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Application of Longshore Transport Equations to the Andhra Coast, East Coast of India

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ABSTRACT

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Ship-reported waves published in the Indian Daily Weather Report are compiled for a period of 16 years and are used for the estimation of the longshore transport rate. Using the two well known longshore transport equations, viz., the Shore Protection Manual equation and the Komar and Inman equation, the longshore transport rate at Visakhapatnam beach is computed and the values are compared with earlier studies. Based on the inference that the Shore Protection Manual equation yields a better estimate for this region, the same equation is used for the estimation of the longshore transport rate along the Andhra coast. This study shows that the general direction of longshore transport is towards northeast during March to October and southwest during November to February. The longshore transport rate is high during the southwest monsoon period from June to September. A higher sediment transport rate is observed for the coastline oriented at 80 degrees east of north. The annual net transport is found to be quite low at the coastal segments near Ramaypatnam, Machilipatnam and Sacremento Light House, whereas it is found to be high near Nizampatnam, Gollapalem and Narasapur.

INTRODUCTION

The Andhra coastline is about 750 km long forming the middle part of the east coast of India (Fig. 1). The coastline in this region is characterised by open sandy beaches, sand bars, spits, bays and river mouths. It has one major port at Visakhapatnam and one minor port at Kakinada. Two major rivers, Krishna and Godavari, transport considerable loads of sediments to the sea which nourish the sandy beaches. The formation of a 15 km long sand bar north of the Godavari river mouth is a distinct feature in this region giving protective shelter for the Kakinada Port. The rich fish potential of this region accounts for a tremendous scope of the development of fishing harbours at Kalingapatnam, Bhimunipatnam, Narasapur, Machilipatnam and Nizampat-

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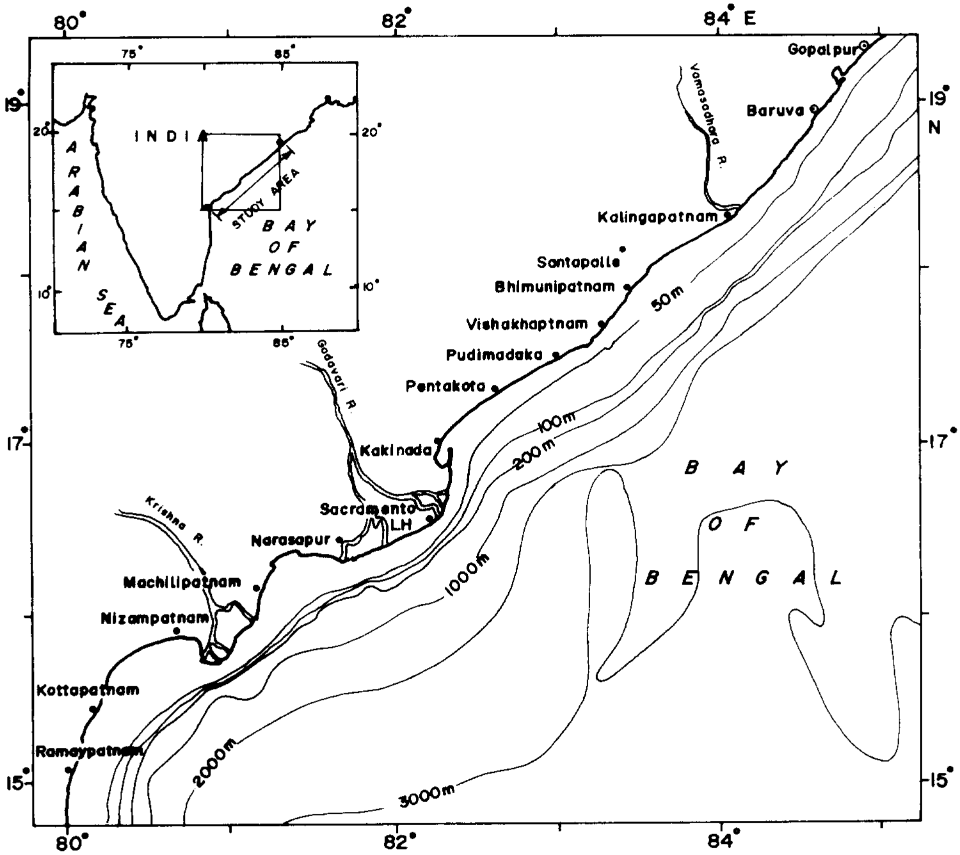

Fig. 1. Location map.

nam. The climatic conditions along this region are influenced by three seasons viz., the southwest monsoon from June to September, the northeast monsoon from October to January and a non-monsoon period from February to May. Apart from vagary monsoons, the Andhra coast is subjected to attacks of cyclones which occur increasingly in the months October to February in the Bay of Bengal. Assessment of the littoral environment for the Andhra coast has not been attempted so far except for a small stretch at Visakhapatnam.

In the present study, ship-observed waves are compiled from the Indian Daily Weather Report for the years 1968 to 1983 and are used as input data for the estimation of the longshore transport rate. Using the Shore Protection Manual equation and the Komar and Inman equation, the longshore transport rate at Visakhapatnam beach is computed and compared with available earlier studies reported for this area. Identifying that the Shore Protection Manual equation estimates better for Visakhapatnam beach, the same equation is used for estimating the longshore transport rate for the entire Andhra coast.

LONGSHORE TRANSPORT EQUATIONS

Longshore transport is commonly computed by means of an empirical equation relating the longshore energy flux in the breaker zone with the longshore transport rate. The general form of the equation is expressed as,

$$S = K P_1 = K(E\,C_n)_b \cos\alpha_b \sin\alpha_b \tag{1}$$

where S = longshore transport rate, K = constant, P_1 = longshore energy flux, $(E\,C_n)_b$ = wave power in the breaker zone and α_b = breaker angle.

Different investigators have proposed different values for the constant K in the empirical eqn. (1) which are listed in Table 1. Based on eqn. (1), the longshore transport rate expressed in immersed weight rate is given by,

$$I_l = K P_l \tag{2}$$

where I_l = immersed weight rate of longshore transport.

The above equation in immersed weight form has the advantage that it is in

TABLE 1

Variation of constant K in different longshore transport equations

Investigator	K	Type of H	Remarks
1. Watts (1953)	0.9	H_s	Immersed weight rate transport, $I_l = K \times P_l$. I_l and P_l can be any systems of units.
2. Caldwell (1956)	0.76	H_s	-do-
3. Moore and Cole (1960)	0.25	H_s	-do-
4. Inman and Frautschy (1965)	0.25	H_{rms}	-do-
5. Komar and Inman (1970) (Silver Strand, California)	0.77	H_{rms}	-do-
6. Komar and Inman (1970) (El Moreno, California)	0.82	H_{rms}	-do-
7. Bruno and Gable (1976)	1.61	H_{rms}	-do-
8. Hou, Lee and Lin (1980)	0.55	H_{rms}	-do-
9. SPM (1975)	1288	H_s	Volume rate of transport, $Q = K \times P_{ls}$ where Q = m^3/year, P_{ls} = Watts/m.

a non-dimensional form and any system of units can be used for the calculation. Though there is a vast inconsistency in determining K, the value of 0.77 proposed by Komar and Inman (1970) for Silver Strand Beach, California has widely been accepted as it was derived from extensive field data collected using better measurement techniques. Thus, eqn. (2) after Komar and Inman (1970) is given by,

$$I_l = 0.77\ (E\,C_n)_b \cos\alpha_b \sin\alpha_b \tag{3}$$

The immersed weight rate is related to volume rate of transport as

$$Q = I_l/(\rho_s-\rho)g(1-p) \tag{4}$$

where ρ_s = sediment density = 2650 kg/m^3, ρ = sea water density = 1025 kg/m^3, g = acceleration due to gravity = 9.81 m/s^2 and p = sand porosity = 0.4.

By considering the shallow water approximations (Wiegel, 1964):

$$n = 1 \tag{5}$$

$$C = (g\,d_b)^{0.5} \tag{6}$$

$$d_b = 1.28\,H_b \tag{7}$$

where d_b = depth of wave breaking and H_b = breaker height.

Using eqns. (3), (5), (6), (7) in eqn. (4),

$$Q = 365\times1.55\times10000(H_b^{2.5})\sin 2\,\alpha_b \tag{8}$$

where Q = volume rate of longshore transport in m^3/yr and H_b = root mean square breaker height in m.

In the Shore Protection Manual (1975), the volume rate of longshore transport is related to the longshore energy flux factor as,

$$Q = 1288\,P_{ls} \tag{9}$$

where Q = volume rate of longshore transport in m^3/yr and P_{ls} = longshore energy flux factor in watts/m computed using significant wave height (H_s).

By linear wave theory (Shore Protection Manual, 1975), the longshore energy flux factor is given by,

$$P_{ls} = \rho\times g\times g\times T(H_o\times K_r)^2 \sin 2\,\alpha_b/64\pi \tag{10}$$

where H_o = deep water significant wave height, T = wave period and K_r = refraction coefficient.

Using eqn. (10) in eqn. (9),

$$Q = 1288\rho\times g\times g\times T(H_o\times K_r)^2 \sin 2\,\alpha_b/64\pi \tag{11}$$

The volume rate longshore transport equation, eqn. (8), based on Komar and Inman's (1970) immersed weight equation and the Shore Protection Manual equation, eqn. (11), are considered in the present study. The above two equations are basically the same and they differ in coefficients and the types of wave parameters used either at breaking or at deep water. According to the coefficients assigned, they are referred to as the Komar and Inman equation and Shore Protection Manual equation, respectively, in order to distinguish them in the text of the paper.

WAVE DATA BASE

The India Meteorological Department compiles the daily synoptic observations over the Indian region and makes it available to users in the form of Indian Daily Weather Reports (IDWR). The information includes visual wave observations reported every day by merchant ships passing along the Indian region. This wave information is reported by codes of wave heights in half metres from 0 to 4.5 metres, periods in classes of one second from 5 to 14 seconds and direction in ten degrees from 10 to 360 degrees. The grid bounded by latitudes 80°E and 85°E and longitudes 15°N and 20°N is considered (see Fig. 1) and the ship-reported waves documented in the Indian Daily Weather Report for this grid from 1968 to 1983 are compiled and stored on magnetic tape. About 560 data points are thus obtained, each one representing a particular wave height, period and direction. As most ship reports are from deep water, the waves are considered as deep water waves. The visual estimate by a trained observer normally fits to the significant wave height. The direct use of visually observed wave height as significant wave height is justified for most applications (Jardine, 1979). The ship-reported visual wave heights are con-

TABLE 2

Percentage distribution of H_0 and T during fair weather season (February–May)

T(sec) H(m)	5	6	7	8	9	10	11	12	13	14	Sum T
									Calm (%)		8.1
0.5	10.1	2.7	1.4	0.0	0.0	2.0	1.4	0.7	0.0	2.0	20.3
1.0	18.2	8.1	1.4	0.0	1.4	1.4	0.7	1.4	0.7	2.7	35.8
1.5	6.1	2.0	2.0	1.4	0.0	0.7	0.7	0.0	0.7	0.7	14.2
2.0	2.7	2.0	0.7	2.0	0.0	2.0	0.7	0.0	0.0	2.0	12.2
2.5	1.4	2.7	0.7	2.0	0.0	0.7	0.0	0.0	0.0	0.0	7.4
3.0	0.0	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.0	0.0	1.4
3.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4.5	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.7
Sum H	38.5	17.6	6.1	6.8	2.0	6.8	3.4	2.0	1.4	7.4	100.0

sidered here as deep water significant wave heights and they are used as input data for the estimation of the longshore transport rate in the present study, i.e.

$$Q = \sum_{H_o=0}^{H_o=\infty} \sum_{T=0}^{T=\infty} \sum_{\theta=0}^{\theta=2\pi} Q(\mathrm{t}) \times f(H_o,T,\theta) \tag{12}$$

where Q = total longshore transport, $Q(\mathrm{t})$ = longshore transport due to a specific wave height, period and direction and $f(H_o,T,\theta)$ = the frequency of occurrence of a specific wave height, period and direction.

TABLE 3

Percentage distribution of H_o and T during southwest monsoon (June–September)

T(sec) H(m)	5	6	7	8	9	10	11	12	13	14	Sum T
									Calm(%)		3.9
0.5	2.2	0.0	0.0	2.2	0.6	0.0	0.6	1.1	0.0	0.0	6.7
1.0	4.4	1.7	1.1	2.2	1.7	1.1	0.6	1.7	0.6	0.0	15.0
1.5	2.2	2.8	2.8	3.3	0.6	1.1	0.6	0.0	1.1	0.0	14.4
2.0	5.6	5.6	2.2	3.9	1.1	0.0	1.1	1.1	0.0	0.6	21.1
2.5	4.4	3.9	2.8	3.9	0.6	1.7	0.0	0.0	0.6	0.0	17.8
3.0	1.1	0.6	1.7	2.8	1.7	0.6	0.6	0.0	0.0	0.6	9.4
3.5	0.6	0.0	0.0	3.3	0.0	0.6	0.0	0.0	0.0	0.0	4.4
4.0	1.7	0.0	0.6	0.6	0.0	1.7	0.6	0.0	0.0	0.0	5.0
4.5	0.0	0.0	0.6	1.1	0.0	0.6	0.0	0.0	0.0	0.0	2.2
Sum H	22.2	14.4	11.7	23.3	6.1	7.2	3.9	3.9	2.2	1.1	100.0

TABLE 4

Percentage distribution of H_o and T during northeast monsoon (October–January)

T(sec) H(m)	5	6	7	8	9	10	11	12	13	14	Sum T
									Calm(%)		8.3
0.5	4.5	2.6	2.6	0.6	0.0	1.3	0.0	1.3	0.6	1.3	14.7
1.0	13.5	6.4	4.5	1.3	0.0	1.9	0.0	1.9	1.3	2.6	33.3
1.5	7.7	3.2	0.6	1.9	0.0	0.6	1.3	0.0	1.9	0.6	17.9
2.0	1.9	2.6	3.2	0.0	0.0	0.0	0.6	0.6	0.0	3.2	12.2
2.5	1.3	0.6	1.3	0.6	0.6	0.0	0.0	0.0	0.0	0.6	5.1
3.0	0.6	0.0	1.9	1.9	0.0	0.0	0.0	0.0	0.0	0.0	4.5
3.5	0.6	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	1.3
4.0	0.0	0.6	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3
4.5	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3
Sum H	31.4	16.0	14.7	7.1	0.6	3.8	1.9	3.8	3.8	8.3	100.0

The percentage distribution of wave height and period grouped from the 560 numbers of ship reported waves for the three seasons viz., non-monsoon (February to May), southwest monsoon (June to September) and northeast monsoon (October to January) are presented in Tables 2, 3 and 4, respectively. It would be important to mention here that the ship reported waves are in general biased towards unequal weather and the observations are made with simple means leading to only a fair estimate. Since the instrumentally recorded waves are sparse and discontinuous along the Indian coast, the use of such ship-reported waves compiled for a longer duration would satisfy for the longshore transport analysis.

BREAKING WAVE CHARACTERISTICS

The ship reported wave data used in the present study are treated as deep water wave characteristics (H_o, T, α_o). The breaker angle (α_b) is obtained using the approximate relationship (Le Méhauté and Koh, 1967),

$$\alpha_b = (0.25+0.55H_o/(g\times T\times T/2\pi))\alpha_o \tag{13}$$

where α_o = deep water wave direction.

The breaker height (H_b) is given by,

$$H_b = K_s \cdot K_r \cdot H_o \tag{14}$$

where K_s and K_r are shoaling and refraction coefficients respectively.

By small amplitude wave theory,

$$K_s = (C_o/2nC)^{0.5} \tag{15}$$

For deep water,

$$C_o = gT/2\pi \tag{16}$$

Using eqns. (5), (6), (7) and (16) in (15),

$$K_s = 0.4697(T^{0.5}/H_b^{0.25}) \tag{17}$$

The present study is intended to compare the values estimated by the Shore Protection Manual equation and the Komar and Inman equation and it is seen that in the formulation of the Shore Protection Manual equation (Shore Protection Manual, 1975), only the effect of refraction is considered for deducing the breaker heights as, $H_b = H_o \cdot K_r$. In order to maintain the identical approach while computing the breaker height values for Komar and Inman equation, the shoaling coefficient (K_s) is taken as 1.0.

For simplicity, assuming the contours are straight and parallel, the wave refraction follows Snell's law (Svendsen and Jonsson, 1976),

$$K_r = (\cos\alpha_o/\cos\alpha_b)^{0.5} \tag{18}$$

LONGSHORE TRANSPORT RATE AT VISAKHAPATNAM BEACH

Visakhapatnam is a major port city situated along the Andhra coast (Fig. 2) and some studies had been carried out earlier by different authors on the longshore transport characteristics along this beach (Saxena et al., 1976; Sastry et al., 1979; Reddy et al., 1984). Saxena et al. (1976) have reported a northeasterly transport of 0.88×10^6 m^3 and a southwesterly transport of 0.18×10^6 m^3 in a year along this beach. Though the type of data and the equation adopted in the estimation are not explained, the above authors have carried out the hydraulic model studies for the Visakhapatnam outer harbour based on their estimated longshore transport rate and accordingly the outer harbour has been constructed. Subsequent to the development of the outer harbour by the construction of new breakwaters, the harbour authorities are bypassing 0.45×10^6 m^3 of sand from March to September for nourishing the down drift beach on the northern side of the breakwater. Later studies by Sastry et al. (1979) and Reddy et al. (1984) had indicated that the sand bypassing rate is insufficient and the down drift Visakhapatnam beach continues to show an annual net erosional trend. Based on visual monthly average breaking wave characteristics, Chandramohan and Ranganatha Rao (1985), estimated an annual transport of 0.81×10^6 m^3 in northeasterly direction and 0.26×10^6 m^3 in southwesterly direction.

In the present study wherein ship reported waves are used, the estimation based on Shore Protection Manual equation, eqn. (11), indicates that the annual longshore transport rate along Visakhapatnam beach is 0.851×10^6 m^3 in a northeasterly direction and 0.323×10^6 m^3 in a southwesterly direction. In the case of the Komar and Inman equation, eqn. (8), it is 1.124×10^6 m^3 in a northeasterly direction and 0.422×10^6 m^3 in a southwesterly direction.

Referring to Table 5 and comparing the present estimates with the earlier studies reported for the Visakhapatnam beach, it is observed that the values

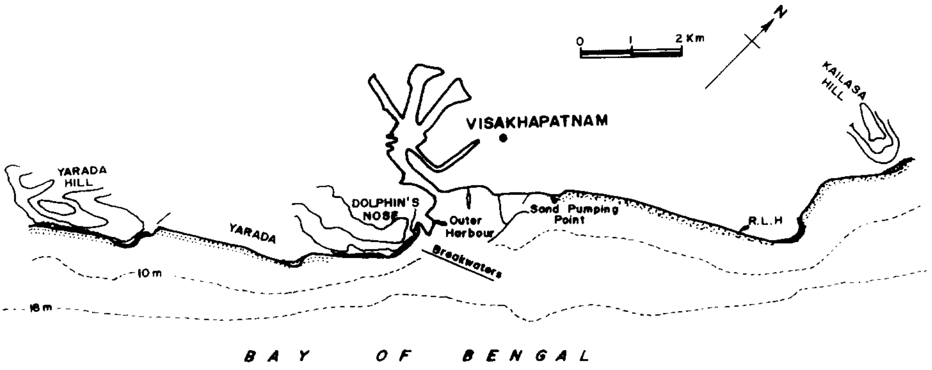

Fig. 2. Visakhapatnam coastline.

TABLE 5

Longshore transport along Visakhapatnam beach

	SW drift ($10^6 m^3/yr$) (Nov–Feb)	NE drift ($10^6 m^3/yr$) (March–Oct)	Gross drift ($10^6 m^3/yr$)	Net drift (NE) ($10^6 m^3/yr$)
Present study				
Eqn. (8)	0.422	−1.124	1.546	−0.702
Eqn. (11)	0.323	−0.851	1.174	−0.528
Earlier studies				
Saxena et al. (1976)	0.180	−0.880	1.060	−0.700
Chandramohan and Ranganatha Rao (1985)	0.260	−0.810	1.070	−0.550

obtained by the Shore Protection Manual equation lie close whereas the Komar and Inman equation estimates values about 30 per cent higher. Here again the reliability of the earlier studies is not well guaranteed as none of them is based on any extensive field observations. However, the values reported by Saxena et al. (1976) and Chandramohan and Ranganatha Rao (1985) are being considered as representative for practical applications.

Several discussions have already appeared on the selection of the ideal equation for the longshore transport computation (Graff and Overeem, 1979; Willis, 1980) and in the present case, where ship-reported wave data have been used as input, the Shore Protection Manual equation is considered to be suitable for this region. However, a definitive conclusion in the selection of the Shore Protection Manual equation and the preponderance of values estimated by the Komar and Inman equation can be drawn only after extensive field investigations.

LONGSHORE TRANSPORT RATE ALONG THE ANDHRA COAST

As it is inferred that the Shore Protection Manual equation can reasonably be used for this region, the same equation is used to estimate the longshore transport rate along the Andhra coast, from Ramaypatnam to Gopalpur (Fig. 1). Using the ship reported waves as explained in eqn. (11), the longshore transport rate computed for every 10 degrees variation in coastline are presented in the form of rose diagrams in Figs. 3 and 4. The rate of longshore transport during different months for a desired orientation of the coastline can be read from Fig. 3 and the net and gross transports can be read from Fig. 4. The computation shows that the general predominant direction of transport along the Andhra coast is towards the northeast from March to October and

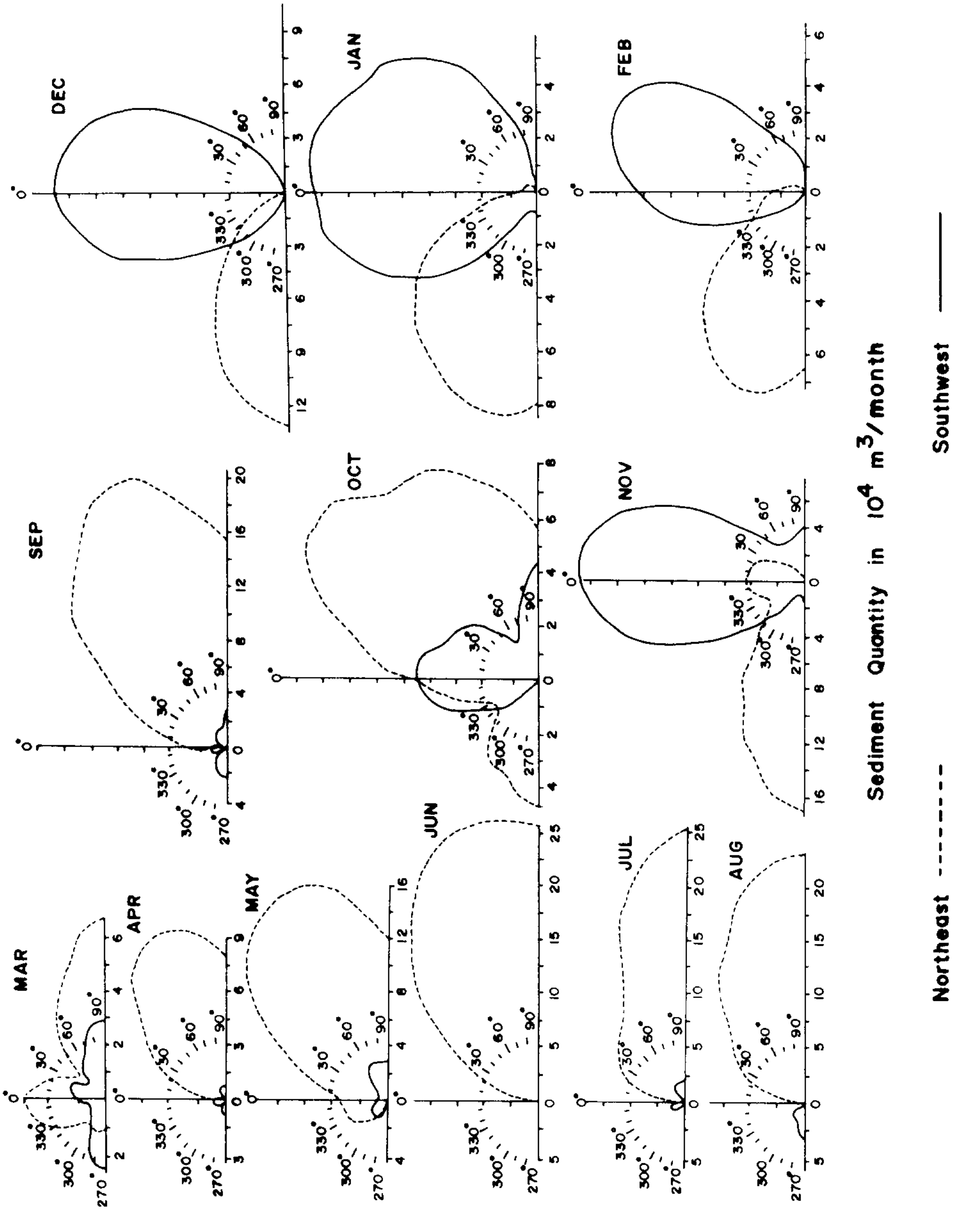

Fig. 3. Monthly longshore transport roses for the Andhra coast.

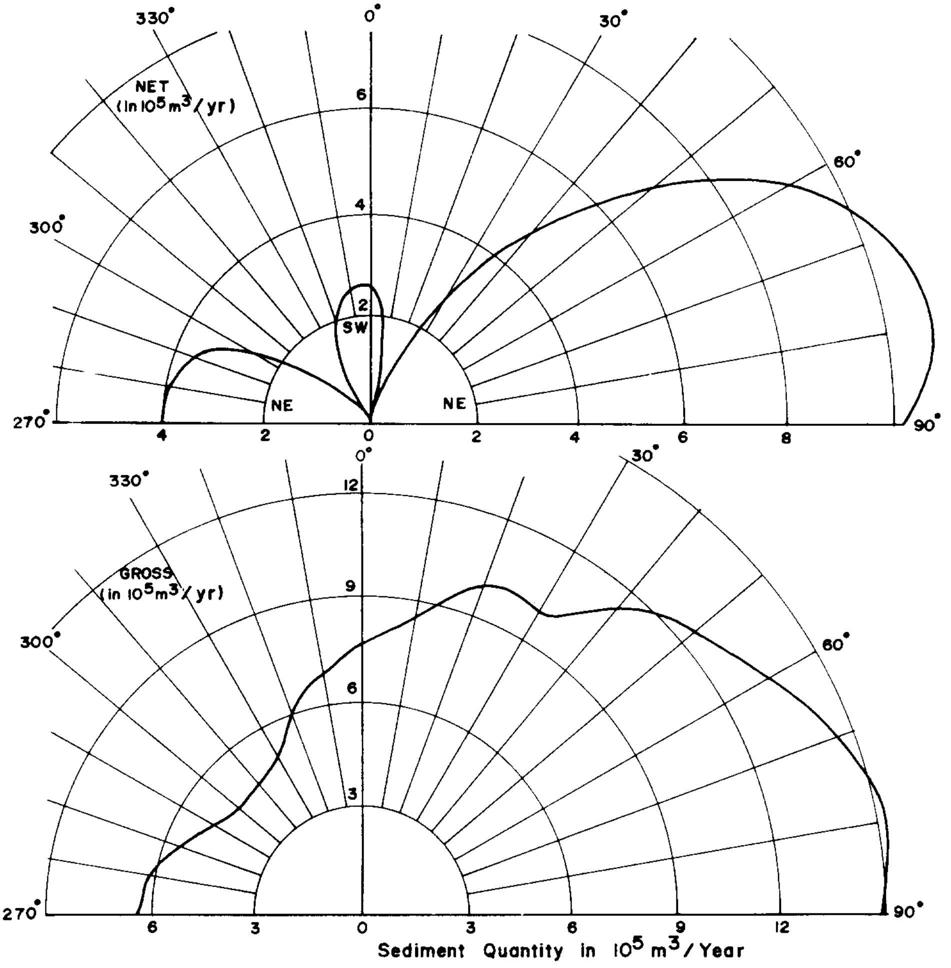

Fig. 4. Annual net and gross longshore transport roses for Andhra coast.

towards the southwest during the remaining part of the year. The rate of sediment transport is very large during the southwest monsoon period from June to September owing to the prevalence of the high wave climate in the Bay of Bengal. The coastline having an orientation of 80 degrees east of north is subjected to the maximum movement of longshore transport with a net volume of 1.09×10^6 m^3 and a gross volume of 1.52×10^6 m^3 in a year. The annual longshore transport rate at a few important coastal towns along this region is given in Table 6. The coastal segments near Ramaypatnam, Machilipatnam and Sacramento Light House have a much lower annual net transport with equal volume of transport on either direction in the one-year cycle. Consequently the coastal segments near Nizampatnam, Gollapalem and Narasapur are subjected

TABLE 6

Longshore transport at important locations along the Andhra coast

Locations	SW drift ($10^6 m^3/yr$)	NE drift ($10^6 m^3/yr$)	Net drift ($10^6 m^3/yr$)	Gross drift ($10^6 m^3/yr$)
1. Ramaypatnam	0.511	−0.250	+0.261	0.761
2. Kottapatnam	0.413	−0.663	−0.249	1.076
3. Nizampatnam	0.229	−1.283	−1.054	1.512
4. Machilipatnam	0.502	−0.444	+0.058	0.946
5. Gollapalem	0.237	−1.259	−1.022	1.496
6. Antarvedi (Narasapur)	0.216	−1.260	−1.044	1.476
7. Sacramento (Yanam)	0.268	−0.966	−0.698	1.234
8. Kakinada	0.268	−0.966	−0.698	1.234
9. Pentakota	0.220	−1.133	−0.913	1.353
10. Pudimadaka	0.218	−1.297	−0.978	1.415
11. Visakhapatnam	0.323	−0.851	−0.528	1.174
12. Bhimunipatnam	0.337	−0.823	−0.486	1.160
13. Santapalle	0.246	−1.049	−0.806	1.294
14. Kalingapatnam	0.268	−0.965	−0.697	1.233
15. Baruva	0.337	−0.823	−0.486	1.160
16. Gopalpur	0.268	−0.965	−0.697	1.233

(−) Sign denotes littoral drift in LHS, along northeasterly direction on east coast of India.

to large movements of longshore transport with a net transport of 1×10^6 m^3 during an annual cycle.

CONCLUSION

The computation of the longshore transport for Visakhapatnam beach based on ship-observed waves and its comparison with earlier studies indicate that the Shore Protection Manual equation may reasonably be used for the estimation of the longshore transport rate along the Andhra coast. The study shows that the general longshore transport direction is towards northeast from March to October and southwest during the remaining part of the year. The volume of transport is high during the southwest monsoon period. The coastline having an inclination of 80 degrees east of north would experience large movements of sediment.

The estimation in the present study is based on ship-reported visual wave observations which has an inherent limitation in its application. Instrumentally recorded waves with directional measurements would be of great value to improve the longshore transport estimation along the Indian coast. It would also be equally important to carry out detailed field studies at a few locations along the Andhra coast in order to validate the results established by the present study.

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