RIP CURRENT ZONES ALONG BEACHES IN GOA, WEST COAST OF INDIA

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ABSTRACT: Goa has a 125-km-long coastline of which two-thirds consists of beautiful sandy beaches. There are mainly 17 beaches having significant importance of tourism. Sporadically, surf drownings have been reported at a few stretches of the beach. Longshore currents were measured at 2-week intervals from November 1993 to October 1994 along these beaches to identify the zones of strong longshore currents and rip currents. Entire beaches were found to be unsafe for swimming during the southwest monsoon season. Parts of stations 5 and 6 in Harmal beach, 16 at Vagator beach, 51–54 at Miramar beach, 75 and 76 at Valsao beach, 84 at Majorda beach, and 116 at Palolem beach are observed to have the risk of permanent rip current zones; and they are unsafe places for swimming all through the year. Parts of Colva, Benaulim, and Agonda beaches, which are suitable for surf swimming, are identified.

INTRODUCTION

Waves breaking at an angle to the shoreline set up a littoral current system comprised of longshore currents, rip currents, and feeder currents. The shape of coastline, beachface slope, nearshore profile, and the presence of sand bars and shoals significantly influence the distribution of littoral currents. While the time-averaged current flowing alongshore between the first breaker and shoreline is termed as longshore current, the rip currents are the narrow, strong return flows directed through the surf into the sea (Basco 1983). The relevant theories to explain longshore currents were reviewed by Galvin (1967) and subsequently by Basco (1982). Many laboratory and field studies have been made to understand the mechanism of longshore currents (Putnam et al. 1949; Galvin 1967; Longuet-Higgins 1970; Dalrymple 1978; Dalrymple and Lozano 1978; Basco 1982). Larson and Kraus (1991) studied numerically the longshore current velocity distribution across a multiple bar and trough beach profile. Recent works by Shemer, Dodd and Thornton (1991), Whitford and Thornton (1996), Dodd et al. (1992) have helped to understand the instabilities involved in the oscillations of the longshore currents. Huntley and Short (1992) gives the characteristics of rip current spacing based on extensive field data. The longshore currents flowing parallel to the coast, often open up as a rip current and flow into the sea perpendicular to the coast. Such currents are balanced by the presence of feeder currents in the adjacent region, which flow perpendicular toward the coast. The presence of cusps on the beach foreshore are a good indication of the existence of rip and feeder currents in the surf zone. The location of rip currents and spacing between two adjacent rips primarily depend on the breaking wave characteristics, beach slope, and variation in bathymetry along the coast. Since the waves are random in nature, the location of rip currents in the surf zone often shifts with time. If waves are assumed uniform, long crested, and unidirectional for a specific duration, then the rip current location remains quasi-steady. A swimmer trapped in such a rip current may get exhausted by swimming against the current, leading to drowning.

Goa has a 125-km-long coastline of which two-thirds consists of beautiful sandy beaches. Panoramic formation of these beaches attracts thousands of foreign and domestic tourists, who largely use the coasts for water sports and surf swimming. Sporadically, surf drownings have been reported at a few stretches of the beach. This paper presents the study made on surf-zone currents during November 1993 to October 1994 along the Goa beaches and the assessment of suitability of the beaches for tourists use.

GOA COAST

Goa coast can broadly be classified into a coastal tract consisting of beaches, sea cliffs, promontories, pocket beaches, estuaries, dunes, hard rock wave cut platforms, etc. Indian Naval hydrographic charts 214 and 215 indicate that the continental shelf off Goa is relatively wide, with a 50-m contour depth occurring 35-km offshore, 100 m at 80 km, and 200 m at 100 km away from the coast. The seabed consists of silty clay at water depths less than 50 m, and sandy silt from 50 to 100 m water depth (Nair and Hashmi 1980). Beach sediments mainly consists of quartz along with feldspars and other heavy minerals (Wagle 1987). They are represented by medium to fine sand, well to moderately sorted. Many studies have been made on different segments of the Goa beaches focusing on beach erosion and nearshore wave refraction (Murthy et al. 1975; Antony 1976; Swamy 1976; Swamy and Varadachari 1981; Veerayya et al. 1981; Murthy et al. 1982; Murthy and Veerayya 1985). Ocean climate of Goa is dominated by three seasons: (1) the southwest monsoon (June to September); (2) the northeast monsoon (October to January); and (3) the fair weather period (February to May). Sea conditions are normally rough during the southwest monsoon and remains calm during the rest of the year.

There are mainly 17 beaches in Goa with a significant tourist industry (Fig. 1). South of Tiracol river, 5-km-long Harmal beach is present. Anjuna and Baga are the pocket beaches followed by the long Calangute beach. Miramar beach is about 4-km long situated along the southern bank of the Mandovi river estuary. The Zuari river joins the sea forming a large bay, and it encloses the major port at Marmagoa. Further south, India's second longest beach is present (i.e., the 27-km-long Colva beach). Small pocket beaches with dense palm fringes are seen near Agonda, Palolem, and Lolliem point. Longshore currents were observed at 2-week intervals from November 1993 to October 1994 along Harmal, Mandrem, Vagator, Anjuna, Baga, Calangute, Candolim, Sinquerim, Miramar, Siridao, Bogmalo, Valsao, Majorda, Colva, Benaulim, Agonda, and Palolem beaches, to identify the zones of strong longshore currents and rip currents.

METHODS

The 122 reference stations were established at 100-m intervals along the selected segments of the 17 beaches as indicated

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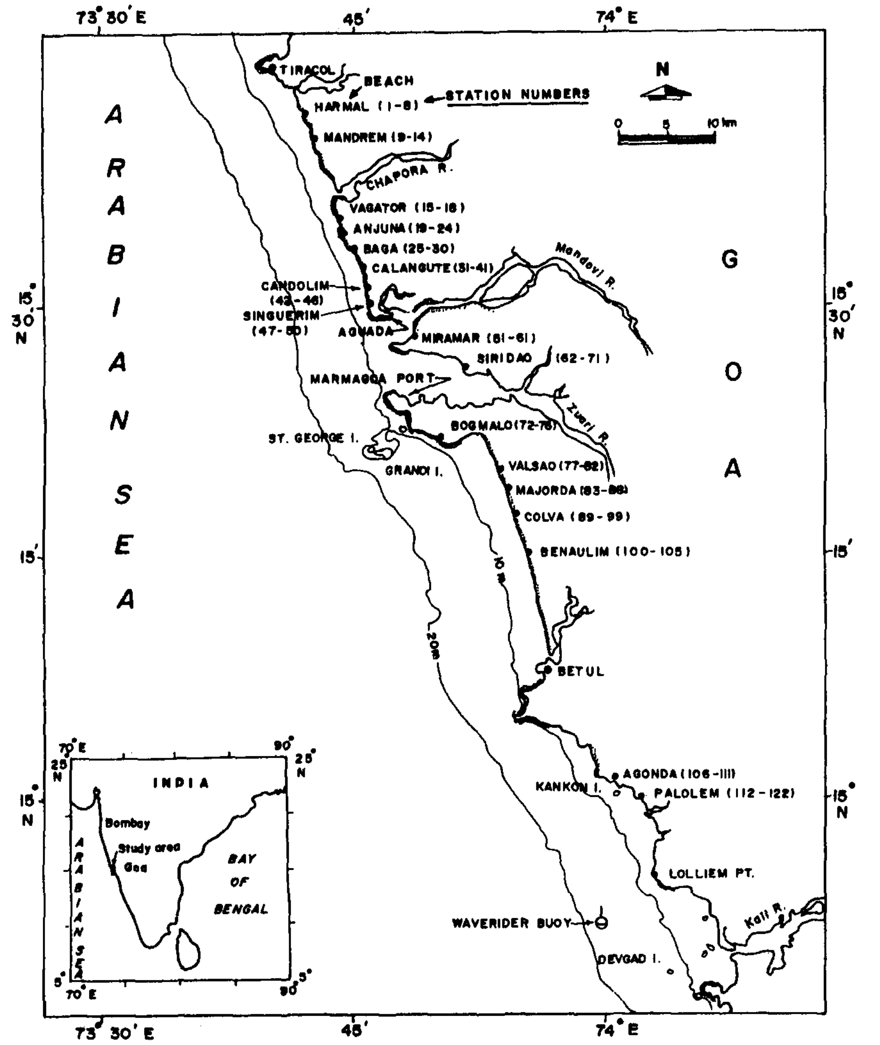

FIG. 1. Location Map

TABLE 1. Details of Beaches and Station Numbers

Beaches (1)	Length studied (m) (2)	Station numbers (3)
Harmal	700	1–8
Mandrem	500	9–14
Vagator	300	15–18
Anjuna	500	19–24
Baga	500	25–30
Calangute	1000	31–41
Candolim	400	42–46
Sinquerim	300	47–50
Miramar	1000	51–61
Siridao	900	62–71
Bogmalo	400	72–76
Valsao	500	77–82
Majorda	500	83–88
Colva	1000	89–99
Benaulim	500	100–105
Agonda	500	106–111
Palolem	1000	112–122

in Table 1. Magnitude and direction of the longshore currents were measured at every 50-m distance along these selected stretches by releasing Rhodamine-B fluorescent tracers in the surf zone and noting the distance it traveled for 2 min. Measurements were made once in every 15 d. Breaking wave height and wave period were visually observed following the CERC procedure for the LEO program (Schneider 1981). Breaking wave angle was measured using the crest breaking time-lapse approach (Chandramohan et al. 1994). Variations in beach levels were measured between backshore dune and 5-m water depth at Colva beach using dumpy level and wave sled.

TABLE 2. Average Monthly Deep Water Wave Characteristics off Goa Coast

Month (1)	Significant wave height (m) (2)	Zero crossing wave period (s) (3)	Wave direction with respect to north (degree) (4)
January	0.49	5.0	315–330
February	0.65	5.1	330
March	0.69	4.8	210–220
April	0.63	5.1	210–230
May	1.02	5.3	210–245
June	1.84	6.6	215–220
July	2.09	7.0	245–260
August	1.69	6.7	245–260
September	0.84	5.6	210–245
October	0.60	5.6	200–210
November	0.45	5.7	200–210
December	0.37	4.9	200–210

The numerical wave refraction study was carried out to identify the wave energy distribution along the Goa coast. The wave refraction study was carried out using the numerical procedure explained in Skovgaard et al. (1975). Nearshore bathymetry was adopted from Indian Naval hydrographic charts 214 and 215. The spacings of rip currents observed in the

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field have been compared with the theoretical values. Spacing of rip currents (Yr) based on theoretical method was estimated based on Irribaren number (Ir) as (Basco 1982)

$$Ir = \tan \beta/(H_b/L)^{1/2} \quad (1)$$

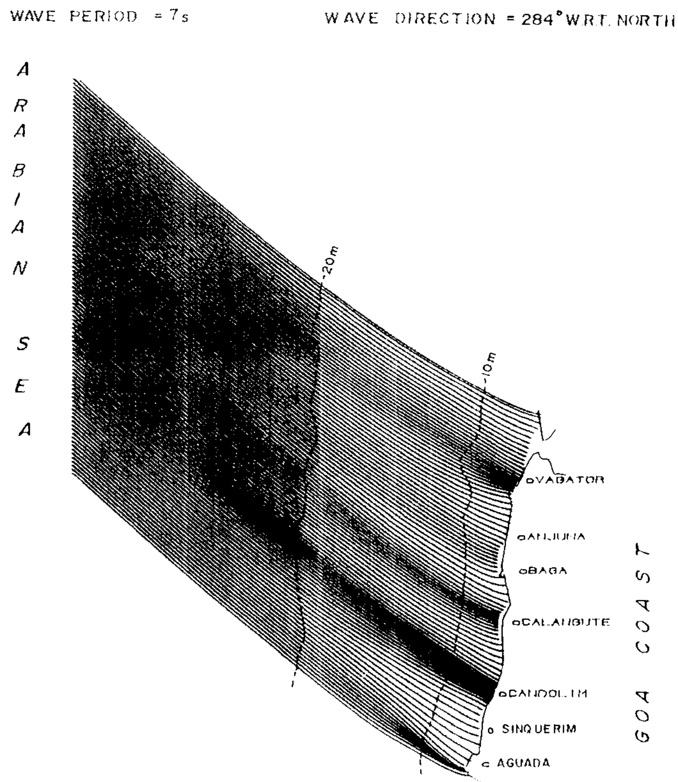

FIG. 2. Wave Refraction between Vagator and Aguada during Northeast Monsoon Period

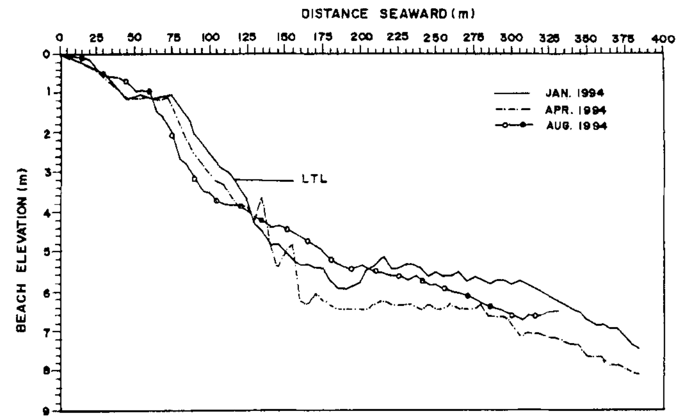

FIG. 3. Beach Profiles at Colva

$$Yr = 157WIr^2 \quad \text{for} \quad Ir < 0.23 \quad (2)$$

$$Yr = 4W \quad \text{for} \quad 0.23 < Ir < 1 \quad (3)$$

$$Yr = 2\pi W/3 \quad \text{for} \quad Ir > 1 \quad (4)$$

where $\tan \beta$ = foreshore slope of the beach, L = wavelength (m), H_b = breaker height (m) and W = surf-zone width (m).

DEEP WATER WAVES

Based on the available information on deep-water waves measured off south Goa (Jain 1990), the monthly average significant wave height, wave period, and wave direction with respect to north are presented in Table 2. Significant wave height persisted around 1.7–2.1 m during June to August and around 0.6 m during the rest of the year. Wave heights were generally high in July and low in December. Predominant wave period persisted around 5–7 s throughout the year. The deep water wave direction was mostly 245–260° during the

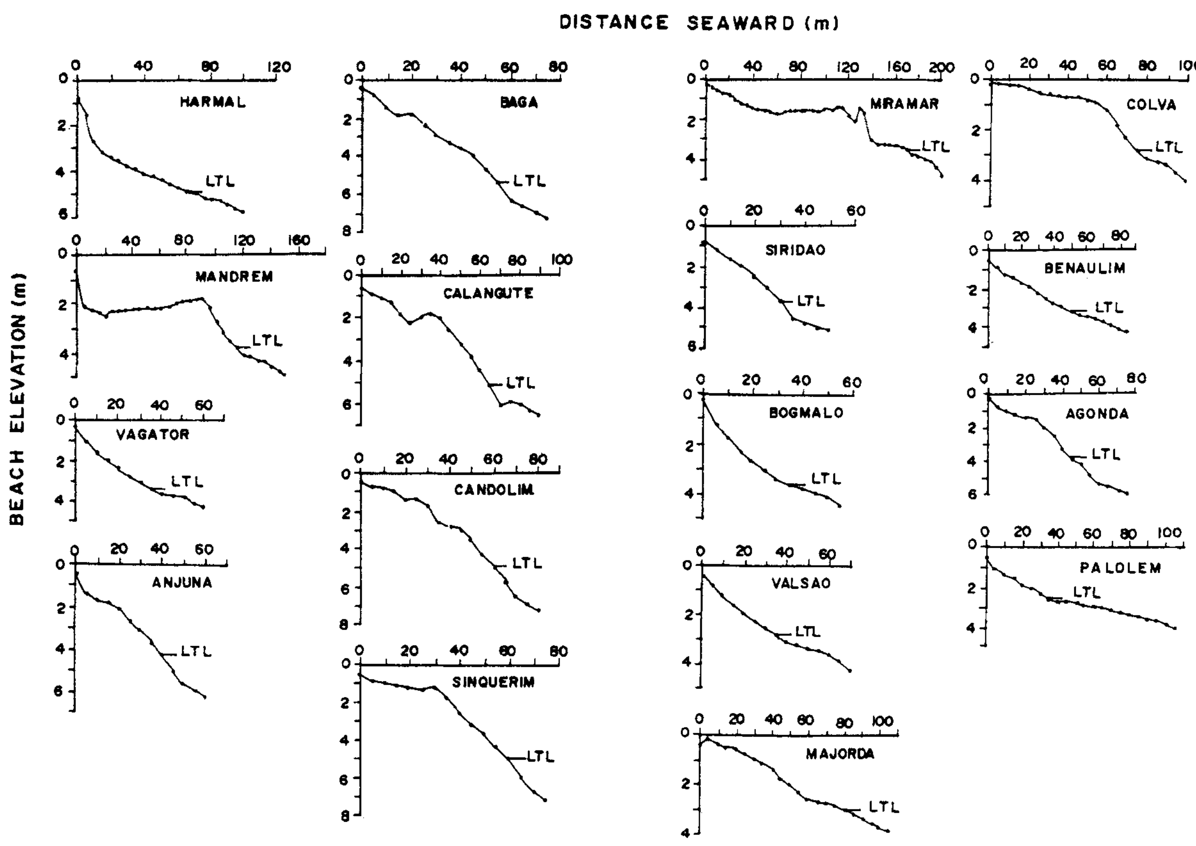

FIG. 4. Variation of Beach Levels in September 1994

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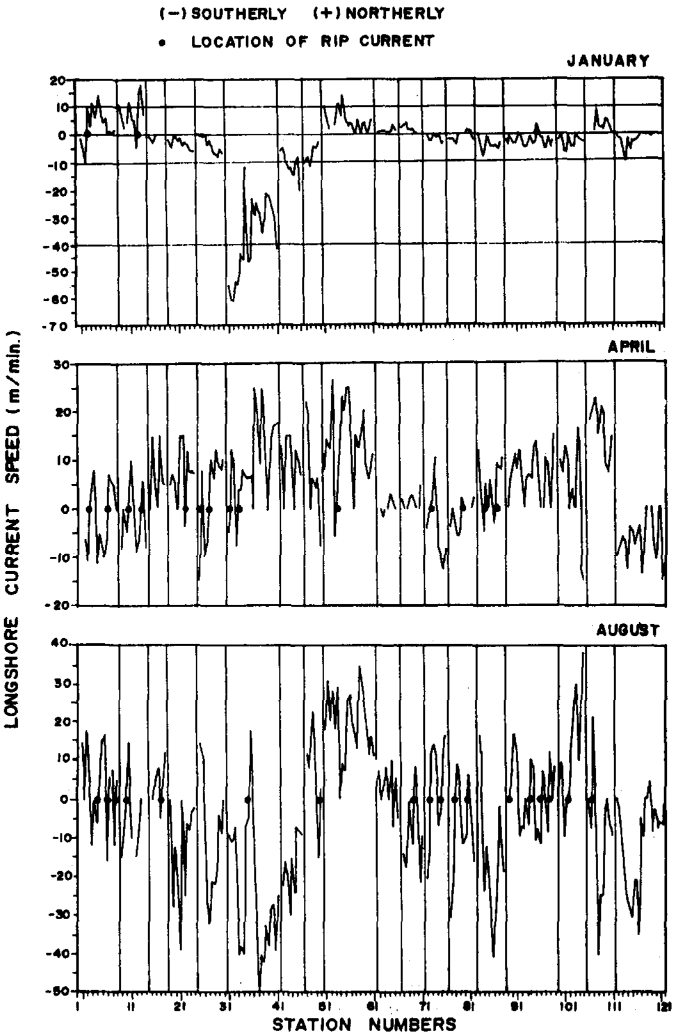

FIG. 5. Variation of Longshore Current

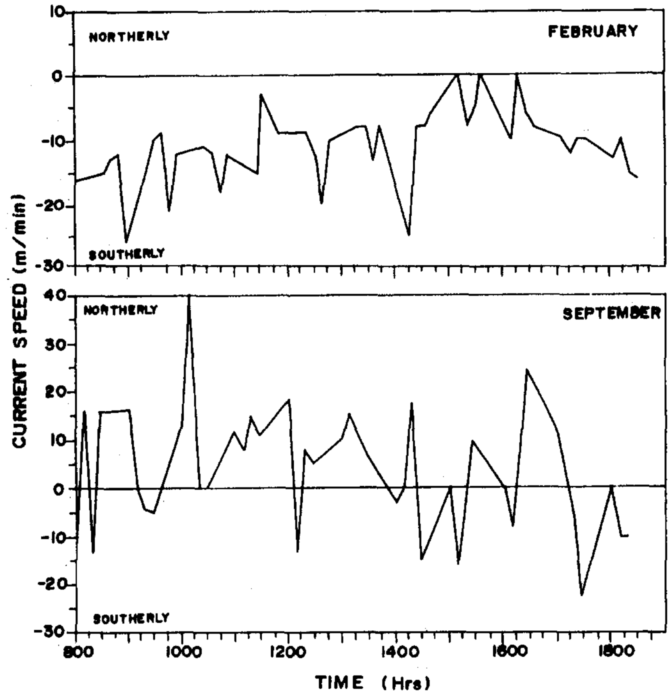

FIG. 6. Variation of Longshore Current at Calangute Beach

southwest monsoon, 315–330° during the northeast monsoon, and 210–230° during the fair weather period.

WAVE REFRACTION

The Goa coastline was divided into four segments: (1) Tiracol–Mandrem; (2) Vagator–Aguada; (3) Bogmalo–Betul; and (4) Betul–Lolliem Point (Fig. 1). For these four segments, wave orthogonals were plotted for the 7-s wave period and predominant deepwater wave directions of 238, 284, and 220° closely representing the southwest monsoon, the northeast monsoon, and the fair weather period, respectively. A typical refraction diagram for the region Vagator–Aguada during the northeast monsoon period is shown in Fig. 2. The following discusses the divergence of wave orthogonals seen along the four segments of beaches of the Goa coastline:

- Tiracol–Mandrem: While divergence of wave orthogonals was seen along the southern part of Harmal beach, concentration of wave energy was noticed along Mandrem and the northern part of Harmal during the southwest monsoon and fair weather period. The phenomenon was the opposite during the northeast monsoon, showing convergence along south Harmal and divergence along Mandrem and north Harmal.
- Vagator–Aguada: During the southwest monsoon and the fair weather period, divergence of wave orthogonals was seen along Anjuna, Calangute, and Candolim beaches. Convergence of wave orthogonals was noticed along the part of Calangute and Candolim beaches during the northeast monsoon.
- Bogmalo–Betul: Wave concentration was noticed at Majorda beach in the southwest monsoon. While divergence of orthogonals was seen along the major part of Colva beach, the south Colva and Benaulim beaches experienced wave energy concentration in the southwest monsoon and fair weather period. In the northeast monsoon, convergence of orthogonals was observed over a small stretch at Colva beach.
- Betul–Lolliem Point: Divergence of wave orthogonals was observed at Agonda and Palolem beaches during the southwest monsoon and fair weather period, and convergence was seen at Palolem in the northeast monsoon.

The refraction analysis indicated relatively strong wave activity at Mandrem, the northern part of Harmal, the southern part of Calangute, Sinquerim, Majorda, and Benaulim during the southwest monsoon, and also in the fair weather period. South Harmal, part of Calangute and Candolim, and south Colva experiences relatively higher wave action in the northeast monsoon.

SURFZONE CHARACTERISTICS

Breaking Wave Height

The breaking wave heights were high during the southwest monsoon at all beaches. They exceeded 2.5 m at Candolim and Sinquerim, were relatively low at about 1 m at Miramar, Siridao, and Majorda, and persisted around 1.5 m along the rest of the beaches. Wave climate during the northeast monsoon and the fair weather period was mostly similar. Candolim beach showed relatively higher breaking waves of 1 m during this period, followed by Calangute beach with 0.9 m. Harmal, Mandrem, Vagator, Anjuna, and Bogmalo beaches showed breaking wave heights of 0.8 m and <0.5 m at the rest of the coastline.

Wave Period

The wave period persisted around 6–8 s during June to August, 10–12 s during December and January, and around 8 s during the rest of the year.

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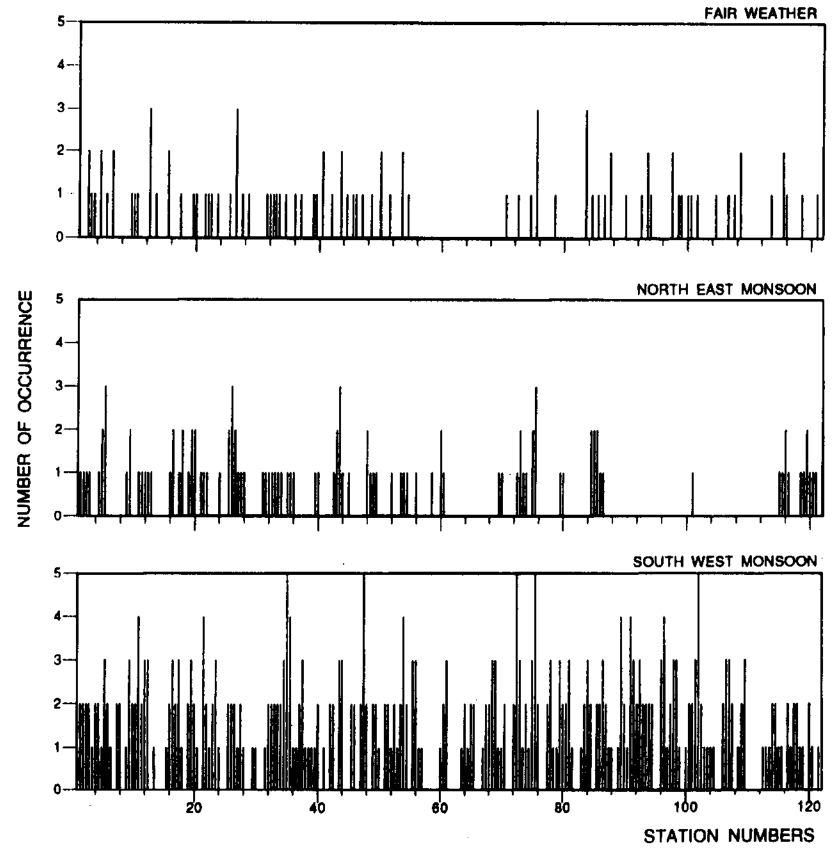

FIG. 7. Number of Occurrence of Rip Currents

Breaker Angle

Along most of the beaches, waves break almost parallel to the coast during the southwest monsoon, but showed 2–5° during the rest of the year. At Vagator, Candolim, Valsao, and Majorda, waves were seen breaking parallel to the coast throughout the year.

Breaker Type

Plunger type breaking was found to be common at all places throughout the year, except at Miramar, Benaulim, and Agonda beaches, wherein spilling breakers were commonly seen during October to April.

Surfzone Width

The width of the surf zone was more (>20 m) during June–September due to high waves breaking during the southwest monsoon. It was relatively narrow (<10 m) during November to February.

BEACH LEVELS

Seasonal variation in beach levels from the backshore berm to 5-m water depth at Colva beach is shown in Fig. 3. Foreshore scouring during the southwest monsoon (August), followed by beach accretion in the northeast monsoon (January), and a well-built beach in April were observed. The similar trend was observed at all beaches in Goa. The profile pattern in September, soon after the southwest monsoon at 17 beaches, is shown in Fig. 4. Foreshore slope was very flat (1 in 55) at Palolem beach, steeper (1 in 10) at Candolim and Sinquerim beaches, and moderate (1 in 30) at other beaches. The steep foreshore slope that occurred during the southwest monsoon at Anjuna, Baga, Candolim, Sinquerim, and Agonda beaches warrants the attention of swimmers using these beaches during June to September. The steeper beach slope caused during monsoon takes nearly 2 months, i.e., October and November to attain a normal slope. Care has to be taken when using the beaches during this transition period due to abrupt depth variation in the surf zone.

LONGSHORE CURRENTS

Based on 2-week measurements, the typical variation of measured longshore current speed and direction in August (southwest monsoon), January (northeast monsoon), and April (fair weather) is shown in Fig. 5. The locations of rip currents are also marked in Fig. 5. From June to September, longshore current direction was variable from beach to beach during the southwest monsoon. At Calangute beach, it was north in June and July, and south in August and September. Strong currents (>25 m/min) were noticed at all beaches in June. Valsao and Majorda beaches experienced strong currents also in August. From October to January, longshore current was relatively weaker during the northeast monsoon at all beaches, except at Agonda, where it was relatively stronger during these 4 months. In addition, longshore currents were relatively stronger at Calangute and Benaulim in December and at Valsao in October. Current was mostly northward at Harmal, Mandrem, Anjuna, Calangute, Candolim, Valsao, Colva, Benaulim, and Agonda; southward at Palolem; and quite variable at other beaches. From February to May, longshore current was relatively weaker in this fair weather period at all beaches. It was southward at Mandrem, Vagator, Calangute, and Palolem; northward at Majorda, Colva, Benaulim, and Agonda; and variable at other beaches. It has been noticed that at Miramar beach, the longshore current was persistently towards east, i.e., into the river side throughout the year.

Variation of Longshore Current over Tidal Cycle

Change in longshore currents was measured every 15 min over a tidal cycle at one location in Calangute beach. Variation

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TABLE 3. Places of Rip Current Occurrence during Northeast Monsoon Period (October–January)

Beach (1)	Station (2)
Harmal	Between 5 and 6
Mandrem	Between 9 and 10
Vagator	Between 16 and 17, 18
Anjuna	Between 19 and 20
Baga	Between 25 and 27
Candolim	Between 43 and 44
Sinquerim	48
Miramar	Between 51 and 54, 60
Bogmalo	73, 75
Majorda	Between 84 and 86
Palolem	Between 119 and 20, 116

TABLE 4. Places of Rip Currents Occurrence during Fair Weather Period (February–May)

Beach (1)	Station (2)
Harmal	Between 2 and 3
	Between 4 and 5
	Between 6 and 7
Mandrem	Between 12 and 13
Vagator	Between 15 and 16
Baga	Between 26 and 27
Calangute	Between 40 and 41
Candolim	Between 43 and 44
Sinquerim	50
Miramar	Between 51 and 54
Valsao	Between 75 and 76
Majorda	Between 83 and 84
	Between 87 and 88
Colva	Between 93 and 94
	Between 97 and 98
Agonda	Between 108 and 109
Palolem	Between 115 and 116

TABLE 5. Rip Current Zones Noticed throughout Year

Beach (1)	Station (2)
Harmal	5 and 6
Vagator	16
Baga	26 and 27
Candolim	43 and 44
Miramar	51 to 54
Valsao	75 and 76
Majorda	84
Palolem	116

TABLE 6. Theoretical Spacing of Rip Currents

Beach (1)	Wave height (m) (2)	Wave period (s) (3)	Surfzone width (m) (4)	Beach slope (5)	Spacing of Rip Current: Theoretical (m) (6)	Spacing of Rip Current: Measured (m) (7)
Harmal	0.4	9	20	1:30	80	500
Mandrem	0.6	7	22	1:48	70	300
Vagator	0.6	8	25	1:35	180	200
Anjuna	0.8	8	35	1:11	140	500
Baga	0.7	8	40	1:14	160	250
Calangute	0.7	6	27	1:25	110	150
Candolim	0.7	8	37	1:10	150	200
Sinquerim	0.5	7	22	1:10	90	150
Miramar	0.6	4	80	1:30	370	350
Siridao	0.4	4	50	1:24	200	250
Bogmalo	0.7	8	35	1:25	140	150
Valsao	0.6	8	37	1:40	210	300
Majorda	0.5	6	30	1:30	120	400
Colva	0.3	7	30	1:37	120	400
Benaulim	0.4	7	30	1:35	120	400
Agonda	0.5	4	50	1:14	200	400
Palolem	0.2	6	50	1:55	325	No rip

of this measured current in February and September is shown in Fig. 6. It shows that the longshore current magnitude and direction considerably change with tidal phase. The change in longshore current direction over a tidal cycle may cause the rip currents to shift location over a tidal phase.

RIP CURRENTS

Based on the measurements carried out every 2 weeks, the number of occurrences of rip currents at different stations during the southwest monsoon (June to September), the northeast monsoon (October to January), and the fair weather period (February to May) is shown in Fig. 7. During June to September, most of the stations had experienced at least once the formation of rip currents. High waves and steep foreshore slope are the main reasons to cause such strong longshore currents associated with occurrence of rip currents at many places. Entire beaches are found to be unsafe for swimming during the southwest monsoon. The places of frequent occurrence of rips during October to January and during February to May are listed in Tables 3 and 4, respectively.

Due to the estuarine environment, the longshore current pattern at Miramar beach is more pronounced with flood and ebb tidal currents of the Mandovi river. Though rip currents were not clearly noticed, longshore current pattern between stations 51 and 54 is complicated due to the influence of tide-induced currents. Hence, swimming at Miramar beach is found to be unsafe throughout the year.

Based on the current pattern observed over three different seasons, the locations listed in Table 5 are frequently found to remain as rip current zones throughout the year. Stations 5 and 6 in Harmal beach, 16 at Vagator beach, 51–54 at Miramar beach, 75 and 76 at Valsao beach, 84 at Majorda beach, and 116 at Palolem beach are observed to have the risk of permanent rip current zone; they form unsafe places for swimming all through the year. Murthy et al. (1975) have also observed the presence of rip currents at Calangute beach near stations 40 and 41 during January to September. The stretch between stations 61 and 71 at Siridao beach is found to be free from rip currents and safe during the northeast monsoon and the fair weather period. Similarly, the stretches between stations 89 and 114 (i.e., Colva, Benaulim, and Agonda beaches) are considerably safer during the northeast monsoon and the fair weather period.

THEORETICAL RIP CURRENTS

Using the observed breaking wave characteristics and the beach slope that occurred during the southwest monsoon, the spacings between rip currents were estimated using (1)–(4) for all beaches and are presented in Table 6. Rip current spacing is predicted to be relatively close to 80 m at Harmal, Mandrem, and Sinquerim. The spacing is predicted to be very large, more than 300 m, at Palolem and Miramar. At other beaches, the spacing was found to be around 120 m. The measured rip current spacing during the same period is also presented in Table 6. In general, most measurements in the field showed that actual rip spacing ranged from 200 to 400 m. Except at five beaches, no close agreement was noticed between theoretical and observed rip current spacing. The measured rip current spacings were found to be larger than calculated spacings, which might have been attributed to local variation in nearshore seabed, irregular formation of offshore sand bars, deformation of wave crest, etc.

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CONCLUSIONS

Breaking wave heights were high at all beaches from May to September, i.e., during the southwest monsoon. A wave refraction study indicated concentration of wave energy at Mandrem, the northern part of Harmal, the southern part of Calangute, Sinquerim, Majorda, and Benaulim during the southwest monsoon and also in the fair weather period. The beaches at the southern part of Harmal, part of Calangute and Candolim, and the southern part of Colva showed concentration of wave energy during the northeast monsoon. Based on observations and analyses, it is calculated that swimming during June to September is unsafe at all Goa beaches. Places listed in Tables 3 and 4 also appear as unsafe during the northeast monsoon and the fair weather period. As the rip current system is variable, extending the field study for several more years would yield better judgment and conclusions. However, the present study would give a basic guideline to understand the current system in order to use the Goa beaches safely.

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