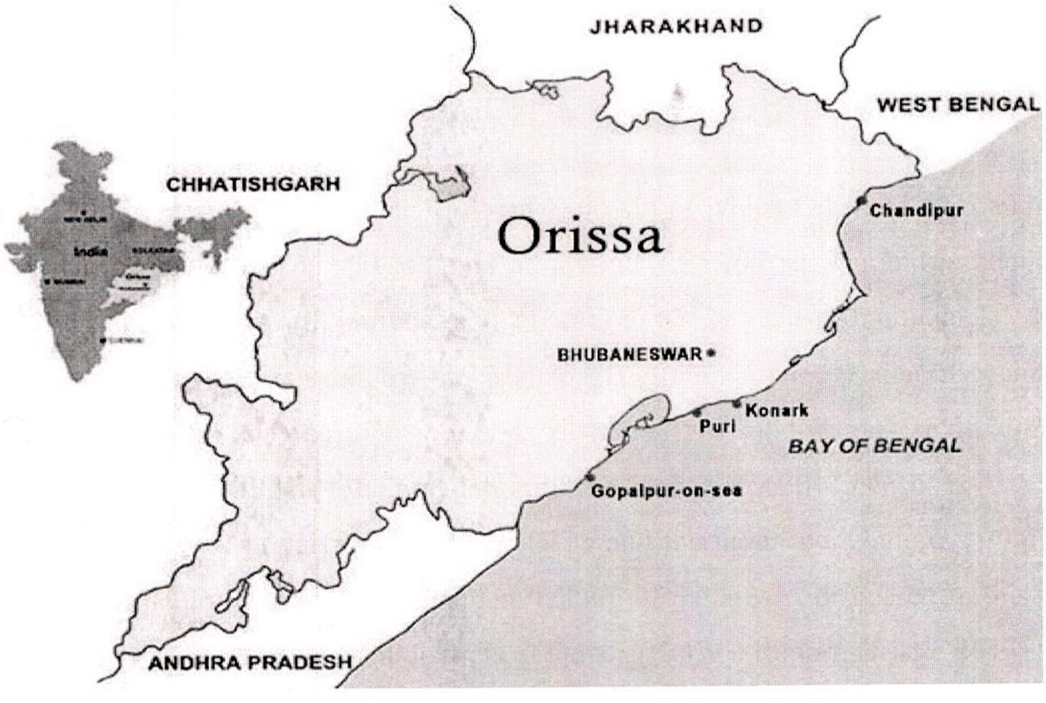


Fig2.1:-Odisha location map (Source:-Odisha tourism).

2.2 TOTAL COASTAL LENGTH

The state of Odisha covers a coastline of 480.4km. The coastal tract of Odisha is comprised of mainly narrow, linear, gently undulating to flat alluvial plain bordering the Bay of Bengal in the east and the erosional plains of the peninsular shield in the west. Like other coastal states Odisha is also endowed with high rainfall, bountiful water resources and fertile soil with rich agriculture. It also has a high population density(S.Das et al,2005).

2.3 PHYSIOGRAPHIC FEATURE

Physio-graphically the state can be divided into five distinct units, namely (i) Coastal plains, (ii) Northern uplands, (iii) The erosional plains of Mahanadi and other river valleys (iv) South Western hilly region and (v) Subdued plateaus(CGWB report, Orissa,2013).

The coastal plains covering parts of Ganjam, Puri, Cuttack and Balasore districts from south to north form an extensive flat alluvial tract between the hills in the west and the coast in the east. It presents a flat topography gently sloping towards east with insignificant elevation difference. The general elevation of coastal plains varies from 1 to 10m above mean sea level (amsl).

South-western hilly region lies to the south and southwest of Mahanadi valley region stretching through Phulbani, Ganjam districts and part of Koraput district. Major part of this region has an elevation over 600m, acting as the watershed of the two sets of rivers, one set flowing directly to the Bay of Bengal, namely Rushikulya, Nagavali and Vamsadhara and the others feeding the Godavari and Mahanadi river systems(Central Ground Water Board Report, 2013-14).

2.4 DRAINAGE

There are eleven principal rivers traversing the entire state that can be grouped under eight major river basins within the state, whereas the Indravati, Kolab, Machkund sub-basins in the south forms part of Godavari river basin. Most of the major rivers flow in easterly and south-easterly direction with gentle gradient. Generally the rivers are effluent in nature CGWB report, Orissa, 2013).

2.5 CLIMATE AND RAINFALL

The state enjoys a sub-tropical climate with three distinct seasons i.e. summer, monsoon and winter. The southwest monsoon rain starts from mid of June and continues till mid of October. Summer season extends from March to early part of June and winter season spreads from November to February. The normal average rainfall of the state is 1482.2 mm. Nearly 86% of the annual rainfall is contributed by the southwest monsoon. The spatial distribution of the rainfall in the State is uneven and erratic (CGWB report, Orissa,2013).

2.6 COASTAL DISTRICTS

Names of coastal Districts in the direction from North to south (total 6 districts): Baleshwar, Bhadrak, Kendrapara, Jagatsinghpur, Puri, Ganjam.

The coastal districts are focused as the sampling was done along the coastline in the coastal districts. Moreover the features like population are taken into account as it shows the water demand and hence the chances of over-pumping to meet the demands. The Coastal hydro-geology shows the soil condition to store, conduct and flow velocity of water in the sub-surface, to see the aquifer condition. The rainfall and major drainage system of the area is also accommodated in the hydro-geology showing the water profile of the area. From these the local feature influencing aquifer condition can be identified.

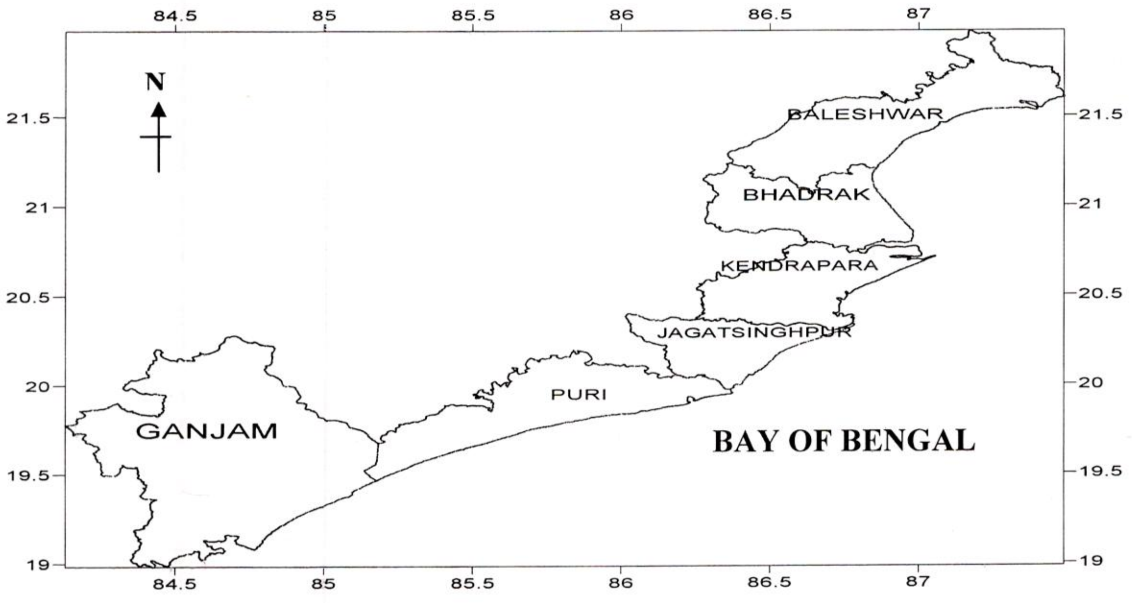


Fig2.2.:- Coastal States of Odisha(Surfer ®)

1. Baleshwar:

- Area:- 3,806.00 sq. Km
- Population:- 2,317,419
- Density:- 609 per sq. Km
- Literacy:-80.66 %
- No. of Villages:- 2952

2. Bhadrak:

- Area:- 2,505.00 sq. Km
- Population:- 1,506,522
- Density:- 601 per sq. Km
- Literacy:- 83.25 %
- No. of Villages:- 1311

3. Kendrapara:

- Area:- 2,494.69 sq .Km
- Population:- 1,439,891
- Density:- 545 per sq. Km
- Literacy:- 85.93 %
- No. of Villages:- 1540

4. Jagatsinghpur:

- Area:- 1,759.00 sq. Km
- Population:- 1,136,971
- Density:- 681 per sq. Km
- Literacy:- 87.13 %
- No. of Villages:- 1320

5. Puri:

- Area:- 3,479 sq. Km
- Population:- 1,697,983
- Density:- 488 per sq. Km
- Literacy:- 85.37 %
- No. of Villages:- 1715

6. Ganjam:

- Area:- 8,206.60 sq. Km
- Population:- 3,529,031
- Density:- 429 per sq. Km
- Literacy:- 71.88 %
- No. of Villages:- 3250

2.7 COASTAL BLOCKS AND POPULATION

Table.2.1- Coastal Blocks and Population

Coastal Districts	Coastal Blocks	District Population (2011)
Baleshwar	Bhograi, Baliapala, Balasore, Remuna, Bahanaga, Soro, Simulia	2,320,529
Bhadrak	Chandbali, Dhamnagar, Bandaripokhari	1,506,337
Kendrapara	Rajnagar, Mhakalapara	1,440,361
Jagatsinghpur	Kujanga, Ersama, Balikuda	1,136,971
Puri	Astranga, Konark, Ramachandi, Sadar, Brahmagiri, Krushna Prasad	1,698,730
Ganjam	Ganjam, Chatrapur, Rangelunda, Chikiti, Patrapur	3,529,031

(Source:- original data from Coastal Odisha Development Council, Block maps of districts prepared by GIS division,NIC).

Baleshwar, is situated in the north eastern part of the Odisha and lies between the latitudes 21°04′00″ to 21°58′30″ North and longitudes 86°16′ to 87° 29′ East. Baleshwar is prosperous in both agriculture and industry. Baleshwar is also the launching station for sounding rockets where tests for various missiles like Agni, Prithvi, Trishul, Dhanus etc. are done at the station Chandipur. The annual average rainfall is 1754.3 mm and the average temperature ranges from 25°C to 32°C (CGWB Report, Orissa, 2013).

Bhadrak is situated the north-eastern part of Orissa and lies between north latitude 20° 14□ and 21°45□ and east longitudes 86°17□ and 86°59□. The average lowest and the highest temperatures (1992-99) for the district are 13.8°C and 38.7°C respectively. The normal annual rainfall is 1568.4 mm (1950 – 1991) (CGWB Report, Bhadrak district, 2013).

Kendrapara district lies between North latitudes 20°21□ and 20°47□ and East longitudes 86° 14□ and 87°03□. The annual average rainfall is 1428.61 mm. The annual average temperature is 27.1°C. The river Mahanadi, Brahmani and Baitarani along with their distributaries form the drainage system of the district having an anastomosis drainage pattern in nature (CGWB Report, Kendrapara district, 2013).

Jagatsinghpur district lies between North latitudes 19°58□ and 20°23□ and East longitudes 86°03□ and 86°45□. Agriculture is the main economy of the district. The annual average rainfall in last seven years is 1436 mm. The temperature varies from 15°C to 37°C (CGWB Report, Jagatsinghpur district, 2013).

Puri district lies between North latitudes 19°28□ and 20° 10□ and East longitude 85°09□ and 86°25□. Average annual rainfall of the district is 1449.1 mm. Chilka lake the largest brackish water lagoon in Asia lies in Puri. The average annual temperature of Puri is 21.2°C (CGWB Report, Puri district, 2013).

Ganjam is located at 19.38°N and 85.07°E. A part of Chilka lake is occupied by Ganjam in the extreme north east portion. The district is rich in mountains and forests. The average annual rain fall of the district is 1296mm.The average temperature in Ganjam is 26.8°C (CGWB Report, Ganjam district, 2013).

2.8 COASTAL HYDROGEOLOGY

Table 2.2-Coastal Hydrology

Coastal Districts	Coastal Hydrogeology
Baleshwar	Alluvium Rivers: Kantiachara, Nunia, Kamachara, Khandita, Budhabalang ,Panchpara, Hanskara, Subarnareka
Bhadrak	Alluvium, laterites and granitic gneisses River: Baitarini
Kendrapara	Recent alluvium Rivers: Mahanadi, Brahmani and Baitarani
Jagatsinghpur	Quarternary to recent Alluvium Rivers: Mahanadi, Devi(tributary of river Kathajori) ,Jatadhar Mohan, Bitikolia, Balijhori
Puri	Alluvium, laterite in patches Rivers: Daya, Devi, Kushabhadra, Bhargavi, and Prachi
Ganjam	Weathered and Fractured Crystalline Rocks, granite, granitic gneisses, Khondalites, Charnockites, Pegmatite and quartz veins River:-Rushikulya, Bahuda Lagoon:-Chilka lake

(Source:-CGWB report of groundwater information booklet of Baleshwar, Bhadrak, Kendrapara, Jagatsinghpur, Puri, Ganjam).

Baleshwar falls in the Burhbalang River Basin. The Baleshwar town is underlain by the Quaternary formation which is represented by alluvium consisting of gravel, sand, silt and clay. Gravel and sand are highly porous and permeable. Ground water occurs under water table conditions in phreatic aquifer and in deeper aquifers it occurs under semi-confined to confined conditions. In Baleshwar town phreatic aquifer exists within 20m depth. The potential deeper aquifers are generally restricted between 25 to 100m depth (CGWB Report, Baleshwar district, 2013).

Bhadrak district is underlain by unconsolidated formations belonging to Quaternary and Tertiary periods down to a depth varying from 165 m in the north-western part to more than 600m in the eastern part along the coast line and are composed of sand, gravel, clay, laterites and lateritic gravel, silt, mud stone, shale, lime stones etc (CGWB Report, Bhadrak district, 2013).

Kendrapara is characterised by alluvium underlain by older alluvium and mid-pilocene sediments. Mahanadi, Brahmani and Baitarani along with their distributaries form the drainage system of the district. The thickness of fresh shallow aquifers normally varies from 15 to 20m. The deeper aquifer bearing fresh water is identified from available borehole data, down to a maximum depth of 612m (CGWB Report, Kendrapara district, 2013).

In **Jagatsinghpur** district inter-granular pore spaces of sand and gravel layers act as a storehouse of ground water. Ground water in the shallow aquifer zone occurs under unconfined condition and within sand dunes underlain by clay beds occurs as perched water table condition. The ground water is also found under semi-confined condition in the deeper aquifer zones. Shallow aquifer is found to a depth of 50m and the deeper aquifers are found at the depth between 50m to 300m in the district (CGWB Report, Jagatsighpur district, 2013).

Puri district spans the geological formations in age from Archaean to Recent (Quaternary). The tertiary and quarternary deposit occupies the larger part of the district while the archaean is only confined to the hilly areas in the west. The Quaternary deposits consist of laterites and alluvium. The younger alluvium occurs as flood plain deposits along the course of major rivers and streams, which covers nearly 90% of the area. These sediments consist of a mixture of silt, sand, gravel and pebble in varying proportions. In shallow aquifers under phreatic condition groundwater is found upto the depth of 135m and are indentified to a maximum depth of 602m in deeper aquifers in Puri (CGWB Report, Bhadrak district, 2013).

Ganjam is mainly underlain by the hard crystalline rocks of Archaean age. The crystalline rocks occupy major part of the total geographical area. The narrow discontinuous patches of recent to sub-recent alluvium occupy about 300 sq. km. Area along the major river courses and on coastal plain. The weathered and fractured zones of the crystallines and the porous alluvial and coastal deposits hydrologically form the main repository of groundwater of area.

2.9 GROUNDWATER SAMPLING:

38 Samples were collected from 21st November to 27th November, 2015 and 3 samples were collected on 31st May 2016; Total 38 groundwater samples, one Chilka lake sample and 2 sea water sample were collected.

Freshwater:- 38 samples
Seawater:- 2 samples
Lagoon water:-1 sample

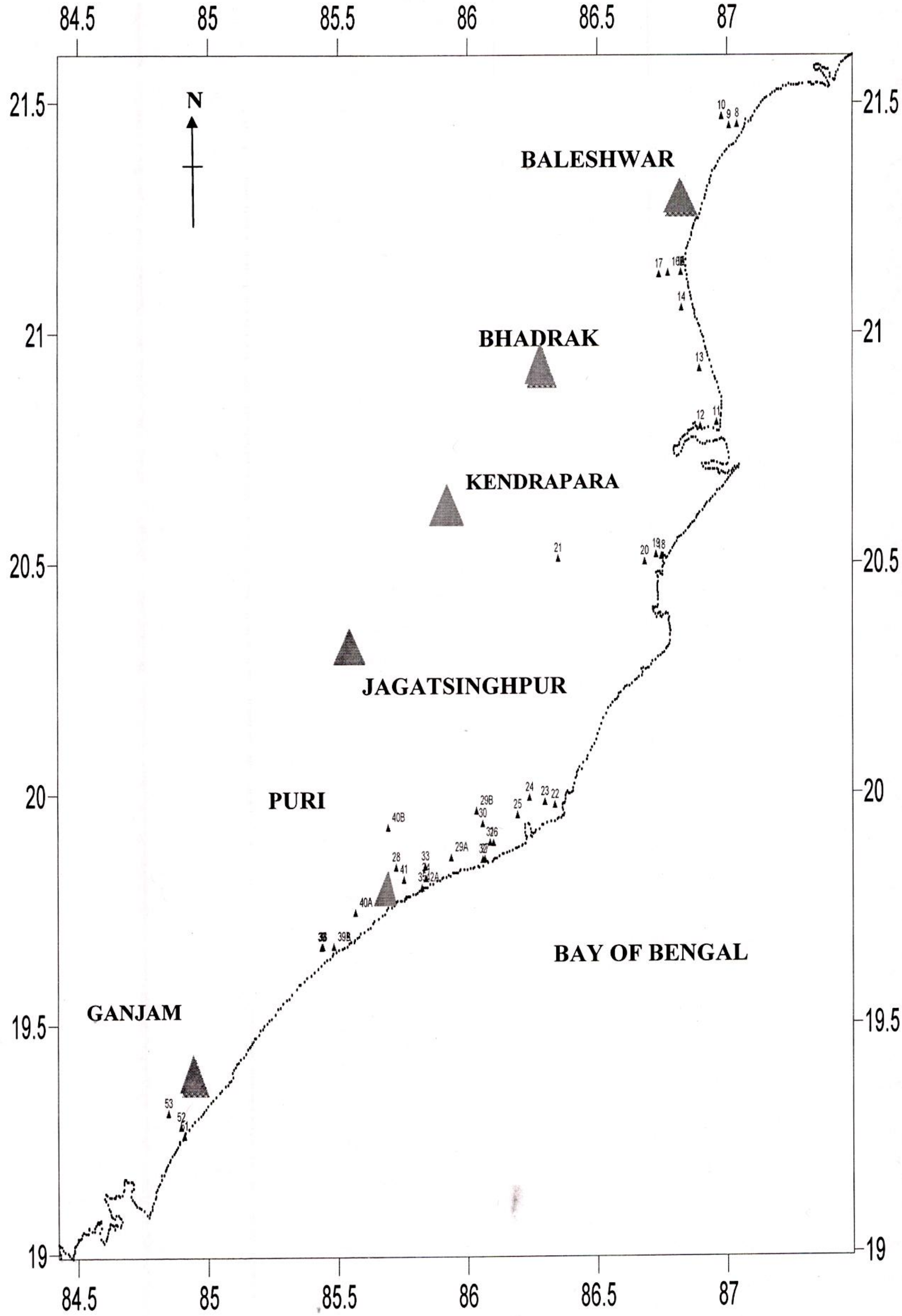


Fig2.3.- Coastline of Odisha along with sampling points(Surfer ®).

2.10 GROUNDWATER SAMPLING STATISTICS WITH RESPECT TO DISTANCE FROM COASTLINE:

Table 2.3-Sampling Sites Distribution With Distance

Distance from the coast (km)	**No. of sampling location**
At the coast	11
<2	05
2-4	10
4-6	07
6-8	03
8-10	03
10-12	00
12-14	01
>14	01

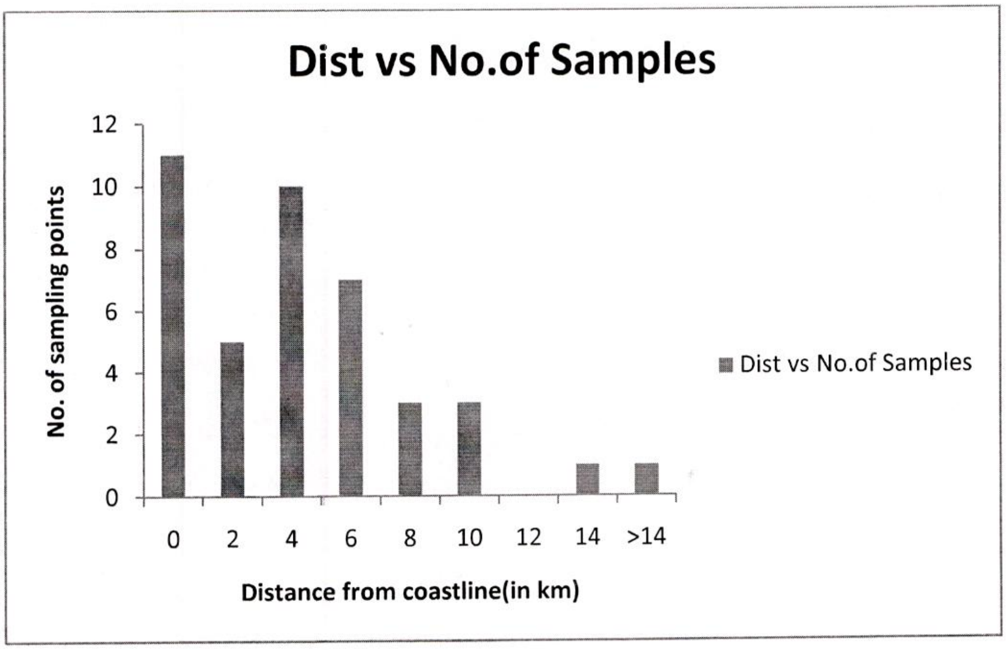


Fig 2.4:-Distance versus no. of sample plots.

Table 2.4.-Location and source of sampling sites

Site ID	Location	Source
SGD-8	Chandipur (Beach)	HP
SGD-9	Naya Sadak, Sonapur road	HP
SGD-10	Tentulipura,way to Chandipur	HP
SGD-11	Rabindranagar,Dosinga	HP
SGD-12	Dhamara Port	HP
SGD-13	Baincha	HP
SGD-14	Bideipur Market	HP
SGD-15	Jetty, Chudamani	HP
SGD-16A	Chudamani(New)	HP
SGD-16B	Chudamani(Old)	HP
SGD-17	Jamujhadi, Basudevpur bus stand	HP
SGD-18	Chakulidiha, Sasana	HP
SGD-19	Tantiapal	HP
SGD-20	Badapalli	HP
SGD-21	Bhagabatpur,Jantilo	HP
SGD-22	Nuagarh (Fishing base)	HP
SGD-23	Damasun, Jharling (Youth Club)	HP
SGD-24	Jiunti chhaka bus stop,Jiunti	HP
SGD-25	Anand Bazar	HP
SGD-26	Konark Fish Market,konark kakatpur road	HP
SGD-27	Marine drive,Puri (A)	SW
SGD-28	Kapileswarpur	HP
SGD-29A	Balighai	HP
SGD-29B	Begunia	HP
SGD-30	kuruma,Sareda	HP
SGD-31	Konark	HP
SGD-32	Ramachandi Temple	HP
SGD-33	Bata mangala Temple	HP
SGD-34	Bus stand, Puri	HP

SGD-35	Golden Beach, Puri	HP
SGD-36	Satapada chilka water	LW
SGD-37	Satapada near Jetty	HP
SGD-38	Near Sub Inspection Exchange office, Satapada	HP
SGD-39A	Baghamunda (A)	HP
SGD-39B	Baghamunda (B)	HP
SGD-40A	Jadupur	HP
SGD-40B	Bali Harchandi Temple,katakpada, Brahmagiri	HP
SGD-41	Gorual	HP
SGD-42A	Sea water Puri	SW
SGD 51	Gopalpur Beach	HP
SGD52	Naraynpur Gopalpur	HP
SGD 53	Dura bahadurpetta,Pathara, Gopalpur	HP

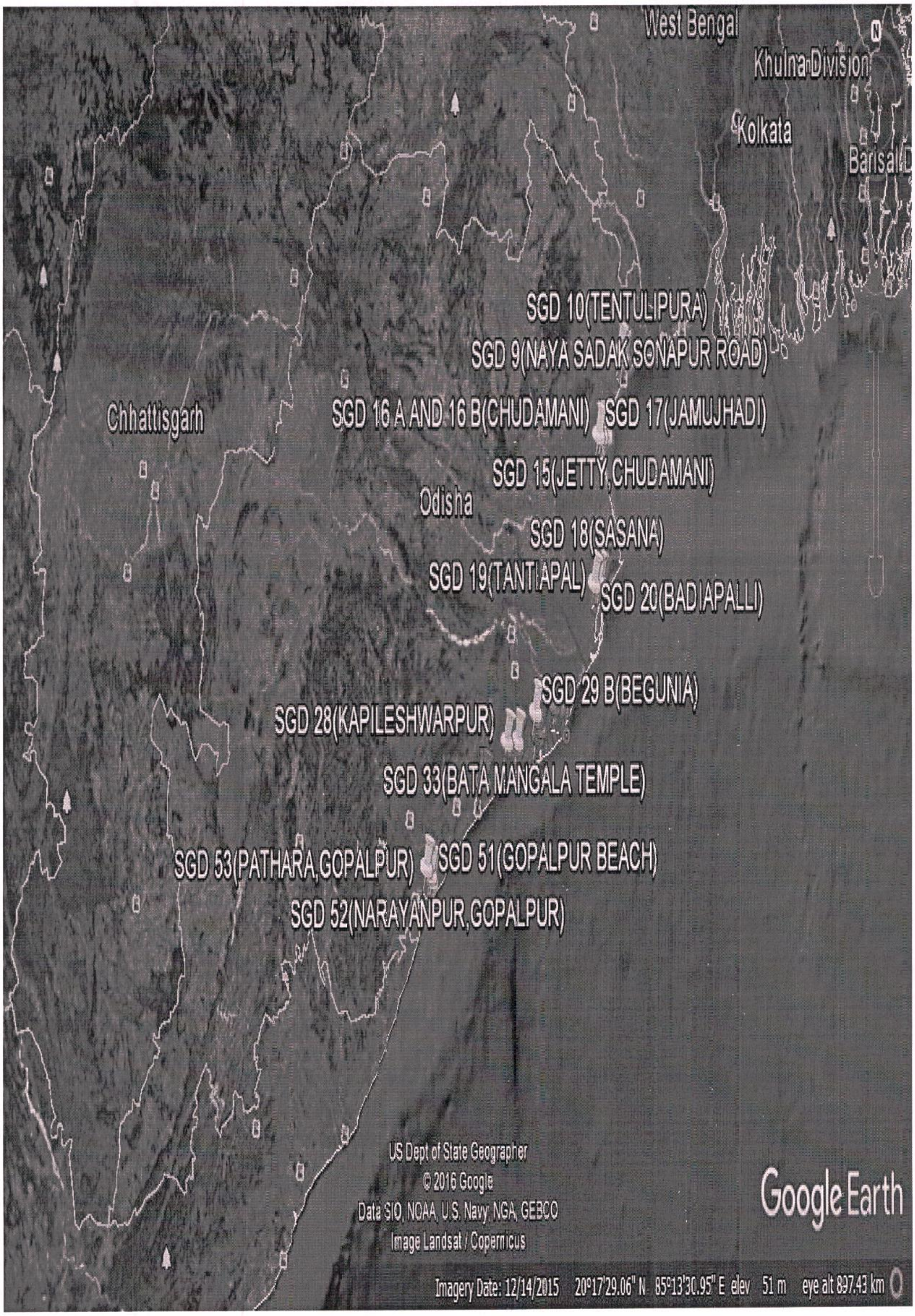


Fig2.5:- Sampling points location (Source:-Google earth)

CHAPTER 3

METHODOLOGIES

3.1 INTRODUCTION

Laboratory technique is used for the calculation of chemical and isotopic features of the samples collected. For chemical analysis Ion-Chromatography (Dionex ICS 5000) instrument is being used. For isotopic analysis Dual inlet isotope mass spectrometer instrument is used.

Moreover electrical conductivity is measured using EC meter, temperature using EC meter, pH using pH meter and radon using Electronic Radon Detector with Real Time Monitoring were also calculated and hence are discussed in this chapter.

3.2 EXPERIMENTAL TECHNIQUES AND METHODOLOGIES USED

The experimental techniques used for the analysis are:-

3.2.1 CHEMICAL ANALYSIS

Water is the pearl that can sustain life hence is the most precious jewel of nature. From the producers to all levels of food chain are dependent on fresh-water for its survival. It is used by man for drinking, agriculture, industrial application and many more purposes. But it is necessary to know the quality of water before using it. The quality of water is a reflection of the various impurities that are present in it. Medical science has established that some of the chemical constituents in water are necessary for health in small concentration but in higher concentration they may be lethal to health hence to know the chemical constituents in water and their concentration is essential.

In this report chemical analysis i.e the presence and concentration of various anions like fluoride, chloride, bromide, phosphate, nitrate, nitrite, sulphate as well as cationic like lithium, sodium, ammonium, potassium, magnesium and calcium in the groundwater and seawater samples of Odisha's different parts will be investigated using Ion-Chromatography (Dionex ICS 5000).Moreover electrical conductivity and temperature were calculated using electrical conductivity meter (EC metre).

3.2.1.1 ION CHROMATOGRAPH

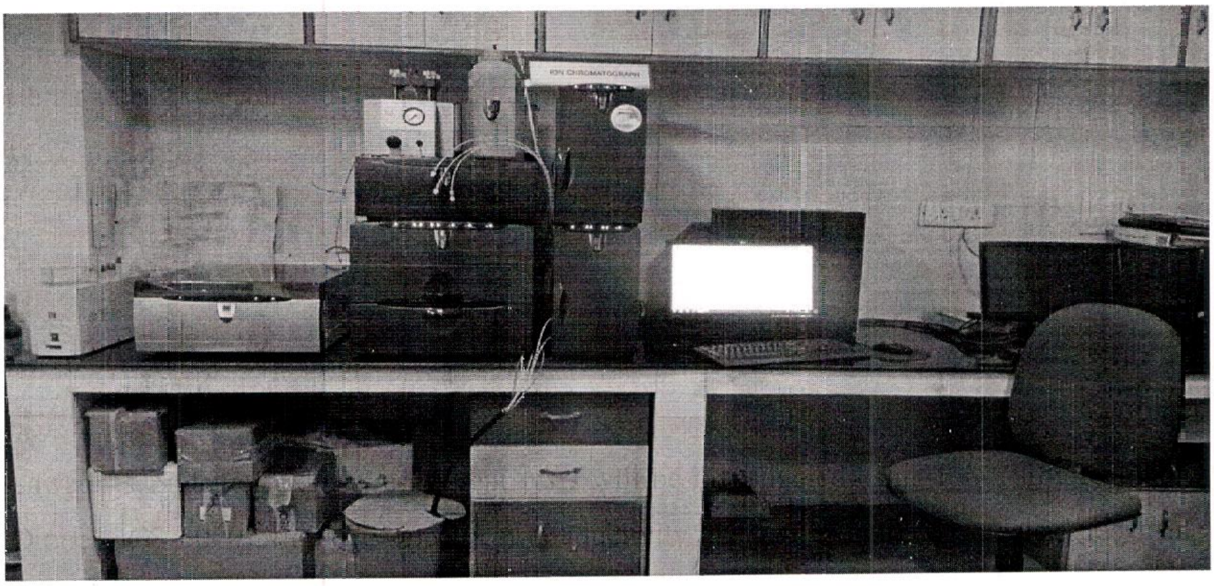


Fig3.1:- Ion chromatography instrument (Source-National Institute of Hydrology).

Ion chromatography is mainly used for water chemistry analysis. It is used to measure the anions and cations present upto parts per billion (ppb) range. It mainly relies on the attraction between oppositely charged stationary phase. It is a type of liquid chromatography where ionic species are separated based on their interaction with a resin (Ion Chromatography, Created by Monica Z. Bruckner).

An innovative approach by Small, Stevens and Bauman at Dow Chemical Co. marked the birth of modern ion chromatography. Anions, as well as cations, could now be separated quickly and conveniently by a system of suppressed conductivity detection. A method for anion chromatography with non-suppressed conductivity detection was published by Gjerde et al. in 1979. This was followed by a similar method for cation chromatography in 1980. Ion chromatography as we know it today did not just happen. It was built on a solid foundation of knowledge that has accumulated over a period of many years (Fritz JS, 2004). The term 'IC' was subsequently introduced when this technology was licensed to the Dionex Corporation for commercial development.

3.2.1.1.1 PRINCIPAL OF ION CHROMATOGRAPH

Ion exchange chromatography relies on the principal of charge to charge interaction between solute molecules of sample and ligands immobilized on a chromatography matrix. Separation in ion exchange chromatography depends upon the reversible adsorption of charged solute molecules to immobilized ion exchange groups of opposite charge. The stationary phase displays ionic functional group (R-X) that combine with analyte ions of opposite charge. Ion exchange chromatography can be further divided into two types: cation exchange chromatography and anion exchange chromatography. The ionic compound consists of M+ cations and N^- anions. The cationic exchange chromatography cling the positively charged ions as the stationary phase is of negatively charged functional group and the anion exchange chromatography retains negatively charged anions as the stationary phase is positively charged functional group.

3.2.1.1.2 WORKING OF ION CHROMATOGRAPH

For Liquid Samples:

Sample Preparation:-

Liquid samples should be filtered prior to evaluation with an ion chromatograph to remove sediment and other particulate matter as well as to limit the potential for microbial alteration before the sample is run. Aqueous samples should be collected using a sterile syringe or bottle rinsed three times with sample water and then filtered through 0.45µm (or smaller) filters. The collection vial should likewise be rinsed three times with filtrate before being filled brim-full of sample filtrate. Samples should be stored cold until they can be processed. The minimum sample required for analysis is approximately 5mL, with no maximum limits. Most ion exchange experiments are performed in five main stages. These steps are illustrated schematically below (Ion exchange chromatography, Amarsham Pharmacia Biotech):-

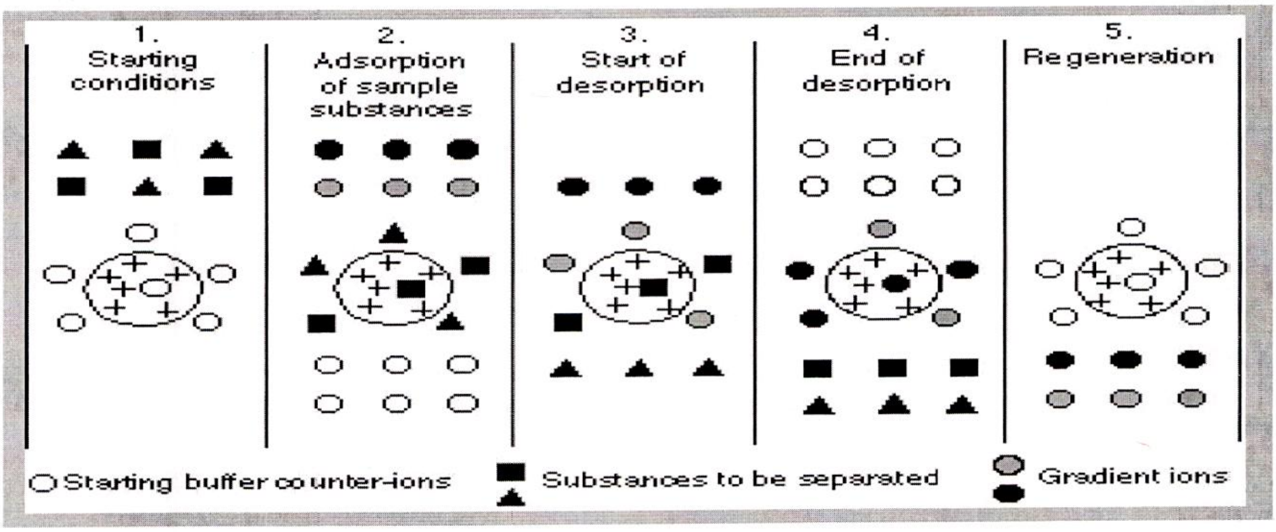


Fig.3.2.- Step wise working of Ion-Chromatograph(Source:- Ion Exchange Chromatography Principles and Methods, Amersham pharmacia biotech).

The step wise working of ion chromatograph is as shown in figure 3.2 is explained hereby. The first stage is equilibration in which the ion exchanger is brought to a starting state, in terms of pH and ionic strength, which allows the binding of the desired solute molecules. The exchanger groups are associated at this time with exchangeable counter-ions (usually simple anions or cations, such as chloride or sodium).

The second stage is sample application and adsorption, in which solute molecules carrying the appropriate charge displace counter-ions and bind reversibly to the gel. Unbound substances can be washed out from the exchanger bed using starting buffer.

In the third stage, substances are removed from the column by changing to elution conditions unfavourable for ionic bonding of the solute molecules. This normally involves increasing the ionic strength of the eluting buffer or changing its pH. Desorption can be achieved by the introduction of an increasing salt concentration gradient and solute molecules are released from the column in the order of their strengths of binding, the most weakly bound substances being eluted first.

The fourth and fifth stages are the removal from the column of substances not eluted under the previous experimental conditions and re-equilibration at the starting conditions for the next purification.

Ion identification is based on the comparison of analyte signal peak retention times relative to those of known standards. Quantification is accomplished by measuring the peak area and comparing it to a calibration curve generated from known standards.

3.2.1.1.3 COMPONENTS OF ION CHROMATOGRAPH

The various components found in an ion exchange chromatograph are (Method 9056a, Determination Of Inorganic Anions By Ion Chromatography,2007):-

i) **Ion chromatograph** -- Capable of delivering 1 to 5 mL of eluent per min at a pressure of 1000 to 4000 psi. The chromatograph must be equipped with an injection valve, a 25- to 100-µL sample loop, and set up with the following components.

ii) **Precolumn** -- A guard column placed before the separator column to protect the separator column from being fouled by particulates or certain organic constituents.

iii) **Separator (or analytical) column** -- A column packed with an anion exchange resin, suitable for resolving F^-, Cl^-, NO_3, NO_2, PO□, and SO□.

iv) **Conductivity suppressor** -- An ion exchange-based device that is capable of converting the eluent and separated anions to their respective acid forms.

v) **Conductivity detector** -- A low-volume flow-through, temperature compensated, electrical conductivity cell (approximately 1.25-µL volume), equipped with a meter capable of reading from 0 to 1,000 Siemens/cm on a linear scale.

vi) **Pump** -- Capable of delivering a constant flow of approximately 1 to 5 mL/min throughout the test and tolerating a pressure of 1000 to 4000 psi (6.5 to 27.5 MPa).

vii) **Syringe** -- Minimum capacity of 1 mL, equipped with a male pressure fitting.

viii) Appropriate chromatographic data and control software to acquire data. Dionex PeakNet was use to record and process the chromatogram shown in Figure 2. Alternatively, an integrator or recorder can be used to integrate the area under the chromatographic peaks. If an integrator is used, the maximum area measurement must be within the linear range of the integrator. The recorder should be compatible with the detector output with a full-scale response time of 2 seconds or less.

3.2.1.1.5 DATA ANALYSIS IN ION CHROMATOGRAPH

The data output are represented as graphs with peak points different for the different ions. Each peak represents a separate ion from the sample solution. The elution time, or time it takes for the ion to move through the column, varies for each ion species as they elute from the column separately as the pH and/or ionic strength of the eluent is increased. The concentration of ions moving through the column at a particular time is represented by the height and the breadth of the peaks and can be correlated to the concentration of a particular species in the sample solution.

Ion concentrations can be calculated using the area under each peak, where a larger area correlates with a higher concentration of a particular ion species. The ion chromatography machine used to provide a software that calculates this area, and also can convert to ppm or other quantity using calibration standard solutions.

Dionex 5000 model of ion chromatography was used for the analysis and the software used is chromeleon software where the programming is done and graphs are generated.

3.2.2 ISOTOPIC ANALYSIS

Isotopes are the different species of the same element having the same atomic number but different mass number. They have the same number of electrons and protons but differ in their number of neutrons in the nucleus of the atomic shell. Environmental isotopes are the naturally occurring isotopes of elements found in nature. Examples are of C, H, N, O and S and are the principal elements of the hydrological, geological and biological systems. Hence are used to trace groundwater provenance, recharge processes, groundwater quality, subsurface processes, geo-chemical reactions, rock-water interactions and reaction rates.

Broadly the environmental isotopes are of two types:-stable isotopes and unstable isotopes.

i) **Unstable isotopes**:- Unstable isotopes are also called radioactive isotopes. For example, ^{3}H is unstable isotope of hydrogen. Naturally occurring radioisotopes provide information about groundwater's age which shows the last time groundwater was in contact with the atmosphere. Once recharge area has been known using isotope fingerprinting methods, radioisotopes may be used to estimate how long it took for a parcel of groundwater to travel from its recharge area to the measurement point.

ii) **Stable isotopes**:- The stable isotopes are popularly called environmental stable isotopes as they are available in the environment and introduced in the hydrological cycle naturally. Thus the investigator does not require them to either purchase or inject into the system for carrying out hydrological studies.

Recharged water has characteristic isotopic signature in terms of □^{1}□O or □^{2}H. When the water takes its journey from the recharge zone it interacts with a variety of waters during movement. As it interacts and mixes with waters from different sources-its isotopic composition gets modified.

Mass spectrometer is used to analyse the stable isotopic composition. Dual inlet mass spectrometer is used in the present water sample analysis.

3.2.2.1 MASS SPECTROMETRY

Mass spectrometry is a powerful analytical technique for identifying the unknown compounds by determining their molecular weights, for qualitative and quantitative determination. In view of its high sensitivity, selectivity and specificity, the technique provides valuable information in the various branch of science viz. nuclear technology, chemistry, physics, biology, medicine, material science, hydrogeology, environment, forensic science geochemistry , archaeology, astronomy etc. The mass spectrometric technique originated from J.J.Thompson's vacuum tube which demonstrated the existence of electrons and 'positive rays' in the early part of the century. The primary application of mass spectrometry in 1920s remained in the realm of physics for isotopic analysis mainly for discovering of new isotopes, finding out their relative abundances and measuring their exact masses.

3.2.2.1.1 PRINCIPLES OF MASS SPECTROMETER

Let us assume that singly charged positive ions of mass m are produced in the ion source with negligible kinetic energy. If the ions are subjected to an acceleration voltage V, then

$$eV = \tfrac{1}{2}(mv^2) \qquad (1)$$

where v is the velocity of ion of mass m. If these ions are subjected to a uniform magnetic field (H or B) perpendicular to their direction of motion, there is a force exerted upon the ion in a direction at right angle to both the direction of motion of the ion and the direction of the applied magnetic field. The magnitude of this force remains constant but its direction keeps on changing remaining always perpendicular to the direction of motion of the ions. The ions thus trace a circular orbit (path) and the force due to magnetic field becomes equal to the centripetal force.

3.2.2.1.2 WORKING OF MASS SPECTROMETER

Different molecules have different masses, and this fact is used in a mass spectrometer to determine what molecules are present in a sample. The molecules present in the sample are vaporised and turned into gas and broken down (ionized) into electrically charged particles, called ions, in the first part of the mass spectrometer. The ions so formed have specified molecular weights. They also have a charge, which means that they will be moved under the influence of an electric field. These ions are then sent into an ion acceleration chamber and passed through a slit in a metal sheet. A magnetic field is applied to the chamber, which pulls on each ion equally and deflects them (makes them curve instead of travelling straight) onto a detector. The lighter ions deflect further than the heavy ions because the force on each ion is equal but their masses are not (this is derived from the equation F = ma which states that if the force remains the same, the mass and acceleration are inversely proportional). The detector measures exactly how far each ion has been deflected, and from this measurement, the ion's 'mass to charge ratio' can be worked out. From this information it is possible to determine with a high level of certainty what the chemical composition of the original sample was. The three processes that occur in a mass spectrometry are:- (i) ionization (ii) sorting of ions and (iii) detection. Hence a mass spectrometer consists of various parts:

(a) Sample introduction / inlet system
(b) Ion source
(c) Analyzer
(d) Detector
(e) Data acquisition and processing system
(f) Vacuum system

Sample in solid, liquid or gas from are introduced using suitable inlet system .usually, the singly charged positive ions (sometimes negative ions or multiply charge) are produced in the ion source .these are accelerated and are sort according to their mass to charge (m/z) ratios in the analyzer. The sorted ions are detected either sequentially or simultaneously using a suitable detector. A vacuum system capable of producing pressure less then 10^{-6} torr in the ion source, analyzer and detector forms an essential part of a mass spectrometer. Most of the present generation mass spectrometers are equipped with a computer for data acquisition and instrument control.

3.2.2.1.3 DUAL INLET MASS SPECTROMETER

Fig.3.3.:- Dual inlet mass spectrometer instrument(Source:-National Institute of Hydrology).

In 1947,Alfred Nier developed the first dual–inlet, double collector gas source mass spectrometer. The double collector allowed the simultaneous measurement of two isotopes and the dual inlet allowed ratio measurement on both a sample and a standard by alternating between inlets.

3.2.2.1.3.1 SAMPLE PREPARATION OF DUAL INLET MASS SPECTROMETER

Take 300-400 µl water in vials by micropipette. In the case of H2 place, Hokko coils with coil above the water surface layer. Place the samples along with standards and seal the vials in the instrument by fitting the metallic plate above the vials. While carrying and placing vials in the sample tray be careful that vials do not get tilted otherwise it will spoil Hokko coils.

3.2.2.1.3.2 MEASUREMENT PROCEDURE

The samples are then mounted in the sample cabin of the dual-inlet Aqun-prep mass spectrometer. The temperature in the sample cabin is maintained at 40°C throughout the experiment. The analyses run for approximately 22 hours for oxygen. High vacuum is created within the valves in the spectrometer. The samples are taken from the vials by automatic sampler. For oxygen analysis CO_2 is equilibrated with oxygen vapours which are made to release from liquid samples.

At first CO_2 is equilibrated with the sample water or standard (VSMOW, SLAP). Measurements are made on the oxygen compound of the CO_2.

$$\delta^{18}{}_{\text{sample/standard}} = ({}^{18}R_{\text{sample}}/\ {}^{18}R_3) - 1$$

$$= ({}^{18}R_{\text{co2 is equalization with water}}/\ {}^{18}R_{\text{co2 is equalization with VSMOW}})$$

As the samples are mounted, software names "MASSLYNX 4.0 I" developed by GV instruments, U.K helps to run the instruments and analysis the samples. The data that is obtained after the experiments is raw in form. It is processed to get rid of instrumental and other errors and is calibrated with respect to standards. Ultimately what we get are certain numbers with respect to standards. In case of oxygen the standards are VSMOW and SLAP.

3.2.2.1.3.3 WORKING OF DUAL INLET MASS SPECTROMETER:-

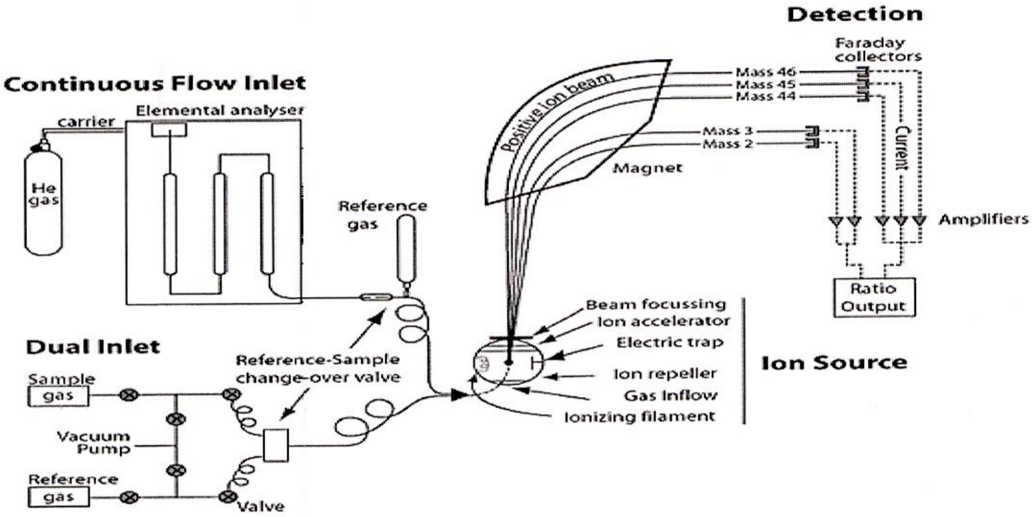


Fig.3.4.:-Working of Dual inlet mass spectrometer(Source:-G-WADI, Water and development information for arid lands: A global network, Methods and analysis).

A heated tungsten-coated iridium (thoria) filament inside the source block cavity ionizes a laminar steam of gas entering the ultra-high vacuum source. The gas molecules are stripped of one electron, producing positive ions (e.g. CO_2^+) which are then accelerated through a voltage gradient and focused into the flight tube upon existing the source. The ionization efficiency varies between 0.01 and 0.1% for different instrument. The ion beam bends as it passes through the field of a magnet installed over the flight tube. Here, the beam separates into a spectrum of masses according to the isotopes present. Each mass beam continues to the ion detectors where preset faraday cup collectors measures each ion current. By collecting two or three ion beams simultaneously, the ion currents can be expressed as a mass ratio. A dual-inlet system allows the mass spectrometer to alternatively measure ratio in the sample and a working or laboratory standard. Thus, the extreme fractionation impacted from drifting electronics, which precluded accurate abundance measurements. These instabilities have since then been overcome with solid-state and fiber optic signal transfer systems.

Figure 3.4 given above shows the schematic of gas source isotope ratio mass spectrometer (IRMS), showing both continues flow and dual inlets. A continues flow inlet here is shown with a sample combustion and gas chromatograph configuration. Capillary tubes ensure laminar, non-fractionating gas flow. Example shows mass range of CO_2 gas, and includes the short radius flight tube for H_2 found a many designs. Other mass ranges (for SO_2 and N_2) are attained by either additional fixed-position faraday collectors or by adjusting the beam.

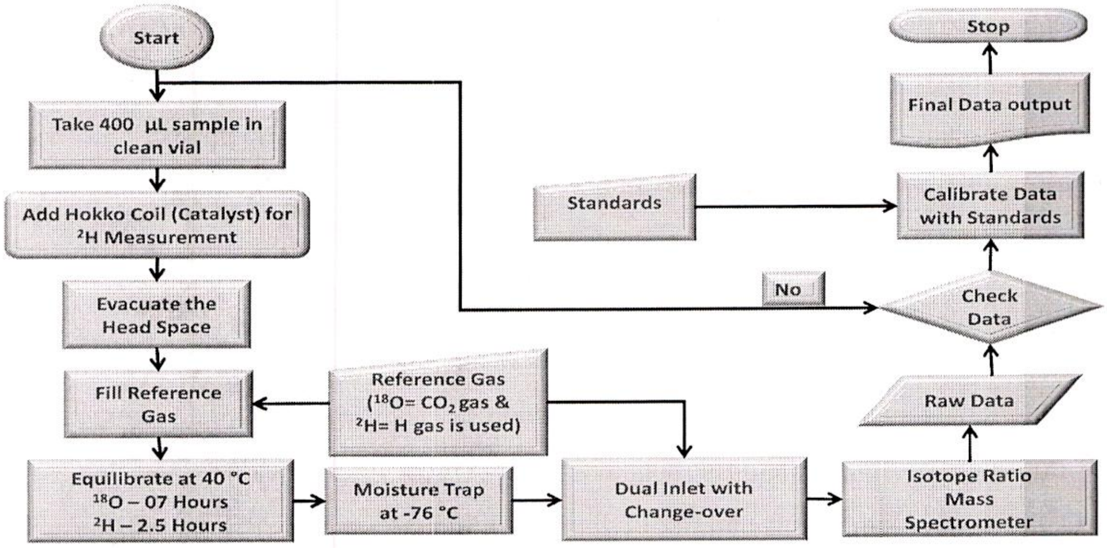


Fig.3.5.:- Flow Chart for Analysis of Stable Isotopes ($\delta^{18}O$ and δ^2H) on Dual Inlet Isotope Ratio Mass Spectrometer(Source:-National Institute of hydrology).

Figure 3.5 shows the whole processing of Dual Inlet Isotope Ratio Mass Spectrometer from sample preparation to the output of results step by step.

3.2.3 OTHER ANALYSIS

Apart from the chemical and isotopic analysis, Electrical conductivity, temperature, pH, radon are also analysed. Electrical conductivity and radon measurement are useful in our study work and measured using Electrical conductivity meter and radon using electronic radon detector with real time monitoring.

3.2.3.1 ELECTRICAL CONDUCTIVITY

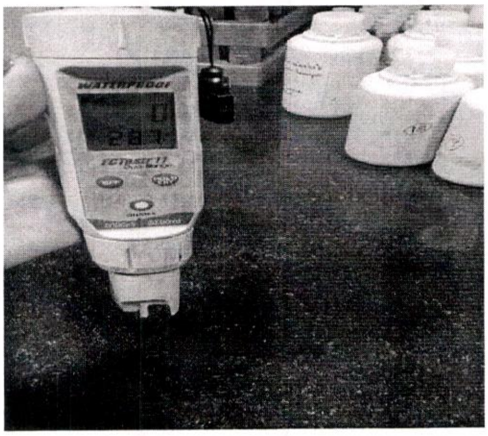


Fig.3.6.:-EC meter(Source:-National Institute of Hydrology).

All aqueous solutions conduct electricity to some degree. EC or Electrical Conductivity of water is its ability to conduct an electric current. Salts or other chemicals that dissolve in water can break down into positively and negatively charged ions. These free ions in the water conduct electricity, so the water electrical conductivity depends on the concentration of ions. The EC of water is an indicator of the purity of water. The purer the water the lower is its conductivity.

3.2.3.1.1 PRINCIPLE OF ELECTRICAL CONDUCTIVITY

Conductivity is measured by a probe that applies voltage between two electrodes, spaced a known distance apart, and records the drop in voltage. This drop reflects the resistance of the water, which is then converted to conductivity. Thus, conductivity is the inverse of resistance and is measured in the amount of conductance over a certain distance. The conductivity units are called "mhos".

3.2.3.1.2 IMPORTANCE IN STUDY

Deionised water hardly conducts electricity but when salts are present in water they dissociate into ions and are electronically conductive. Salinity is the measure of dissolved salts (ions) in a solution. As such, conductivity readings provide a good indication of salinity. In general, as salinity increases, the total dissolved solids (TDS) of a solution increases, and so too does conductivity. Moreover the temperature of water at the time of collection is also found by the electrical conductivity meter.

3.2.3.2 RADON MEASUREMENT

Natural radon is an excellent tracer for identifying areas of significant groundwater discharge because of its conservative nature, short half-life, high abundance in groundwater compared to surface water and easiness in measurement. ^{222}Rn is particularly useful in locating submarine freshwater springs as radium may not enrich under such conditions. One of the limitations of ^{222}Rn is that, being an inert gas, it escapes into the atmosphere. From the continuous monitoring of ^{222}Rn in coastal waters, it is possible to quantify Submarine groundwater discharge. Radon measurement is done using real-time radon monitoring unit.

The United States Environmental Protection Agency is reportedly prepared to set an maximum contaminant Level of 300 to 4,000 pico curies per litre for radon in drinking water. Radon is a naturally-occurring radioactive gas that may cause cancer, and may be found in drinking water and indoor air. Some people who are exposed to radon in drinking water may have increased risk of getting cancer over the course of their lifetime, especially lung cancer.

3.2.3.2.1 ELECTRONIC RADON DETECTOR WITH REAL TIME MONITORING

3.2.3.2.1.1 SAMPLE COLLECTION

Groundwater should be collected in air tight glass bottles with any air bubble inside the bottle upto the neck of the bottle and measured within 3 days after sample collection.

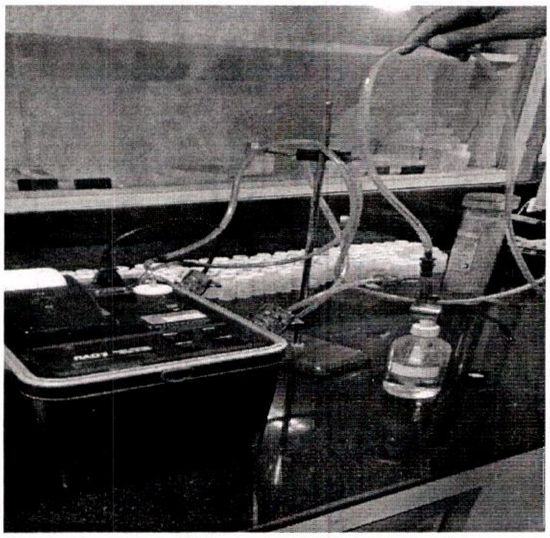


Fig.3.7.- Electronic Radon detector with real time monitoring(Source:-National Institute of hydrology)

3.2.3.2.1.2 MEASUREMENT

Firstly switch on the instrument and press purging to remove the moisture present inside the instrument by pressing the command:

Test» Purge» Enter

After 15 minutes to stop purging press:

Enter» Stop purging» Yes

Put the printer above the instrument and match that the blue light of the printer should match the indicator of the instrument. Moreover set the unit of measurement as pico curie per litre (pCi/l).

A porous tube is inserted in the sample water so that the radon can move up and locked tightly.

Two tubes present in the instrument one red and other black. The red tube is connected to the outlet of the instrument and the black tube is connected to silica gel. Then press:

Test» Start» Enter

The moisture is soaked by the silica gel and the moisture free air is sent back to the instrument.

After one hour the result will be given by the printer.

3.2.4 ARC-GIS TECHNIQUE USED

Arc-GIS technique has been used in the study to create shapefiles of the study area and coastline and site locations are developed from the shapefiles wih the use of Surfer software.

A shapefile is an Esri vector data storage format for storing the location, shape, and attributes of geographic features. It is stored as a set of related files and contains one feature class. Shapefiles often contain large features with a lot of associated data and historically have been used in GIS desktop applications such as ArcMap. If we have a small amount of data in a shapefile—generally fewer than 1,000 features—you can make it available for others to view through a web browser by adding it as a .zip file containing the .shp, .shx, .dbf, and .prj files to a map we create with the map viewer. Shapefiles can support point, line, and area features. Area features are represented as closed loop, double-digitized polygons.

The coastline and coastal districts of the study area are then digitized using Surfer software and the spatial distribution of the chemical and isotopic parameters analysed are shown along the coastline as per the sampling location.

Moreover area zoning is done to demarcate areas having freshwater, areas having salinity and seawater.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

The samples collected are mostly freshwater samples (except three i.e 2 seawater and 1 chilka lake water) used for drinking purpose by the local people and hence must satisfy the standard tests to see if the water quality is under permissible standard and safe for consumption. The areas which do not fulfil the standardised limit should be marked and further analysis should be done to find the reason of deflection and rectify the water quality. The accepted and permissible limits of various parameters are provided by Bureau of Indian Standards (BIS) IS 10500-2012 and World Health Organisation (WHO) for drinking water and irrigation water that have been used for finding the suitability of groundwater.

4.2 RESULTS

The objective behind the Groundwater quality monitoring is to develop an overall picture of the groundwater quality of the samples collected along the coastal districts of Odisha. During the year 2015, the team has carried out the groundwater quality monitoring of 40 hand pumps. The sampling of groundwater from 38 hand pumps was carried out in the month of November (Post-monsoon period) 2015 throughout the coastal districts of the state and 3 samples were collected in May (Pre-monsoon period). The general parameters analyzed in the collected samples of groundwater are pH, Electrical Conductivity (EC). The samples were also analysed for major cations viz. Magnesium (Mg^{2+}), Calcium (Ca^{2+}), Sodium (Na^{+}), Potassium (K^{+}), Ammonium (NH_4^{+}) and anions viz. Nitrite (NO_2^{-}) Sulphate (SO_4^{2-}), Chloride (Cl^{-}), Nitrate (NO_3^{-}) and Fluoride (F^{-}). Moreover, isotopic analysis of the samples for calculating value of $\delta^{18}O$ (‰) and δD (‰). The district wise collection of groundwater samples is summarised in Tables below.

Table 4.1:-Table For EC, pH, Temperature and Radon

Site ID	Source	EC(µS/cm)	Temp(°C)	pH	Rn(pCi/L)
SGD-8	HP	920	29.8	8	3755.69
SGD-9	HP	6700	28.4	7.1	2732.07
SGD-10	HP	1250	29	7.1	6876.22
SGD-11	HP	1050	31.2	7.5	4075.73
SGD-12	HP	940	28.2	7.3	
SGD-13	HP	810	31.1	8.1	7489.73
SGD-14	HP	1020	29.1	7.4	9611.84
SGD-15	HP	1220	28.3	7.7	2054.3
SGD-16A	HP	1970	27.9	6.8	4261.97
SGD-16B	HP	1480	27.8	6.7	1120.15
SGD-17	HP	560	28.7	6.9	9205.12
SGD-18	HP	1370	29.6	6.9	7597.14
SGD-19	HP	800	31.5	7.5	4720.19
SGD-20	HP	830	31.2	7.4	7847.87
SGD-21	HP	830	29.7	7.7	9320.55
SGD-22	HP	13900	28.2	6.6	3412.22
SGD-23	HP	1070	29	6.5	3874.05
SGD-24	HP	320	28.2	7.2	4006.3
SGD-25	HP	420	28.3		
SGD-26	HP	420	28.4	6.6	5135.97
SGD-27	SW	19780	27.7	7.4	
SGD-28	HP	200	28.1	7.9	
SGD-29A	HP	210	27.4	7.5	6340.84
SGD-29B	HP	1020	29.8	7.6	
SGD-30	HP	1700	29.3	7.7	
SGD-31	HP	330	28.2	7.9	3791.22
SGD-32	HP	210	29.7	8.3	4915.94
SGD-33	HP	820	28.8	7	4738.94
SGD-34	HP	750	30.1	6.7	

SGD-35	HP	1770	29.2	7.2	3953.47
SGD-36	LW	1390	26.8	8.3	
SGD-37	HP	610	28.4	7	
SGD-38	HP	1320	29.5	6.3	
SGD-39A	HP	420	27.9	6.9	
SGD-39B	HP	510	29.4	6.4	
SGD-40A	HP	250	31.8	7.2	
SGD-40B	HP	270	29.9	7.5	
SGD-41	HP	280	29.5	7.6	145.37
SGD-42A	SW				72.96
SGD 51	HP	1830		7	10.16
SGD52	HP	450	29.6	6.9	22.26
SGD 53	HP	1480	30.2	6.7	194.22

Table 4.2:-Table For Isotopic Values

Site ID	**Date**	**Source**	**□^{18}O(‰)**	**□D(‰)**
SGD-8	21-11-2015	HP	-3.77	-24.60
SGD-9	21-11-2015	HP	-3.00	-19.47
SGD-10	21-11-2015	HP	-2.88	-17.57
SGD-11	22-11-2015	HP	-2.44	-15.57
SGD-12	22-11-2015	HP	-2.99	-17.97
SGD-13	22-11-2015	HP	-3.50	-22.78
SGD-14	22-11-2015	HP	-2.83	-18.76
SGD-15	23-11-2015	HP	-2.75	-16.53
SGD-16A	23-11-2015	HP	-3.18	-21.61
SGD-16B	23-11-2015	HP	-3.37	-19.90
SGD-17	24-11-2015	HP	-2.78	-19.46
SGD-18	24-11-2015	HP	-2.89	-18.53
SGD-19	24-11-2015	HP	-3.24	-21.30
SGD-20	24-11-2015	HP	-2.96	-18.95

SGD-21	24-11-2015	HP	-2.70	-17.39
SGD-22	25-11-2015	HP	-3.00	-18.55
SGD-23	25-11-2015	HP	-3.74	-26.61
SGD-24	25-11-2015	HP	-4.83	-33.76
SGD-25	25-11-2015	HP	-4.19	-30.13
SGD-26	25-11-2015	HP	-4.32	-30.27
SGD-27	25-11-2015	SW	-4.21	-29.68
SGD-28	25-11-2015	HP	-4.52	-30.76
SGD-29A	25-11-2015	HP	-3.72	-27.01
SGD-29B	26-11-2015	HP	-4.34	-30.14
SGD-30	26-11-2015	HP	-4.36	-30.79
SGD-31	26-11-2015	HP	-5.24	-8.78
SGD-32	26-11-2015	HP	-5.47	-37.86
SGD-33	26-11-2015	HP	-3.28	-23.24
SGD-34	26-11-2015	HP	-4.59	-32.80
SGD-35	26-11-2015	HP	-5.24	-36.37
SGD-36	27-11-2015	HP	-2.00	-15.37
SGD-37	27-11-2015	HP	-5.39	-36.87
SGD-38	27-11-2015	HP	-6.03	-36.30
SGD-39A	27-11-2015	HP		
SGD-39B	27-11-2015	HP	-4.30	-26.33
SGD-40A	27-11-2015	HP	-2.74	-17.70
SGD-40B	27-11-2015	HP	-4.81	-31.72
SGD-41	27-11-2015	HP	-2.84	-18.58
SGD-42A	27-11-2015	SW	-1.61	-8.90
SGD 51	31-05-2016	HP	-5.36	-34.61
SGD52	31-05-2016	HP		
SGD 53	31-05-2016	HP	-4.91	-31.99

Table 4.3:-Table For Chemical Analysis (For anions):-

Site ID	F^-(mg/l)	Cl^-(mg/l)	NO_2^-(mg/l)	SO_4^{2-}(mg/l)	NO_3^-(mg/l)
SGD-8	3.0	94.0	23.6	40.6	2.2
SGD-9	13.2	1279.6	173.4	180.7	29.0
SGD-10	0.8	119.1	26.4	99.9	0.4
SGD-11	3.9	86.3	29.2	57.1	1.9
SGD-12	4.0	48.0	28.1	42.6	0.8
SGD-13	4.9	78.2	17.3	31.3	1.9
SGD-14	0.8	118.0	23.3	124.6	2.2
SGD-15	1.8	129.9	26.4	190.1	0.8
SGD-16A	5.8	354.2	32.3	173.8	23.6
SGD-16B	5.4	224.7	31.6	122.0	8.9
SGD-17	3.1	122.7	19.3	46.0	0.8
SGD-18	2.3	228.2	27.9	41.9	4.3
SGD-19	3.8	105.4	25.1	23.8	8.1
SGD-20	3.6	122.7	37.5	50.1	142.3
SGD-21	0.1	128.2	23.5	43.5	17.5
SGD-22	n.a.	3717.9	164.0	1123.3	9.3
SGD-23	1.6	190.2	20.6	127.5	16.0
SGD-24	2.1	27.8	9.0	14.0	6.0
SGD-25	0.6	52.6	6.3	23.6	7.8
SGD-26	0.9	41.3	2.3	26.7	46.3
SGD-27	n.a.	3356.5	106.6	909.2	36.6
SGD-28	1.9	14.8	7.1	3.9	1.0
SGD-29A	2.0	43.7	8.7	9.0	11.9
SGD-29B	5.1	177.5	26.4	24.0	1.8
SGD-30	8.4	290.2	18.1	6.8	n.a.
SGD-31	0.4	34.1	12.4	7.7	2.4
SGD-32	2.0	35.0	14.3	22.9	9.8
SGD-33	4.1	104.0	20.9	46.3	1.8
SGD-34	1.4	109.3	24.3	33.7	0.6

SGD-35	1.0	237.6	44.3	337.0	207.9
SGD-36	1.8	1635.3	75.6	882.2	61.1
SGD-37	1.5	94.3	9.9	53.7	85.1
SGD-38	1.9	197.1	25.5	121.3	122.1
SGD-39A					
SGD-39B	2.8	112.8	2.6	69.0	47.5
SGD-40A	2.3	251.4	15.8	87.8	n.a.
SGD-40B	n.a.	99.8	8.8	23.2	0.7
SGD-41	3.8	255.5	12.6	132.7	3.1
SGD-42A	n.a.	5889.9	n.a.	2659.8	36.5
SGD 51	ND	272.30	19.51	74.08	10.45
SGD52					
SGD 53	ND	204.81	7.97	30.19	95.47

Table 4.4:-Table For Chemical Analysis (For cations):-

Site ID	**Na^+(mg/l)**	**NH_4^+(mg/l)**	**K^+(mg/l)**	**Mg^{2+}(mg/l)**	**Ca^{2+}(mg/l)**
SGD-8	167.5	5.3	4.9	5.8	13.5
SGD-9	752.4	44.4	18.1	175.6	519.1
SGD-10	148.8	2.4	4.2	24.8	42.9
SGD-11	125.9	3.7	11.8	24.8	48.3
SGD-12	116.2	2.6	8.5	20.9	31.7
SGD-13	131.5	3.2	4.2	9.0	11.4
SGD-14	113.6	6.9	8.6	25.7	61.4
SGD-15	150.1	4.2	6.6	33.2	52.6
SGD-16A	167.5	15.9	3.7	56.3	160.9
SGD-16B	105.3	2.4	3.2	43.0	116.0
SGD-17	105.7	1.8	4.0	24.5	55.6
SGD-18	166.1	2.9	9.2	36.3	56.3
SGD-19	122.2	2.2	6.0	16.7	29.3
SGD-20	124.7	3.7	5.6	34.9	117.9
SGD-21	150.4	2.5	8.3	11.0	27.9

SGD-22	3328.1	83.3	116.7	292.2	142.3
SGD-23	160.3	6.9	9.7	25.5	35.4
SGD-24	32.4	1.4	4.3	9.2	7.5
SGD-25	31.1	4.2	5.0	6.8	11.5
SGD-26	21.9	1.2	3.8	4.6	16.3
SGD-27	2164.2	123.1	98.3	263.6	152.5
SGD-28	27.7	1.5	9.1	2.0	2.9
SGD-29A	47.8	1.2	5.1	6.7	6.6
SGD-29B	228.1	6.1	7.8	8.1	11.5
SGD-30	346.4	8.1	9.5	9.3	17.9
SGD-31	22.7	0.7	3.6	7.6	35.9
SGD-32	28.5	0.5	1.9	14.1	34.7
SGD-33	95.3	2.2	6.7	14.9	42.2
SGD-34	62.9	4.4	7.7	28.7	53.9
SGD-35	136.2	6.5	101.4	69.0	106.9
SGD-36	3397.9	n.a.	123.2	411.7	128.0
SGD-37	66.1	3.2	7.3	11.3	13.2
SGD-38	164.8	9.6	3.0	23.9	39.2
SGD-39A					
SGD-39B	106.7	3.1	13.4	12.6	13.9
SGD-40A	389.0	n.a.	14.1	22.8	46.7
SGD-40B	66.4	2.7	5.5	12.8	18.2
SGD-41	416.7	n.a.	12.6	41.5	46.2
SGD-42A	7691.2	9.3	276.0	913.7	286.4
SGD 51	294.19	6.80	32.06	32.96	159.40
SGD52					
SGD 53	126.90	3.91	82.46	29.60	101.77

Table 4.5-Table for SP, SAR, KR

Site ID	ESP(meq/l)	KR(meq/l)	SAR(meq/l)
SGD-8	86.47	6.28	9.57
SGD-9	44.97	0.81	7.26
SGD-10	60.97	1.54	4.46
SGD-11	56.30	1.22	3.66
SGD-12	61.32	1.52	3.92
SGD-13	81.51	4.33	7.03
SGD-14	49.76	0.95	3.06
SGD-15	55.40	1.21	3.98
SGD-16A	36.69	0.57	2.89
SGD-16B	33.20	0.49	2.11
SGD-17	49.34	0.95	2.96
SGD-18	56.11	1.24	4.23
SGD-19	65.68	1.86	4.45
SGD-20	38.73	0.62	2.58
SGD-21	74.49	2.83	6.08
SGD-22	82.44	4.60	36.48
SGD-23	64.96	1.79	5.00
SGD-24	57.11	1.23	1.86
SGD-25	56.55	1.19	1.79
SGD-26	46.82	0.80	1.23
SGD-27	76.56	3.18	24.46
SGD-28	82.21	3.87	3.05
SGD-29A	71.24	2.33	3.11
SGD-29B	89.00	7.93	12.54
SGD-30	90.16	9.01	16.48
SGD-31	30.81	0.41	0.90
SGD-32	30.69	0.43	1.03
SGD-33	56.30	1.24	3.20
SGD-34	36.56	0.54	1.71

SGD-35	43.45	0.53	2.51
SGD-36	78.76	3.63	32.75
SGD-37	65.69	1.80	3.21
SGD-38	64.72	1.81	5.10
SGD-39A			
SGD-39B	74.03	2.65	4.96
SGD-40A	80.30	3.99	11.62
SGD-40B	60.52	1.46	2.90
SGD-41	76.17	3.14	10.67
SGD-42A	79.06	3.70	49.72
SGD 51	55.95	1.19	5.53
SGD52			
SGD 53	50.25	0.73	2.84

Table 4.6:- Measured Parameters, Value Range (Maximum, Minimum And Average Value) And Location Name:

Parameters	**Minimum & Maximum concentration & the Observed place**			**Permissible limit(BIS)**	**No. Of Samples exceeding limit**
	Minimum	**Maximum**	**Average**		
EC (μS/cm)	200(Kapileshwarpur)	13900(Nuagarh, fishing base)	1732.75		
Temp(°C)	26.8(Satapada Chilka Water)	31.8(Jadupur)	29.20		
pH	6.3(Near Sub-inspection exchange office, Satpada)	8.3(Ramachandi Temple)	7.24		
Radon(pCi/L)	10.16(Gopalpur	9611.84(Bideipur	4489.2		

	Beach)	Market)	4		
$\delta^{18}O$(Permille)	-6.03(Near Sub-inspection exchange office,Satpada)	-2.44(Rabindranagar, Dosinga)	-3.85		
δD(Permille)	-37.86(Ramachandi Temple)	-8.78(Konark)	-24.91		
F(mg/l)	0.1(Bhagbatpur,Jantilo)	13.2(Naya sadak, Sonapur road, Chandipur)	3.0	1.5	23
Cl(mg/l)	14.8(Kapileshwarpur)	3717.9(Nuagarh, fishing base)	265.0	1000	2
Nitrate(mg/l)	0.4(Tentulipura, way to Chandipur)	207.9(Golden Beach, Puri)	26.6	45	7
Nitrite(mg/l)	2.3(Konark fish market)	173.4(Naya sadak,Sonapur road)	27.7		
Sulphate(mg/l)	3.9(Kapileshwarpur)	1123.3(Nuagarh, fishing base)	99.1	400	1
Na(mg/l)	21.9(Konark Fish market, Konark-Kakatpur road)	3328.1(Nuagarh, fishing base)	239.1		
K(mg/l)	1.9(Ramachandi Temple)	116.7(Nuagarh, fishing base)	15.4		
Mg(mg/l)	2.0(Kapilsehwarpur)	292.2(Nuagarh, fishing base)	33.2	100	2
Ca(mg/l)	2.9(Kapileswarpur)	519.1(Naya sadak ,Sonapur road,Chandipur)	62.4	200	1
Ammonium(mg/l)	0.5(Ramachandi Temple)	123.1(Nuagarh, fishing base)	7.5		

The electrical conductivity(EC in uS/cm), sulphate, magnesium(Mg) and calcium(Ca) of Kapileshwarpur, sampling site at 19.83867°N latitude and 85.72483°E longitude has the lowest value i.e 200uS/cm,3.9ppm,2.0ppm,2.9ppm respectively.

Satpada Chilka water, sampling site at 19.66578°N latitude and 85.43715°E longitude has minimum temperature i.e 26.8°C but also has maximum pH value i.e 8.3.

The pH and $\delta^{18}O$ value of Near Sub-inspection exchange office, Satpada, sampling site at 19.66687°N and 85.44138°E has minimum value i.e 6.3 and -6.03‰ respectively.

Radon value is minimum i.e 10.16pCi/l in Gopalpur beach, sampling site at 19.25663°N latitude and 84.90788°E longitude.

Ramachandi Temple, sampling location at 19.85575°N and 86.05932°E has the minimum δD, potassium(K) and ammonium value i.e -37.86‰,1.9ppm and 0.5ppm but also has maximum pH value i.e 8.3.

The fluoride content of Bhagbatpur, Jantilo, sampling site at 20.50808°N and 86.35215°E is lowest i.e 0.1ppm.

Kapileshwarpur sampling site at 19.83867°N and 85.72483°E has minimum chloride, sulphate, magnesium and calcium values i.e 14.8ppm,3.9ppm,2.0ppm and 2.9ppm respectively.

The nitrate value is minimum i.e 0.4ppm at Tentulipura, way to Chandipur sampling location at 19.46885°N and 86.97905°E.

The nitrite and sodium values are minimum for Konark fish market, Konark-Kakatpur road i.e 2.3ppm and 21.9ppm respectively at sampling location 19.89167°N and 86.10082°E. The EC, Cl, Sulphate, sodium, potassium, ammonium and magnesium are maximum at sampling location 19.97378°N and 86.33872°E at Nuagarh (fishing base) i.e 13900uS/cm, 3717.9ppm, 1123.3ppm, 3328.1ppm, 116.7ppm, 123.1 and 292.2ppm respectively.

The maximum temperature of water is found at Jadupur sampling location at 19.41702°N and 85.76893°E i.e 31.8°C.

The radon value of Beidipur Market, sampling location at 21.05217°N and 86.82617°E has the maximum value i.e 9611.84pCi/l.

δD is maximum at Konark, sampling location at 19.8927°N and 86.08747°E i.e -8.78‰.

The fluoride, calcium, nitrite value are maximum in Naya Sadak, Sonapur road, sampling location at 21.44888°N and 87.00813°E i.e 13.2ppm, 519.1ppm and 173.4ppm respectively.

δO^{18} value is maximum at Rabindranagar, Dosinga i.e -2.44.

4.3 SUITABILITY OF WATER FOR DRINKING PURPOSE

To see if the sample water of freshwater collected meet up the desirable and permissible limit of the prescribed standards, the samples collected are analysed and interpreted.

Table 4.7:-Drinking Water Standards BIS 10500-2012(Second Revision Of IS 10500)

Sl. No.	**Substance/Characteristic**	**Requirement(Desirable limit)**	**Undesirable effect outside the desirable limit**	**Permissible limit in absence of alternate source**
1.	Nitrate(as NO□) mg/l	45	Beyond this methaemoglobinemia takes place/indicative of pollution.	No relaxation
2.	Fluoride(as F) mg/l	1.0	Fluoride may be kept as low as	1.5

			possible. High fluoride can cause fluorosis.	
3.	Chlorides(as Cl) mg/l	250	Beyond this limit taste, corrosion and palatability are affected.	1000
4.	Sulphate(as SO□) mg/l	200	Beyond this cause gastro-intestinal irritation when magnesium and sodium are present.	400
5.	Calcium(as Ca) mg/l	75	Encrustation in water supply structure and adverse affect on domestic use.	200
6.	Magnesium(as Mg)mg/l	30	Encrustation in water supply structure and adverse affect on domestic use.	100

(Source:-BIS)

Table 4.8:-WHO's Drinking Water Standards 1993

WHO's Guidelines for Drinking-water Quality, set up in Geneva, 1993, are the international reference point for standard setting and drinking-water safety.

Element/ substance	**Symbol/ formula**	**Normally found in fresh water/surface water/ground water**	**Health based guideline by the WHO**
Aluminium	Al		0.2 mg/l
Chloride	Cl		250 mg/l
Ammonia	NH_4	< 0.2 mg/l (up to 0.3 mg/l in anaerobic	
Fluoride	F	< 1.5 mg/l (up to 10)	1.5 mg/l
Nitrate and nitrite	NO_3, NO_2		50 mg/l total nitrogen
Sodium	Na	< 20 mg/l	200 mg/l
Sulphate	SO_4		500 mg/l

(Source:-WHO)

4.3.1 COLLECTED SAMPLE CHLORIDE CHART

High concentrations of chloride give a salty taste to water and beverages. Taste thresholds for the chloride anion depend on the associated cation and are in the range of 200–300 mg/l for sodium, potassium and calcium chloride. Concentrations in excess of 250 mg/l are increasingly likely to be detected by taste, but some consumers may become accustomed to low levels of chloride-induced taste. No health-based guideline value is proposed for chloride in drinking-water. Chloride is present in lower concentrations in common rock types, than any of the other major constituents of natural water and it is assumed that bulk of the chloride in groundwater is primarily either from atmospheric source, sea water contamination or from anthropogenic sources. Abnormal concentration of chloride may result from pollution by sewage wastes. The large lateral variation in the chloride concentration and observed high concentration in some subsurface water indicate local recharge and may be attributed to the contamination by untreated industrial and domestic waste effluents from nearby area. High chloride content in coastal aquifers can be a indicator of possible chance of intrusion from sea and hence is an important parameter for measuring seawater intrusion. Table below shows the sample's deviation from the permissible level of chloride value.

Table 4.9:- Number Of Samples Within Permissible Limit And Exceeding Permissible Limits Of Chloride.

Chloride value (mg/l)	**No. of points**
0-250	31
250-1000	4
>1000	2

Most of the samples collected approximately 75% samples lie within the desirable range of chloride value i.e 250mg/l and 4 samples lie within the permissible limit of BIS Standards of Groundwater Quality for drinking water as per 10500-2012 ,one sample remain unanalysed. The two samples which exceed the permissible standards are of areas:-

i) Naya Sadak, Sonapur road, Chandipur, Chloride value:-1279.6 mg/l
ii) Nuagarh (Fishing base), Chloride value:-3717.9 mg/l

Hence the water of these two areas are not proper for drinking purpose and may have been intruded. Further analysis and research in these area's geology and hydrology should be done to find the root cause of this high chloride content in the water samples.

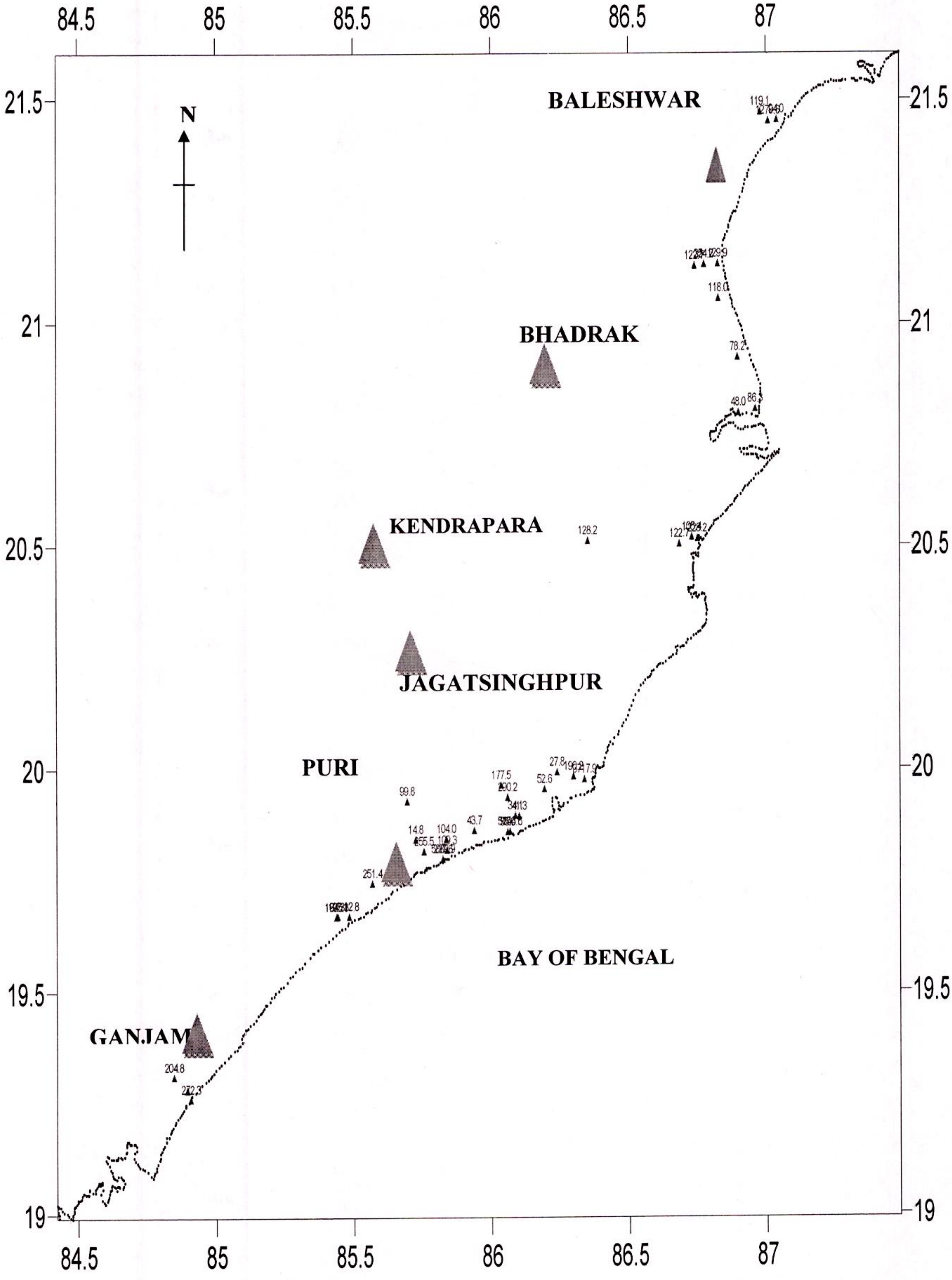


Fig.4.1:- Plot of chloride value along the sampling location in Odisha (Surfer ®).

4.3.2 COLECTED SAMPLE SULPHATE CHART

Sulphate in drinking-water can cause noticeable taste, and very high levels might cause a laxative effect in unaccustomed consumers. Taste impairment varies with the nature of the associated cation; taste thresholds have been found to range from 250 mg/l for sodium sulphate to 1000 mg/l for calcium sulphate. High sulphate levels in drinking water results in gastro-intestinal disorders, and hence, it is recommended that health authorities be notified of sources of drinking water that contain sulphate concentrations in excess of 500 mg/l (WHO, 2011). BIS (2012) has prescribed 200 mg/l as acceptable limit and 400 mg/l as permissible limit for sulphate in absence of alternate source for drinking and other domestic usage. Sulphate (SO_4^{2-}) concentration in samples of coastal parts of Odisha groundwater varies between 3.9mg/l to 1123.3 mg/l in freshwater and 2659.8 in seawater (avg. 245.7mg/l) . The sulphate is usually derived from the oxidative weathering of sulphide bearing minerals like pyrite, gypsum or anhydrite. Apart from these natural sources, sulphate may be introduced through the application of sulphatic soil, conditioners and fertilizers. The observed high concentration of (SO_4^{2-}) in some samples indicates the effects of industrial and anthropogenic activities in the area.

Table 4.10:- Number Of Samples Within Permissible Limit And Exceeding Permissible Limits Of Sulphate.

Sulphate value (mg/l)	**No. of points**
0-200	35
200-400	1
>500	1

Most of the samples collected approximately 92% samples lie within the desirable range of sulphate value i.e 200mg/l and 1 samples lie within the permissible limit of BIS Standards of Groundwater Quality for drinking water as per 10500-2012 ,one sample remain unanalysed. The sample which exceed the permissible standards is of area:-

i) Nuagarh (Fishing base), Sulphate value:-1123.3 mg/l

Hence the water of this area are not proper for drinking purpose and may have been intruded. Further analysis and research in these area's geology and hydrology should be done to find the root cause of this high sulphate content in the water samples.

4.3.3 COLECTED SAMPLE NITRATE AND NITRITE CHART

Nitrate and nitrite are highly soluble in water. Nitrate (NO_3^-) is found naturally in the environment and is an important plant nutrient. It is present at varying concentrations in all plants and is a part of the nitrogen cycle. Nitrite (NO_2^-) is not usually present in significant concentrations except in a reducing environment, as nitrate is the more stable oxidation state. According to the Indian Standard for drinking water (IS 10500:2012), the maximum allowable nitrate concentration in drinking water is 45 mg/l as NO_3.

Table 4.11:- Number Of Samples Within Permissible Limit And Exceeding Permissible Limits Of Nitrate.

Nitrate value (mg/l)	No. of points
0-45	29
>45	7

Out of the 38 freshwater sampling sites 29 samples are bound to the permissible limit of BIS while four samples were not analysed with nitrate and the 7 samples which exceed the nitrate permissible values are:-

i) Badapalli, Nitrate value:-142.3 mg/l
ii) Konark Fish Market, Konark-kakatpur road, Nitrate value:-46.3 mg/l
iii) Golden beach, Puri, Nitrate value:-207.9 mg/l
iv) Satapada near Jetty, Nitrate value:-85.1 mg/l
v) Near Sub Inspection Exchange office, Satapada, Nitrate value:-122.1 mg/l
vi) Baghamunda, Nitrate value:-47.5 mg/l
vii) Dura bahadurpetta,Pathara, Gopalpur, Nitrate value:-95.47 mg/l

4.3.4 COLECTED SAMPLE FLUORIDE CHART

Fluoride is found in all natural waters at some concentration. Seawater typically contains about 1 mg/L while rivers and lakes generally exhibit concentrations of less than 0.5 mg/L. In groundwater, however, low or high concentrations of fluoride can occur, depending on the nature of the rocks and the occurrence of fluoride-bearing minerals. Fluoride occurs as fluorspar (fluorite), rock phosphate, triphite, phosphorite minerals etc in nature. Among the factors, which control the concentration of fluoride includes climate of the area and the presence of accessory minerals in the rock mineral assemblage through which the groundwater is circulating. Concentrations in water are limited by fluorite solubility. It is the absence of calcium in solution which allows higher concentrations to be stable. High fluoride concentrations may therefore be expected in groundwater from calcium-poor aquifers and in areas where fluoride-bearing minerals are common (Nanyaro et al., 1984; Gaciri and Davis, 1993; Kundu et al., 2001). Many epidemiological studies have shown that fluoride in drinking water has a narrow range between intakes that cause beneficial and detrimental health effects. Fluoride intake to humans is necessary as long as it does not exceed the limits. The WHO (2011) and BIS (2012) estimates the maximum allowable limit for fluoride uptake to human's in drinking water as 1.5 mg/l. Excess fluoride intake causes different types of fluorosis, primarily dental and skeletal fluorosis. White line striations followed by brown patches and, in severe cases, brittling of the enamel are common symptoms of dental fluorosis. Skeletal fluorosis first causes pain in the different joints, then limits joint movement and finally causes skeletal deformities, which become particularly acute if fluoride uptake occurs during growth. Since these ailments are incurable, fluorosis can only be mitigated by preventing intake of excess fluoride.

Table 4.12:- Number Of Samples Within Permissible Limit And Exceeding Permissible Limits Of Fluoride.

Fluoride value (mg/l)	No. of points
0-1	6
1-1.5	3

>1.5	23

Most of the areas exceed the permissible limit of fluoride in drinking water and hence the water are not safe for drinking and needs vigorous treatment. The areas exceeding fluoride limits are:- i)Naya Sadak, Sonapur road,Chandipur ii) Chandipur (Beach) iii) Rabindranagar,Dosinga iv) Dhamara Port v) Baincha vi) Jetty, Chudamani vii) Chudamani(New) viii) Chudamani(Old), ix) Jamujhadi, Basudevpur bus stand x) Chakulidiha, Sasana xi) Tantiapal xii) Badapalli xii) Damasun, Jharling (Youth Club) xiii) Jiunti chhaka bus stop,Jiunti xiv) Kapileswarpur xv) Balighai xvi) Begunia xvii) Kuruma,Sareda xviii) Ramachandi Temple xix) Bata mangala Temple xx) Gorual xxi) Near Sub Inspection Exchange office, Satapada xxii) Baghamunda (B) xxiii) Jadupur . In two samples fluoride was not detected and in rest samples fluoride was not analysed.

4.3.5 COLECTED SAMPLE CALCIUM CHART

Calcium (Ca+) ion and calcium salt are among the most commonly encountered substances in water. Calcium in water arising mostly from dissolution of Ca bearing minerals of the aquifer formation and often it is the most abundant cation in aquatic water. Weathering and dissolution of calcium carbonate (limestone and dolomite) and calc-silicate minerals (amphiboles, pyroxenes, olivine, biotite etc) are the most common source of calcium is aquatic system. BIS (2012) had prescribed 75 mg/l as acceptable limit and 200 mg/l as permissible limit for calcium in absence of alternate source for drinking and other domestic usage.

Table 4.13:- Number Of Samples Within Permissible Limit And Exceeding Permissible Limits Of Calcium.

Calcium value (mg/l)	No. of points
0-75	29
75-200	9
>200	1

Most of the sample values lie within the permissible range of calcium and hence are safe for drinking purpose. The fresh water sample that exceed the permissible limit is:-

One sample having high calcium value in freshwater is of:- Naya Sadak, Sonapur road, Chandipur having chloride value as high as 519.1 mg/l

4.3.6 COLECTED SAMPLE SODIUM CHART

The sodium in the aquatic system is derived from the atmospheric deposition, evaporate dissolution and silicate weathering. The weathering of Na and K silicate minerals like albite, anorthite, orthoclase and microcline are the major source of the Na and K in the aquatic system. Although, the World Health Organization (W.H.O) does not have a set limit for sodium in drinking water, they do recommend that the concentration of sodium in drinking water should not exceed 25 mg/L. In case sodium concentration in potable water exceeds 25 mg/L, W.H.O. recommends that a health advisory be given by municipalities and this is more applicable for infants, people over 50 years of age and people with hypertension and cardiovascular disease and that the maximum daily dietary intake of sodium be limited to 1500 mg/day (U.S. Environmental Protection Agency, 2003; American Water Works Association, 1999). More sodium ions can also be an indication of intrusion from sea. Groundwater typically contains higher concentrations of minerals and salts than surface waters, especially in areas with an abundance of sodium mineral deposits or in areas with sea or estuarine water intrusions (WHO 1979).

4.3.7 COLECTED SAMPLE MAGNESIUM CHART

Natural sources contribute more magnesium to the environment than all anthropogenic sources. The principle source of magnesium in natural water is ferromagnesian mineral in igneous rock and magnesium carbonate in sedimentary rock. The sulphate and chloride of magnesium are very soluble. The presence of calcium and magnesium make the water hard. BIS (2012) have prescribed 30 mg/l as acceptable limit and 100 mg/l as permissible limit for magnesium in absence of alternate source for drinking and other domestic usage.

Table 4.14:- Number Of Samples Within Permissible Limit And Exceeding Permissible Limits Of Magnesium.

Magnesium value (mg/l)	No. of points
0-30	27
30-100	7
>100	2

Most of the areas comes under the permissible criteria. The samples which exceed the permissible criteria are of:-

i) Naya Sadak, Sonapur road having magnesium value as high as 175.6 mg/l
ii) Nuagarh (Fishing base), magnesium value:-292.2 mg/l

4.4 SUITABILITY OF WATER FOR IRRIGATION PURPOSE

Water quality, soil types and cropping practices play an important role in assessing the suitability of water for irrigation. Total salt concentration (EC), sodium adsorption ratio (SAR), sodium percentage (Na%) and Kelly's ratio (KR) are the important parameters which are widely used in assessing the suitability of water for irrigation uses (K. Srinivasa Reddy, 2013).

Table 4.15:-Guidelines For Evaluation Of Quality Of Irrigation Water (IS: 10500: 1991)

Water class	Sodium (Na) %	Electrical Conductivity µmhos/cm at 25°C	Alkalinity measure
			% SAR
Excellent	<20	<250	<10
Good	20-40	250-750	10-18
Medium	40-60	750-2250	18-26

Bad	60-80	2250-4000	>26
Very Bad	>80	>4000	>26

Table 4.16:-Effects Of Water Quality Parameters On Irrigation Water (After Ayers R.S. And Westcott.D.W.1985)

S. No.	Parameters	Prescribed limits		Probable effects
		Desirable	Permissible	
1	Salinity/EC in Mmhos/cm at 25^{0}c	Sensitive crops <1500 Semi-tolerant 1500-3000 Tolerant >3000		Plant growth is retarded with stunted fruits, leaves and stem in high salinity
2	SODICITY/SAR	SAR<10 10-18 18-26 >26	Excellent Good Medium Bad	Causes deflocculation of soil, restricting free movement of water
3	R.S.C meq/l	<1.25 1.25-2.5 >2.5	Excellent Good Bad	Result in increase of Sodium causing adverse effects.
4	SODIUM (Na) %	No Guideline		Increase total salinity, has adverse effect on sodium sensitive species such as stone fruit trees and avocados
5	CHLORIDE, (Cl) mg/l	No Guideline		May have direct toxic effect with sodium.
6	NITRATE, (NO_3) mg/l	No Guideline		An essential plant nutrient but its excess may delay maturity and seed growth in some plants

4.4.1 ELECTRICAL CONDUCTIVITY

It was a measurement of all soluble salts in samples, the most significant water quality standard on crop productivity which was the water salinity hazard. The primary effect of high EC water on crop productivity was the failure of the plants to compete with ions in the soil solution for water. The higher the EC, the lesser the water available to plants, even though the soil may show wet, because plants can only transpire "pure" water; useable plant water in the soil solution decreases significantly as EC increases. The amount of water transpired through a crop was directly related to yield; therefore, irrigation water with high EC reduces yield potential.

Table 4.17:- Number Of Samples Within Permissible Limit And Exceeding Permissible Limits Of Electrical Conductivity.

EC value (µS/cm)	Class	No. of samples
<250	Excellent	03
250-750	Good	13
750-2250	Permissible	20
2250-4000	Doubtful	00
>4000	Unsuitable	02

The places which exceeded the limit are:-

i) Naya Sadak, Sonapur road, EC value:-6700 µS/cm

ii) Nuagarh (Fishing base), EC value:-13900 µS/cm

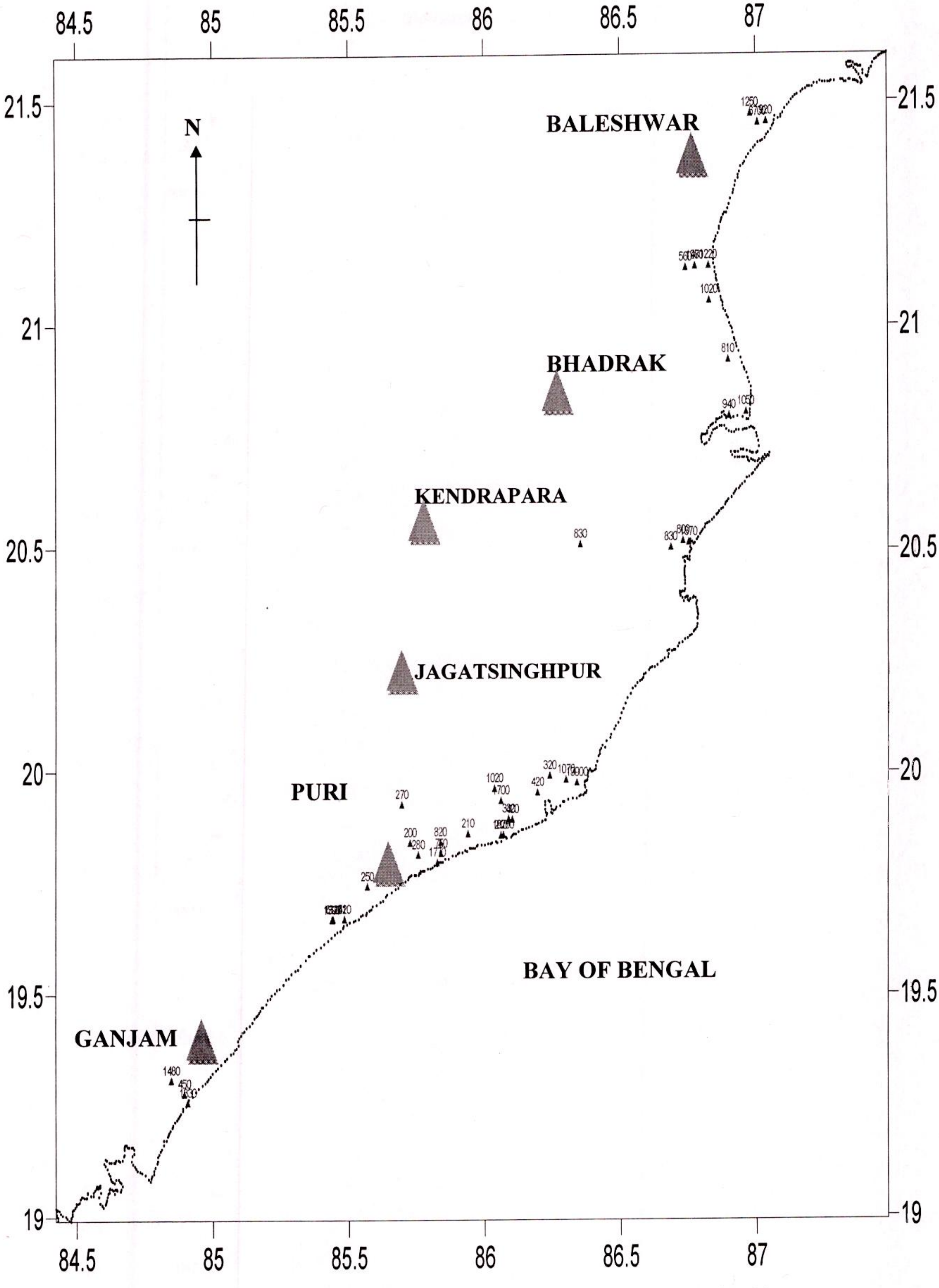


Fig4.2.:- Plot of Electrical conductivity of the sampling sites of Odisha(Surfer ®).

4.4.2 EXCHANGEABLE SODIUM PERCENTAGE (Na %)

Sodium hazard was an important factor in irrigation water quality. The use of high percentage sodium of water for irrigation was stunts, the plant growth and sodium reacts with soil to reduce its permeability (Joshi et al., 2009). The finer the soil texture and the greater the organic matter content, the greater the impact of sodium on water infiltration and aeration. The classification for SP was given (Wilcox, 1955) in table below. The sodium percentage (Na %) in the water samples (meq/l) of sub-surface water is calculated by the equation :

$$Na\% = (Na+K)/(Ca+Mg+Na+K)\times 100$$

Table 4.18:- Number Of Samples Within Permissible Limit And Exceeding Permissible Limits Of Exchangeable Sodium Percentage.

SP (%)	CLASS	NO.OF SAMPLES
<20	Excellent	00
20-40	Good	06
40-60	Permissible	13
60-80	Doubtful	12
>80	Unsuitable	07

The samples which exceed the sodium percentage above 80 and are unsuitable for agriculture are of areas:-

i) Chandipur beach, SP:-86.47%
ii) Baincha, SP:-81.51%
iii) Nuagarh(Fishing base),SP:-82.44%
iv) Kapileshwarpur, SP:-82.21%
v) Begunia, SP:-89.00%
vi) Kuruma, Sareda, SP:-90.16%
vii) Jadupur, SP:-80.30%

4.4.3 SODIUM ADSORPTION RATIO (SAR)

It was a significant parameter for the determination of suitability of irrigation water; excess sodium in water produces the undesirable effects of changing soil properties and reducing soil permeability (Biswas et al., 2002). The measure to which irrigation water tend to penetrate into cation-exchange reactions in soil can be indicated by the sodium adsorption ratio, sodium replacing adsorbed calcium and magnesium was a hazard as it causes damage to the soil structure, it becomes compact and impervious. The classification for SAR as is given (Richards, 1954) in Table below.

SAR is express as (Richard, 1954):-

$SAR = Na / \sqrt((Ca + Mg)/2)$

All ionic values are in meq/l.

Table 4.19:-Number Of Samples Within Permissible Limit And Exceeding Permissible Limits Of Sodium Adsorption Ratio.

SAR Value	**Class**	**No. Of samples**
<10	Excellent	32
10-18	Good	04
18-26	Fair	00
>26	Poor	01

The sample that has SAR value in poor class is of:-

i) Nuagarh, (fishing base) having SAR Value:- 36.48 meq/l

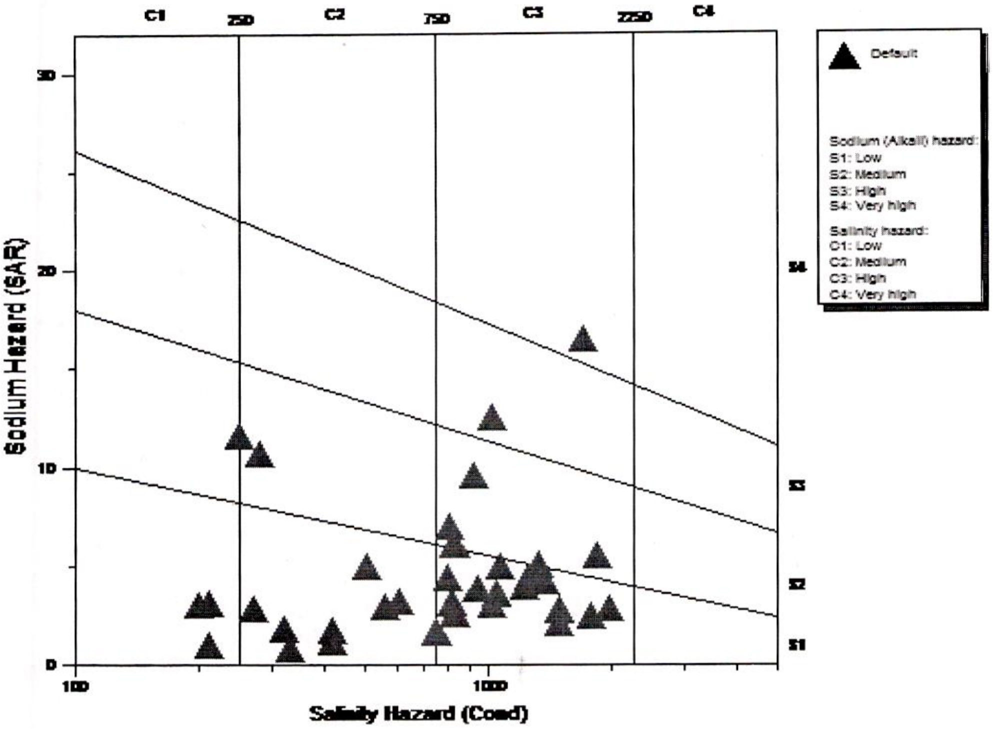


Fig 4.3.:-Wilcox diagram.

The plot of data on the US salinity diagram, in which the EC is taken as salinity hazard and SAR as alkalinity hazard, shows that most of the water samples fall in the category C1S1, C2S1, C3S2, And C3S3 indicating medium to high salinity and low medium alkali water. This water can be used for plants with good salt tolerance.

4.4.4 KELLY'S RATIO

Based on Kelly's ratios (Kelly, 1963) ground water was classified for irrigation, Kelly's ratio was more than 1 indicating an excess level of sodium in water; therefore the water Kelly's ratio of less than 1 was suitable for irrigation.
This was calculated employing the equation (Kelly, 1963) as:

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

(Concentrations are in meq/L)

Table 4.20:- Number Of Samples Within Permissible Limit And Exceeding Permissible Limits Of Kelly's Ratio.

KR Value	**Class**	**No. Of samples**
<1	Safe	12
>1	Unsuitable	22

Hence according to kelly's ratio only 31.5% samples are safe for irrigation purpose and rest 59% samples are unsuitable for irrigation purpose.

4.5 ANALYSIS OF ISOTOPIC MEASURE OF SAMPLES

4.5.1 □O^{18} VALUE CHART

The isotopic values are the signature of the actual source of origin of water, for example the isotopic value of seawater sample is ideally considered zero as sea or ocean is considered to be the ultimate source of water. The isotopic values increases as we move inland and the freshwater sources have a isotopic values greater than-3‰ or -4‰.

In the data three divisions are done to demarcate the samples into freshwater having □O^{18} value more than-4 ‰, saline water or brackish water having □O^{18} value less than -2 ‰ or equal to it and water showing chances of salinity having □O^{18} value between -2‰ and -4 ‰.

Table 4.21:- Number Of Samples Within Various □O^{18} Value Ranges.

□O^{18} Value	**No. of points**
[0 to -2]	02
[-2 to -4]	22
[less than -4]	17

Both the samples of □O^{18} value of less than -2 permille are of sea water and chilka lake water. All the freshwater samples collected have □O^{18} value above -2 ‰.

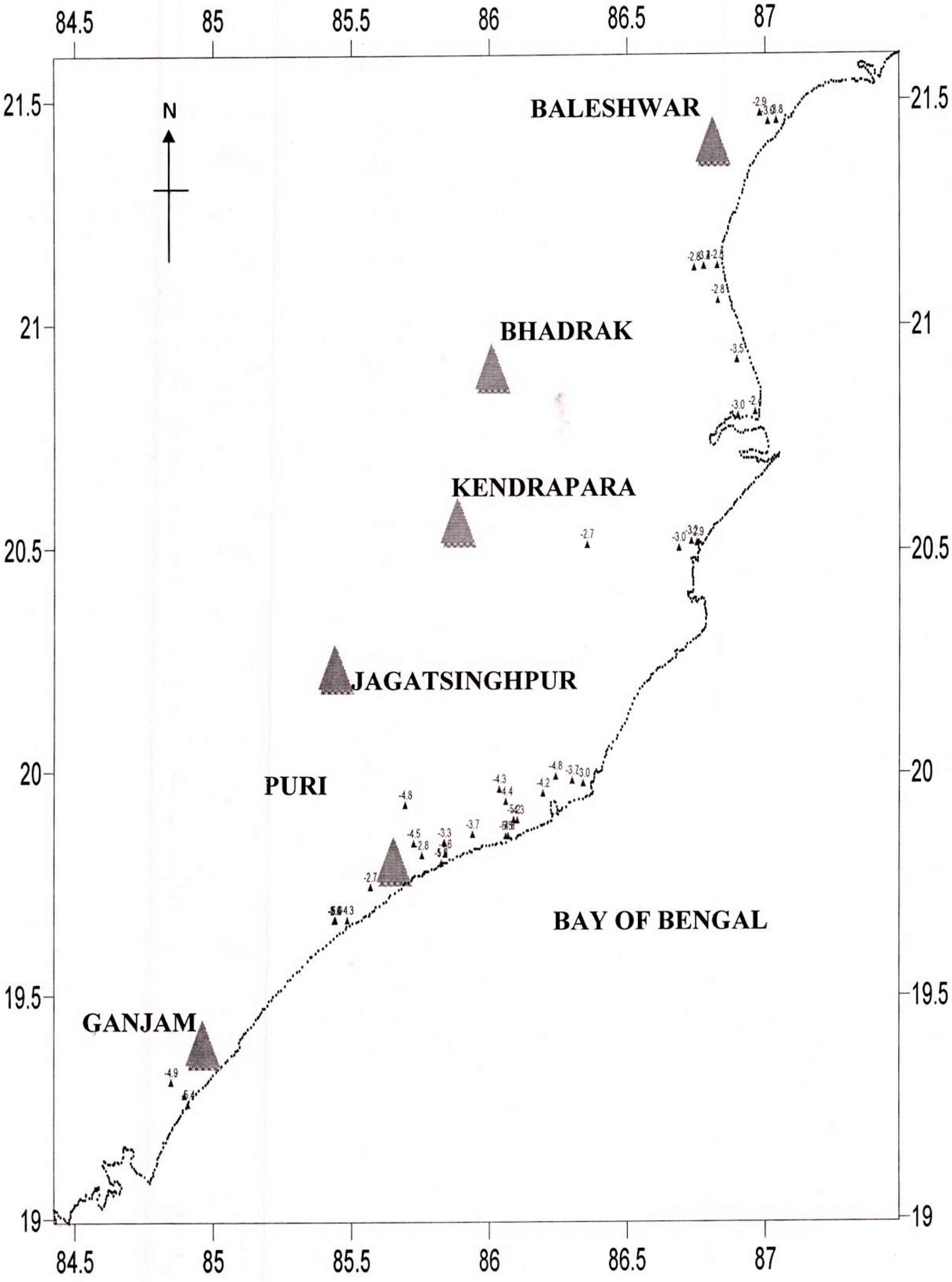


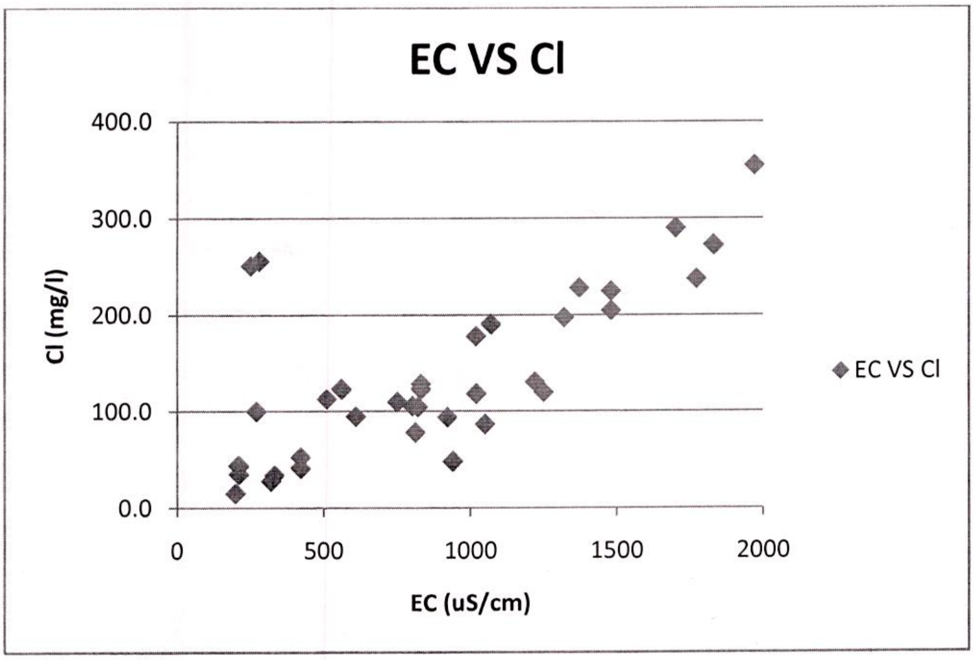
Fig 4.4:- Plot of $\delta^{18}O$ of the sampling sites of Odisha (Surfer ®).

4.6 ANALYSIS FOR PREDICTING SALTWATER INTRUSION AREAS

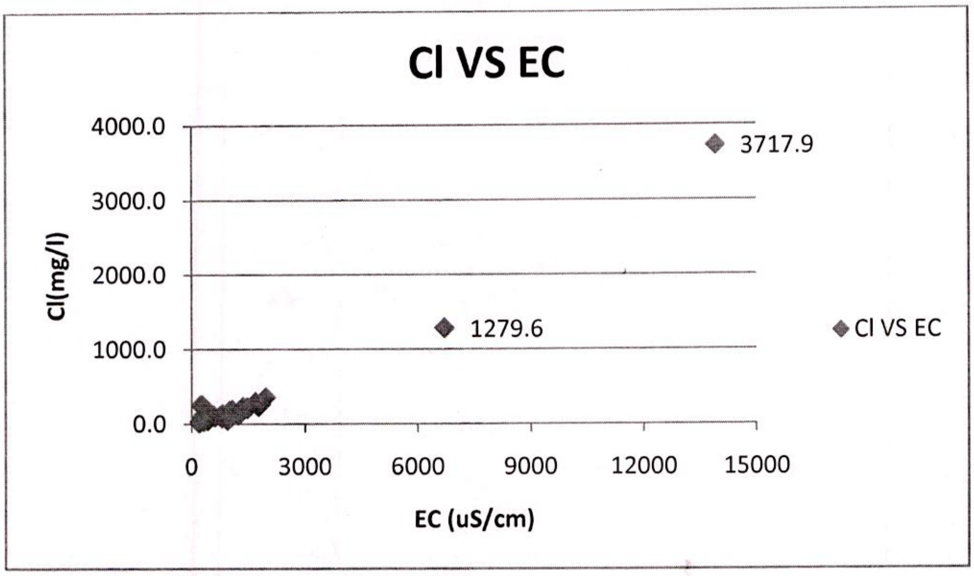
The World Health Organization states that mixing of only 2% saltwater (250 ppm) in a freshwater aquifer exceeds aesthetic objectives for the upper limit of chloride (Cl) (water begins to taste salty)(Custodio, 2005; Nova Scotia Environment, 2008). If mixing exceeds 4%, then the water becomes unusable for many uses, and if mixing exceeds 6% water becomes unusable except for cooling and flushing purposes (Custodio, 2005; Darnault and Godinez, 2008).

Bear et al. (1999) outlined several indicators that can be used to distinguish SWI from other sources of salinity. These, as well as a few other indicators, are described below (J. Klassen, D.M. Allen and D. Kirste, 2014):-

1. An elevated chloride concentration. An alternative graphical approach is to plot Cl vs. electrical conductivity (EC) (Washington State Department of Ecology, 2005). Figure shows a plot of Cl vs. EC. Figure 3 shows that groundwater samples with Cl exceeding 200 mg/L and EC exceeding ~1000 μS/cm are most likely influenced by saltwater water intrusion.



(a)



(b)

Fig 4.5.:- Cl vs EC plots.

In plot (a) it can be seen that the chloride values of most samples lie within chloride value of 400mg/l and EC of 2000 μS/cm. The points which exceed the Cl value of 200 mg/l and EC of 1000 μS/cm are in sites:-

i) Chudamani(New)
ii) Gopalpur Beach
iii) Golden Beach, Puri
iv) Kuruma, Sareda
v) Chudamani(Old)
vi) Dura bahadurpetta, Pathara, Gopalpur
vii) Chakulidiha, Sasana

It can be seen in plot (b) that 2 sampling sites showing Cl values 1279.6 mg/l and 3717 mg/l having EC values also above 6000μS/cm and 12000 μS/cm respectively shows intrusion chances. Most of the freshwater samples lie below Chloride range of 1000mg/l and EC of 3000μS/cm.

The sampling sites are of:-i) Naya Sadak, Sonapur road, Chandipur and ii) Nuagarh (Fishing base)

2. Na/Cl ratios are typically lower in wells intruded by seawater than in ocean water; as a result, Na/Cl ratios less than 0.86 (molar ratio) may represent wells impacted by SWI. Na/Cl ratios greater than 1 are typical of groundwater contaminated by anthropogenic sources.

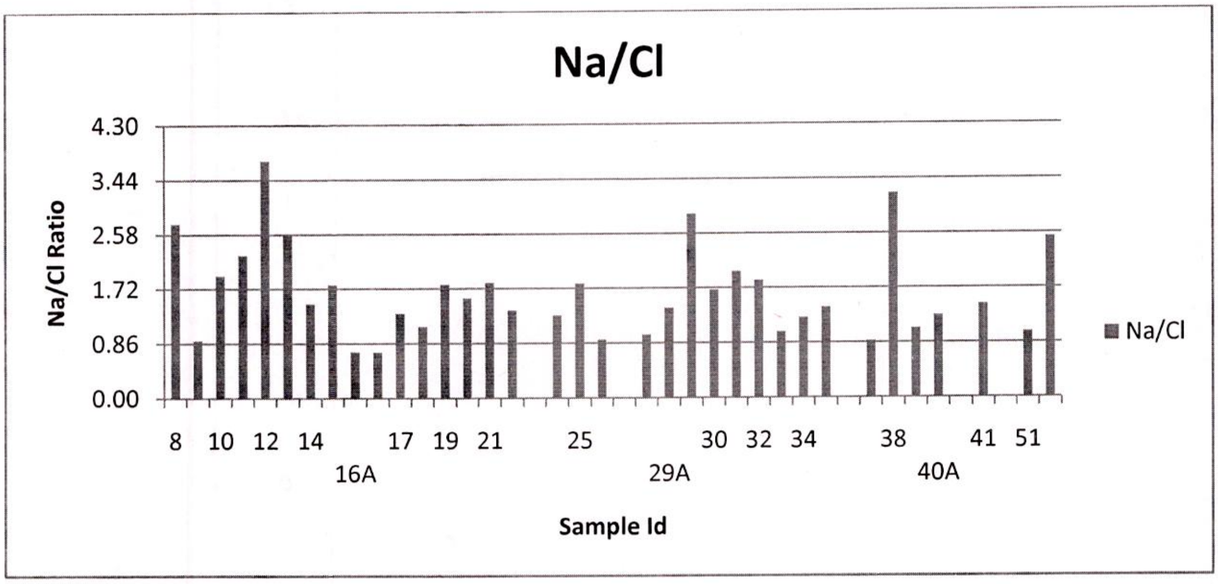


Fig 4.6.:- Na/Cl ratio plot.

The sample site showing Na/Cl ratio less than 0.86 is of Chudamani(New) and Chudamani(Old).

3. Base exchange indices (BEX) can also be used to distinguish if an aquifer is undergoing salinization or freshening; according to Stuyfzand (2008), the best index (for a dolomite free aquifer system) is BEX = Na + K+ Mg – 1.0716Cl (meq/l) (Stuyfzand, 1986). A positive BEX represents freshening, a negative BEX represents salinization and a BEX with a value of zero represents no base exchange.

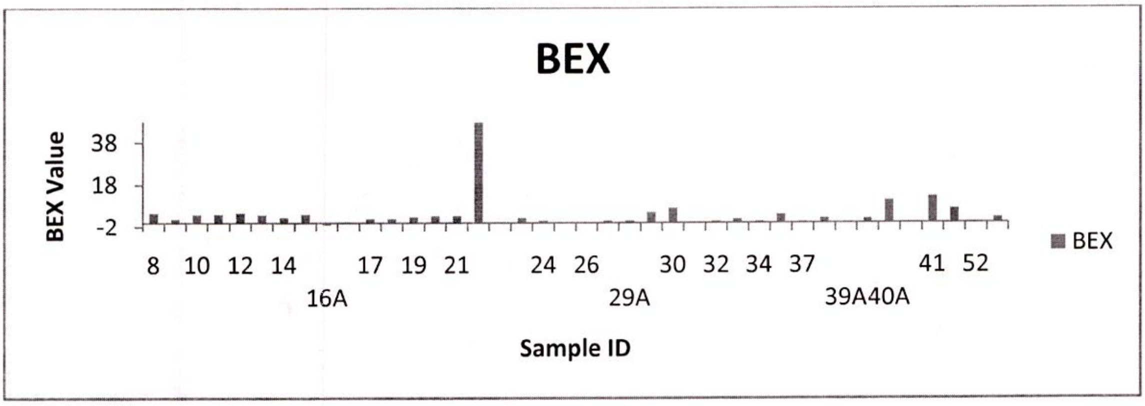


Fig 4.7:-BEX Value plot.

From the plot it can be seen that three samples shows a negative value that are of:-

i) Chudamani(New)

ii) Chudamani (Old)

iii)Konark fish market,Konark-Kakatpur road.

4. Enrichment of Ca can indicate SWI (Bear et al., 1999). Enrichment is reflected in Ca/Mg >1(molar ratio). A low Ca/Mg ratio may be indicative of salt water contamination because magnesium is present in sea water in much greater concentration than calcium. Therefore, Ca/Mg ratio is considered as a parameter for determining sea water contamination.

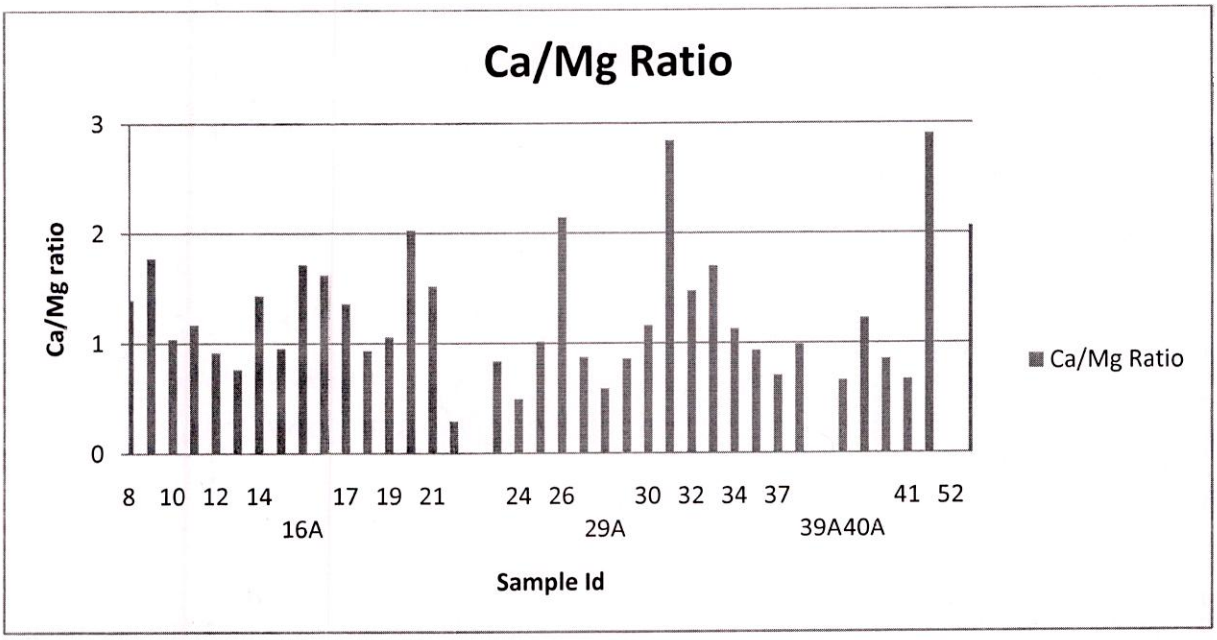


Fig 4.8.:- Ca/Mg Ratio.

The plot shows that 16 samples shows Ca/Mg ratio less than 1 and hence shows chances of salinity occurrence. The places where the Ca/Mg ratio are less than 1 are:-

i)Dhamara Port ii)Baincha iii)Jetty, Chudamani iv) Chakulidiha, Sasana v)Nuagarh(Fishing base) vi) Damasun, Jharling (Youth Club) vii) Jiunti chhaka bus stop, Jiunti viii)Kapileshwarpur ix)Balighai x)Begunia xi) Golden Beach, Puri xii) Satapada near Jetty xiii) Near Sub Inspection Exchange office, Satapada xiv) Baghamunda (B) xv) Bali Harchandi Temple,katakpada, Brahmagiri xvi) Gorual.

4.7 SPATIAL DISTRIBUTION OF HYDO-GEO CHEMISTRY OF ODISHA

1. A division of areas sampled based on Isotopic, chemical and physical parameter.

Table 4.22:-Preliminary Criteria Used To Classify The Hydrological Process Leading To Groundwater Salinity: $\delta^{18}O$ And Chloride.

Water type	**Indicator**	**Indicative colour**
Fresh	$\delta^{18}O > -2‰$ & Cl <500mg/l	Blue
Evaporation enrichment + Salinity due to leaching of salts	$\delta^{18}O \leq -3$ ‰ & Cl b/w(500-1200)mg/l	Purple
Possible intrusion of sea water	$\delta^{18}O \leq -3‰$ & Cl >1200mg/l	Red

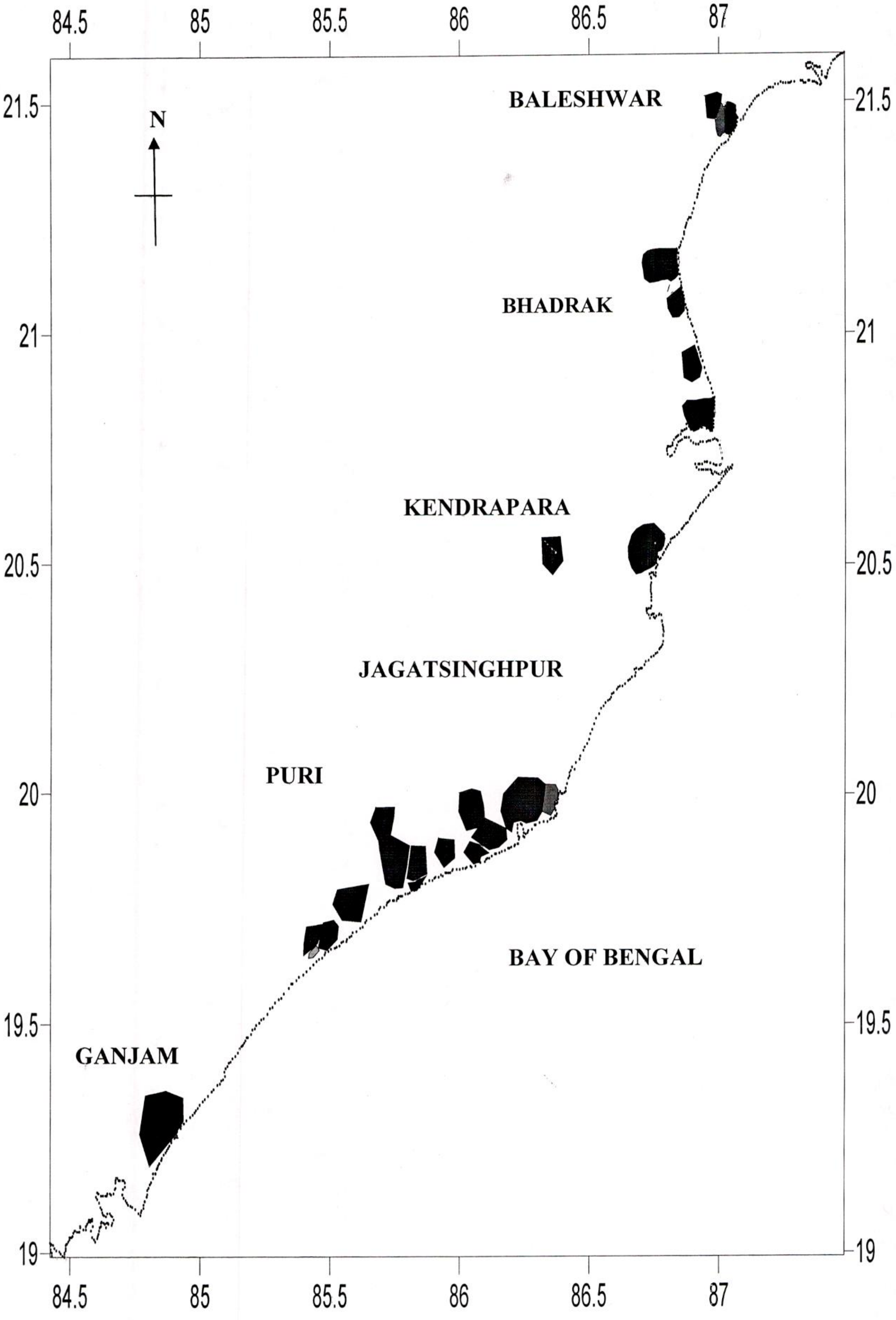


Fig 4.9.:-Plot of water type along the sampling sites of Odisha(Surfer ®).

From the figure, it can be found that most of the area sampled comes under freshwater condition marked by blue colours. Only two locations are marked by red colours where there can be chances of intrusion. The areas marked red are:-

i) Naya sadak, Sonapur road, Chandipur having δ^{18}O value -3.00‰, Electrical Conductivity value 6700uS/cm and chloride value 1279.6ppm

ii) Nuagarh (Fishing base),fresh water having δ^{18}O value -3.00‰, Electrical Conductivity value 13,900uS/cm, and chloride value 3717.9ppm.

The area marked by dark blue colour are of sea water from:-

i) Marine drive, Puri, sea water having δ^{18}O value -2.63, Electrical Conductivity value 16,200uS/cm, and chloride value 5144.6ppm

ii) Sea water from Puri having δ^{18}O value-1.61 and chloride value 5889.9ppm marked red.

The area marked with green colour is of chilka water:-

i) Satpada Chilka water, water of chlika lake having δ^{18}O value -2.00, Electrical Conductivity value 1390uS/cm and chloride value 1635.3ppm

From this it can be concluded that two areas of freshwater can have a chance of intrusion as the the EC values, Chloride values and δ^{18}O value exceed the limited value i.e i)Naya sadak, Sonapur road, Chandipur ii) Nuagarh (Fishing base)

Out of 38 freshwater samples 2 areas are marked red hence area under red mark is only approximately 5%. Rest 95% freshwater samples are fresh without any chance of intrusion.

5. Distance–wise changes in □O^{18} and Chloride value chart from sea level. Polyline deviation of values depending on distance from sea. Different lines are plotted to accommodate sampling points according to the distance from the sea and their O^{18} and chloride values are analysed to see changes taking place as the distance from the sea increases.

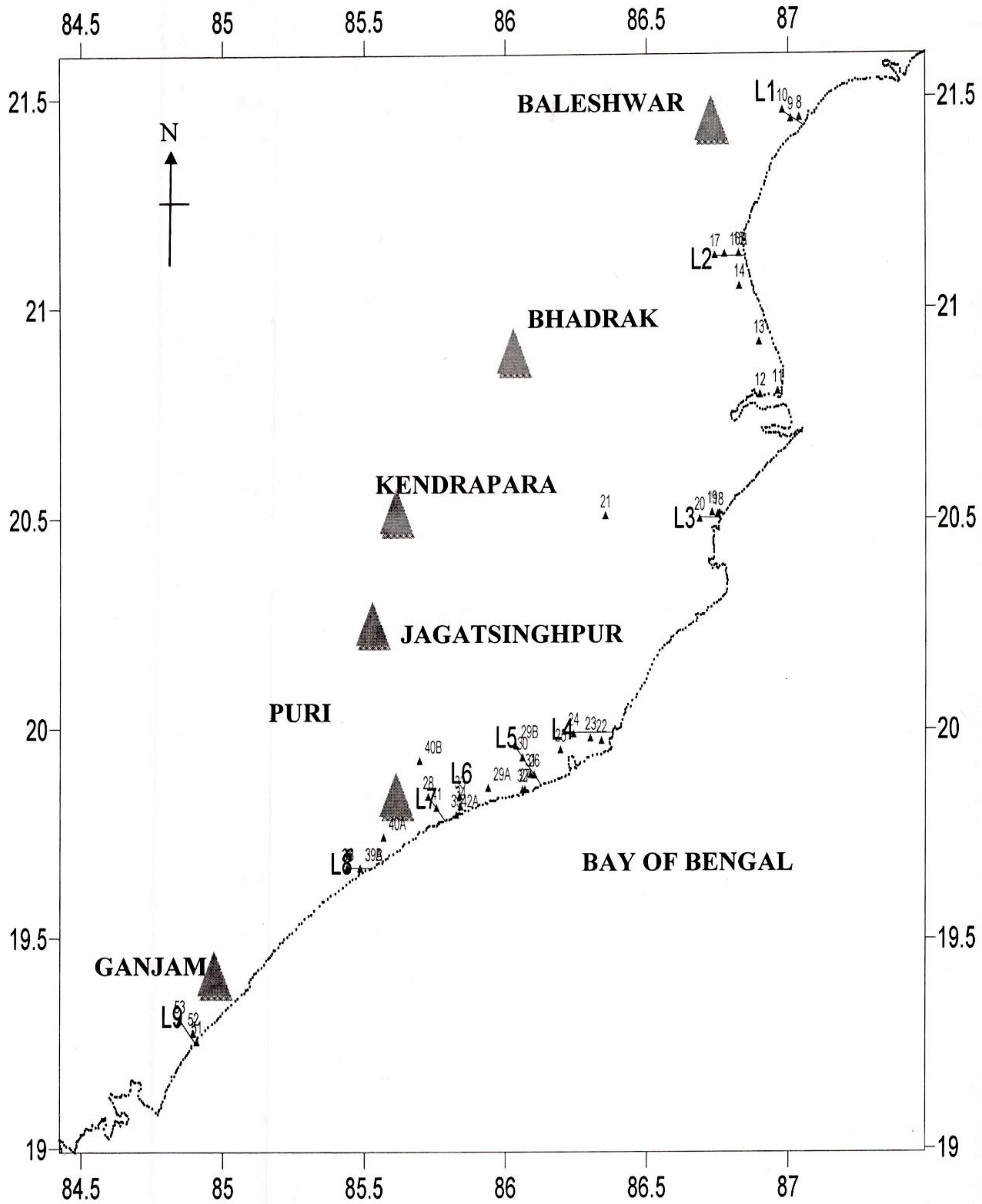
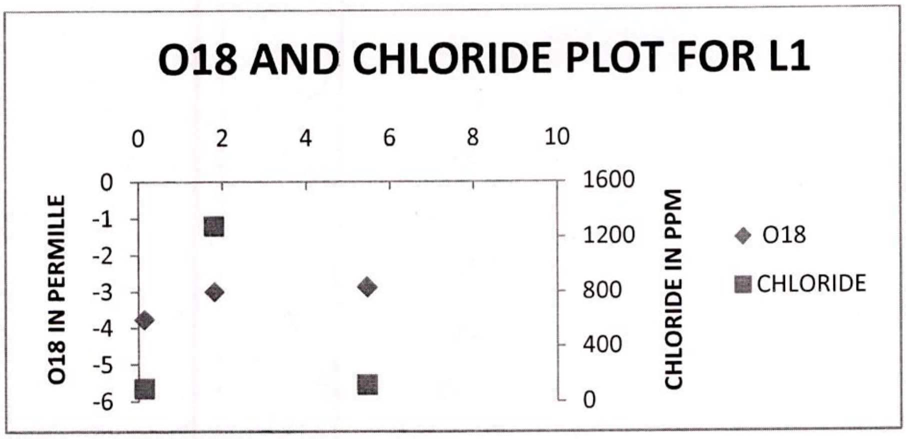
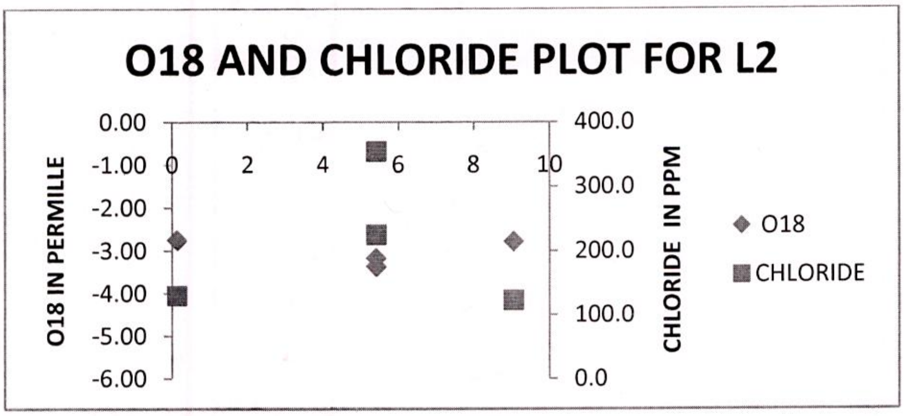
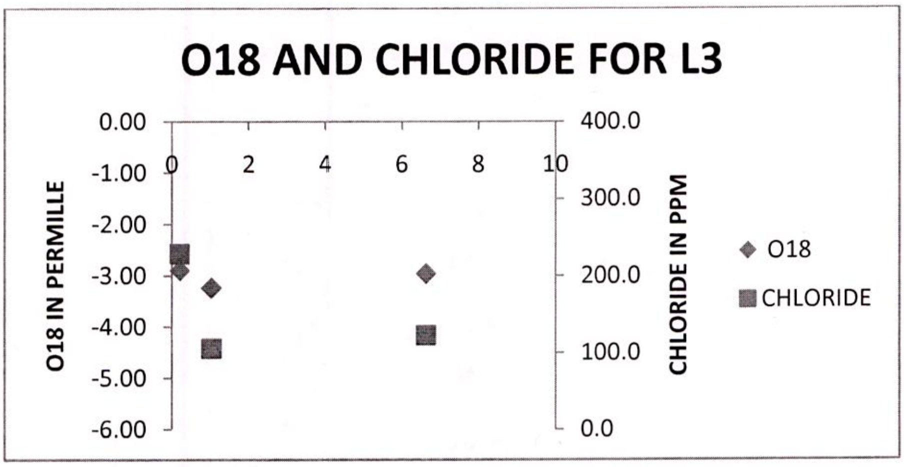
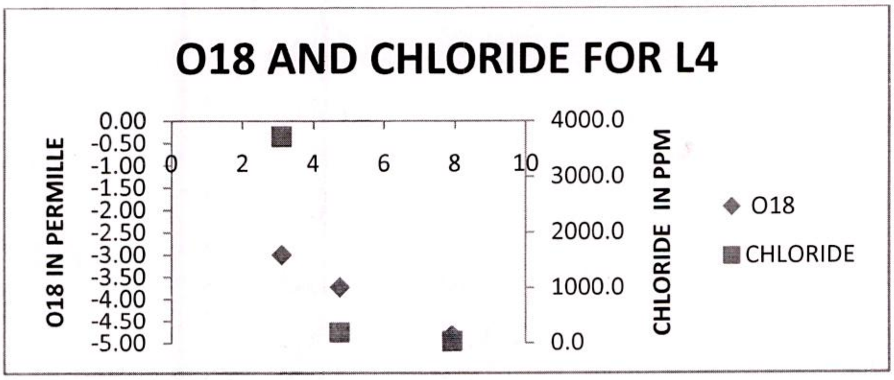


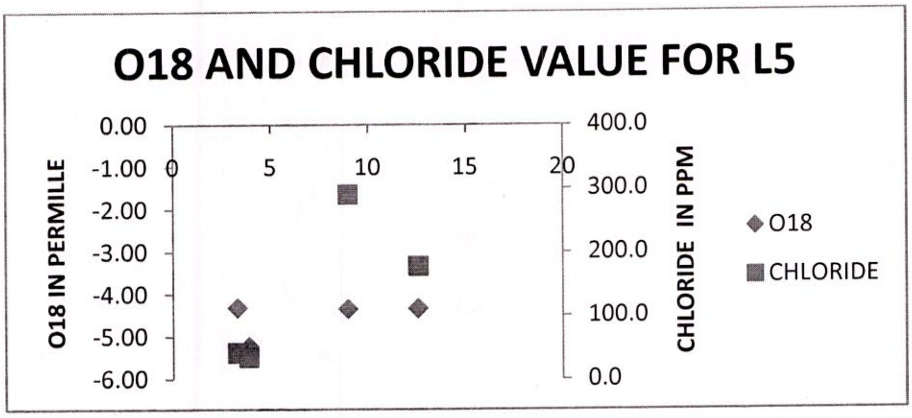
Fig 4.10:- Polyline plot to accommodate sampling points according to distance from the sea(Surfer ®).

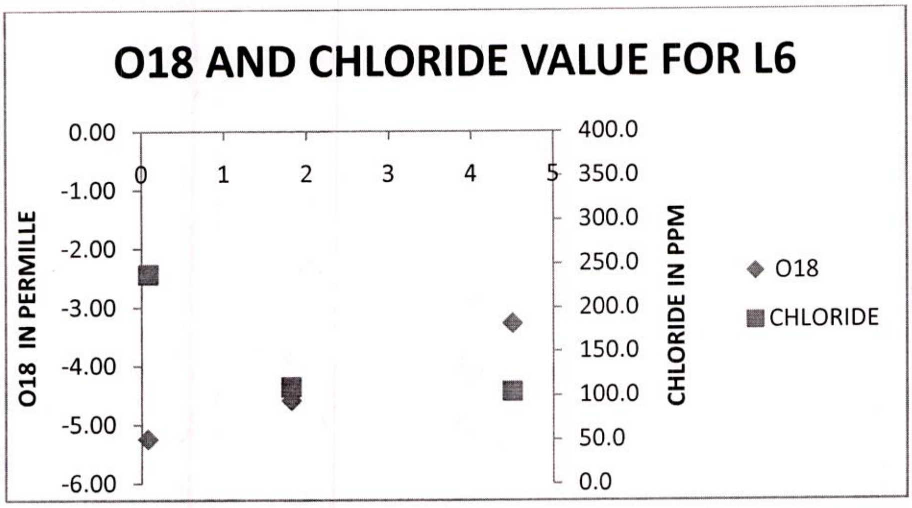

O18 AND CHLORIDE PLOT FOR L1

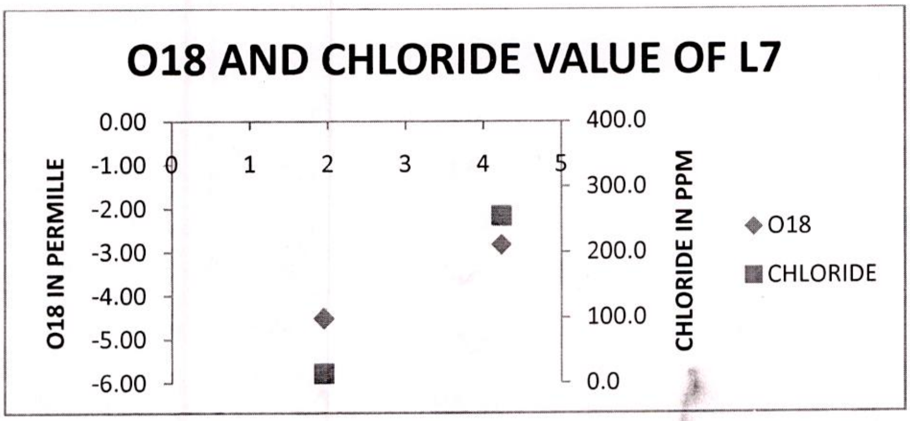

O18 AND CHLORIDE PLOT FOR L2

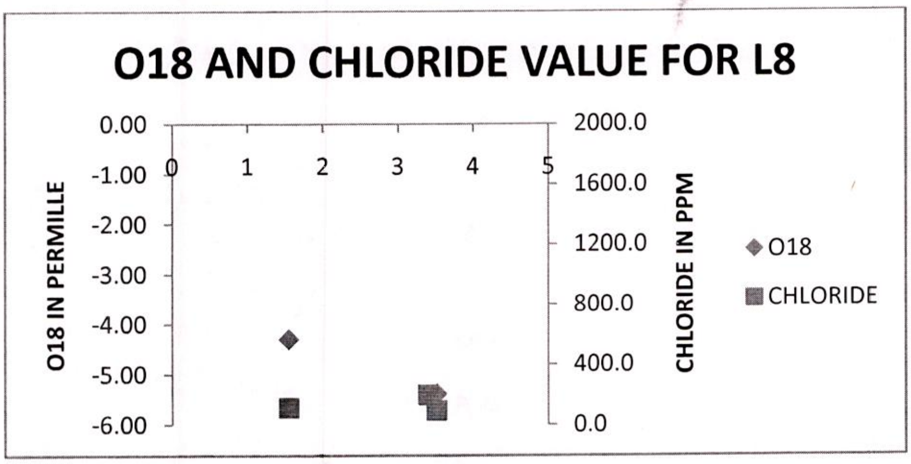

O18 AND CHLORIDE FOR L3


O18 AND CHLORIDE FOR L4


O18 AND CHLORIDE VALUE FOR L5
O18 IN PERMILLE
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00
0
5
10
15
20
CHLORIDE IN PPM
400.0
300.0
200.0
100.0
0.0
O18
CHLORIDE


O18 AND CHLORIDE VALUE FOR L6
O18 IN PERMILLE
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00
0
1
2
3
4
5
CHLORIDE IN PPM
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
O18
CHLORIDE


O18 AND CHLORIDE VALUE OF L7
O18 IN PERMILLE
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00
0
1
2
3
4
5
CHLORIDE IN PPM
400.0
300.0
200.0
100.0
0.0
O18
CHLORIDE


O18 AND CHLORIDE VALUE FOR L8
O18 IN PERMILLE
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00
0
1
2
3
4
5
CHLORIDE IN PPM
2000.0
1600.0
1200.0
800.0
400.0
0.0
O18
CHLORIDE

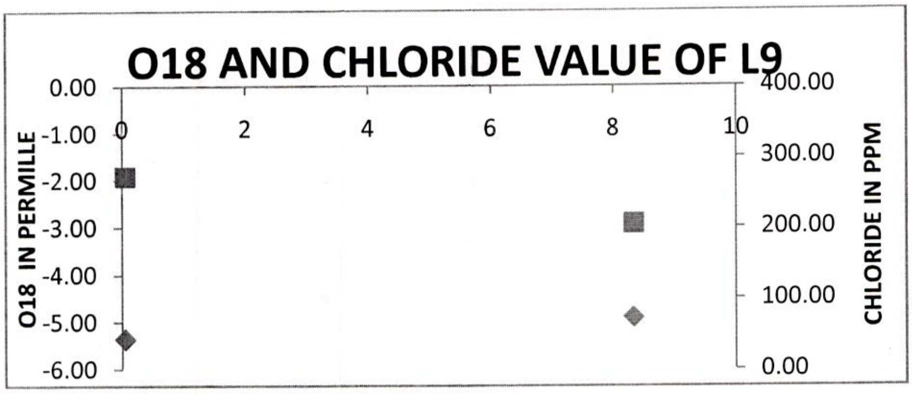


Fig 4.11:- O^{18} versus Chloride plots for different polyline.

As moving away from the sea in general the □O^{18} value should increase and the chloride content should decrease in ideal situation. A deviation from this phenomenon shows that some mixing or other cause of change like river, lake etc. may be present there.

In plot 1 for L1, it is seen that the second point i.e at SGD-9 at Naya Sadak, Sonapur road, Chandipur the □O^{18} value decreases and chloride value increases and hence might be mixing from seawater present there.

In plot 2 for L2, it is seen that at SGD-16A and 16B at Chudamani(New) and Chudamani(Old) also shows a increase in chloride content and hence may also be influenced by salinity.

In plot 3 for L3 the □O^{18} value increases and chloride value decreases with distance but at SGD-20 i.e near Badapalli there is a small decrease in □O^{18} value decreases and chloride value increases but very slight change is observed hence monitoring is required.

In plot 4 for L4 the □O^{18} value increases and chloride value decreases with distance showing freshwater samples but high chloride value is seen at the first sampling site i.e in Nuagarh (Fishing base).

In plot L5 also a very slight decrease in □O^{18} value decreases and chloride value increases in seen in last two points in SGD-29B and SGD-30 i.e at Begunia and Kuruma, Sareda respectively but the changes are very minor.

In plot L6 the chloride value decreases with distance but the $\square O^{18}$ values also decreases with distance in places like Bata mangala Temple and Bus stand, Puri.

In plot L7, $\square O^{18}$ value decreases and chloride value increase is seen in Gorual.

In plot L8 and L9 the $\square O^{18}$ value increases and chloride value decreases with distance showing freshwater samples.

CHAPTER-5

SUMMARY AND CONCLUSION

5.1 INTRODUCTION

Groundwater is the authentic and vital resource for the sustainability of life and for any progression activity. Most of the coastal sites rely on groundwater as their main source of freshwater. But the coastal aquifers are often and increasingly menaced by seawater intrusion and other human induced activities like rapid urbanisation, groundwater exploitation etc.

Hence a regular monitoring, analysis and interpretation of these aquifers is required.

5.2 SUMMARY

Groundwater has been used for eras for satisfying the human needs and is considered to be fresh in origin. But recent expansion of urbanisation, industrialisation and over-population has deteriorated the condition of groundwater. Moreover in coastal aquifers groundwater contamination due to the salinity intrusion is a common phenomenon. India has a very long coastline and 25% of the country's inhabitants lives in the coastal zone. Similarly, citified centres are located mostly along the coast when compared to other parts of the country. Along with it the stress due to development of industries, trade and commerce and tourism along the coastal zone aggravate the situation leading to over-use of groundwater and its contamination. Therefore investigation of coastal aquifers is necessary to know the current situation of freshwater there and demarcate areas affected by salinity. Hence the coastal aquifers of Odisha are chosen for sampling as the study area.

The coastal tract of Odisha covering 480.4km presents a narrow, gently undulating to flat alluvial plain bordering the Bay of Bengal on the east and delimited by the erosional plains of the peninsular shield in the west.

The sampling is done from the coastal districts of Odisha covering six districts Baleshwar, Bhadrak, Kendrapara, Jagatsinghpur, Puri and Ganjam. 38 Samples were collected from 21st November to 27th November, 2015 and 3 samples were collected on 31st May 2016; Total 38 groundwater samples, a chilka water sample and 2 seawater sample were collected.

The chemical analysis for anionic i.e fluoride, chloride, nitrate, nitrite, sulphate as well as cationic i.e lithium, sodium, ammonium, potassium, magnesium and calcium concentration in the groundwater and seawater samples of Odisha's different parts is done using Ion-Chromatography (Dionex ICS 5000). Dual inlet isotope mass spectrometer instrument is used for the analysis of isotopic values of the sample. The analysis of stable isotopes of oxygen (□O^{18}) and hydrogen (□H^{2}) is done by it. Moreover electrical conductivity, temperature, pH and radon were also calculated.

The results obtained by analysis are then interpreted whether the samples collected of freshwater abide to the permissible limit norms of drinking water and are safe for drinking or not by comparing the anionic and cationic values of samples with that of the norms given by BIS and WHO.

The freshwater samples are safe for irrigation purpose or not by measuring the parameters like SP, SAR, EC and KR. The areas unsafe are mentioned.

The salinity affected areas are also demarcated by geochemical and isotopic studies by plotting and interpreting the EC vs Cl ratio, Na/Cl ratio, BEX, Ca/Mg ratio.

The freshwater zones, areas prone to intrusion, saline water zones and Chilka water area are all demarcated by area polygon map of Odisha. Moreover distance wise freshwater quality changes from the ocean is also studied using plots.

5.3 CONCLUSIONS

From the analysis of the samples collected and their interpretation the various conclusions that were drawn are as follows:-

- The chloride, sulphate and magnesium values of Nuagarh (Fishing base) exceeds the permissible limit of drinking water and hence the freshwater of that area is unsafe for drinking purpose.

- The chloride, fluoride, calcium and magnesium values of Naya sadak, Sonapur road, Chandipur also exceeds the permissible limit of drinking water and hence is also unsafe for drinking.

- Out of the 38 freshwater samples collected 23 samples exceed the permissible limit of fluoride i.e almost 60% samples deviate from the safe fluoride limit in water and hence the coastal districts need extensive fluoride monitoring and its mitigation measures to be implemented in their groundwater bodies. The areas exceeding fluoride limits are:- i)Naya Sadak, Sonapur road,Chandipur ii) Chandipur (Beach) iii) Rabindranagar,Dosinga iv) Dhamara Port v) Baincha vi) Jetty, Chudamani vii) Chudamani(New) viii) Chudamani(Old) ix) Jamujhadi, Basudevpur bus stand x) Chakulidiha, Sasana xi) Tantiapal xii) Badapalli xii) Damasun, Jharling (Youth Club) xiii) Jiunti chhaka bus stop,Jiunti xiv) Kapileswarpur xv) Balighai xvi) Begunia xvii) Kuruma,Sareda xviii) Ramachandi Temple xix) Bata mangala Temple xx) Gorual xxi) Near Sub Inspection Exchange office, Satapada xxii) Baghamunda (B) xxiii) Jadupur. In two samples fluoride was not detected and in four samples fluoride was not analysed.

- Seven freshwater samples also exceed the permissible limit of nitrate for drinking water and hence nitrate mitigation measures should be employed in these areas. 7 samples which exceed the nitrate permissible values are:-i)Badapalli, ii)Konark Fish Market, Konark-kakatpur road, iii)Golden beach, Puri, iv)Satapada near Jetty, v) Near Sub Inspection Exchange office, Satapada, vi)Baghamunda, vii) Dura bahadurpetta, Pathara, Gopalpur.

- The electrical conductivity value of i) Naya sadak, Sonapur road, Chandipur and ii) Nuagarh (Fishing base) are found above 4000μS/cm and hence are unsuitable for irrigation purpose.

- According to the sodium percentage the areas exceeding sodium percent value of 80 are seen in 7 freshwater sampling locations and unsuitable for agriculture. These are:- i) Chandipur beach, ii) Baincha, iii) Nuagarh(Fishing base),iv) Kapileshwarpur, v) Begunia, vi) Kuruma, Sareda, vii) Jadupur.

- As per the Sodium adsorption ratio calculated only one freshwater sample exceed SAR value 26 i.e of Nuagarh(Fishing base).

- Kelly's ratio of the freshwater samples is also calculated and it is found that according to kelly's ratio only 31.5% samples are safe for irrigation purpose and rest 59% samples are unsuitable for irrigation purpose.

- The □O^{18} value of the freshwater samples are greater than -2 ‰ and hence are considered to be of fresh in origin.
- Chloride versus Electrical conductivity plot has been made and according to the plot two freshwater samples shows mixing and hence may be affected by intrusion from seawater. These areas are of Naya sadak, Sonapur road, Chandipur and Nuagarh (fishing base).

- The Na/Cl plot is also made and the ratio less than 0.86 is found in Chudamani(New) and Chudamani(Old) hence can also be affected by salinity intrusion.

- Base exchange indices (BEX) is also calculated distinguish if an aquifer is undergoing salinization or freshening. The values having negative value and showing salinisation are of three areas i.e i)Chudamani(New) ii)Chudamani(Old) iii)Konark fish market, Konark-Kakatpur road.

- Ca/Mg ratio plot to indicate salt water contamination is also made. The plot shows that 16 samples have value less than 1 showing chances of salinisation. The areas are:- i)Dhamara Port ii)Baincha iii)Jetty, Chudamani iv) Chakulidiha, Sasana v)Nuagarh(Fishing base) vi) Damasun, Jharling (Youth Club) vii) Jiunti chhaka bus stop, Jiunti viii)Kapileshwarpur ix)Balighai x)Begunia xi) Golden Beach, Puri xii) Satapada near Jetty xiii) Near Sub Inspection Exchange office, Satapada xiv) Baghamunda (B) xv) Bali Harchandi Temple,katakpada, Brahmagiri xvi) Gorual.

- A division of areas sampled based on Isotopic, chemical and physical parameter combined is done and areas are marked as freshwater zones, seawater, chilka lake water and freshwater were there is possibility of intrusion. The areas found with possible chance of intrusion is of i) Naya sadak, Sonapur road, Chandipur and ii)Nuagarh (Fishing base).

The main conclusion drawn from all these is that of all the freshwater sampled, physically chemically and isotopically analysed and interpreted the areas having exceeding most permissible limits and showing major chances of salinity are of:- i) Naya sadak, Sonapur road, Chandipur and ii)Nuagarh (Fishing base).

Moreover it is seen that in Naya sadak, sonapur road, Chandipur (1.80 km from sea) there is chances of salinity whereas sample taken at Chandipur beach (0.13 km from sea) is fresh and the sampling done at Tentulipura, way to Chandipur (5.45 km from sea) in the same line of sampling location is also fresh hence it can be concluded that the salinity found in Naya sadak, sonapur road, Chandipur is a local characteristic and the cause of salinity is not seawater intrusion.

Whereas in case of Nuagarh (Fishing base), sampling is done about 3.10 km from sea has a water body i.e Devi river passing nearby it that drains into ocean hence the chance of salinity may be saltwater intrusion from the sea.

Fig5.1:- Sampling point Naya sadak, Sonapur road, Chandipur (Source-Google earth).

Fig 5.2:-Sampling point Nuagarh (Fishing base) (Source-Google earth).

5.4 SPECIFIC CONTRIBUTION OF THE PRESENT WORK:-

- This study presents a data summary of the chemical and isotopic analysis of the freshwater samples, seawater samples and Chilka lake water sample collected from the coastal districts of Odisha.

- The analysis of the collected data are used to demarcate the freshwater samples suitability for drinking purpose.

- Moreover the freshwater samples suitability for irrigation purpose are also checked. The areas prone to be unsafe are marked.

- The areas having freshwater that are prone to saltwater intrusion are also found. Hence the freshwater areas prone to salinity from seawater are also interpreted.

- Previously the sampling and interpretation of the groundwater sampling of whole coastal Odisha's aquifer is not done and hence the study is unique in that respect.

5.5 LIMITATIONS OF THE PRESENT WORK

- All the parameters are not interpreted due to lack of time.

- Management measures are not suggested in the areas prone to unsafe drinking and unsuitable for irrigation.

- The contouring and elevation profile of the areas are not taken in account.

5.6 FUTURE DIRECTION OF WORK

- Management measure to control seawater intrusion in areas prone to salinity can be suggested and implemented.

- The areas unsafe for drinking water should be reviewed.

- The radon and isotopic data found can be used to demarcate the interface zone.

REFERENCES

1. Abhay K. Soni, and Paras R. Pujari, "Sea -Water Intrusion Studies For Coastal Aquifers: Some Points To Ponder", The Open Hydrology Journal, 2012, Vol 6, pp 24-30.
2. Adrian D. Werner, Mark Bakker , Vincent E.A. Post , Alexander Vandenbohede , Chunhui Lu, Behzad Ataie-Ashtiani , Craig T. Simmons , D.A. Barry, 2013, "Seawater Intrusion Processes, Investigation And Management: Recent Advances And Future Challenges", Elsevier, 51, pp 3-26.
3. Basic Ground-Water Hydrology by Ralph C. Heath, 1983, U.S. Department of the Interior, U.S. Geological Survey Paper 2220, pp. 86,.
4. C. P. Kumar, Management of Groundwater in Salt Water Ingress Coastal Aquifers, 2006.
5. Cavazza S. And Pagliara S., "Groundwater and Surface Water Interactions", Encyclopedia of Life Support Systems, Vol.I.
6. Coastal Zones of India, 2012, ISRO, Sponsored By Ministry of Environment & Forests, Govt. Of India.
7. Dileep K.Panda and A. Kumar, 2011, "Evaluation of an Over-Used Coastal Aquifer (Orissa, India) Using Statistical Approaches", Hydrological Sciences Journal, Vol.56, Issue 3, Pp 486-497.
8. Dionex ICS-5000 Ion Chromatography System Operator's Manual, 2011 Thermo Fisher Scientific.
9. FAO (Food and Agriculture Organization), "Seawater Intrusion In Coastal Aquifers: Guidelines For Study, Monitoring And Control" FAO Water Reports 11, Rome Italy: Fao; 1997, pp 163.
10. Gopal Krishan, M. Someshwar Rao, C.P. Kumar, Sudhir Kumar, M. Ravi Anand Rao, 2015, "A Study on Identification of Submarine Groundwater Discharge in Northern East Coast of India", Aquatic Procedia 4.

Government Of India Ministry Of Water Resources Central Ground Water Board.

11. Ground Water Information Booklet Ganjam District, Orissa, 2013, South Eastern Region, Bhubaneswar, Central Ground Water Board, Ministry of Water Resource.

12. Ground Water Information Booklet of Jagatsinghpur District, Orissa, 2013, South Eastern Region, Bhubaneswar, Central Ground Water Board, Ministry of Water Resource.

13. Ground Water Information Booklet of Kendrapara District, Orissa, South Eastern Region, Bhubaneswar, Central Ground Water Board, Ministry Of Water Resource.

14. Ground Water Information Booklet, Bhadrak District, Orissa, 2013, Central Ground Water Board, Ministry of Water Resources.

15. Ground Water Quality Standards, Central Groundwater Board, Ministry of Water Resources, Government of India.

16. Groundwater and Surface-Water Interactions, 2016, U.S. Department of the Interior, U.S. Geological Survey.

17. Groundwater Depletion, 2016, U.S. Department of the Interior, U.S. Geological Survey.

18. Groundwater Information Booklet, Puri District, Orissa, 2013, South Eastern Region, Bhubaneswar, Central Ground Water Board, Ministry of Water Resources.

19. Groundwater Year Book, 2013-14, South Eastern Region, Bhubaneswar, Central Ground Water Board, Ministry of Water Resource.

20. Indian Standard Drinking Water — Specification (Second Revision), 2012, Bureau of Indian Standards.

21. Indu S Nair, S P Rajaveni, M Schneider and L Elango, 2015, “Geochemical and Isotopic Signatures for The Identification of Seawater Intrusion in an alluvial aquifer”, Indian Academy Of Sciences, No. 6, pp. 1281–1291.

22. Ion Exchange Chromatography Principles and Methods, Amarsham Pharmacia Biotech.

23. J. Klassen, D.M. Allen and D. Kirste, 2014, "Chemical Indicators of Saltwater Intrusion for the Gulf Islands, British Columbia".

24. K. Srinivasa Reddy, 2013, "Assessment of Groundwater Quality for Irrigation of Bhaskar Rao Kunta Watershed, Nalgonda District, India", International Journal of Water Resources and Environmental Engineering, Vol. 5(7), pp. 418-425.

25. M.Mohan Babu, G.K.Viswanadh and S.Venkateswara Rao, 2013, "Assessment of Saltwater Intrusion along Coastal Areas of Nellore District, AP", International Journal Of Scientific & Engineering Research, Volume 4, Issue 7.

26. Makoto Taniguchi, William C. Burnett, Jaye E. Cable and Jeffrey V. Turner, 2002, "Investigation Of Submarine Groundwater Discharge", Wiley Interscience, No. 16, pp 2115–2129.

27. Monica Z. Bruckner, Ion Chromatography, Microbial Life Educational Resources.

28. P.P.Das et. al, 2016 in The Paper Titled "Hydro-Geo-Chemical Evolution and Potability Evaluation Of Saline Contaminated Coastal Aquifer System Rajnagar, Odisha, India: A Geospatial Perspective".

29. Radhakrishna, 2001, "Saline Freshwater Interface Structure In Mahanadi Delta Region, Orissa, India", Environmental Geology, Volume 40, Issue 3, pp 369–380.

30. Reilly, T.E. and Goodman, A.S., 1985, "Quantitative analysis of saltwater-freshwater relationships in groundwater systems: a historical perspective", Journal of Hydrogeology 80, pp 125-160.

31. Report On Status Of Ground Water Quality In Coastal Aquifers In India, 2014, Central Ground Water Board , Ministry Of Water Resources, Government Of India.

32. Revathee T, 2016, "Coastal Influence on the Groundwater Regime of an Urban Aquifer", Ph.D Thesis, Anna University, Chennai, India.

33. S. Das and K.J Anandha Kumar, 2005, "Management of Groundwater in Coastal Orissa, India", International Journal of Ecology and Environmental Science, Pp 285-297.

34. S. K. Sharma Influence Of Sea Water Ingress: A Case Study From East Coast Aquifer in India, 20th Salt Water Intrusion Meeting.

35. Seth Rose, "Groundwater Recharge and Discharge", Encyclopedia of Life Support Systems, Vol.III.

36. Stuyfzand, P.J. (2008) Base exchange indices as indicators of salinization or freshening of (coastal) aquifers. In Proceedings of 20th Salt Water Intrusion Meeting. Florida, June 23-27, 2008,pp. 262-265

37. V.Baskaran, M.Mangalam, V.Murugaiyan, 2016, "Study of Seawater Intrusion in a Coastal Aquifer by Hydrochemical Method – A Review", International Journal of Advanced Research, Vol. 4, Issue 2, pp. 120-126.

38. Who's Guidelines For Drinking-Water Quality, Set Up In Geneva, 1993, Are The International Reference Point For Standard Setting And Drinking-Water Safety.

39. Zeynel Demire, 2010, "The Influence Of Seawater On A Coastal Aquifer In An International Protected Area, Goksu Delta Turkey", Journal Of Water Resources And Protection, Vol.2, pp.651-659