

Rip current-related fatalities in India: a new predictive risk scale for forecasting rip currents

S. V. V. Arun Kumar · K. V. S. R. Prasad

Received: 5 March 2013 / Accepted: 20 July 2013 / Published online: 1 August 2013
© Springer Science+Business Media Dordrecht 2013

Abstract This study analyzes fatalities caused by rip currents in important locations along east and west coasts of India for the period 2000–2010. Results include the frequency of fatalities from rip currents, their cause, and their spatial distributions. Rip current fatalities are most common in the southeastern India, with a non-uniform spatial distribution. August and October are identified as most favorable for rip current generation. In India, rip current-related drowning is estimated as 39 per year during the last decade. East coast of India averaged 30–40 drownings, and west coast of India averaged 5–10 drownings per year. In coastal Andhra Pradesh, more than 350 people had been drowned due to rip currents and only 10 people were rescued. Visakhapatnam recorded highest drowning (293); R. K. beach is the most vulnerable potential rip current zones. From 2007 onward, rip current deaths increased at an alarming rate. The frequency of rip current drownings increased markedly during shore-normal wave incidence and mid-low tidal stages. A new empirical forecasting technique has been developed for prediction of rip current risk in India for the first time. FORTRAN-based software was developed to generate automatic rip current forecast report for any given location. The scale's performance was tested with field data and by using different statistical methods. The new predictive scale is predicting rip current occurrences reasonably well.

Keywords Rip currents · Empirical forecast · Predictive risk scale · Wave data · Fatalities

S. V. V. Arun Kumar (✉) · K. V. S. R. Prasad
Department of Meteorology and Oceanography, Andhra University,
Vishakhapatnam 530003, Andhra Pradesh, India
e-mail: arunocean@gmail.com; arunkumar@sac.isro.gov.in

Present Address:

S. V. V. Arun Kumar
Space Applications Centre (SAC), Indian Space Research Organisation,
Ahmadabad 380015, India

1 Introduction

Rip currents are strong, jet-like, seaward-directed flows that originate within the surf zone owing to alongshore gradients in wave-induced radiation stresses and pressure (Huschke 1959; Bowen 1969; Dalrymple 1975, 1978; Bascom 1980; Haller et al. 2002). Offshore flow velocities of rip currents average around 0.3 m/s but have been observed to exceed 2 m/s (Lushine 1991b). They can occur on many types of beaches under a variety of wave conditions and tidal levels. The usual ranges of rip currents are 1–3 surf-zone widths in the offshore direction, 10–500 m in the alongshore direction, and 1–10 m in depth (Dalrymple et al. 2011). Several factors have been shown to be important in the formation, strength, frequency, and spacing of rip currents. The rip current formation and strength increases as incident wave height increases (Shepard et al. 1941; Bowen 1969; Guza and Inman 1975). The direction of swell energy impacting in a nearshore-normal direction produces a larger shoreward transport of water than obliquely incident waves (Engle 2003; Gutierrez 2004). Rip current events have been documented to occur during fair weather under decreasing swell-and-wind conditions (Lushine 1991a, b; Larson et al. 2000; Engle 2003). Modeling studies have shown longer peak wave periods increase rip current strength and occurrence (Larson et al. 2000). The beach terrain and near-shore bathymetry are also important factors in the formation of rip currents, and in determining the types of breakers that will occur in the surf zone (Bowen 1969; Guza and Inman 1975; Lascody 1998; Larson et al. 2000). Rip current intensity has been observed to increase during low tide (Sonu 1972; Cook 1970; Brander and Short 2001) based on laboratory studies (Dronen et al. 2002), and rip channels become more constrained at low tide; thus, they become more hydrodynamically efficient pathways (Mac Mahan et al. 2004, 2005). Finally, natural and man-made obstacles such as headlands, jetties, and piers often force rip currents by blocking long-shore currents and redirecting them offshore.

2 Evolution of rip current prediction scales

Originally, Lushine (1991a, b) correlated wind direction, wind velocity, swell height, and time of low tide to rescues at a beach in southeast Florida and developed Lushine Rip Current Scale (LURCS). Later, Lascody (1998) modified the LURCS technique for east-central Florida beaches (ECFL LURCS), based on the observation that the wave climate was more severe on this portion of the Florida coast and that wave period plays a greater role. Engle (2003) analyzed the effect of wind, waves, and tide to rip current occurrence for Daytona Beach and New Smyrna Beach in Florida to assess the accuracy of the ECFL LURCS and found that the direction of the incident waves was correlated with rip current rescues. Later, Schrader (2004) examined the use of the Engle-modified ECFL LURCS at two additional Florida beaches, including one on the Gulf of Mexico, and noticed that there are some site-specific factors for rip current prediction. He found a relationship between rip current occurrence and the presence of weather systems that are accompanied by strong winds and larger waves with long periods. Using rescue data at Ocean City, Maryland, Nelko and Dalrymple (2008) had shown that the ECFL LURCS was not that successful. In addition, he stressed that the local conditions also dictate the rip current occurrences on beaches, and empirical techniques such as the LURCS and its derivatives need to be calibrated locally. The US National Weather Service is predicting rip currents at beaches all around the United States (<http://www.ripcurrents.noaa.gov/forecasts.shtml>) as part of the surf-zone forecasts in the following categories: low risk, moderate risk, and high risk.

In India, neither of such predictive indices used so far, nor implemented the LURCS schemes in any one of the beaches due to relatively less importance given to rip current-related drownings. Some very sparse short-term studies had been done by Chandra Mohan et al. (1997) at Goa beaches and identified potential rip current zones based on traditional methods, and Prasad (2002) has identified rip current zones along Visakhapatnam coast using wave refraction diagrams.

3 Need for rip current forecasting in India

In India, there are many rip current-related drownings (see Fig. 1a) occurred every year, but a comprehensive study was not taken up so far in evaluating or maintaining the drowning data or attempting to take measures for protecting the beach-goers. India has beautiful coastline of 7,600 km and has wide sandy beaches, which are attracting people from all over the world. Beaches in Goa, Mumbai, Visakhapatnam, Chennai, and Kochi are the major hot spots of world's tourism. In India, most of the visitors would not enter surf except during full moon days or during some festival days for bathing in relation to traditional divine aspects. Therefore, people entering into surf are relatively less, and the number of people exposed to rip currents per day is very less; only those who entered deep into the surf zone without knowing swimming or any prior knowledge on surf-zone currents are getting endangered with rip currents. Most of the beaches do not have life guards to save the victims of rip currents except at small stretches of beaches. Even though the ratio of number of people entering into the surf zone to the number of beach visitors is very less, frequent drownings may reduce the beach-goers, thereby ultimately causing loss to beach tourism, especially the states like Goa which is mainly dependant on tourism through various beaches. Goa is one of India's richest states with the highest GDP per capita and two and a half times that of the country as a whole; tourism itself handles 12 % of all foreign tourist arrivals in India.

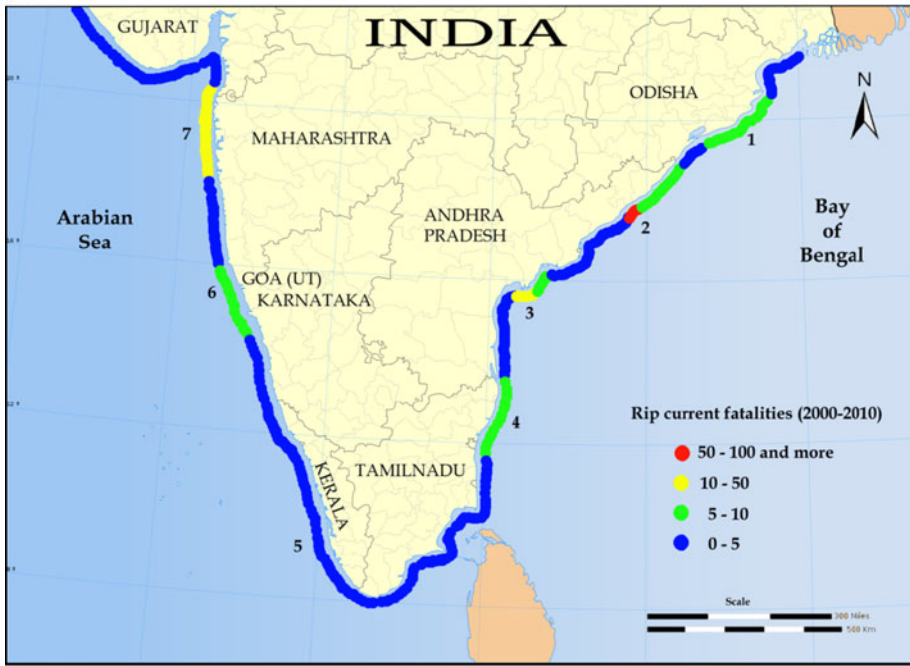
So the determination of a predictive risk index for rip currents is vitally important for the protection of human life. Such an index allows governmental agencies to issue rip current warnings directly to the public and allows lifesaving associations to set up preventative measures according to the magnitude of the rip current threat. The US National Weather Service (NWS) has developed rip current forecasting techniques and issues statements detailing rip current risk through the media, such as National Oceanographic and Atmospheric Administration (NOAA) weather radio and by news media. In India, INCOIS (Indian National Centre for Ocean Information Services), an autonomous institute under Ministry of Earth Sciences, is responsible for issuing warning during tsunamis, high sea-state; at present stage, no forecast is issued for surf-zone dangers.

4 Data and methodology

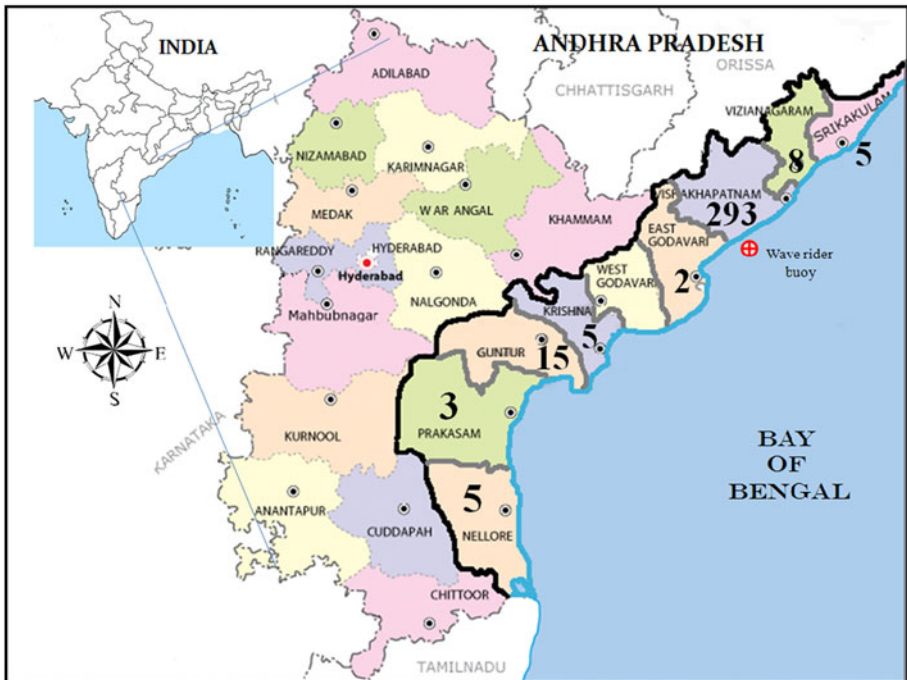
4.1 Fatality catalog compilation

The true number of rip current deaths in India is difficult to estimate because of data-gathering limitations. The online news agencies such as The Hindu, Times of India, IBN Live, etc., were queried to locate rip current fatalities across India from 2000 to 2010. Report from Internet sources is not a faultless or a complete database (Doswell and Burgess 1988; Changnon and Changnon 1999; Curran et al. 2000; Ashley and Mote 2005; Gall et al. 2009) because of the underreporting of both casualties and damage estimates.

(A)



(B)



◀ **Fig. 1 a** Rip current-related drownings in India based on data collected from various sources during 2000–2010. The numbers indicate major beaches which receives huge visitors throughout the year. (1) Bhubaneswar (Chandrabhaga beach); (2) Visakhapatnam (RK Beach, Rushikonda, and Yarada beach); (3) Guntur (Suryalanka beach); (4) Chennai (Marina beach); (5) Kochi (Kovalam beach); (6) Goa (Morjem beach, Panaji), and (7) Mumbai (Aksa beach, Juhu beach). **b** Rip current-related drownings along coastal Andhra Pradesh during 2000–2010 by districts

However, as also noted by Ashley and Ashley (2008a, b), fatal weather events are more likely to be reported due to enhanced media attention. Therefore, careful examination of this data provides us with an adequate first estimate of the actual number of fatalities. In addition, beach-drowning data have been collected from the police commissioner’s office through local police stations neighboring the beaches. Upon examining the data, it has been observed that the drownings that happened in the sea are reported as Sect. 174 (drowning at sea) under law has many categories such as suicides, boats capsize, and jetties accidents. Therefore, we requested data in the following proforma

1. Name of the beach
2. Date and time of drowning
3. Demographic information of report (e.g., age and gender)
4. Number of victims
5. Additional details and comments about the report (e.g., what the victim was doing surrounding the time of the fatality or meteorological features present during the day).

The data were carefully examined, and the irrelevant data were filtered; accidental drowning at beach while playing/bathing/swimming especially reported as “*dragged into the sea towards offshore*” was only considered for the present study. It is well known that the dragging of person toward offshore can only be happened with the strong rip currents (offshore velocities > 1 m/s), and no other forces except the “rip currents” are directed toward offshore in a nearshore circulation system (Shepard and Inman 1950). It has been observed that 78 % are reported as accidental drownings due to rip currents, 5 % each for suicide and boat accidents, 10 % are accidents inside the harbor, and the remaining 2 % are unknown cases.

4.2 Spatial analysis

Using a geographic information system (GIS), fatality locations were mapped to depict the spatial distribution of fatal rip currents. East and west coasts of India were mapped in 100 km grid cells using the latitude and longitude of a fatality and summing the number of fatalities along a 100 km stretch of coastline. In the Andhra Pradesh only, more than 350 people had lost their lives due to rip currents (Fig. 1a). Hence, a detailed number of drownings happened in Andhra Pradesh were depicted in Fig. 1b. Visakhapatnam has reported highest number of drowning cases to around 293 during the last decade. Details of the orientation of important coastal sites where tourism is high along Andhra Pradesh coast are presented in Table 1, and the information related to rip current drownings at Visakhapatnam coast is provided in Table 2. It has been observed that R. K. beach is the most vulnerable potential rip current zones where 92 people were drowned in the surf zone due to rip currents for the past 10 years. For drowning cases in the other neighboring beaches, the Table 2 can be referred.

Table 1 Mean orientation of coastline at some specific locations with respect to true north in Andhra Pradesh

S. No.	District	Famous beach	Coastline orientation (°)	Coast normal angle (°)	Offshore facing
1	Visakhapatnam	RK Beach	68°	158°	SE facing
		Rushikonda	26°	116°	E facing
		Yarada Bheemunipatnam	65°	155°	SE facing
		Rushikonda	43°	133°	SE facing
2	Guntur	Suryalanka beach	65°	155°	SE facing
3	Prakasam	Vodarevu beach	60°	150°	SE facing
4	Krishna	Manginapudi beach	18°	108°	E facing
5	Nellore	Mypadu beach	10°	100°	E facing

4.3 Meteorological and oceanographic data

The high frequency of drownings in Visakhapatnam makes it a favorable location to utilize rip-related drownings as a gauge of rip occurrence. So, we emphasize that this part of the coast needed immediate rip current prediction to reduce the number of deaths. For this purpose, the wave data are collected from a Datawell wave-rider buoy, which is placed approximately 3 km away from the Visakhapatnam coast anchored at 20-m depth. It provides wave spectrum information viz., significant wave height (H_s), wave direction (θ), wave period (T_m), and spreading factor. For formulation of a new rip current scale, this dataset is quite sufficient as it covers calm, monsoon, and severe weather conditions. The wave-rider buoy data are available during 2008–2010, and therefore, for understanding the inter-annual variations of rip current drownings (2000–2010), observed wave data are essential, which is presently unavailable. Hence, the ECMWF ERA reanalysis wave data for 2000–2010 years have been utilized and extracted the 3 hourly deep-water wave data at 17.6°N and 83.5°E location (close vicinity to Visakhapatnam). The sea-level data at the above location and period have been obtained from TOPEX-POSEIDON and JASON altimeters merged product (<http://www.avisio.oceanobs.com>). Wind data are obtained from Cyclone Warning Centre, India Meteorological Department (CWC-IMD), Visakhapatnam. For tidal information, Survey of India tide tables have been referred. In addition, wave and water-level data collected from field surveys during 2009–2010 were also utilized to fill any data gap. Longshore currents have been measured using floating bottle method at bi-monthly intervals along Visakhapatnam coast to compare with the forecast derived by our new scale. For coherence, all the wave, wind, and tide data are transformed to hourly interval; wind and wave direction were transformed so that zero degrees corresponds to a shore-normal, onshore orientation.

4.4 Nearshore morphological state

There are several factors in addition to meteorological and oceanographic processes that lead to the formation of rip currents along any coast (Bowen 1969; Guza and Inman 1975; Lascody 1998; Larson et al. 2000). Out of which, topographically controlled rip currents are the major hazardous, which are forced by local geology and nearshore bathymetry (Short 1985; Larson et al. 2000) that in turn determines the number and strength of rip

Table 2 Zone wise classification of rip current-related fatalities in Visakhapatnam during 2000–2010

Sl. No.	Location	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Total	% of total
1	Tikkavanipalem beach	0	0	0	0	0	0	0	0	1	0	0	1	0.34
2	Yarada (3)	2	3	0	1	1	1	3	3	1	4	5	24	8.19
3	Sagardurga Beach	5	0	0	1	2	0	1	3	0	0	0	12	4.10
4	Coastal Battery	0	0	0	1	0	1	0	3	0	3	2	10	3.41
5	Gokul Park	0	0	0	0	0	0	0	0	1	0	0	1	0.34
6	RK Beach (1)	4	10	8	4	2	13	4	13	18	10	6	92	31.40
7	Kursura Museum	0	0	0	0	0	0	1	1	2	0	1	5	1.71
8	YMCA (5)	0	2	1	2	4	0	1	0	1	4	1	16	5.46
9	Palm Beach	0	1	1	1	0	1	1	1	0	1	1	8	2.73
10	Vuda Park	3	1	2	1	1	0	0	1	2	1	0	12	4.10
11	Lumbini Park	1	0	0	0	0	1	0	0	1	1	0	4	1.37
12	Tenneti Park	0	0	0	2	0	0	1	2	0	1	1	7	2.39
13	Jodugullapalem	2	1	0	3	1	0	0	0	2	2	2	13	4.44
14	Sagar Nagar	1	0	2	0	1	0	0	1	2	1	0	8	2.73
15	Rushikonda (2)	9	10	3	2	1	5	5	3	2	4	12	56	19.11
16	Yendada	0	0	1	0	0	0	0	0	0	1	0	2	0.68
17	Uppada	0	0	0	1	0	0	0	0	0	0	0	1	0.34
18	Red sand hills	0	0	0	0	0	0	1	0	1	0	1	3	1.02
19	Bheemunipatnam (4)	1	1	0	2	0	5	3	0	2	0	4	18	6.14

Numbers in brackets indicate the ranking of potential rip current location

currents. When the sea state is favor with higher wave energies and swell, rip currents will be prominent. In contrast, accretion rips develop in response to decreasing wind and wave energy that drives shore face recovery and a transition from a dissipative to a reflective profile (Wright and Short 1984). The change in nearshore morphological state is driven by a change in the surf scaling parameter (ε) described by Guza and Inman (1975):

$$\varepsilon = \frac{a_b \omega^2}{g \tan^2 \beta}$$

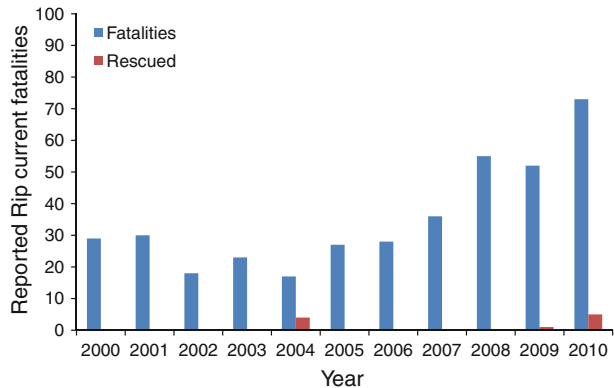
where a_b is the breaker amplitude ($H_b/2$, H_b is the breaker wave height), ω is the radian frequency of the incident waves ($2\pi/T$, T is the wave period), g is acceleration due to gravity, and β is the gradient of the beach/surf zone. As wave energy decreases following a storm, the beach changes from dissipative ($\varepsilon > 20$) to reflective ($\varepsilon < 2.5$) by passing through each of four intermediate states: longshore bar-trough, rhythmic bar-beach, bar rip, and low-tide terrace ($2.5 < \varepsilon < 20$). Each of these intermediate states is characterized (to varying degrees) by the presence of accretion rips. As the shoreface evolves, there is an increase in the rip current velocity as the cross-sectional rip channel area decreases and the ability of the bar system to block return flows increases, until the innermost bar completely welds to the beachface. These rips do not have the characteristic form and may be difficult to identify from the perspective of a beach user.

5 Results and discussion

5.1 Fatality distribution

As anticipated, data from Internet sources did not capture all reported rip current fatalities in India during the period 2000–2010. Examination of Internet queries identified 90 fatalities over this period, bringing the total number of fatalities for this study to 388. On average, approximately 39 people are reportedly killed each year from a rip current along Indian coastline (Fig. 2). Although this value is lower than that of US annual rip current fatalities (Lushine 1991a, b; Gensini and Walker 2010), it is still significant. East coast of India averaged 30–40 drownings, and west coast of India averaged 5–10 drownings per year during this period. However, it is still likely that some fatal rip current events may have gone undocumented in data sources because fatal rip current events are typically isolated and are not associated with damage that may attract media attention. Thus, it is plausible that the number fatalities associated with rip currents could be higher; yet, we have no competing dataset to confirm this assumption.

Figure 2 reveals that rip current deaths are increasing drastically every year from 2005 onward. Although rip current danger increases with increase in nearshore wave and changing complex bathymetry, increase in beach attendance (increase in tourism activity) may also increases the density of persons who enters the surf zone and ultimately may be exposed to rip current activity (if rips already exists). As Visakhapatnam is one of the peaceful cities located along east coast of India with wide natural beaches encompassing along Eastern Ghats, the number of tourists is increasing every year (<http://en.wikipedia.org/wiki/Visakhapatnam#Tourism>). This can also be the reason for increasing rip current drowning cases in the recent years. In addition, as the beaches are closely connected with Visakhapatnam harbor and Eastern Naval Command of the Indian Navy, many sailors and tourists across the world (especially from Russia, China, Thailand, and Japan) are the

Fig. 2 Reported rip current fatalities by year

favorite visitors of Visakhapatnam beaches (mainly to R. K. beach, Rushikonda, and Yarada) during their leisure periods for recreation. In the recent years, frequent drowning cases of foreign tourists were also recorded. It should be envisaged that the number of persons rescued was comparatively very less to the total number of rip current fatalities due to the fact that many of the beaches were unguarded. For a scientific evidence of increase in rip current fatalities during recent years, the key causative factors like waves, wind, and sea level have been examined. We observed that there is a slight increase in H_s (0.4 cm/year), T_m (0.006 s/year), wind speed (0.3 cm/s/year), and sea-level anomalies (0.24 cm/year) at Visakhapatnam from 2005 onward (Fig. 3a–e). Even though the rate of increase of the above parameters is less, still this increase can impact the generation mechanism and strength of rip currents. Increased rate in primary rip current generation parameters may also be one of the factors responsible for increased rip current cases.

Monthly distribution of rip current fatalities suggest that during August and October months, more number of drowning cases occurred which infers that fatal rip current exist during these months. Also, secondary maximum occurs during March–July and November (Fig. 4). This infers that in India, majority of the days in a year are vulnerable to rip currents. Many of these fatalities occurred on weekends when beach tourism and population of people in the surf zone are peak. Interestingly, an average of more than 30 drownings had occurred on each day of the week (Fig. 5) reveals that people will always like to visit on every day for their refreshment, and they are more exposed to dangerous rip currents everyday. Hence, rip current forecast is essential for Indian coast on both hourly and daily basis.

5.2 Role of winds

The hourly wind observation closest to the rip current event was determined. To obtain the best relationship between winds and occurrence of rip current drowning, wind rose was plotted against frequency of direction and the average wind speed (Fig. 6a). Note that most of the wind directions were alongshore from SW direction when rip current events had happened. This is in contrast with the Lushine (1991a) results in which he stated that the onshore winds are more favorable for rip current formation. Lascody (1998) stated that ocean swells play major role rather than the coast normal winds. In Fig. 6b, Plot A, wind speeds from 1 to 5 m/s had drowning frequencies account for 50 % of the total drownings, indicating the rip current activity is relatively uniform over those wind speeds. The significance of low wind conditions almost certainly is related to an increased number of

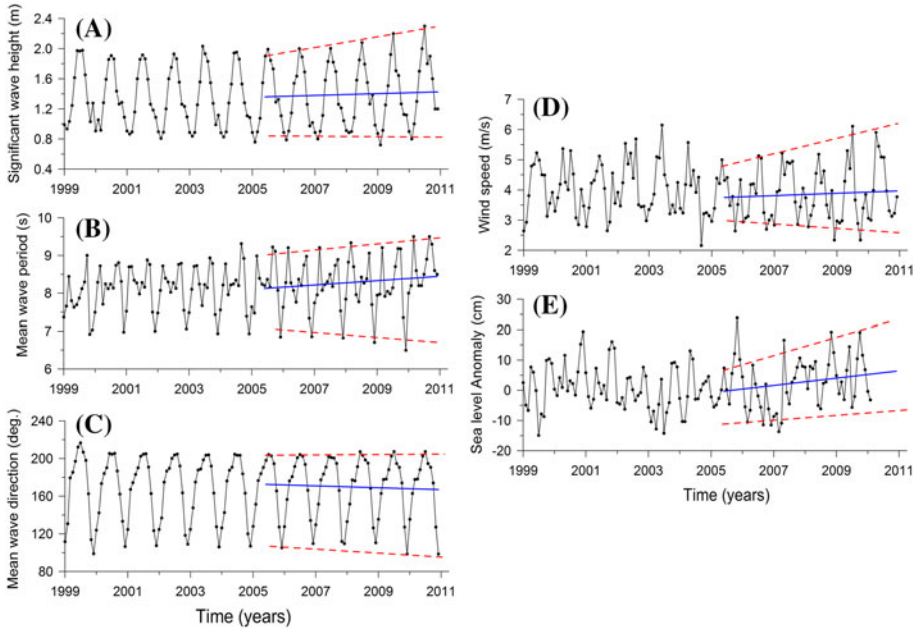


Fig. 3 a Significant wave height, b mean wave period, c mean wave direction, d wind speed e sea level anomaly at Visakhapatnam

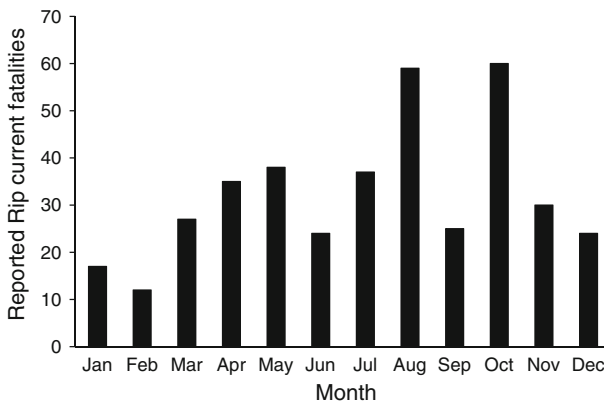
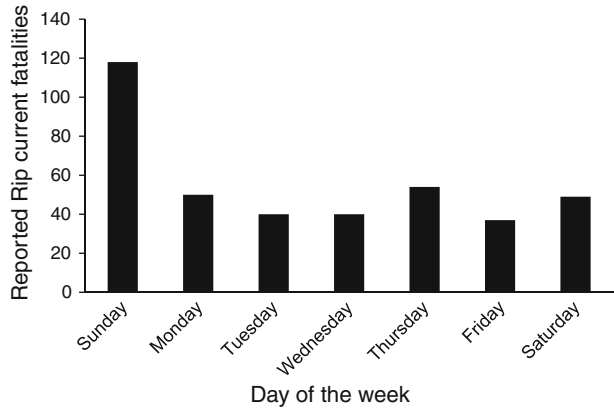


Fig. 4 Reported rip current fatalities by month

beach-goers and swimmers on those mild days and not an increase in rip current activity due to low wind speeds (Engle et al. 2002). A reduced number of drownings occurred after wind speed exceeded 9 m/s, which may be due to fewer people entering the surf.

Wind direction, depicted in Fig. 6b, Plot B, appears that wind direction has little relationship with the rip-related drownings, which coincides with the concept of Lascody (1998). The maximum number of drownings happened within 60°–80° of wind approach in the study region. However, this is due to the fact that the coast always experiences

Fig. 5 Reported rip current fatalities by day of the week



monsoonal winds from south-western direction most of the time in a year. Hence, this investigation eliminates wind direction and speed from the forecasting technique based on the lack of statistical and scientific evidence linking wind direction and velocity with rip current fatalities.

5.3 Role of tides

Tides are one of the major rip current factors that modulate the flow velocities in the nearshore environment. During low-tide times, more people will go into surf and are therefore more exposed to rip current (Engle 2003). During spring tide (new moon/full moon days), the water level reaches to minimum during low-tide time. An effort has been done to correlate rip current drownings with the phase of the moon (Fig. 7a, b, c). We observed that frequency of drownings had increased 2 days before and 3 days after full moon or a new moon day. While considering only the spring tidal stage, it is more pronounced that the relative rip current drownings were recorded high on either side of spring time (2 days before and up to 3 days after). This suggests that tidal stage is playing vital role in generating rip current (Guza and Inman 1975). The time of the event were correlated with the drowning in Fig. 7d reveals that more number of drownings had happened at the time of low tide and before 1 h and after 3 h on either side of low-tide time. This suggests that mid-low tide time on a day may have strongest rip currents (Brander and Short 2001; Cook 1970; Wright and Short 1984). Hence, tidal stage is considered as one of the forecasting element in our rip current scale.

5.4 Role of waves

The recorded rip current drownings were high when wave heights ranges from 0.5 to 1.2 m (Fig. 8a) accounted for 65 % of total drownings. Drowning frequency falls off at higher wave heights even though rip currents themselves are almost certainly stronger (Shepard et al. 1941; Bowen 1969; Guza and Inman 1975), and this may again be due to either fewer people venturing into the surf during these rough weather conditions. Wave periods from 5.0 to 8.0 s accounted for 60 % of rip current drownings, and wave periods less than 5.0 s accounted for only 10 %. These intermediate-period waves produce good surf and still allow beach-goers into the water resulting in increased frequency of drownings (Prasad 2002; Engle 2003). Long-period waves will be affected by the sea bottom at deeper depths

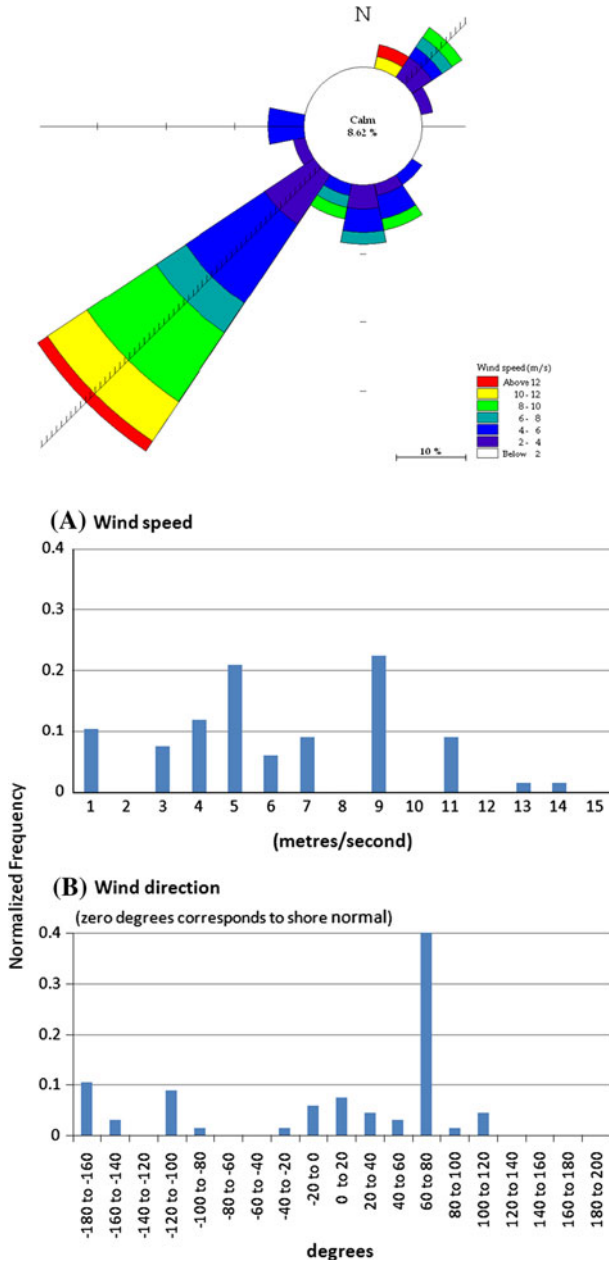


Fig. 6 a Wind rose plot for rip current events during 2009–2010. b Normalized frequency distribution of rip current drownings related to wind speed and direction

and will break further from shore, resulting in a larger wave setup (Johnson and Pattiaratchi 2006).

Wave direction had a strong correlation with rip current drownings (Fig. 8c). Wave directions between -20° and -10° accounted for 70 % of drownings (Engle 2003;

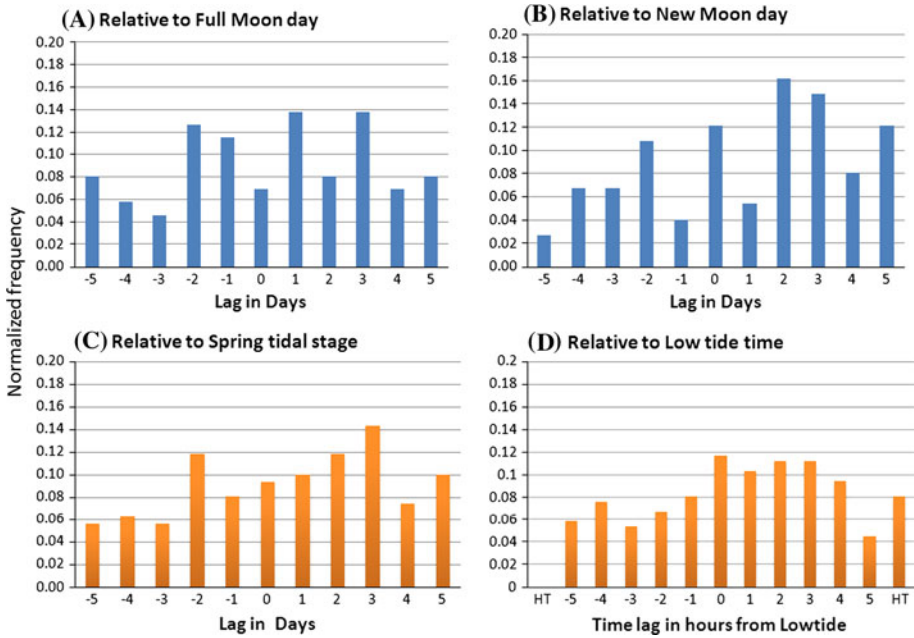


Fig. 7 Normalized frequency distribution of rip current drownings related to tidal stages

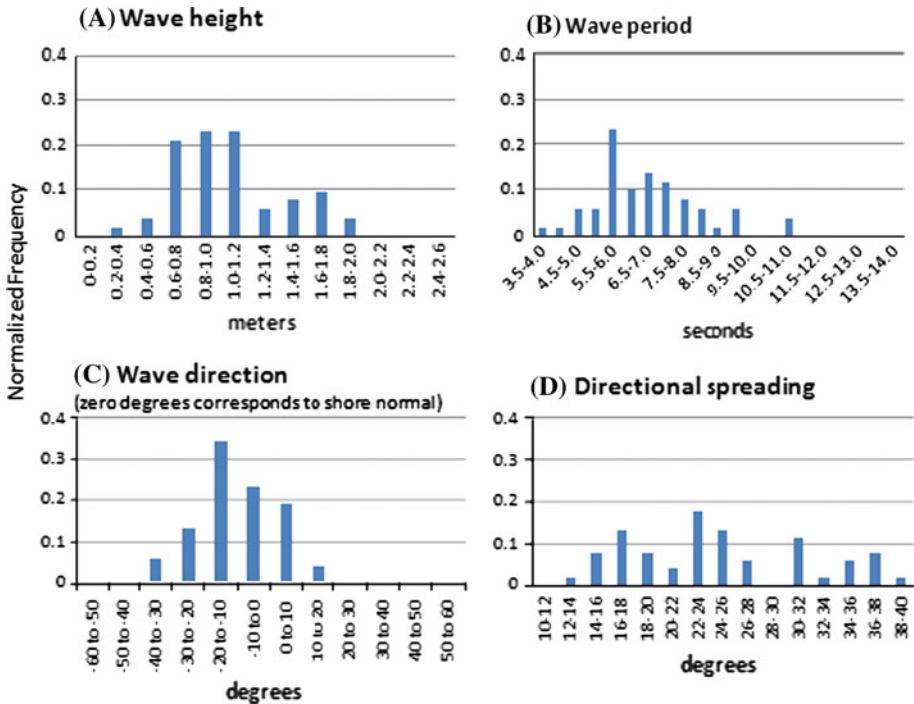


Fig. 8 Normalized frequency distribution of rip current drownings related to wave conditions

Gutierrez 2004). Only 15 % of drownings had taken place when the direction was less than -20° or greater than 20° , suggesting that rips seldom formed were weak under large oblique wave angles. More number of drownings account for waves approaching from -20° to -10° . The rescue frequency is skewed toward negative angles, which is probably due to the southern swell that impacts east coast of India during summer season (SW Monsoon). Engle's (2003) research indicated an especially strong correlation of rip current events will happen when both wave direction and directional spreading favors. We examined the directional spreading factor relationship with frequency of drownings (Fig. 8d). More than 60 % of drownings were happened when the directional spreading is less than 25° although some occurrences of drownings happened greater than 30° . This implies that directional spreading is another important rip current scaling factor to be implemented in risk scale.

5.5 Role of nearshore bathymetric variations

It is obvious that nearshore bathymetry tends to follow in the same trend as that of surf similarity parameter (ε). From Fig. 9a, it is clear that higher values of ' ε ' are observed during high sea state mainly during SW monsoon period (June to September) within the range of 15–20, and sometimes, the value reaches to greater than 30. This implies that the nearshore bathymetry is fully dissipative and therefore more vulnerable to rip currents. Peak values of ' ε ' are observed after the cyclone 'LAILA' ($\varepsilon > 40$), which indicates dissipative type of beach stage with shore parallel bars and rip channel connected by mega rips. As the cyclone makes landfall, the beach recovery takes place and creates long linear offshore bars (dissipative stage) and ultimately bar moves back onshore, finally reattaching to the shoreline. This is referred to as a reflective beach ($\varepsilon < 5$), which takes some weeks to months of time for entering this stage usually during NE monsoon (Fig. 9a). When $\varepsilon < 3$, it represents fully reflective beach, which does not favor for morphological rip currents. Hence, relatively less number of rip current drowning cases during December, January, and February has been observed (Fig. 4). The welding process of sand bar with beachface undergoes for different stages of the nearshore bathymetry following more pronounced crescentic sand bar, horns of the crescents facing the shoreline to transverse bars, incised rip channels, and embayments ($2.5 < \varepsilon < 20$). Rip currents are present during all the evolving beach stages with the current intensity depending on the alongshore variability of the bathymetry. Observations of the changes in the nearshore morphology have been correlated with rip current drowning cases in the Fig. 9b. It has been examined that even though ' ε ' is highest during monsoon and cyclone periods, and there is relatively less number of rip current drowning cases reported. It can be due to the fact that nobody will enter into the surf during such rough environs, while there are some reported events for higher ' ε ' values also. We observed that relatively higher frequency of drowning cases reported with ' ε ' values lie between 6 and 10 (rhythmic bar and runnel type stage with rip channels). This provides some scope that nearshore bathymetric variations can induce rip currents; it is believed that most beaches support rip currents, because no beach is completely alongshore uniform.

5.6 Development of an empirical rip current 'risk' forecast scale

The LURCS (Lushine 1991a), ECFL LURCS (Lascody 1998), and modified ECFL LURCS (Engle et al. 2002) scales are computed on a daily basis, which is not practical for issuing warnings to the public in India, as evident from time of the events had happened

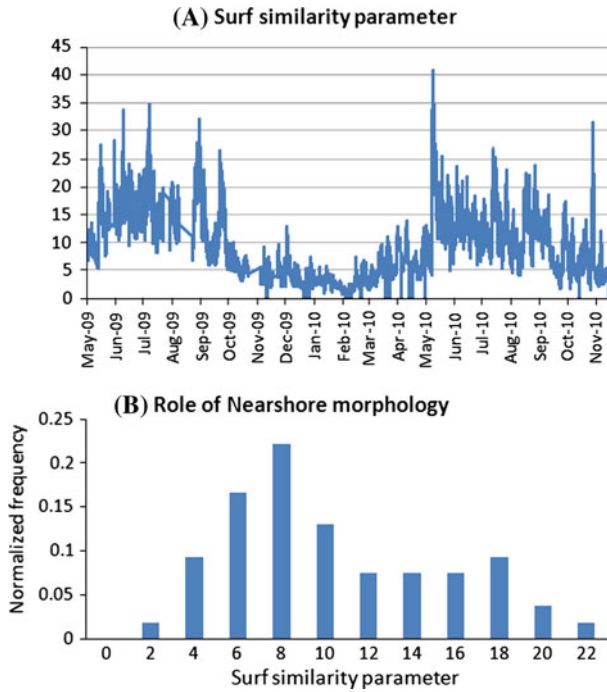


Fig. 9 a Variation of surf similarity parameter with time and b normalized frequency distribution of rip current drownings related to nearshore morphology

(Fig. 7c, d). The uniform distribution of drownings infers that the events had occurred during all hours. Hence, more precise warnings should be issued on an hourly basis. With the prior knowledge gained from LURCS evolution, we tried to develop a new forecasting scheme based on several wave, tide, and other miscellaneous factors. All the past procedures use mean values of wind speed, wave height and wave period, and median values of wave direction collected between 11:00 AM and 5:00 PM (period of highest beach attendance in US). Averaging the wave parameters may mask the higher energy waves approaching the coast at any point of time (Engle et al. 2002). This may lead to false forecast, and the public may get in danger. This was proved in case of NWS severe warning verification tests (Lushine 1991a; Engle et al. 2002; Prasad 2002).

Hence, hourly values of significant wave height (H_s), wave period (T_m), wave direction (the direction was transformed with respect to shore normal), spreading factor, and water level were considered for preparation of the scale. Predicted tide data collected from Survey of India tide tables (2009, 2010) were used in this study. Another important parameter is the day of the week. If it is the weekend, ultimately more number of public will visit beach and can have a chance to catch in rip currents (Fig. 5). As rip current rescues are very less, rip current drownings were used in this investigation as markers for the existence of rip currents at the time of the event. Adhering to the rip current generation mechanisms discussed in Sect. 1 of this paper, we prepared a comprehensive scale consists of all the important factors (Fig. 10). In contrast to that of previous rip current scales, we used ‘ranking’ in descending priority instead of assigning arbitrary values for each category. For every hour, the scale computes the algebraic sum of all the categories and defined as ‘Rip current Risk (RCR)’. If RCR is less than or equal to 11, it is assigned as ‘Very high

risk condition—VHR’ which is an additional risk condition compared to previous scales. ‘High risk—HR’ will be assigned when RCR lies between 11 and 15, ‘Moderate risk—MR’ when RCR is between 15 and 18, and above means ‘Low risk—LR’ condition. The risk condition will be issued every hour, and the final risk factor of the day will be forecasted in the form of an ‘ALERT ALARM’ when any risk condition (HR/VHR) exists for maximum number of times of that day. The total risk hours in a day will be computed when alarm was issued. A VHR condition forecasts ‘HIGH ALERT ALARM.’ This ALARM technique is used for the first time in this paper, as this alerts the public as well as administrator to pay attention before entering the surf on the day of ‘ALERT ALARM.’ This reduces the expenditure on lifeguards and creates awareness among public. The beach-goers may not try to penetrate into surf if proper ‘ALERT’ forecast is given. Similar to earlier rip current scales, our rip current scale also provides only the extent of risk due to rip currents but on hourly and daily basis. Hence, we coined the name called ‘*Rip current Risk forecast scale.*’ For execution of this scale, we need wave data and tide data. In forecasting mode, wave data from buoys are not used; instead, we can use validated wave forecast data in the shallow waters.

5.7 Rip current risk forecasting and validation of scale

We identified some major tourist beaches along coastal Andhra Pradesh coast (Fig. 2), which are known to be vulnerable for rip currents. We modified the name of the scale as coastal Andhra Pradesh LURCS (CAP-LURCS). This scale can be used at any part of the coast-provided forecasted wave data and coastline orientation. We present some coastline angles for important beaches in Andhra Pradesh (Table 1). In this paper, we have validated the scale for the past events reported during the study period. At a scale of district level, the coast facing the same side will have almost similar forecast. For example in Visakhapatnam district, RK beach, Yarada, and Bheemunipatnam could get the similar forecast if they have uniform bathymetry. This exercise reduces the cost of deploying buoys, deputing forecasters, reduces forecast time, and approaches to the local concerned authorities. When wave data are not available, ‘No forecast’ will be issued. We developed software in FORTRAN language which generates forecast based on our new scale (Fig. 11).

To assess the accuracy of our scale, we performed statistical verification like probability of detection (POD), false alarm ratio (FAR), and alarm ratio (AR). POD is the accuracy of the scale, which is ratio of number of events that the scale has identified rip currents to the total number of events happened. The FAR is the fraction of the forecasts of the rip current events associated with non-occurrences. AR is the percentage of days that the scale predicted rip currents. The scales’ utility is greatly diminished if it predicts rip currents too often, so AR should be comparatively low and more or less equal to POD, and the former must be higher.

A comparative analysis was done with that of 2002 and 2004 rip current scales. The 2002 scale has predicted 68 % (POD) of the events and has not given forecast for 31 % of the events (FAR) happened (Fig. 12). It detected that rip currents might exist for 68 % days (AR) during the study period. This scale seems to be given good results as POD and AR are equal and predict rip current events for greater than 60 % of the days. But this scale will only give forecast on daily basis which is not suitable for Indian coasts as discussed in earlier sections.

The 2004 scale (Fig. 13) is able to detect 97 % of the rip current events (POD) with very less 2 % FAR. But its higher AR of 94 % is not suitable for forecasting. Everyday alarm forecast will not achieve expected results. But our new scale (CAP-LURCS) has

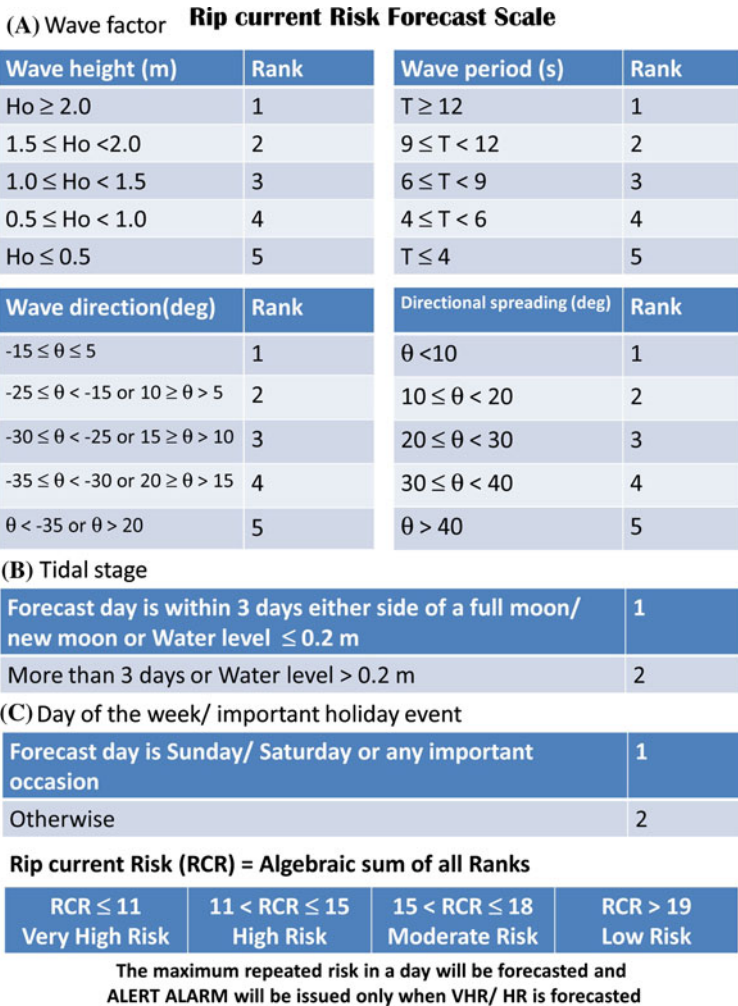


Fig. 10 New rip current predictive risk scale

POD 76 % (Fig. 13) and lower FAR of 23 %. The moderate AR for 67 % days ensures good percentage of predictability. Moreover, hourly rip current forecast will warn the public even though the daily forecast has no any ‘Alert.’ Therefore, for Indian coast, our new predictive risk scale is more appropriate for issuing rip current forecasts.

5.7.1 Validation of rip current forecast with measurements

We have checked the performance of our new predictive risk scale with the field measurements carried out during 2010 along Visakhapatnam coast to provide ground-truth validation. As a part of our regular field monitoring, littoral environmental observations (LEO) covering nearshore wave, breaker, and littoral current conditions have been recorded. Fig. 14 shows the patterns of littoral currents for different months. It is observed

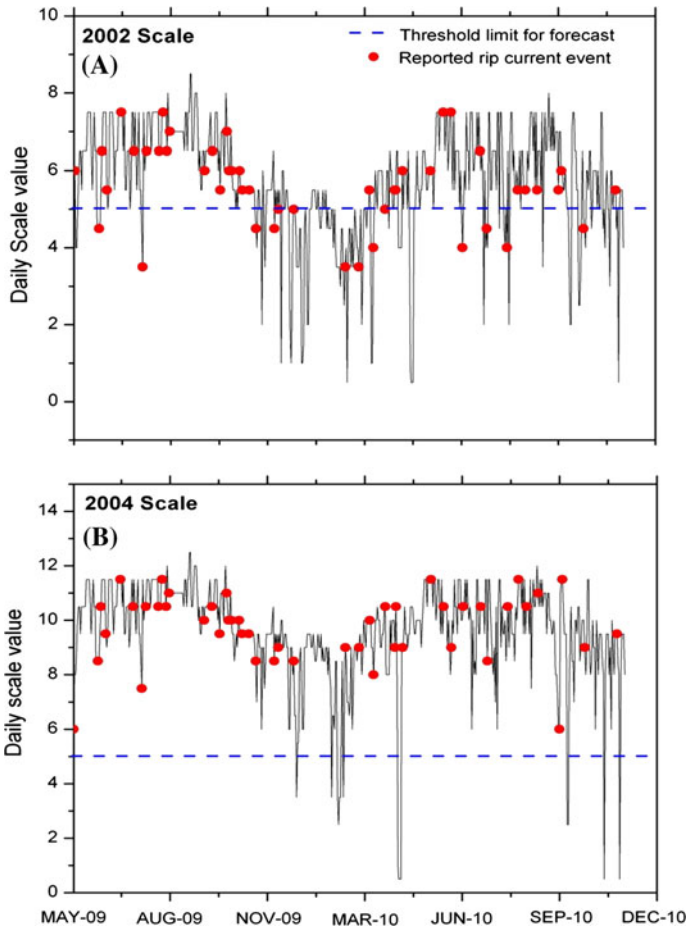


Fig. 12 The daily rip current scales along with rip current events following **a** ECFL LURCS 2002 and **b** modified ECFL LURCS 2004 scales

6 Summary and conclusions

The study analyzed fatalities caused by rip currents in important locations along east and west coasts of India for the period 2000–2010. Rip current fatalities are most common in the southeastern India, with a non-uniform spatial distribution. Pre-monsoon, post-monsoon, and south-west monsoon season are identified as most favorable conditions for rip current generation. In India, rip current-related drowning is estimated as 39 per year during the last decade. East coast of India averaged 30–40 drownings and west coast of India averaged 5–10 drownings per year during this period. In coastal Andhra Pradesh, more than 350 people had drowned and only 10 people are rescued. Visakhapatnam district recorded maximum number of drownings of about 293. The empirical forecasting technique developed by Lushine (LURCS) and Lascody (ECFL LURCS) was modified to introduce a new rip current predictive risk scale for the first time in India. The drowning data are examined in an effort to correlate with concurrent wave, wind, tide, and nearshore morphology. An increase in the frequency of rip-related drownings has been observed from

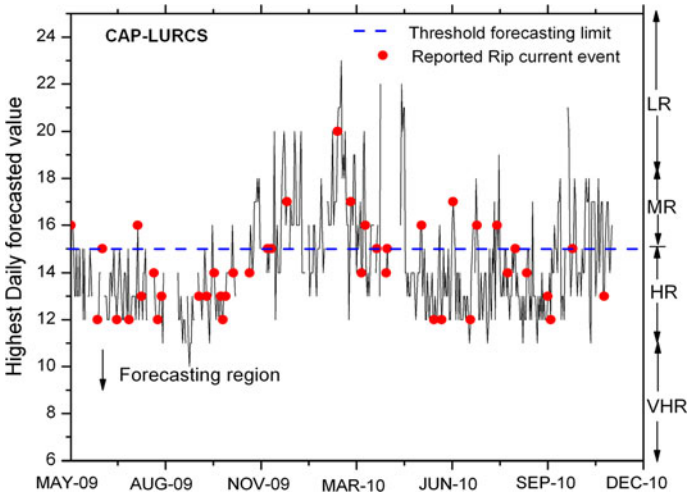


Fig. 13 Same as Fig. 12 but with new CAP-LURCS scale

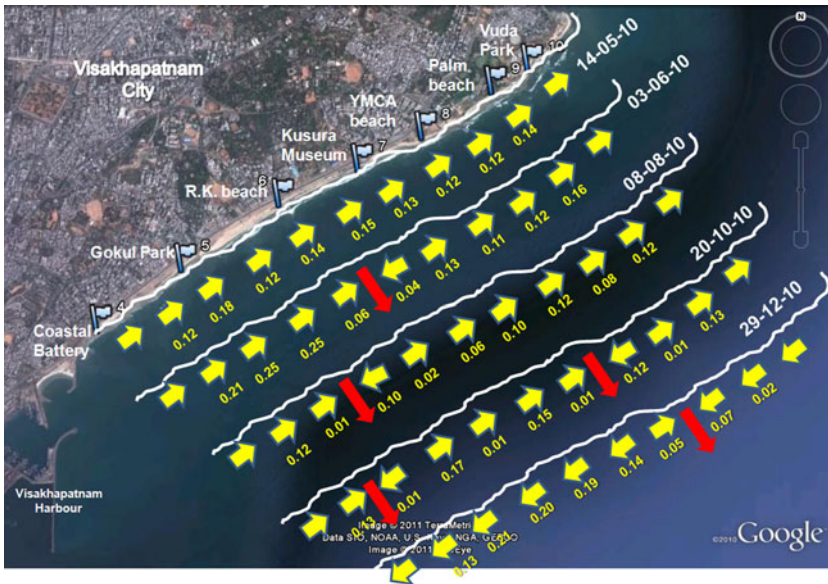


Fig. 14 Distribution measured longshore currents (m/s) and observed rip currents (in red arrows directing offshore) along Visakhapatnam during 2010 (Flags indicate stations mentioned in Table 2)—Image courtesy: Google Earth

2005, may be due to increase in nearshore wave, wind, and sea-level conditions, and also due to increase in tourism activity. The frequency of rip current events increased markedly during shore-normal wave incidence and mid-low tidal stages. Statistical analysis like probability of detection (POD), false alarm ratio (FAR), and alarm ratio (AR) infers that our scale has given better results compared to that of 2002 and 2004 scales. The

Table 3 Field measurements of surf-zone currents and validation of rip current forecasting scale

Date of Field observations	Mean L.S Current speed ($m\ s^{-1}$)	Mean wave height (m)	Mean Wave period (s)	Mean Wave direction ($^{\circ}$)	Nearshore Morphological state (ϕ)	Rip current details	New Scale CAP-LURCS forecast		
							Total risk hours	Alert issued	Remarks
10/3/2010	0.42 (S)	0.43	7.29	160	2.6—Low-tide terrace	No rip current	16	MR—No Alert	Conditions not favor for rip currents
14/5/2010	0.13 (N)	1.03	5.26	149	7.9—Bar and rip	No rip current	14	MR—No Alert	-do-
03/6/2010	0.12 (N)	1.61	6.37	159	15.2—Dissipative (Beach cusps & crescentic bars)	Rip current observed at station 6	19	HR—Alert issued	High surf; favor for rip currents
08/8/2010	0.07 (N)	1.35	6.37	162	11.9—Rhythmic bar and beach	Rip current observed between stns. 5 and 6	22	HR—Alert issued	-do-
20/10/2010	0.06 (N)	0.73	7.18	147	4.6—Bar and rip	Rip current observed at stations 5 and 8	14	HR—Alert issued	High surf and swells; rip currents may exist
29/12/2010	0.13 (S)	-NA-	-NA-	-NA-	4.3—Bar and rip	Rip current observed between stns. 8 and 9	-NA-	-NF-	No information

MR moderate risk, HR high risk, NF no forecast due to no wave data, NA not available, N for northward current, and S for southward current

performance of the new scale and forecast is validated with measured data and found to be well correlated. Hence, the authors recommend CAP-LURCS scale for issuing forecast in surf zone.

Acknowledgments The authors would like to thank the Police Commissioner of Visakhapatnam city for providing dataset on rip current drownings. We also thank our senior professor Prof. B. S. R. Reddy for his constructive suggestions during the preparation of this manuscript. We also deeply acknowledge Randy Lascody and James Lushine of NOAA National Weather Service, Florida, and Prof. G. Bharathi for motivating suggestions during the initial preparation of this paper. The first author would like to thank CSIR, New Delhi, for providing fellowship during the study. We equally thank Dr. B. R. Subramaniam, Director, and Dr. V. Ranga Rao ICMAM, MoES, Government of India, for their wonderful co-operation during the execution of our Gangavaram—SLM project. We thank Dr. K. V. K. R. K. Patnaik and Mr. Ch. Venkata Ramu for their comments and discussions throughout this paper. We equally thank anonymous reviewers for their constructive suggestion in improving the quality of the paper. This paper is proudly dedicated to rip current fatalities in India.

References

- Ashley ST, Ashley WS (2008a) Flood fatalities in the United States. *J Appl Meteorol Climatol* 47:805–818
- Ashley ST, Ashley WS (2008b) The storm morphology of deadly flooding events in the United States. *Int J Climatol* 28:493–503
- Ashley WS, Mote TL (2005) Derecho hazards in the United States. *Bull Am Meteorol Soc* 86:1577–1592
- Bascom W (1980) Waves and beaches. Anchor Press/Doubleday, Garden City, New York, pp 227–230
- Bowen AJ (1969) Rip currents, 1, theoretical investigations. *J Geophys Res* 74(23):5467–5478
- Brander RW, Short AD (2001) Flow kinematics of low-energy rip current systems. *J Coast Res* 17:468–481
- Chandra Mohan P, Sanil kumar V, Jena BK (1997) Rip current zones along beaches in Goa, west coast of India. *J Waterw Port Coast Ocean Eng* 123:322–328
- Changnon SA, Changnon D (1999) Record high losses from weather disasters in the United States during the 1990s: how excessive and why? *Nat Hazards* 13:287–300
- Cook D (1970) The occurrence and geologic work of rip currents off Southern California. *Mar Geol* 9:173–186
- Curran EB, Holle RL, Lopez RE (2000) Lightning casualties and damages in the United States from 1959 to 1994. *J Clim* 13:3448–3464
- Dalrymple RA (1975) A mechanism for rip current generation on an open coast. *J Geophys Res* 80:3485–3487
- Dalrymple RA (1978) Rip currents and their causes. In: Proceedings 16th international conference coast. ASCE, England, Washington, DC, pp 1414–1427
- Dalrymple RA, Mac Mahan JH, Reniers AJHM, Nelko V (2011) Rip currents. *Annu Rev Fluid Mech*. doi:10.1146/annurev-fluid-122109-160733
- Doswell CA III, Burgess DW (1988) On some issues of United States tornado climatology. *Mon Weather Rev* 116:495–501
- Dronen N, Karunarathna H, Fredsoe J, Sumer BM, Deigaard R (2002) An experimental study of rip channel flow. *J Coast Eng* 45:223–238
- Engle J (2003) Formulation of a rip current forecasting technique through statistical analysis of rip current-related rescues. Master's thesis. University of Florida, Gainesville
- Engle J, Mac Mahan J, Thieke RJ, Hanes DM, Dean Robert G (2002) Formulation of a Rip Current Predictive Index Using Rescue Data. Proceedings of National Conference on Beach Preservation Technology, FSBPA, Biloxi, MS
- Gall M, Borden KA, Cutter SL (2009) When do losses count? Six fallacies of natural hazards loss data. *Bull Am Meteorol Soc* 90:799–809
- Gensini AV, Walker SA (2010) An examination of rip current fatalities in the United States. *Nat Hazards*. doi:10.1007/s11069-009-9458-0
- Gutierrez E (2004) Effects of longshore currents on rip currents. M.S. thesis
- Guza RT, Inman DL (1975) Edge waves and beach cusps. *J Geophys Res* 80:2997–3012
- Haller MC, Dalrymple RA, Svendsen IA (2002) Experimental study of nearshore dynamics on a barred beach with rip channels. *J Geophys Res* 107:3061
- Huschke RE (1959) Glossary of meteorology. American Meteorological Society, Boston, Massachusetts, p 484

- Johnson D, Pattiaratchi C (2006) Boussinesq modelling of transient rip currents. *Coast Eng* 53(5–6):419–439
- Larson M, Capobianco M, Hanson H (2000) Relationship between beach profiles and waves at duck, North Carolina, determined by canonical correlation analysis. *Mar Geol* 163(1–4):275–288
- Lascody R (1998) East central Florida rip current program. *Natl Weather Dig* 22:25–30
- Lushine J (1991a) Rip currents: human impact and forecastability. In: *Proceedings of the coastal zone*. ASCE, New York, pp 3558–3569
- Lushine J (1991b) A study of rip current drownings and related weather factors. *Natl Weather Dig* 16:13–19
- Mac Mahan J, Reniers A, Thornton E, Stanton T (2004) Infragravity rip current pulsations. *J Geophys Res Oceans* 109:C01033
- Mac Mahan J, Thornton E, Stanton T, Reniers A (2005) RIPEX: observations of a rip current system. *Mar Geol* 218:113–134
- Nelko V, Dalrymple RA (2008) Rip currents: mechanisms and observations. In: Smith JM (ed) *Proceedings of the 31st international conference on Coastal Engineering*. World Science, Singapore, pp 888–900
- Prasad KVS R (2002) Surfzone currents off Visakhapatnam. *Proc AP Akad Sci* 6(1):73–78
- Schrader M (2004) Evaluation of the modified ECFL LURCS rip current forecasting scale and conditions of selected rip current events in Florida. Master's thesis. University of Florida, Gainesville
- Shepard FP, Inman DL (1950) Nearshore circulation related to bottom topography and wave refraction. *Trans Am Geophys Union* 31:196–212
- Shepard FP, Emory KO, La Fond EC (1941) Rip currents: a process of geological importance. *J Geol* 49:337–369
- Short AD (1985) Rip-current type, spacing and persistence, Narrabeen Beach, Australia. *Mar Geol* 65:47–71
- Sonu CJ (1972) Field observations of nearshore circulation and meandering currents. *J Geophys Res* 77(181):3132–3147
- Wright LD, Short AD (1984) Morphodynamic variability of surf zones and beaches: a synthesis. *Mar Geol* 56:93–118