

Remote Sensing Approach to Determine Net Shore Drift Direction—A Case Study along the Central East Coast of India

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ABSTRACT

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Thematic Mapper imageries of Landsat 5 are visually interpreted to determine long-term sediment transport direction also called net shore drift direction along central east coast of India. Two approaches are adopted while utilizing the remote sensing data for this purpose. Net shore drift direction is determined firstly by studying various coastal landform indicators and secondly by studying offshore turbidity distribution patterns. The results of both the approaches are compared and presented here. Landform indicators study suggests that shore drift direction is towards the southwest direction during northeast monsoon and towards northeast direction during southwest monsoon period. From offshore turbidity pattern, shore drift direction is determined as towards the southwest. Based on these studies and other related evidence, it is concluded that net shore drift direction is towards south-southwest. The present study demonstrates the capability of satellite remote sensing, which provides periodic, integrated and synoptic views, for determining net shore drift direction correctly, economically, and quickly.

ADDITIONAL INDEX WORDS: *Thematic Mapper, visual interpretation, sediment transport, landform indicators, littoral drift cell.*

INTRODUCTION

Qualitative understanding of net shore drift, as well as identifying areas of coastal erosion and sediment accumulation, is a prerequisite in many projects that deal with ports and harbors, fisheries, coastal protection, marine recreation, pollution control, land reclamation, etc. Waves generated in the deep ocean propagate into the near shore region and expend their energy on the coast causing suspension of sediments, generating long-shore currents and producing littoral sediment transport. Alongshore drift is the process by which sediment supplied to the margin of a landmass by sub-aerial and wave-induced erosional processes is transported parallel to the coast. Net shore drift transcends seasonal variations in shore drift directions and is defined as overall long-term direction of sediment transport along the shore (TAGGART, 1989).

Short-term studies of net shore drift are prone to errors. Investigations employing tracers or sediment traps over a few months time only record drift for that particular time frame; drift determinations based upon wave hindcasting and the construction of wave orthogonals are subject to

the vagaries of judgment and calculations of the investigators. Serious mistakes can be made by utilizing these methods without adequate verification of the geomorphology and sedimentology of the coastal stretch under consideration (SCHWARTZ *et al.*, 1985).

In the last two decades, efforts have been made to outline the advantages of geomorphic and sedimentologic indicators in determining net shore drift direction. Such investigations have been conducted by NODA (1974), SELF (1977), ENGSTROM (1978), FINKELSTEIN and SCHWARTZ (1981), FINKELSTEIN (1982), MORELOCK *et al.* (1985), SCHWARTZ *et al.* (1985), SCHWARTZ and ANDERSON (1986) and WALLACE (1988). Comprehensive accounts of salient principles and methods regarding the use of geomorphological and sedimentologic indicators of net shore drift have been succinctly summarized by JACOBSEN and SCHWARTZ (1981) and more recently by TAGGART and SCHWARTZ (1988).

As far as the Indian coast is concerned, few attempts have been made to determine the net shore drift, in general and along the Andhra State coast in particular. The distribution of longshore current velocities and sediment transport rates across the width of the surf zone off Paradeep Port have been evaluated by SUNDER *et al.* (1987)

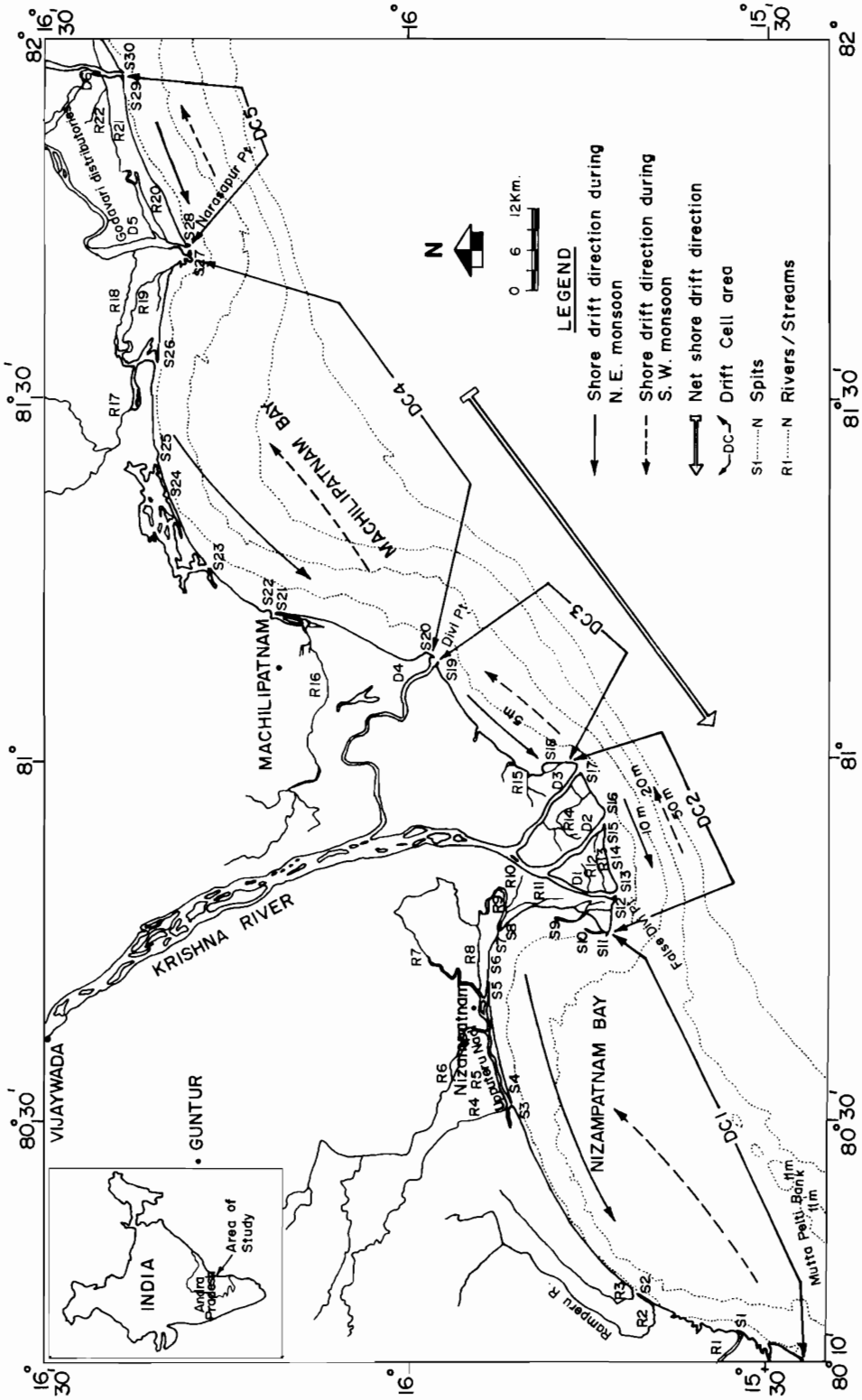


Figure 1. Map showing shore drift direction based on landform indicators.

using the model developed by KOMAR (1973). Wave-induced longshore sediment transport rates near Visakhapatnam Port, have been estimated by SARMA and REDDY (1988) using an energy flux method. PRAKASH and PRITHVIRAJ (1988) have studied seasonal longshore transport direction through grain size trends for the Quilon coast, Kerala. Based on the longshore energy flux equation, an empirical sediment transport model has been developed by CHANDRAMOHAN (1989) to study distribution of longshore sediment transport along the Indian coast.

In this paper, an attempt is made to demonstrate the utility of remote sensing techniques for determining net shore drift effectively and correctly. For this, Thematic Mapper imageries are interpreted visually to identify and map characteristic coastal landforms which are further used as indicators to determine shore drift direction. An attempt is also made to determine shore drift direction by studying offshore turbidity distribution patterns. Finally, net shore drift direction is determined based on these two approaches after considering other related oceanographic evidence.

Area of Study

The study area, a long coast line of about 320 km, is located along the central east coast of India in Andhra State and extends N-S between 15°25'N and 16°30'N latitude and E-W between 80°10'E and 82°00'E (Figure 1). The most important and durable wave generating winds are the northeast and southwest monsoons on the east coast. They strike the shore obliquely generating coastal currents, or drift. The fetch of the northeast monsoon that affects the east coast is about 1,500 km.

GEOMORPHOLOGICAL CHARACTERISTICS

Thematic Mapper (TM) imageries in 5 spectral bands (TM1-5) in scene D142-049 (dated 17 March 1985) (Figure 2) of Landsat 5 were collectively studied in an effort to better understand the geomorphological characteristics of the area. An hydrographic chart (No. 355) of the area was examined to study shallow water topographic features. The following coastal landforms and near-shore features (Table 1) were identified and mapped (Figures 3 and 4).

The area is mainly occupied by two crescent shaped bays (Nizampatnam and Machlipatnam) which are separated by a lobate-type prograded delta of the Krishna River. This river, which contains several channels and point bars

within the main channel, discharges its sediment load through four major distributaries (Figure 3). The maximum discharge (RAO *et al.*, 1988) of the river is 1,027 m³/sec. The contribution of the suspended load at Vijaywada anicut is estimated as 156.5 × 10⁶ m³/year. The main channel and distributaries have developed natural levees bordering their channels. The levees project far into the sea giving the delta a 'bird foot' characteristic. While more growth has occurred on the western side of the delta, it is this side that still is submerged during high tide leaving behind only elevated portions as an offshore bar. The width of the shelf break of this delta is narrow compared to the bays on the adjacent sides. This is probably due to the advancement of the delta.

The northwest part of the Nizampatnam Bay is quite shallow—up to 11 meters in depth—while the seabed of the bay is gently sloping or nearly flat between the 10 and 20 meter depths, whereas in the southern part of the bay, large number of banks and shoals exists between the 10 and 20 meter depths. Machalipatnam Bay is somewhat deeper than Nizampatnam Bay and has a more gently sloping bottom. Large spits and spit bars are developing on either side of delta. The progradation of delta is taking place due to the development of sandbars and spits and consequently a filling of the lagoonal areas is occurring (RAO *et al.*, 1988).

Two distributaries of the Godavari River are situated in the northeast part of study area. The onshore area is almost flat with a gradient of less than 10° and is devoid of headlands or offshore islands. It is noted from imageries that drainage density of the area is low. Some rivers like the Upputery Nadi flow along the coast for considerable distances before opening into the sea (Figure 3). The mouth of the majority of the rivers is seen diverted because of spit formation.

Several abandoned river channels are located in the Krishna delta and can be recognized by their dark gray tone against the lighter background (Figure 2). The channels are oriented nearly perpendicular to the general shore line. Gray toned low lying areas fringing the coast line and occupied by stagnant water and mangroves are interpreted as swamps. Tidal flats are mainly located on the lobes of Krishna delta. Bright-toned thick linear patches occupying seaward position of the delta are recognized as delta front sands. A thin bright-toned ribbon lining the coast is recognized as sandy beaches on the TM imageries.



Figure 2. Thematic Mapper picture of the study area.

Table 1. Coastal landforms and nearshore features.

Coastal Landforms		
Fluvial	Marine	Offshore Features
Drainage	Swamps	Banks/shoals
River delta	Tidal flat	Wave pattern
Delta front sand	Mangroves	Suspended Sediment plumes
Abandoned channels	Lagoons	
	Beaches	
	Spits	
	Paleo-beach ridges	

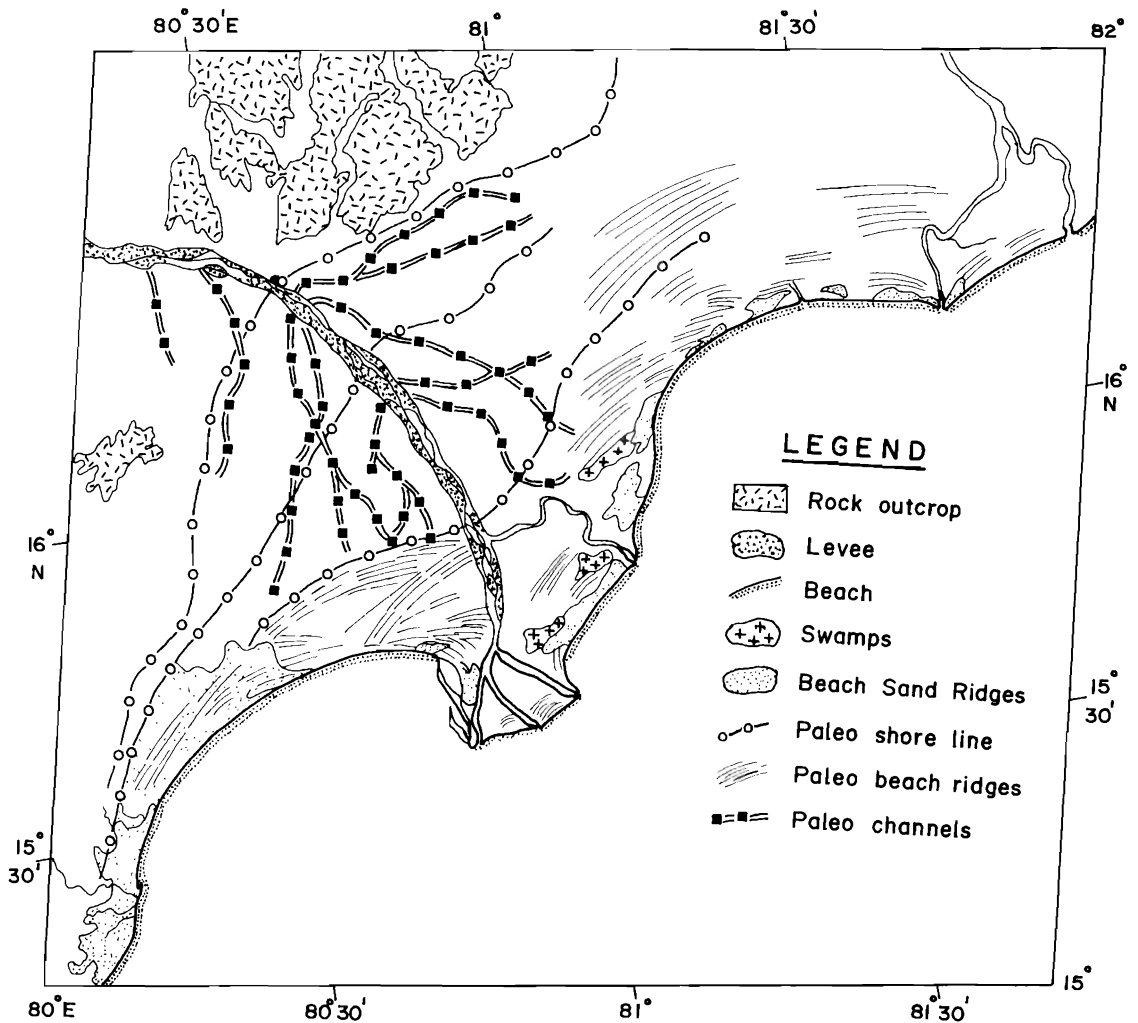


Figure 3. TM overlay showing geomorphic landforms.

These beaches at many places are backed by mud flats (gray tone), lagoons (dark tone), tidal flats, creeks, etc. Crescent shaped, light-toned, thin lines oblique or near parallel to the shore line are located on the image and these are interpreted as paleo-beach ridges (Figure 3).

SHORE DRIFT DIRECTION DETERMINATION

Net shore drift is the direction in which sediments are transported along the shore over a period of years in spite of short-term seasonal trans-

port in the opposite direction (TAGGART and SCHWARTZ, 1988). Shore drift directions may change from one coastal sector to the next due to the variations in coastal orientation and nearby oceanographic conditions. Each coastal segment with a particular shore drift direction forms a discrete unit called a 'drift cell'. Based on the irregularities of coastline, five drift cells are identified in the study area. They are marked as DC1 to DC5 on the map (Figure 1). Each drift cell consists of three broad zones: the zone of sediment supply, the zone of transport, and the zone of

accumulation. Demarcation between these zones is not very clear, but zones are merging into one another along the shore.

As net shore drift direction is the result of all shore drift directions, it is necessary to understand shore drift within each drift cell. Since the shore drift is variable with or in respect to direction, time, place, duration and amount, the task of determining the shore drift requires the use of a methodology that will take these variables into consideration. The following two methods have been used for determining net shore drift in the study area.

Using Coastal Landform Indicators

Coastal landforms respond to all the variables of shore drift during their course of formation and hence these landforms can be considered the most reliable of long-term shore drift indicators. Their shape, size, form, pattern, development and their location, orientation, and association with other landforms are important in the study of the determination of shore drift direction.

Several shore drift indicators like beach width, sediment size gradation, beach slope, bluff morphology, headland-bay beaches, structures interrupting shore drift, stream mouth diversions, inlet migrations, spit growth, identifiable sediment, plan configuration of delta and inlet fans, beach pads and nearshore bars are reported in literature. Since the aim of the present study is to demonstrate the utility of remote sensing techniques, only limited but definite landform indicators which can be clearly mapped by remote sensing technique are considered. Two indicators, *viz.* shifting of river courses and paleo-beach ridges, which are not previously reported in literature are also used. These indicators and their utilizations are described below:

- (a) Beach Width: Beach width within a drift cell increases in the downdrift direction (TAGGART and SCHWARTZ, 1988). Within the narrow beaches of the study area, comparatively speaking, the major number of the wide sectors are located in the southern sector of Nizampatnam and Machlipatnam on either sides of delta and on the delta front.
- (b) Stream Mouth Diversions: As sediment is transported to the updrift side of a stream mouth, the stream discharge erodes and moves the sediment in the nearshore zone. If the volume of sediment accumulating on the updrift side of the stream exceeds the stream's capacity to remove it, the stream will become progressively offset in the direction of net shore drift (TAGGART and SCHWARTZ, 1988). In the study area, several stream mouths are seen to be diverted. The mouth of the streams R1, R2, R3, R4, R6, R15, R16, R17, R22, *etc.* are diverted towards the northeast whereas the mouth of the streams R8, R9, R10, R11, R12, R13, R18, R19, *etc.* are diverted towards the southwest (Figure 1).
- (c) Inlet Channel Migration: The inlet channel migration is similar in principle to what takes place in a stream mouth diversion. In this case, the channel connecting the estuary or lagoon with the open ocean migrates in the direction of shore drift. Creeks and channels like R5, R20, R21, *etc.* are migrating towards the northeast or southwest (Figure 1).
- (d) Shifting of the River Course: In the normal deltaic evolution, as the delta progrades further and further into the sea, the gradient and carrying capacity of the river gradually decreases and shorter routes to the sea are sought out. This causes a shift of the river courses into successive distributaries, which correlates with the direction of net shore drift. On the basis of the orientation of paleo-beach ridges and paleo channels, it is inferred that during its evolutionary stages, the Krishna River has shifted its course a few times in the past (BAPU, 1975). The direction of the river mouth shift was from distributaries d4 to d1; *i.e.*, towards a southwesterly direction.
- (e) Spit Growth: A spit is a sediment embankment attached to the shore at its 'root' and terminating in open water at its distal end. These are depositional features that develop where there is a marked change in coastal orientation. They form in response to wave action and prograde in the direction of net shore drift (TAGGART and SCHWARTZ, 1988). In the study area, nearly 30 spits/spit bars are located. In Figure 1, they are marked as S1, S2, *etc.* Most of the spits have developed across the river/stream mouth. It is observed in the imagery that 3 spits at the southwestern tip and one large spit at northwestern tip of the delta have formed. Various other locations of the spits are shown in Figure 1. Vegetation covering some of the spits (S9, S10) attests to their stability.
- (f) Plan View of Deltas: These depositional fea-

tures associated with the stream mouth can act as an obstacle to net shore drift in a fashion similar to that of a groin or jetty. The net shore drift of sediment along the shore tends to accumulate on the updrift side of the delta (TAGGART and SCHWARTZ, 1988). In the study area, the Krishna delta is acting as an obstacle to the net shore drift. It is noticed in the imagery that on both sides of the delta, sediments are accumulating. Development of spits on both sides of the delta supports this fact. This uneven process of sediment accumulation is modifying the delta geometrically so that it appears asymmetrical in plan view. The western part of the delta is the area exhibiting major growth.

- (g) **Paleo-Beach Ridges:** The multiple lines of beach ridges are formed under prograding conditions. The retrograding shore line may cut back at an angle to the previously formed ridges; and, if there is renewed progradation, this coastal revision is preserved in the form of an angular discontinuity between the direction of the older and younger ridges. Paleobeach ridges indicate changes in the orientation of former shore lines. An established trend can be determined which in turn is useful in understanding shore drift direction. In the study area, the successive paleo-beach ridges (light toned) are seen separated by what is likely to be plains of silt or clay (dark tone) indicating alternate phases of sedimentation. Complicated patterns of intersecting and diverging beach ridges located at some places are probably indicative of change in shore drift direction in the past.

In addition to the above landform indicators, orientation and location of shallow water topography features like banks and shoals can also be used in determining shore drift direction. Terrestrial sediments discharged by the Krishna River during the monsoonal months are transported towards the west by diverging currents. Part of the sediments are transported directly towards the north which contributes to the widening of the delta westward while the rest of the sediments are diverted towards Nizamapatnam Bay. Weak local currents in the bay allow suspended sediments to settle leading to the formation of extensive shoals and banks (Figure 1) shifting the 20 meter contour line seawards. The orientation and location of the banks and shoals with respect to

river, which is major source of sediment supply, suggests drift direction towards south-southwest.

Based on the study of landform indicators, shore drift direction in each cell is identified and marked on a map (Figure 1).

Off-Shore Turbidity Distribution Pattern Study

Shore drift causes churning and subsequent transportation of submarine sediments along with suspended sediments discharged by rivers causes turbidity in nearshore waters. These turbid water masses are distinctly seen on the Thematic Mapper imageries. The first band of TM imagery (Figure 2) has provided a clear synoptic view of turbid water masses which helps in understanding distribution, variation and dispersion of these masses.

Based on tonal and textural variation, five distinct types of water masses are identified qualitatively: (1) highly turbid water, (2) moderately high turbid water, (3) turbid water, (4) less turbid water and (5) clear water. These are, of course, related to the concentration of suspended sediments. The highest concentration of suspended sediments occurs in the highly turbid water while the minimal is reflected by clear water. Highly turbid water masses are seen off Krishna delta to the north and at Machalipatnam Bay in the nearshore area. A reduction in turbidity is seen on the seaward side. Tonal variation in Nizamapatnam Bay indicates high to low gradation in turbidity from northeast of the bay towards the southwest. A sediment plume in the northeastern part of the bay is seen bifurcating into finger-shaped plumes, pointing southwestwards. These finger-like plumes have indentations on the southern margin while the northern margin is plain and curved. The plumes are seen slowly diminishing towards the southwest. An almost uniform, moderately high turbid water band is seen encircling the delta towards the seaward side. Moderately high to high turbid water masses are located near the shore area covering more of an area of the south Machalipatnam Bay than to the north. Sediment plumes in the south bay are seen bifurcating and extending northeastwards.

Upon close observation of the imagery, parallelly arranged alternate gray and dark curvilinear bands are located over the deep sea region. This pattern is interpreted as deep sea ocean waves. Similar patterns observed at various locations are marked and numbered on the map.

Directions of propagating waves are shown by arrows (Figure 4).

Based on the above study of tonal, textural variation, direction of propagation of waves and dispersion pattern of the sediment plumes, local current direction, shore drift direction and net shore drift direction are determined and marked on an offshore turbidity distribution map prepared by overlaying on the TM imagery (Figure 4).

RESULTS AND DISCUSSION

Northeasterly and southwesterly monsoonal winds are striking the shore obliquely and generating coastal currents and drift. Southwesterly monsoons motivate drift towards a northeasterly direction during June to September, whereas, northeasterly monsoons are responsible for the southwestwards drift during October to January. Evidence obtained from the above study of landform drift indicators suggests that all drift cells in the area have shore drift directions towards both the northeast and southwest which are coincident with monsoonal drift. Hence, it is evident that during the southwest monsoon period, shore drift direction is towards the northeast, whereas during the northeast monsoon period, it is towards the southwest.

Based on numerical modeling of wave data (CHANDRAMOHAN, 1988), annual rate and direction of longshore sediment transport is computed as $0.222 \times 10^6 \text{ m}^3/\text{year}$ towards north and $1.28 \times 10^6 \text{ m}^3/\text{year}$ towards south at Nizampatnam whereas at Machlipatnam, it is $0.502 \times 10^6 \text{ m}^3/\text{year}$ towards north and $-0.44 \times 10^6 \text{ m}^3/\text{year}$ towards south. Chandramohan's study suggests that the longshore transport direction is towards the north along the east coast from April to September, towards the south from November to February, and is variable in March and October which also supports the above finding.

Though each drift cell indicates drift direction towards both the northeast and southwest based on the orientation of paleo-beach ridges, shifting direction of Krishna distributaries, spit growth direction, beach width and plan view of delta, net drift direction is confirmed as towards the south to southwest.

Studies based upon observed currents and the estimated directions of the nearshore currents using wave refraction diagrams clearly indicate that sediment discharged by the main branch of the Krishna River flows into the Nizampatnam Bay throughout the year (VARADARAJULU, 1985) which

clearly suggests net drift direction towards the south to southwest.

Turbidity pattern distribution study for TM images acquired during successive months for two or three consecutive years should be carried out to confirm the accurate net drift direction of the study area. The turbidity distribution pattern exhibited by TM imagery is for the month of March, 1985, as these features are detected by remote sensing during same month. Nevertheless, present turbidity pattern distribution study also supports the same net shore drift direction.

The rate of accretion or the erosion at the Machlipatnam beaches obtained through beach profile monitoring at 6 transects, between February 1978 to 1982, shows that average eroded volume is $58.6 \text{ m}^2/\text{m}$ whereas average deposited volume is 118.9 m^2 and, hence, the sediment budget between 1978–1982 is 107.8 m^2 . This indicates the accretionary nature of the beach (CHAUHAN, 1990).

Based on sedimentary characteristics of these beach ridges, the ages are reported to be 6,500, 4,700, 3,600, and 2,450 years B.P., respectively. The entire coast has prograded at an average rate of $3.34 \text{ m}/\text{year}$ whereas the present rate of progradation is about $0.58 \text{ km}^2/\text{year}^{-1}$ since 1928 (RAO *et al.*, 1990). This implies the dominance of terrestrial geomorphic processes over marine processes in shore building. Though strong and durable monsoonal winds prevail in the study area, the magnitude of the shore drift is found to be weak at first since they strike nearly parallel or slightly oblique to the coast. Further, the orientation of the coast is such that the mainland causes a lee effect on the study area with reference to the monsoonal winds.

Qualitatively higher shore drift indicated by turbidity distribution patterns in the weak energy zone is probably due to (1) silt and clay which is present over the offshore seabed remains in suspension for a longer time, and (2) depth exerts an influence on the tone of the turbid water masses.

Based on the above shore drift study, it is expected that in the future the Krishna delta will prograde seawards, but at the same time, both of the banks of the delta will spread laterally until adjacent bays are filled with sedimentation. Eventually, the shore will align itself parallel to the direction of the resultant monsoonal winds.

From the above study, it is concluded that: (1) TM data can be effectively used in identifying and mapping coastal landforms. (2) Study of

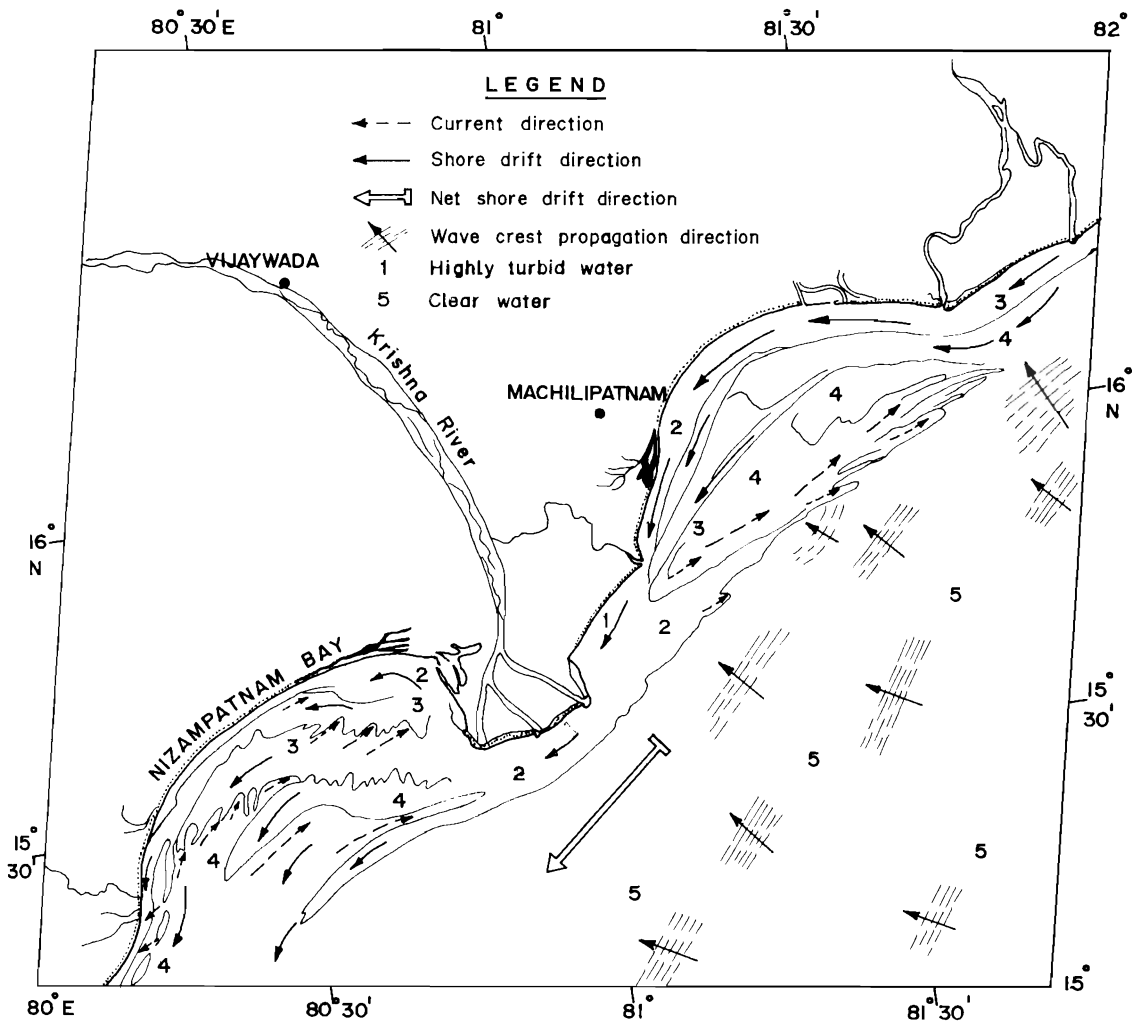


Figure 4. TM overlay showing offshore turbidity distribution patterns and drift directions.

coastal landforms and offshore turbidity distribution patterns is of immense value in determining shore drift as well as net shore drift direction. (3) Though each drift cell indicates drift direction towards both the northeast and the southwest, net drift direction in the study area is towards the south to southwest.

In short, the current study demonstrates the capability of satellite remote sensing to provide a periodic, integrated and synoptic view in determining net shore drift direction correctly, economically, less laboriously and in short time.

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