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Geomorphological study of Sand Dunes with special reference to their Hydrogeology in Southern Coast of Odisha, India

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Abstract

The southern coast of Odisha enjoys a humid tropical climate. Availability of favourable conditions for dune development i.e. abundant sand supply, strong onshore wind and flat ground adjacent to the coast has given rise to all the possible types of dunes like embryo dune, fore dune, frontal dune, intermediate dune, back dune and palaeo-dune etc. These dunes differ from each other in their geometry and place of accumulation of sand. They support different types of vegetation like casurina, cashew, coconut, date palm, kewra as well as act like a buffer zone in protecting the coastal part from destructive effects of wave, tide, cyclone and tsunami. The sand dunes also serve as storehouses of different placer minerals like monazite, zircon, ilmenite, rutile and sillimanite. Being made up of unconsolidated and well sorted sands, the dunes possess appreciably high porosity and permeability making them good receptacles for storage of fresh groundwater. The water is mostly alkaline, moderately hard, fresh and potable and is used for drinking and agricultural purposes by the people of the coastal saline environment. The electrical conductivities of ground water varies from 399 to 1313 µs/cm. When the ground water is fresh the facies is (Na+K) - HCO_3 type but when it is brackish facies is (Na+K) - (Cl + NO_3) type. Unsystematic exploitation of the sand dunes has resulted in imbalance of the coastal ecosystem, which is to be restored for the welfare of the inhabitants.

Keywords: Coast, sand dunes, aquifer, placer, saline.

Introduction

A dune is a sand hill formed by aeolian process[1]. Coastal sand dunes are generally formed in close proximity of beaches where waves promote accumulation of sand and prevailing onshore winds blow this sand inland[2]. The size and character of the coastal sand dune system depends on the combination of physical factors, such as the wind and wave regime, the sand supply from the beach and offshore bars, and biotic controls, such as plant succession and grazing pressure. Dunes sand is usually very well sorted sand of medium to fine size. Dry sand is easily picked up at even moderate wind speeds and moves mainly by saltation across the beach and on to the dunes[3]. These are abundant in the back beach areas where there is large sand supply and winds are strong and persistent enough to move it to suitable places for accumulation[4]. Large sand supplies are commonly associated with large tidal ranges, which expose extensive sandy beaches during low tide period. Though coastal sand dunes develop in many coasts, these are more common and extensive in areas of strong onshore winds and sufficient supply of medium to fine- grained well-sorted sand suitable for entrapment. Coastal dunes are widespread along humid temperate and arid tropical coasts, but are uncommon in humid tropical coasts. Three main types of coastal sand dunes have been identified by King (1972)[5]. These are transverse dunes, vegetated dunes and parabolic dunes. Some coastal areas have one or more sets of dunes running parallel to the beach[2].

The aim of the present work is to study the geomorphology, flora and hydrogeology of the coastal sand dunes and anthropogenic impact on sand dunes from a part of the south coast of Odisha.

Study area: The study area (figure-1) is located in the eastern part of Ganjam district, Odisha, India. It extends for 75 km from the Prayagi in the north to Sunapurpentha in the south being bounded by 19° 00' and 19° 50' north latitudes and 84° 40' to 85° 12' east longitudes. The drainage in the southern part of the study area is mainly controlled by two major rivers namely Bahuda and Rushikulya. Both the rivers originate from northwestern part of the study area and flow in the southeastern direction emptying into the Bay of Bengal. The coastline of the area is almost straight with an overall concavity toward the sea. An elongated fresh water body parallel to sea is located north of Chhatrapur which is called *Tampra* in local language. A number of sand dunes are located adjacent to the coast.

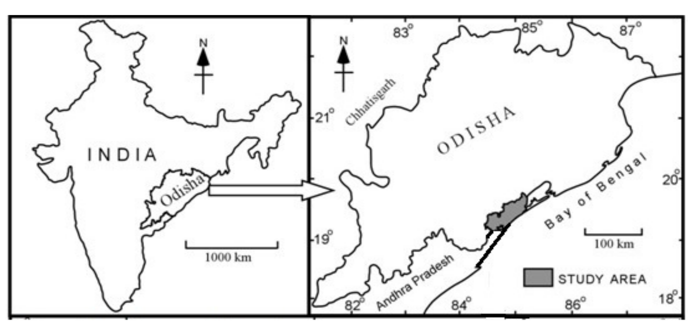

Figure-1
Location map of the study area

The Eastern Ghats Supergroup comprising khondalite and charnockite suites of rocks form the basement of the study area. The khondalite suite is represented by quartz-feldspar-garnet-sillimanite schist/gneiss, garnetiferous quartzite and calc-granulite. The charnockite suite consisting of basic granulite and different varieties of charnockites exhibits discordant relationship with khondalite suite of rocks. These two rock groups are intruded by granite plutons, pegmatite and quartz veins. All these rocks of Precambrian age are unconformably overlain by laterite/iron stone of Tertiary age. Unconsolidated alluvium of Quaternary age consisting of transported laterite, kankar, fluvial and marine clays and sands of different size grades unconformably overlay the Tertiary laterites. The sand dunes are the youngest geomorphic-cum-sedimentary units in the study area.

Denudational hills, spit, estuary, saltpan, mud flat, paleo- and present day sand dunes are different geomorphological features of the area. Due to frequent shifting and abandonment of river channels in geologic past, a good number of paleo-channels have been left out in the investigated area. A number of water bodies of varying dimension are dotted here and there as well as several creeks serving as tidal channels exist in the area. Though the coast was subjected to accretion due to fluvial activity in the past, recently wave erosion is prevalent along Ganjam coast. The detailed geomorphological features of the study area is given in figure-2.

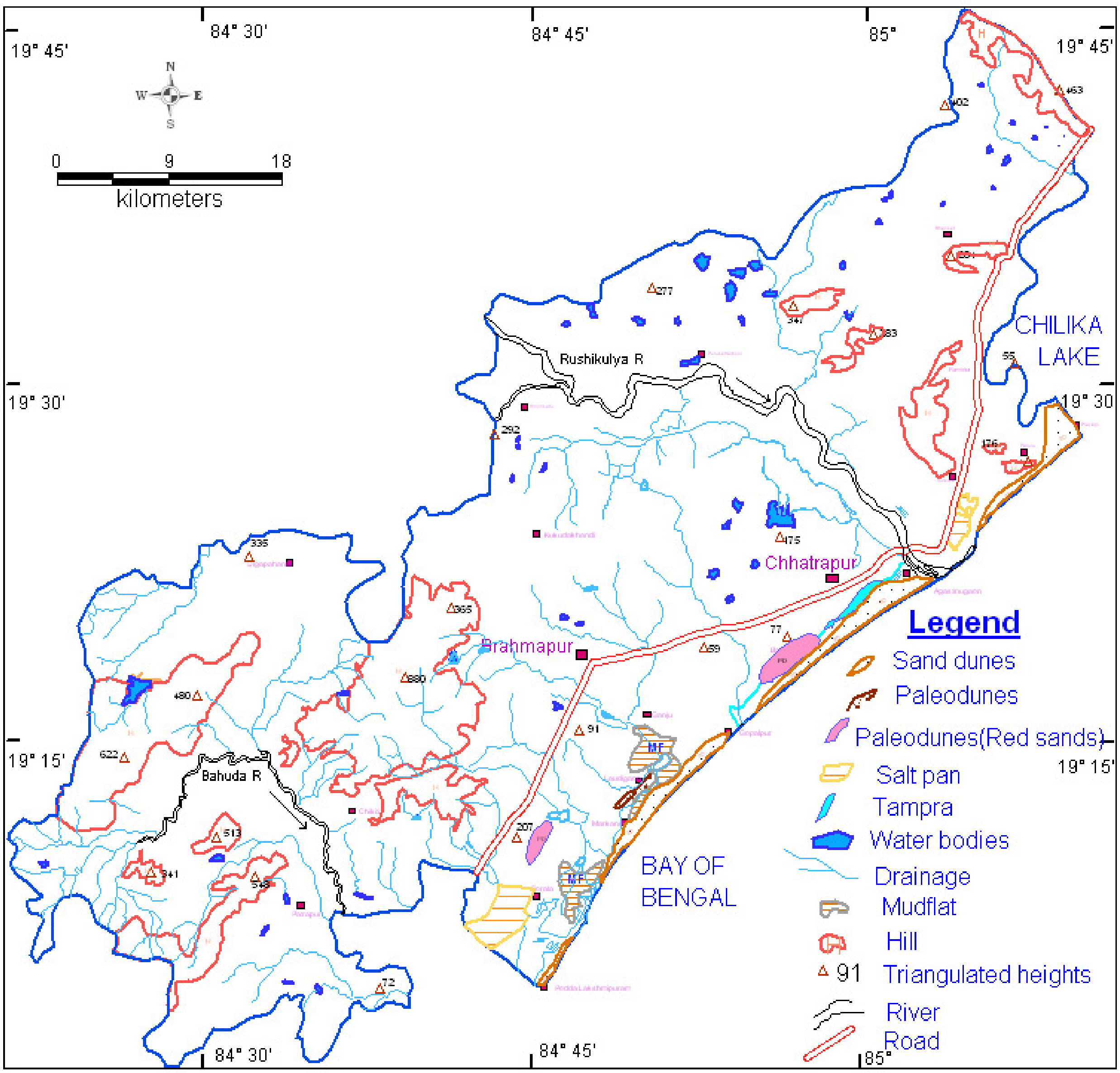

Figure-2
Geomorphological features of the study area.

Material and Methods

In the present study, visual interpretation of IRS – 1D panchromatic image in 1: 25,000 scale was done to study the geomorphology of the areas as well as the sand dunes. Detailed field investigations was carried out throughout the study area. Depths to water tables were measured to study the hydrologic condition of the aquifers and to delineate fresh water zones. Groundwater samples were collected both during pre- and post-monsoon periods. Physical parameters like pH and electrical conductance (EC) were measured on the spot. Other chemical parameters such as total hardness (TH) and concentration of calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), carbonate (CO_3), bicarbonate (HCO_3), chloride (Cl), Sulphate (SO_4), nitrate (NO_3) and fluoride (F) were determined in the laboratory following the standard methods[6].

Results and Discussion

Development of Dunes: Coastal sand dunes are sculptured by the prevailing wind, sand supply, climate, vegetation and anthropogenic activities. Various types of sand dunes on the basis of shape, size and morphology have been described by Tinley[7], Mc Gwynne and Mc Lachlan[8] and Silverside[9]. The ideal condition for the development of sand dune is availability of enormous quantities of sand, which is readily available in the beaches. The beaches, in turn, receive a constant supply of sand from the near shore region from where it is thrown up and well-sorted on the beaches by continuous wave action. Wind plays a major role in the formation of coastal sand dunes. The sand grains on the beach move landward when wind velocity exceeds the critical shear stress. Different types of coastal sand dunes of the study area are described below.

The embryo dunes are the initial stage of dune formation[10]. These are unconnected series of circular/semicircular low mounds up to 1 m height with radius varying from 1 to 3 m formed in the upper slope of the beach. *Hydrophylax maritima* and *Ipomoea biloba* are seen on these dunes in the first and second stages of dune development respectively, which trap the blowing sand and are known as dune builders. As the embryo dune progresses landward its dimension increases. Gradually it coalesces with adjoining embryo dune to form a fore dune oriented parallel to the shore line. In IRS-ID PAN Images the fore dunes are easily recognizable owing to their perfect orientation almost parallel to the shore line. These are light toned (if bare) smooth in texture and light grey in color. The fore dunes are mostly seen in sandy beach and sand dune complexes. The dune builder species change with increase of height of the dune. *Spinifex littoralis* (marram grass), a thick and thorny variety of grass is seen over these dunes which can survive in dry condition and act as a sand binder in third stage of dune development. The fore dunes are seen in the landward side at distances varying from 34 to 105 m form the low tide line (LTL), but are more common within 30 to 90 m from the low tide line[11]. Detailed geomorphological features of the study area is given in figure 2. Embryo dune with successive dune growth (Inset:Sand binder species, *Ipomoea biloba)* is given in figure-3.

Figure-3
Embryo dune with successive dune growth Inset: Sand binder Species (*Ipomoea biloba*)

Frontal dune: The frontal dunes are characterised by steep windward slopes and gentle leeward slip faces. These dunes, extending over a width of 250 m and reaching up to heights of 18 m are prominent in greater length of the coast. Frontal dunes are seen between 30-90 m from the low tide line (LTL) running more or less parallel to the coast[12]. In the study area, the prevailing summer and monsoon winds blow constantly across the coast at angles of 30° - 40° for over a period of six months in a year, which along with abundant supply of sand from the beach has resulted in the development of these dunes. The frontal dunes form a continuous ridge parallel to the shore line from south west of Puri to north of Gopalpur. The average width of the sand dune is 240 m with height varying from 3 to 15 m. Unlike desert dunes, the coastal dunes have steep wind ward slopes of 14° to 35º and gentle leeward slopes of 5º to 6º. Such variation is mostly due to presence of vegetation cover on the coastal dunes. Front dune with red sand flat at Gopalpur is given in figure 4.

Figure-4
Front dune with red sand flat at Gopalpur.

Intermediate dune: The sands, which are blown across the frontal dune, migrate forward forming intermediate dunes, mostly oriented parallel to wind direction (oblique to the coastline). In the study area, these dunes are seen from south of Bhagabanpur to Hasimpur with longer axes trending N30°E-S30°W to N40°E- S40°W. In IRS – ID PAN data these dunes are clearly discernible by their oblique orientation to the coastline. These are smooth textured, grey in color and of light tone (if bare) with variable dimensions. These are mostly elliptical in shape with the longer axes oriented along the wind direction and are associated with sand dune complexes. The lengths of these dunes vary from 600 to 1500 m[12]. The dunes are separated from each other by inter-dunal depressions. The sediments are mostly windblown fine sands with cross bedding, laminations and color bandings. Casuarina trees are commonly planted over these dunes for their stabilization and to check their forward movement.

Back dunes: The back dunes are transverse to the coast and occur at the extreme landward limit of the dune system. Their forward movement is hindered either by natural water bodies as in case of *Tampara* that stretches over a length of six km in Chatrapur area or by man-made structures like canals, roads, fences of Kewada etc. The canal running from the southern end of *Tampara* up to Gopalpur creek forms as a barrier for landward migration of back dunes in the study area. In IRS-ID PAN images these dunes are identified by light tone (if bare), smooth texture, elongated to elliptical in shape and medium to large in size. In the study area, isolated back dunes are seen at the east of Upalpati, Kalipalli, Matikhala and Chatrupur *Tampara*. From Kantiagarh to Prayagi, a continuous stretch of back dune is seen running for a length of about nine kms with average width of 150 m and variable height of 6 to 8 m. Unlike frontal dune, back dunes have smooth rounded tops with gentle wind-ward slope of 8º to 10º and steep lee-ward slop of 20º to 30º. These dunes are similar to desert dunes as these are totally devoid of sand binder plant species owing to their greater distance from the shore line[11]. The sediments are mostly fine-grained sands with color banding and graded beddings. These dunes sustain cashew/casuarinas plantations. Back dune at Kallipalli with laminations of heavies is given in figure-5.

Figure-5
Back dune at Kalipalli with laminations of heavies

The colour bandings in the sand dunes are mostly due to the presence of heavy minerals, the thickness of which varies from few a few mm to as much as 10 cm. The heavy mineral concentration decreases from the beach to back dunes[11].

Palaeodunes: The palaeodunes formed in geologic past are situated in the land areas beyond the back dunes. They appear either as isolated patch of sand dunes or as long and narrow stretch of low relief sand. In IRS-ID PAN images, these dunes are recognized by their dull tone, smooth texture and dark grey color. These dunes are semi-circular, elliptical or elongated in shape of variable sizes. The palaeodunes are seen around Jaganathpur, Keluapalli, Bakshipalli, Kalipalli, Barahaputi, Chatrapur and Agastinuagaon areas. In the field, these dunes are red in color and are termed as red sand deposits (may be equivalent of *Terri* deposits of Tamil Nadu). Around Kalipalli and Barhaputi areas, the upper surfaces of the palaeodunes have been hardened due to concentration of iron oxide forming duricrust. Near Kalipalli and Barahaputi areas the palaeodunes sustain coconut and cashew plantations whereas at other places these are barren. Older dune at Kallipalli with development of duricrust is given in figure-6. The different geomorphological zones in the area was studied[13]. The different geomorphological zones are given in figure-7.

Figure-6
Older dune (red sands) at Kalipalli with development of duricrust.

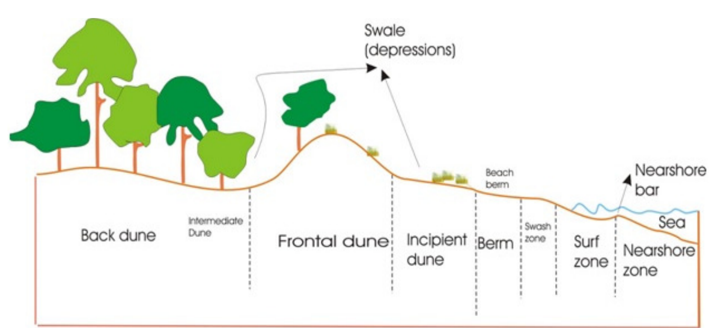

Figure-7
The geomorphological zones of a coastal dune system.

Table-1
Chemical parameters of groundwater from sand dunes

Location	pH	E.C.	T.H.	Na	K	Ca	Mg	CO_3	HCO_3	Cl	NO_3	F	SO_4
(A) Pre-monsoon													
Prayagi (Dug well)	8.41	570	163	51	4.2	28	22	24. 0	397	60	1.19	0.09	
Prayagi (Tube well)	8.53	588	170	51	1.9	22	28	18	31	113	0	0.01	
Dhabaleswar	8.17	1236	245	164	9.4	64	21	6	220	241	11	0.2	
(B) Post-monsoon													
Prayagi (Dug well)	8.39	780	205	71	8.11	30	32	0	262	104	1.83	0.1	6
Laudigaon (Dug well)	7.02	1313	365	99	6.63	96	30.4	0	61	355	27	0.27	
Kontiagarh (Dug well)	8.51	399	95	39	10	22	9.7	4.5	165	36	0.75	0.7	17

Importance of sand dunes: The sand dunes support different types of vegetation like cashew, casurina, kewra, mango, coconut etc. They act as the buffer zones between the sea and the landmass thus minimizing the destructive effects of cyclone, wave, tide and tsunami. Congenial geomorphologic, geologic and hydrodynamic conditions have favoured the accumulation of heavy minerals in sand dunes. The sand dunes of the Ganjam coast contain appreciable amounts of monazite, zircon, ilmenite, rutile and sillimanite. These heavy minerals are being exploited by the Indian Rare Earth Limited located at Gopalpur.

Anthropogenic impact on sand dunes: Because of easy availability of good quality sand, the dunes are indiscriminately mined for construction material. Further, due to their bountiful heavy mineral resources, the Indian Rare Earth Limited mining sands without replenishing back. As a result, the sand dunes suffer loss in dimensions and beach profile is imbalanced which may lead to coastal erosion and more damage to life and properties during cyclone, tsunamis etc.

Hydrogeology and hydrogeochemistry of sand dunes: The area adjacent to the coast slopes towards the sea. As a result, greater part of the rainfall is directly discharged into the sea. The coastal sand dunes, being made up of unconsolidated and well sorted sands, possess appreciably high porosity and permeability. These sand dunes form good repositories for storage of fresh groundwater and behave as typical phreatic aquifers. The groundwater from the sand dunes is exploited by both shallow tube wells and large diameter dug wells. The depths of dug wells vary from 6 to 9 m and in many instances, the depths of water columns are less than 4 m. Pumping tests in large diameter dug wells indicate that the drawdown is very high and the wells go dry within a few minutes. Since the sandy aquifers are highly permeable, the recuperation is also very quick[14].

The pH, EC, TH and concentration of major cations and anions of groundwater from selected sites are presented in table-1. The pH varies from 7.02 to 8.53, which indicate that the water is mostly alkaline in nature. The electrical conductivities from 399 to 1313 µs/cm suggest variation of chemical constituents in the water samples to a considerable extent. Total hardness of the water samples of the study area varies from 95 to 365 mg/l. On the basis of hardness values the waters are classified as moderately hard (75 to 150 mg/l) to hard (150 to 300 mg/l). Sodium is the dominant cation in the groundwater of the sand dunes and its concentration varies from 51–164 mg/l. Potassium content of the water samples of the study area varies from 1.9 to 10 mg/l. Greater concentration of Na is largely due to proximity of the sand dunes to the coastal environment while low concentration of K may be attributed to minimal effect of weathering of dune sand. The calcium concentration varies from 22 to 96 mg/l. Magnesium precipitates less rapidly than calcium and hence its concentration is usually less than that of Ca. In the study area the same pattern is followed and the Mg content of the groundwater samples of the study area varies from 9.7 mg/l to 34 mg/l. Chloride and bicarbonate are the dominant anions of the dune ground water. The concentration of chloride in the water samples varies widely from 36 to 355 mg/l and that of bicarbonate varies from 31 to 397 mg/l. The carbonate concentration varies from 0 – 24 mg/l and that of nitrate varies from 0 - 27 mg/l, which are well within the permissible limits. The fluoride content of the water samples varies from 0.01 to 0.70 mg/l, which is less than the desirable limit. The sulphate concentration of the water samples is much less, the highest being 17 mg/l.

Four ground water samples were plotted in Piper diagram. The different facies are1: (Na+K) - (Cl + NO_3), 2: (Na+K + Mg + Ca) - HCO_3, 3: (Na+K +Ca + Mg) - (Cl + NO_3),4: (Na+K +Ca + Mg) – (HCO_3). When water is fresh and electrical conductivity is less than 1000µs/cm facies is HCO_3 type. But when water is brackish and electrical conductivity is more than 1000µs/cm it is Cl + NO_3 type. Na + K are dominant cations and Cl or HCO_3 are dominant anions.

To study the hydrochemical evolution of ground water and correlation between different parameters 6(n) ground water samples are plotted as X-Y scattered plot in figure 8. Groundwater samples, when plotted for calcium vs nitrate show a positive correlation with regression coefficient (r^2) of 0 .967. Ca also shows positive correlation with chloride (r^2 = 0.93) and total hardness (r^2 = 0.931). Chloride show positive correlation with nitrate (r^2 = 0.88) and also with Total Hardness (r^2 = 0.90). Electrical conductivity shows positive correlation with chloride (r^2 = 0.88), calcium (r^2 = 0.83), Total Hardness (r^2 = 0.82), nitrate (r^2 = 0.70) and sodium (r^2 = 0.68). pH shows positive correlation with calcium (r^2 = 0.80), nitrate (r^2 = 0.95),Total

Hardness (r^2 = 0.80) and chloride (r^2 = 0.77). In the coastal saline enviornment chloride is high and in some ground water samples nitrate is high because it is contributed from roots of plants during fixation of nitrogen in soil.

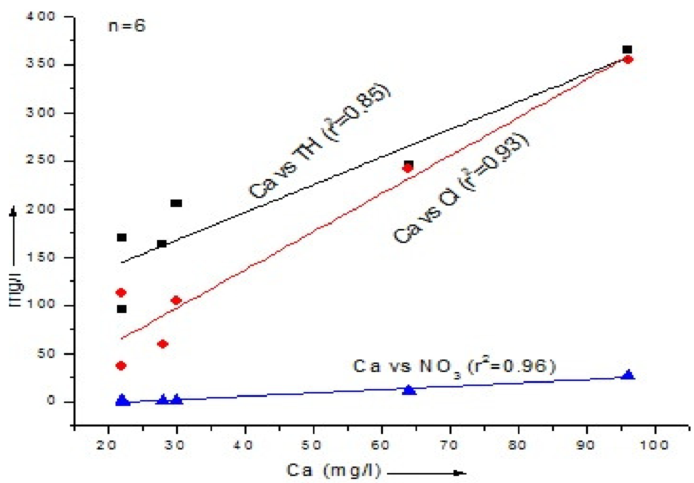

Figure-8a
Plot of Ca vs Cl, NO_3 and TH

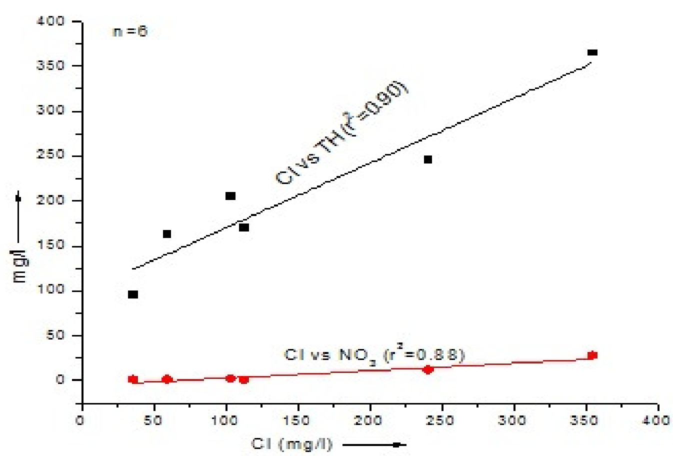

Figure-8b
Plot of Cl vs NO_3 and TH

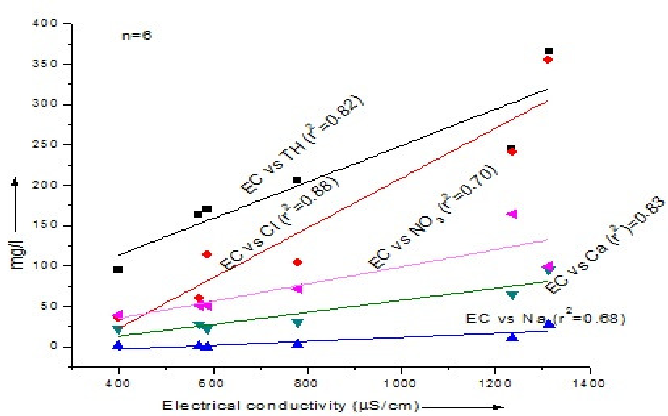

Figure-8c
Plot of EC vs Na, Ca, Cl, NO_3 and TH

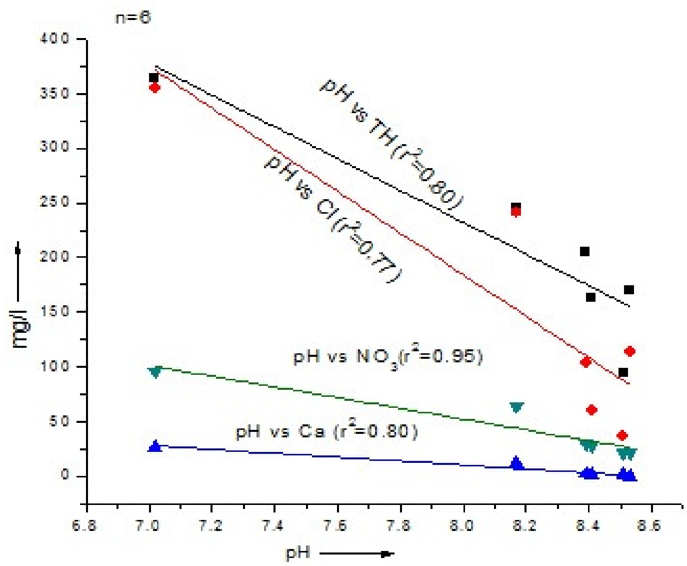

Figure-8d
Plot of pH vs Ca, Cl, NO_3 and TH

Conclusion

Due to existence of favourable conditions all the types of sand dunes mentioned above are seen in the Ganjam coast. Apart from supporting vegetation like cashew, casurina, kewra, mango, coconut etc, they act as the barrier zones in minimizing the destructive effects of cyclone, wave, tide and tsunami. The sand dunes also contain substantial amounts of heavy minerals like monazite, zircon, ilmenite, rutile and sillimanite. Due to high porosity and permeability, the sand dunes form good phreatic aquifers. The groundwater from the sand dunes is exploited by both shallow tube wells and large diameter dug wells. The groundwater is mostly alkaline, moderately hard to hard and fresh potable type. The fresh water in the sand dunes form the lifeline of the people adjacent to coast where availability of fresh , potable water is limited. Apart from sustaining different types of vegetation, the groundwater of the sand dunes caters to the need of population within coastal saline environment. Due to indiscriminate exploitation the sand dunes are in danger. This is to be taken into consideration for maintaining a balance in the coastal ecosystem.

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