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The Failed Resilience, Grim Water Future, and Salinity Intrusion through GIS of Kendrapara Coast, Odisha

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Abstract

Salinity intrusion to groundwater has turned it brackish, and has polluted the coastal aquifers. It is common in coastal tracks. The ground water of Kendrapara district of Odisha, India has turned brackish and unfit for drinking, agriculture and industrial uses. The coastal buffer zone (0-15km) of the district is thickly populated, hotspot for biodiversity, numbers of creeks and safe hatchery for crocodiles, Olive Ridley tortoise and mangroves. The over exploited fresh water aquifers without recharging have caused salinity intrusion from adjacent Bay of Bengal. The water in aquifers has turned brackish and fresh water ground water has depleted down more than 600m near the coastal zone.

The present research is on chemical characteristics of the ground water aquifers through laboratory methods. The recommended ratio's like **$Na+$ / Cl^-, $Mg+$ / $Ca+$, and Cl^-/ HCO_3^-** to learn the extent of propagation of sea water through subsoil to inland buffer zone to ascertain depth, vertical and horizontal zone of extension. The GIS maps either generated or exported from some sources to study the geomorphology, geohydrology, deltaic slope, LULC and aquifers of the area and their characteristics.

It is inferred that the SE trending of anastomosed creeks and drainage channels, salinity ingress has been found. The average result emphasizes most of the Kendrapara area are suffering from salinity intrusion in the district. The increased salinity ingress shall reduce the yield of the farms, deteriorate the quality of drinking water, deepening fresh ground water aquifers. Due to regular floods, sea level rise, the water logging and drainage congestion have increased so it is essential to save the ground water for further deterioration.

Keywords: Aquifers, salinity intrusion, geomorphology, geohydrology, Deltaic slope, LULC.

Introduction:

Huge amount of capital investment has been made through government resources for the innovations of water resources, On-Farm-Development (OFD) activities and irrigation projects. But a lion's shares remain unutilized for lack of proper management and decisions about the proper quality of the surface and the ground water in the aquifers. Exponential rise in demography and over exploitation of ground water for drinking, irrigation and industries has invited influx of the adjacent marine water to contaminate the potential sweet water resources. The salt water intrusion and it's inland ingress through aquifers and backwaters has created alarming issues since last three to four decades. Even the wells nearshore, has become unfit for drinking, agriculture and industries within the varying buffer zone. The problem is not confined along coastal Odisha but also coastal fringes all around the world.

Salt water intrusion along 0-15km buffer zone of coastal north-Odisha has made the area vulnerable. Especially, the mosaic of lower delta of the Bramhani and the Baitarani Rivers has deteriorated its aquifer regime during 21st century. The coastal aquifers have become brackish due to salinity ingress of Bay of Bengal water. The problem has become acute in populous Rajnagar and Mahakalpada blocks of the Kendrapada district (20.4969° N, 86.4289° E) and covers the SOI (Survey of India) Topo sheets No. 73 L/11, 14 and 15 (**Fig 1).**

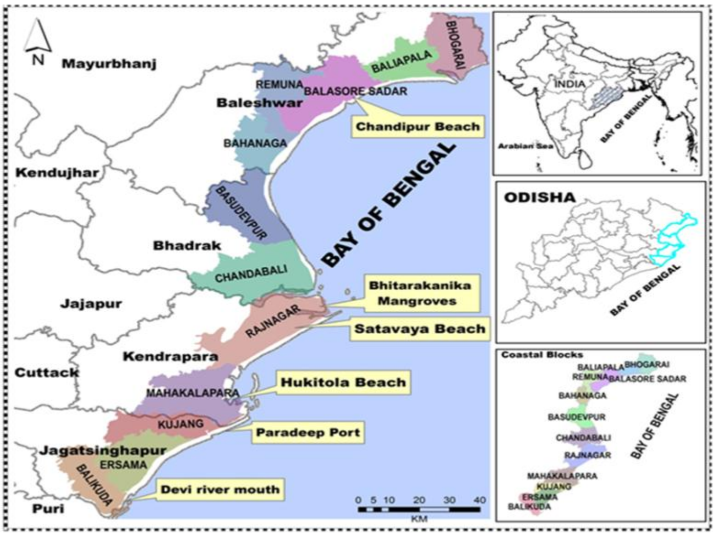


Fig 1: The index map of the Kendrapara area, Odisha, India

The study area:

The agro-economic district comprises of 1540villages in 2644km^2 geographical area with population of 1440361 (2011 census) and demographic density of 545persons/km^2. The district houses Kendrapara Municipality and Pattamundai NAC with rural to urban population ratio of 94:26. The Brahmani, the Baitarani and some branches of the Mahanadi, conglomerates along with their distributaries or 2ndary drainage systems like Kharsuan, Luna, Chitrotpala, Karandia, Gobari, Gupti, Kani, Hansua and Paika flowing through the area. The geological formations of the district is vast sandy coast, tortoise hatchery (Gahiramatha), levees, creeks, flood plains, swamps (Bhitarkanika) and estuaries (Barunei).

The anastomosed drainage system maintains the ground water table just below the surface but the people of the area have to struggle hard for portable water for their domestic and consumptive use due to salinity intrusion, Vaidyanadhan (1987)[1], Chandramohan et al, 2001[2], Sethi et al., 2014[3] **(Table 1).**Multiple cyclones have slammed the Kendrapada coast but there was less damage to the mangroves of Bhitarkanika, an erosional coast in last decade **(Fig 1).**

Table 1: The profile of Rajkanika, Rajnagar and Mahakalpada Bloks of Kendrapara district

District	Block	Latitude	Longitude	Area (km^2)	Popul^{n}2011 (Census)	No of houses	Total wells
Kemdrapara	Rajkanika	20.724° N	86.708° E	263.49	138979	30697	191
	Rajnagar	20.57°N	86.71°E	346.25	170110	35005	02
	Mahakalpada	20.421^{0}N	86.579^{0}E	490.57	212463	47966	132

The buffer zones along the coast can be segregated as coastal sands (0-5km), swamps and alluvium of recent origin (5-10km) and mixed old and new alluvium (10-15km). The dominant sediment soil stratum of the delta comprises of sandy clay, sandy loam and gravels of Tertiary and recent alluvium origin transported by the drainage channels of the Mahanadi and the Bramhani system **(Fig 2 (a) & Fig 2 (b)).**

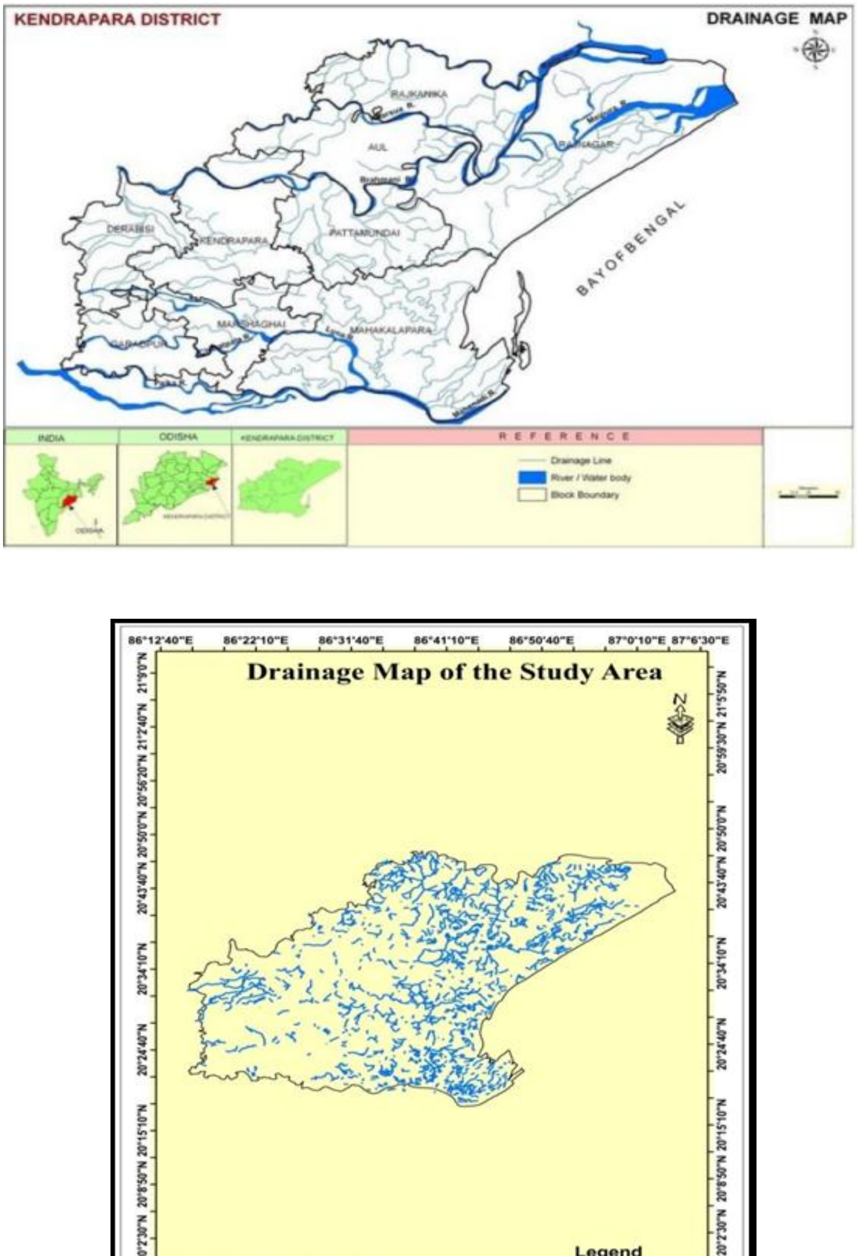


Fig 2(a) and Fig 2(b): The anastomosed drainage pattern of Kendrapara district

The Inceptisols (mixed grey soil) shields ≈143390ha of Kendrapara is arable and alluvium of old and recent formations. Block wise Inceptisols areas in Mahakalpada, Rajkanika and Rajnagar are 25600.36ha, 12584.98ha and 30127.37ha respectively (ICAR 2016[4]). The coastal track comprises of the aeolian and sandy soil of Rajnagar, and parts of Rajkanika block). Other soils are Alfisols (phosphate & nitrogen deficient and pH values 6.5 - 7.3) Aridisols (rich in calcium, magnesium and organic matter), and Entisols (lacking nitrogen, acids of phosphorous, but humus).

Review of literature:

The causes of salinity intrusion along coastal blocks of Kendrapara are overexploitation of (GW) groundwater abstraction without significant recharge, copious shallow, deep, and intake wells dug along coastal buffer zone. The salinity ingress as surged in the coastal wells since last few decades are the key drivers of deteriorated human life, ecosystem, Ernest, (1969[5]), Ramanathan, et al., (1993)[6]. Ferguson et al. (2012)[7], Prusty et al., 2020[8], Mishra S. P. 2021[9]. Central Water pollution index (CWPI) and Water Quality index (WQI) are useful indices that tells about the influence of salinity intrusion which deteriorate the water portability along the coastal aquifers, Upadhyay et al., 1982[10], Das et al., 1996[11], Panda et al., 2013[12]. About >80% of rural drinking wells and ≈60% of water supply for the irrigation is met from aquifers as source. Sahu S., 2019[13], .

The Ca/Mg values for portable, irrigation, and industrial use and the yardstick and limits are based upon the adjusted sodium adsorption ratio (SAR) values, EC values, dominance of (Na++K+)-HCO3 ion or predominance of(Na++K+)-(Cl+NO3) values and other water quality indices, Suarez (1981)[14], Minhas et al., (1992)[15], Das Madhumita et al. (2010)[16], Ravi et al. (2014)[17]. Bhunia et al. (2018)[18], Mishra S. P. 2016[19], Barik et al., 2021[20]. Wentworth (1951)[21] have reported about sea water transport mechanism and sea water intrusion into the inland aquifers and the allied complications to the humanity has posed subject of interest for the scientists and hydrogeology engineers. The Kashef A. I. (1972)[22], Todd (1980)[23], Kayod et. al., 2017[24] have discussed about the inland flow pattern of the seawater to the fresh water aquifers,

Reasons for present work

There is a wide gap in research between the phenomenon, quantities, degree, and quality of base line information for analysis of GW and its role in the aquifers, agriculture, yield and productivity of the coastal area. Present study aims at delineating surface areas and aquifers, risk involved, and suitability of use for domestic and agricultural use during pre and post monsoon.

Methods and Methodology:

The methodology comprises of the collection of ground trotting data taken during pre-monsoon and post-monsoon months in the year 2016 from wells of Rajkanika, Rajnagar and Mahakalpada blocks of Kendrapara district. The dissolved +ve ions are Na^+, K^+, Ca^{++}, Mg^{++} , Fe+3, Al^{+3} and and –ve ions are Cl^{--}, SO_4^- , NO_3^- , PO_4^{-2} and HCO_3^- *etc.* The analysis shall determine the hydrologic and physico-chemical parameters like head of water, temperature, pH, electrical conductivity (EC), Total dissolved solids (TDS) taking the help of, Central Groundwater Board (CGWB), Ministry of Water Resources, Government of India, Regional office Bhubaneswar and RWSS (Rural water supply and Sanitation), Govt. of Odisha. The Odisha Groundwater Services, and Sewerage Board. Samples were collected from 62 wells (both bore and shallow wells) and analysed as per standard collective procedures (2 lit bottle ringed with 1:1 HNO_3) and in-situ observations for EC, pH and temp.) as per sanctions in literatures of Rainwater et al., 1960[25]; Berg, 1983(EPA- 600/4-82-029)[26], ASTM, D4043[27] and D4044 -1991[28], APHA 1975[29], Sekhar et al., 2017[30] **(Table 2)**

Table 2: The procedures adopted in finding physicochemical parameters during study

Parameters/symbol	Unit	Activity	Apparatus	Methodology
Electrical conductivity (EC)	1meq/l = 100s/cm; 1mg/l=1.56 S/cm	Movement of ions & strength of Ions in GW	Conductivity meter; (HI2003)	
TDS (Total dissolved solid)	s/Cm	Signifies ionic strength	TDS meter	100 - 5000 S/cm
pH	Number	Signifies acidity / alkalinity of solution	pH meter	1-6 acidic; 7 – neutral; 8-14 alkaline
Elect. Resistivity (Digital resistivity meter)	Ohms	The electrical resistivity between two layers	Verti. Elec. Sounding (VES)	$\rho = \frac{RA}{L}$
Determination Cl^- ion	mg/l	$[Cl]^- = \frac{(A-B)*N*33400}{ml\ of\ sample}$ where A&B = ml titration of sample and Blank &N=Normality of AgNO3	Titrated with Std $AgNO_3$ soln.	Argentometric method
Determination HCO_3 ion	mg/l	Natural component of all mineral waters &buffering acids	Titrated with standard acids below pH 8.2	As alkali keep the acid-base balance of the body stable.
Determination anions (Calcium)	mg/l	EDTA Titrimetric method	Amt. of Ca^{2+} (mg/l) +Vol of EDTA(ml) *50	Make water tasty & act as a pH stabilizer
Determination anions (Na^+ & K^+)	mg/l	Saline intruded aquifers rich in Na^+ & K^+	Flame photometer	Liable for brackish aquifer
Abbreviation: ρ (ohm-m)= Resistivity; R = Resistance; A =Area; L = Length				

Source: Todd 1980[23], Alpha -1995[29]; Davis et al., 1998[33]; Madhab et al 2018[34]

For saltwater intrusion, the ratio of Mg^{++} / Ca^{++} and Cl^{-} / HCO_3^- was calculated. If the calculated ratio value is greater than two in Mg^{++} / Ca^{++} and Cl^- / HCO_3^- then the area can be treated as saltwater affected area. Similarly, if the ratio value of Na / Cl ranges between 0.08 to 1.0meq./lit then the area can be treated as a saltwater included area.

The calculated ratio values were fed into GIS platform for preparation of saltwater intrusion map through interpolation techniques. The combined results of the ratio parameters like Cl^- / HCO_3^- and Mg^+ / Ca^+ of the area affected by susceptibility weighted imaging (SWI) are determine by the methods of Inverse distance weighting (IDW) interpolation technique. Later the interpolation was done by approximating the values while processing each neighborhood of unit cell by giving more weightage in the averaging process. The processed image shows that the salt affected areas are in the vicinity of Brahmin River where in the saltwater from the sea intermix with the inland aquifers, Das et al., 2018[31], Prusty et al, 2020[32].,(**Fig 2):**

Aquifer disposition:

The bore holes lithological data of the study area was as reported by Das et al, 2016[35] and considering the data a pannel diagram has been prepared to decifer the distribution factor of the aquifers in the study area considering the borehole locations.

The observed data is volumnuous. Analysis of big data can be done graphically and popular methodology applied in the present study Pipers trilinear diagram or Durov's diagram. Ionic Ratio parameters like Mg^{2+}/Ca^{2+}, Cl^-/HCO_3^-, and Na^+/Cl^- meq/l used for application in the digital elevation model (DEM) in GIS technique. The surface flow, the fresh and brackish water aquifers both shallow and deep has been identified and shown in **Fig-3 and Fig -4**

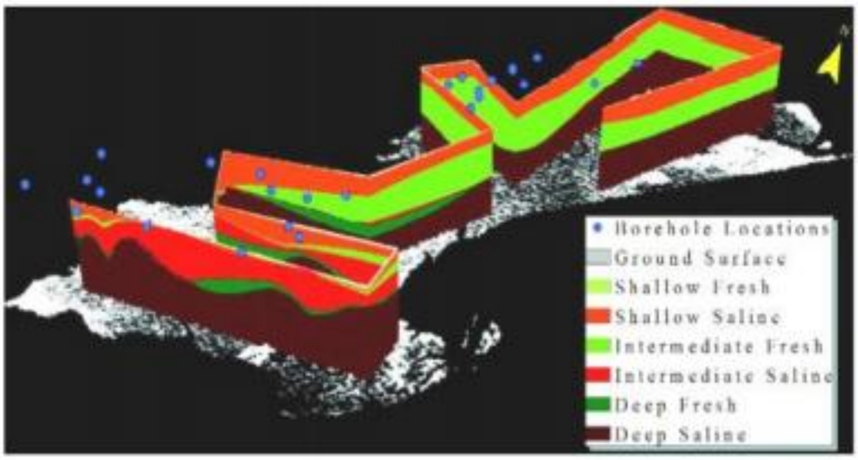


Fig 3: The disposition of aquifer's water zoning at interfaces in Kendrapara coast

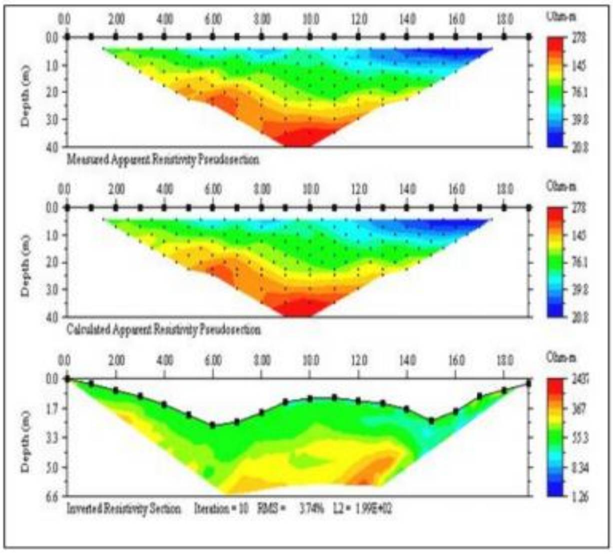
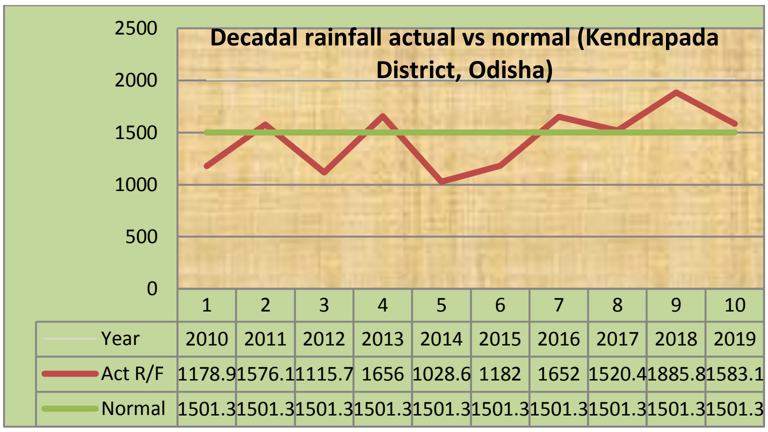


Fig 4: Subsurface layer disposition by Vertical electrical sounding (VES) method

Climatology:

The study area is humid tropical Savanna climate with high humidity scorching summer and a good southwest monsoon rainfall. The average, Min, Max, temperature are 26.8°C, 13.9°C, and 37.8°C with average RH 78.5%. The normal rainfall of the Kendrapara is 1501.3mm and actually it is increasing from year 2016 onwards and isohyet of various blocks are in *Fig 4(a), Fig 4 (b)*, Ground Water Year Book 2019-2020.



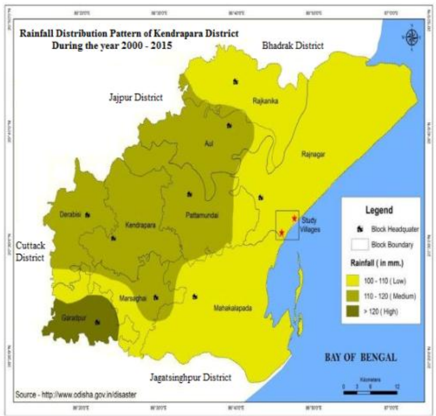


Fig 4(a) & 4(b): The actual vs normal rainfall and isohyet map of Kendrapara Dist., (2010 – 19)

Geology:

The Kendrapara, in the northern lower Mahanadi tri-delta comprising of drains and creeks (Ardisol, rich in calcium, magnesium and consist of half decomposed organic matter, sand dunes, recent and old alluvium (alfisol of 90%) over the Precambrian rocks. The soils are of riverine sediments with aeolian and sandy soil of the coastline around Rajnagar, and parts of Rajkanika block. Mixed Grey Soil (Inceptisols) being the dominated soil type is assumed to envelop about 143390 ha. The coastal soil is mixed with organic matter of mangroves are re-worked by sea-wind and backwater action deficient in nitrogen, phosphoric acid and humus, but lack in potash and lime. The area lies between the Chilika and Dhamara Lineament zone and a part to Mahanadi graben **Fig 5(a) and Fig 5(b).**

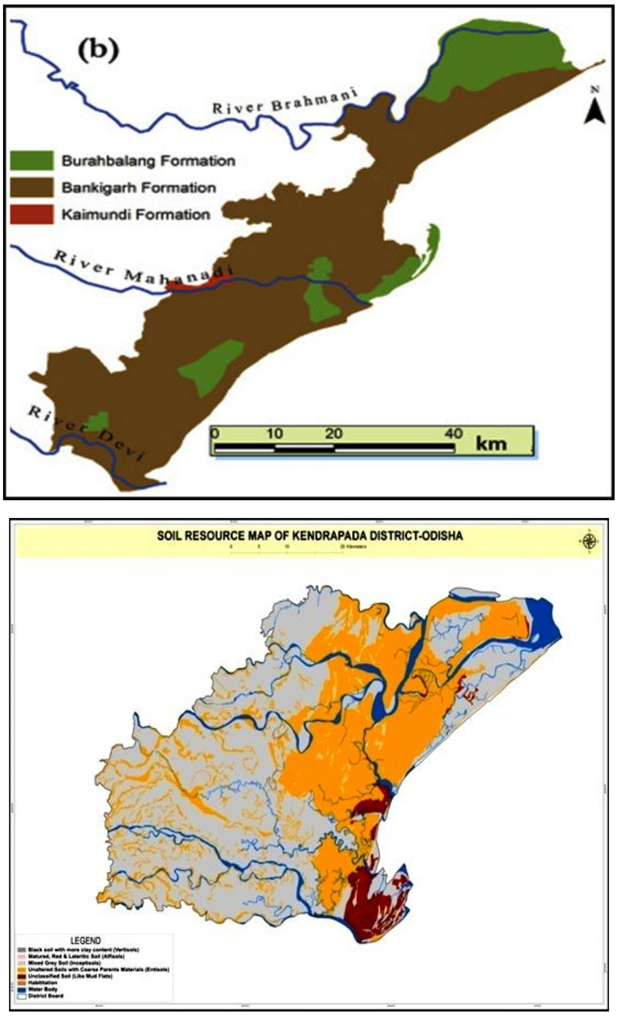


Fig. 5(a): Geology map of the study area (Source: SRTM data of CGIR-CSI) and **Fig 5(b):** Soil resources map of Kendrapara District, (Source: GSI Technical report 2011)

The Ersama Formation is due to geomorphologic alteration due to hydrologic regime of the river

Alaka which had formed by, alluvial plains, mud flats, and sand ridges in the mid deltaic plains of the Mahanadi tri-delta a part to the present abandoned channels the Sukhbhadra, the old Kathjodi, the Burdha, the Alaka, the Prachi, and the Ratnachira systems, Bharali et al., 1991[37], Mahalik et al., (1996)[38], Kumar et al., 2016[39].

Stratigraphy of the study area

The coastal and the delta region that encompasses three formations are Kaimundi Formation, Bankigarh Formation and Budhabalanga Formation. The Kaimundi and Budhabalanga Formations contain significant amount of marine deposits whereas the Bankigarh Formation is mainly composed of alluvial deposits. The Kaimundi Formation has formation by ion-exchange processes, and that of Bankigarh Formation is due to calcareous nodules. The detailed geological sequences having various deposits are in **Table -3.**

Table 3: The stratigraphy of the Odisha Coast and geological sequences like formation or lithology deposits of study area (source: (after DSR, 2018),

Age	Formation	Lithology
Late Holocene	Present day flood deposits, due to continuous riverine changes	Sand and silt due to point, lateral bars, and meander scrolls (new/ old) alluvium
Mid-Holocene	Bankigarh formation	Black clay (Organic) as lower deltaic facies and brownish silty clay as upper deltaic facies
Pre-Holocene and Pleistocene	The formations of the Bramhani and the Mahanadi rivers	Residual soil and alluvium
Late Pleistocene to early Holocene	Kaimundi Formations	Clay with calcareous concretion

Hydrogeology:

Under multifaceted ground water scenario of the study area comprises of the unconsolidated alluvial sediments of Upper Tertiary (Mio-Pliocene) to recent period which is considered as the foremost storehouse of Groundwater and varying aquifer extent **(fig-6).** The complex hydrogeological setting; thickness of the sedimentary sequence gradually rises towards coastal areas of BoB. The heterogeneous sediment pattern is primarily due to change of the river courses, estuarine and lagoon environments, marine transgressions and regressions.

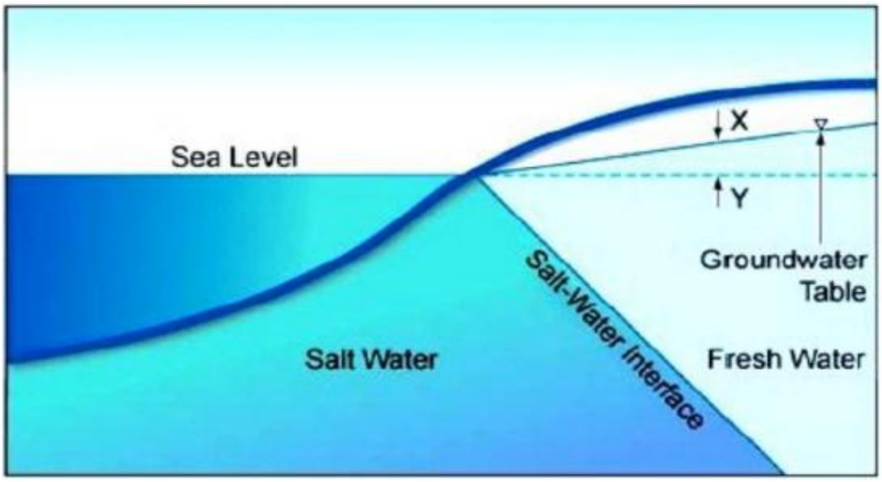


Fig 6: Salinity intrusion along salt and fresh water interface (Kayode, O., et. al., 2017)

Ground water (GW) is over exploited and the use along coastal Odisha have amplified from 23% in 1999 to 43% in 2009, Srivastava et. al.,2013[40], Sahu et al., 2021[41]. The layers comprise of sand and gravel which induces development of inexhaustible aquifers. They can form like lenses or perched, laterally interconnected and repetitive, founding multi aquifer systems. The unconfined aquifers are found to a substantial depth due to lack of persistent and thick confining beds. The confined aquifers are formed in deeper beds between extensive clayey beds thickening towards the coast. The ground water lithology reports dissimilar occurrence, potentiality and quality based on the litho-types, topography, and mode of sediment deposition, Naik et al., 2005[42].

RESULTS AND DISCUSSION

A large part of the coastal area suffers from salinity hazard and the coastal area can be broadly divided into two broad divisions (Das et al, 2020).

(1) *Non salinity hazard area:* This area occurs along the western part of the coastal area and ground water is fresh in nature down to bed rock depth.

(2) *Salinity Hazard area:* This area is located east of non-saline hazard region and extends up-to the shore line. The width of this zone is variable along the regional trend (NE-SW). In the NE sector the average width is around 10 to 12 km where as in extreme SE sector, it is around 20 km. The maximum width is observed in the Central part where the maximum width is around 75 to 80 km. An overall statistics of maximum total dissolved solids (TDS) and different parametric ratios like Na+ / Cl - (Meq./L), Mg+ / Ca+ (Meq./L), and Cl^-/ HCO_3^- (Meq./L) are in **Table 4**

Table.4: Hydro-chemical data of GW in Rajnagar, Rajkanika & Mahakalpada Blocks, KDP

Dist./ No. of blocks	GW stns.	Total dissolved solids (TDS)			Na+ / Cl - (Meq./L)			Mg+ / Ca+ (Meq./L)			Cl^-/ HCO_3^- (Meq./L)		
	Nos.	Mg/l			Millie equivalent/lit.			Mille equivalent/lit.			Millie equivalent/lit.		
		Max	Min	Av.	Max	Min	Av.	Max	Min	Av.	Max	Min	Av.
KDP (2)	32	707.5	163.9	512	3.9	0.0	1.3	3.4	0.3	1.1	2.0	0.0	0.2
Stns: Stations; KDP: Kendrapada ; Nos: Numbers, Av.: Average													

The average result emphasizes most of the area under study are suffering from salinity intrusion in the Kendrapara district.

The coastal and deltaic tracts have both the saline and fresh water dispositions are inconsistent at various depths. The fresh zones are disjointed from saline zones by thick clayey sedimentary layers. The discrete detachments, thickening and thinning of various aquifer layers are observed at several locations both vertically and laterally matching the basin configuration. The characteristic of saline and fresh water bearing zones is mainly of four categories (Fig. 2 .8).

i. Area having saline water is overlain by fresh water. The thickness of fresh water zone ranges from 30 to 150 m in average of 50 to 75 m depth.

ii. The area with fresh water is overlain by saline water i.e. top saline water and bottom freshwater barring few meters (4 to 5 m) at top and this shallow zone of fresh phreatic aquifers as a perched zone.

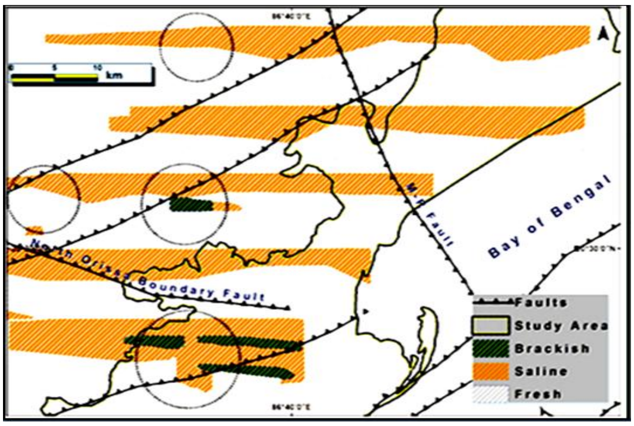


Fig. 7: Disposition of the Coastal aquifers, Odisha Coast (Source: Das et al., 2020)

iii. The top thin fresh/saline water zones in the form of local pockets in alternate extend up to a depth of 15 to 20 m. They are found in the outskirts of derelict paleo channels, present paleo and recent sand dunes. The top saline zone extends down up to depth of 80 to 200 m of average thickness of 100 to 125 m and the fresh water zones are underlain.

The brackish water at depth with very thin fresh zones is found towards the extreme SE part of the saline hazard tract. The thickness of individual aquifer within fresh zone fluctuate from 1 m to 20 m with the average thickness of 5 to 10 m. Normally, cumulative thickness of fresh water bearing aquifers varies from 30 to 50 % of total thickness of fresh zone in the region.

GEOMORPHOLOGY

The Physiography:

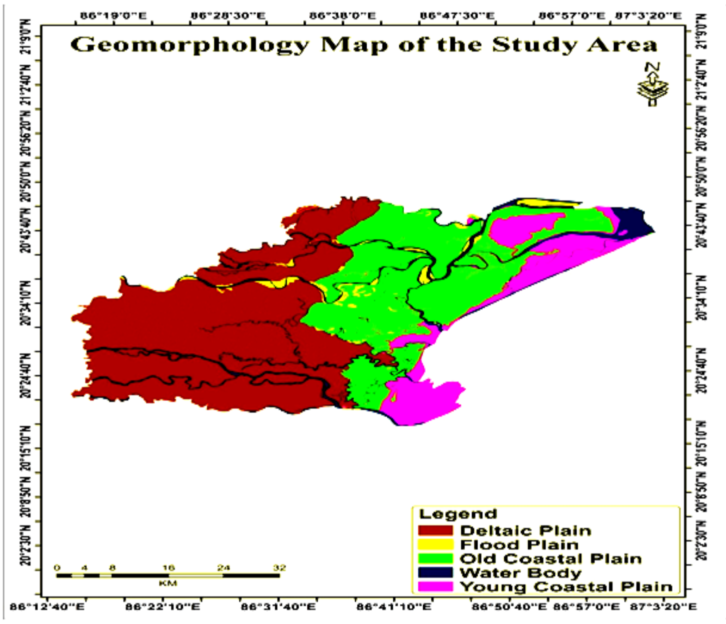


Fig.8: Geomorphology map of the study area (Source: SRTM data of CGIR-CSI)

The physiography of the area can broadly be divided into two distinct units, viz. *the saline marshy tract along the coast,* and *the gently sloping plain.*The saline marshy area of long and narrow strip along the coastal tract is found of width 3 to 15 m which is intersected by tidal streams or covered by shrubby inland vegetation or mangroves. The gently sloping alluvial plains of variable altitudes of about 10.5 m above mean sea level (MSL) are found in the NW fringe or nearly 2.15 m above MSL towards east. The general slope of the district is towards east and southeast that varies from 5m/km in the west where as it is 1.6 m/km in the east, (**Fig-8**).

The geo-hydrology

Kendrapara District belongs to the river delta, which is formed by the combine effect of rivers Brahmani, Baitarani and tributaries of Mahanadi. The well-known Bhitarakanika Mangroves, Bhitarakanika National Park, Gahirmatha Beach are located in this district. Brahmani River and its distributaries have resulted in development of various channel deposits. The deposits essentially comprise of sand, silt and clay litho-types. Physiographically, Kendrapada district is classified broadly into two categories. These are: - Coastal saline marshy land and sloping plane. The marshy land tract is in association with narrow alluvium sandy region. The dimension of this marshy land ranges from 3 to 15 km (Das et al., 2020[43]).

Deltaic Slope:

The parameters which are essential for the significant morphometric analysis of the study area is slope aspect, and curvature of the terrain. These aspects are documented to acquire the synoptic view of the study area. The slope of the terrain has been calculated from elevation displaying the gradient between two points of the drainage movement. The landform of the coastal plain adjoining the BoB in the east illustrates an extensive flat alluvial expanse between the western hills, and the coastal area in the east. The width of the plain varies from north to south. The coastal plain have several geomorphic features like flood plains, natural levees, paleo channels, beach ridges, tidal flats, swamps and lakes. The flat topography having is gently sloped towards east without any significant change in altitude.

The drainage channel flow and the land slope are seen towards the south east (SE). The flow direction towards west is observed zig- zag, and the possible movement is from west to east. Small water patches are found in the NE sector indicating low lying region whereas towards east there are sharp and straight drainage pattern indicating NE-SW trend of land slope. In the map the red and orange colour patches are gripped together.

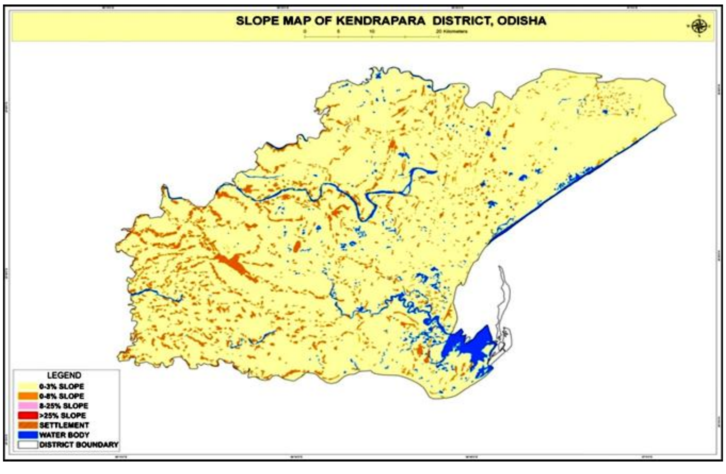


Fig. 9 Slope map of Kendrapara District, Orissa (Source: DLIC, 2016)

The gradient usually decreases from west to north east. There are two predominant slope attitude having minimum and maximum slopes of 0^0 and 25^0 respectively are observed from the slope map of the terrain (**Fig. 9**). The slope is less along the stream channels. Vertical slopes are found in the flat lying areas of the terrain and in the mangroves and forested region.

GROUNDWATER SCENARIO

The soil and sub-soil stratification determine the nature and characteristics of seepage that contributes to the groundwater positioning and the depth of the water table. Higher levels of underground (UG) water tables are noticed in rainy season and floods. The groundwater potential zone of the area of study has been demarked in the map **(Fig. 10).**

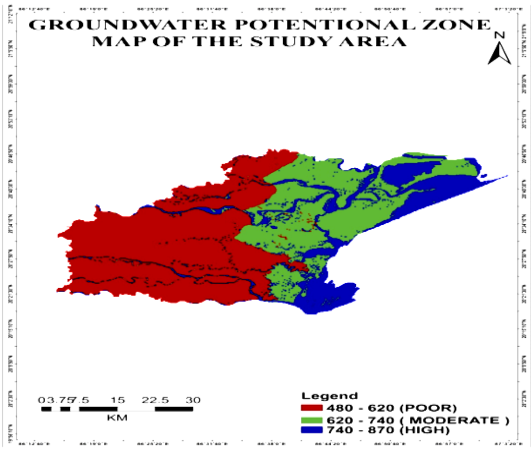


Fig. 10: GW Potential Zone of the study area (Source: SRTM data of CGIR-CSI)

Aquifer System:

The aquifer condition in the concern district may be broadly divided into either shallow aquifer or deep aquifers.

Shallow Aquifers: The shallow aquifers in the study area vary widely from 00 to 95m in thickness due to salinity problem except a narrow tract towards the extreme western part of the district where salinity problem is less. The occurrence of clay horizon at the top surface (from ground level) reduces the thickness of fresh water bearing zones to almost zero level. In an average the thickness of fresh shallow aquifers varies from 15m to 20m or more within the saline intrusion zone lying towards west of Indipur-Kendrapara-Karliopatana section. The thicknesses of shallow aquifers are of negligible, and usually found except in some isolated pockets (in abandoned drainage channels and around sand dunes). In those areas the shallow/top fresh water bearing zones extend down to a maximum depth of 10m to 15m with the average thickness of 5m to 6m. The top fresh water bearing zones extends down up to a depth of 90m even 95m in the south-western part of the district.

(II) Deeper Aquifers: The borehole observations of fresh water bearing deep aquifers are identified down to a maximum depth of 612m. The depth of boreholes is about 300m in the major part of the district. However, for a small part the sweet water aquifer is available down to 600m depth Rajnagar area (Dakhinaveda). For better access, those tube well platforms are kept at 4mtrs above the ground level during floods. The data point out that in general, the deeper fresh water bearing zones are characteristically sandwiched between saline water bearing zones. The sand, silt, clay, gravel, as well as gravel horizon and more over mixture of varying sand and gravel zones are assumed to have prolific fresh water bearing aquifers. The given map manifest groundwater development and prospectus of Kendrapara district **(Fig. 11(a) & Fig 11(b)).**

LAND USE AND LAND COVER (LULC)

The Kendrapara district occupies approximately 83 km-long-coastal tract. It has two coastal provinces, i.e. Rajnagar and Mahakalpada. The Land use and Land cover (LULC) maps of Kendrapara district (Fig. 12) indicates different aspects such as water body, plantation with settlement, wetland, scrub, mangroves, agricultural land and sand cover. According to Barik et al., (2017), in Kendrapara district, the settlement and the mangroves have increased, whereas agricultural land has been reduced. In fact the increase of settlement is due to high population density and increase of mangroves owing to plantation awareness program made through State government. Often the coastal zones of Odisha meet natural hazard due to frequent cyclonic and flooding activity **(Fig 12).**

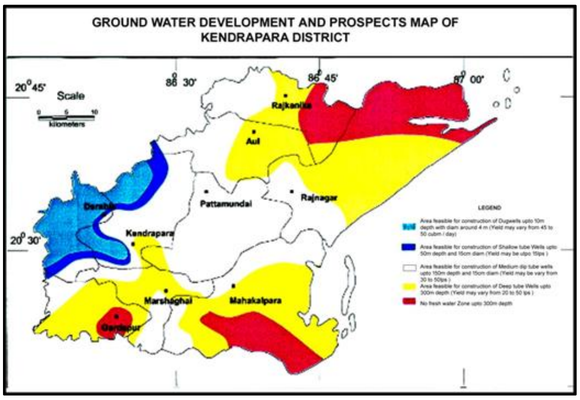


Fig 11(a) : The deep tube well bored depth 612m at Dakhinaveda, Rajnagar, Kendrapada and **Fig11(b)** GW development and prospect map of Kendrapara District (Source: CGWB, 2011)

The changes of coastal environment and calculation of LULC classes using supervised classification is the present study. The LULC map shows that the plantation area with settlement is higher than the agricultural land of all the districts of the coastal zone. The presence of the mudflats and mangroves in these areas indicate low energy condition along the coast having weak coastal processes. It is also inferred that the uses of multi resolution satellite images have proved an effective measure for estimating and monitoring shoreline modification in extremely dynamic coastal regimes which shall augment the planning for the coastal zone management.

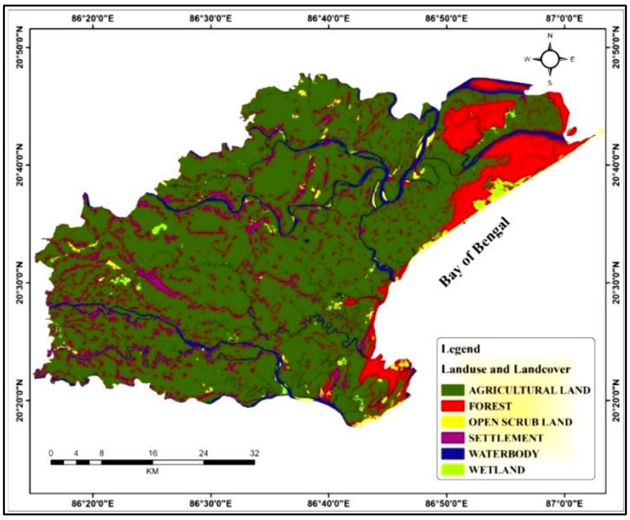


Fig.12 Land use and Land Cover map of Kendrapara District
(Source: SRTM data of CGIR-CSI)

The laboratory studies of 32 GW samples of the bore wells from three blocks of the Kendrapara district reveals that in major cases the pH values lies between 7 to 8 and the temperature of GW samples varied between 26^0C to 30^0C (mostly 27^0C to 28^0C). Higher TDS values were observed near-coastal zones, and primarily in the outskirts of the shrimp ponds and lower TDS values were recorded inland locations away from the coast ranging 104 and 3892 mg/l during pre-monsoon and between 105 and 19500 mg/l in the post-monsoon. At some places the TDS values recorded to be > 1000 mg/l. The EC pattern of variation was closely shadowed the TDS contour. The TDS DEM map of the study area, also followed the laboratory findings which remained high adjacent to coast and around the shrimp culture areas in comparison to inland. This predicts that formation of brackish groundwater may be either from the shrimp ponds or directly from the sea.

Conclusion:

Being in proximity of the eroding coastal zone, there is salinity intrusion in the coastal buffer zone. Fresh water body is in the middle layer of av 50m to 75m and sand witched between the brackish water layers. The result has indicated that the GW has more contaminated up to the extent of SWI. In Kendrapara district the ratio values of Cl^- / HCO_3^- has a different picture as compare to adjacent coastal districts. The causes such as salinity intrusion from the aquaculture pond may contribute a lot to the salinization of the groundwater underneath. The brackish ground water layer is very close to Brahmin River estuary and creeks of Bhitarkanika area. The advocating mechanism is the the structural lineament, which allows the saltwater from the sea to flow into landward and contaminate the aquifers near shore. The second mechanism can be the direct infiltration of shrimp ponds saline waters into the groundwater. The third point can be over exploitation of freshwater for anthropogenic uses like agriculture, industrial and water supply *etc.* without recharging. The imbalance forces to impinge the saline water from nearby Bay of Bengal to the buffer zone of Kendrapada district.

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