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Rip Current Hazard in Klayar Beach, Pacitan, Indonesia: Inferred from Fluorescent Dye and UAV

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***Abstract*— South coasts of Java have a unique landscape that exhibits exotic and phantastic natural view which is very attractive as tourist destinations. Indonesia has the world's longest coastlines, the world's highest coral diversity, and spectacular seascapes, therefore Indonesia's coastal tourism potential is very promising. However, despite their attractiveness coastal water can be very dangerous to their visitors due to rip currents which isinhospitable to them. Klayar Beach (KB) is one of the most popular recreational beaches in Pacitan Regency, East Java Province, Indonesia. However, KB poses a hazard due to rip currents. This paper presents the result of field observations of rip currents utilizing fluorescent dying and unmanned aerial vehicle (UAV). We used UAV multirotor DJI Mavic 2 Zoom with video camera to take and monitor aerial photo and video of rip current flows. The result of this study proves that there is rip currents in KB. It also reveals that the maximum velocity reaches 0.8 m/s, with average width of 11 m, and total length 99.99 m. The type of rip current in the KB is structural boundary controlled and predicted as a permanent rip. Therefore, this evidence should be considered for promoting beach safety in this area.**

Keywords—*Hazards, Klayar Beach, Tourism, Permanent Rip, Safety.*

I. Introduction

Southern Java coastal area is directly facing an open sea of the Indian Ocean, therefore the width of the fetch from where the wind blows that generating incoming waves to this area is nearly unlimited. Consequently, the height of incident waves as well as incoming breaking waves are relatively high, whose significant wave height (Hs) is ranging from 4 to 7 m with periods of more than 10 second [1]. This yields the value of $Hs^2T^2 > 300$, indicating highly exposed coast (Hays, 1979). Combining with its tidal characteristics, that has semi-diurnal tides with tidal range of about 2.18 m, the southern Java coastal area is classified as wave dominated coast [1]. Hilly and mountainous morphology, heterogeneity of rocks composition with igneous rocks intrusion at some places, combined with swell dominated oceanographic environment lead this area possess unique landscapes. Embayed sandy beaches are very common along the hilly and mountainous wave-exposed coasts in southern coast of Java. Therefore, it exhibits very exotic and phantastic natural view that attracts beachgoer who come not only from domestic but also from foreign countries.

Tourism industries in Indonesia is one of the largest foreign exchange contributors to the country. One of the most attractive tourist destinations is coastal area that globally represented around 26 percent of ocean-related value-added (OECD 2016). Indonesia has the world's longest coastlines, the world's highest coral diversity, and spectacular seascapes, therefore Indonesia's coastal tourism potential is very promising.

Coastal waters, especially in the nearshore is an active zone that very attractive to the tourist. However, despite their attractiveness coastal water can be very dangerous to their visitors due to rip currents which is really inhospitable to them [2, 3, 4]. Rip currents are among the most dangerous coastal hazards for the bathing public in the coastal water [5, 6], particularly swell dominated environment as it is possessed by southern Java coastal area, since swell waves seem to present more hazardous rip current conditions than wind waves [5, 7]. Unfortunately, study on rip currents in the southern coast of Java is still very rare, hence there is lack information of rip current, accordingly. Since these conditions, it offers a favourable challange to investigate rip currents in this area.

Rip current is water masses that move in the opposite direction to the incoming waves which extend normal to the beach [8, 9, 7, 10, 2, 3, 4, 11], shallow and narrow, can be very strong, and concentrated offshore ward-directed jet stream [7, 12, 4, 11], associated with wave action in the breaker zone [8, 13, 11], the characteristics depend on the variability of incident wave height [7, 4, 14], and heterogeneity of the sea floor topography [8, 13, 15].

This paper presents the result of the field observation of rip currents utilizing fluorescent dye and unmanned

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aerial vehicle (UAV). It is expected that the result of this study can benefit all stake holders especially government official to formulate mitigation measures concept against the rip current risk.

II. METHOD

A. Study Area

Klayar Beach is one of the most popular beaches recreational tourisms that located at south coast of Pacitan Regency, East Java Province, Indonesia with the boundary of 8º13'23"S; 110º56'46"E to 8º13'28"S; 110º56'43"E and 8º13'30"S; 110º56'54"E to 8º13'33"S; 110º56'30"E (Fig. 1). KB shows spectacular landscape with rocky coast, embayed beach with hilly headlands and cliffed coast, sea stacks and wave cut terraces, very heigh and attractive incoming breaking waves. This feature of the study area is typical of the secondary coast that wave action is dominant processes [1].

Google Earth™ maps were utilized to obtain beach recreational location where rip currents supposed to be occurred and giving thread to the visitors. Satellite imageries of Google Earth™ have been widely used by researchers for rip identification [16, 17, 18, 19, 20, 21, 1]. We used eight satellite imageries of Google Earth™ from 2009 to 2023 that show rip currents continually occur (Fig. 2).

B. Rip Current Observation

This study used fluorescent dying solution of Na-fluorescein (*uranine*, $C_{20}H_{10}Na_2O_5$) to observe the existence and to demonstrate the flow of rip currents in the study area. Uranine is an organic salt that has been widely used as a water flow tracing since it is environmentally harmless in adequate concentration. It has extremely low toxicity, highly soluble and stable in water. Uranine in water is also highly detectable at low concentration and visible to the naked eye [22, 23, 24, 25, 26, 27, 28].

In ideal conditions, uranine can be detected in a very low limit concentration that up to 0.001 g/L. When dissolve in water, uranine has a red color at > 1g/L concentration, and a bright green color at >10μg/L.

The rip currents observation has been carried out by injecting the fluorescent dye uranine solution in the seawater that close to the shoreline and the movement of the pigmented seawater carried by rip current was then monitored and recorded by aerial video mounted on the unmanned aerial vehicle (UAV). We used UAV/drone multirotor DJI Mavic 2 Zoom. Aerial photo data collection is carried out using auto-pilot control Drone Deploy software that has the ability to automatically create a flight path in accordance with specified area of

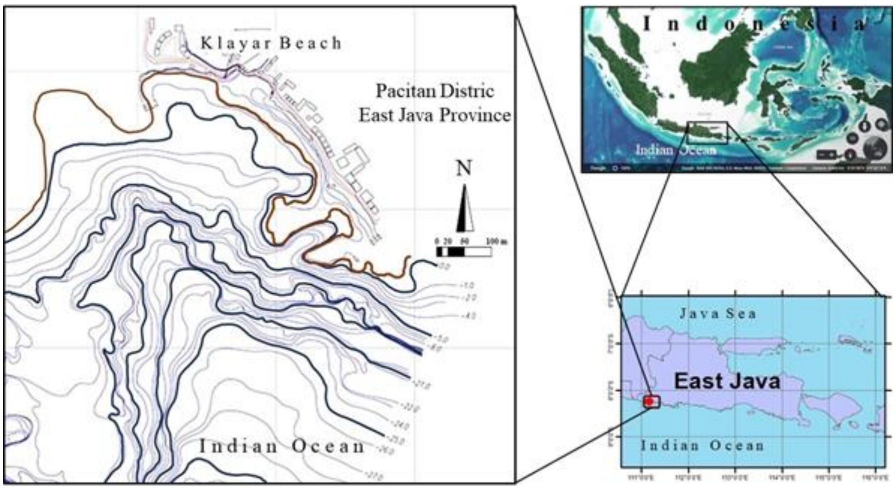

Figure 1. Location of study in the Klayar Beach, Pacitan Regency, East Java Povince, Indonesia

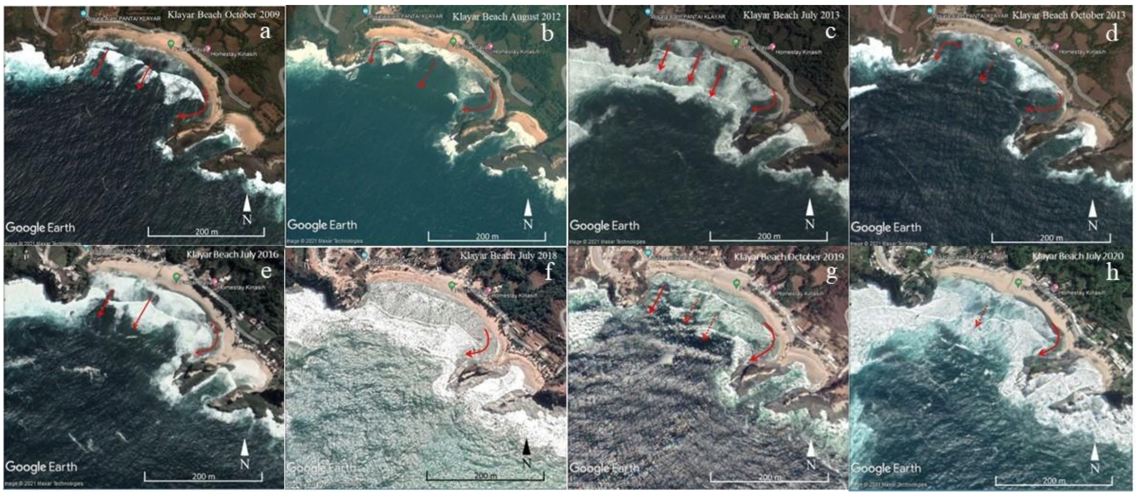

Figure. 2. Google Map™'s satellite imageries of the study area from 2009 to 2020. a. October 2009; b. August 2012; c. July 2013; d. October 2013; e. July 2016; f. July 2018; g. October 2019; and h. July 2020 (Wahyudi *et al.*, 2023)

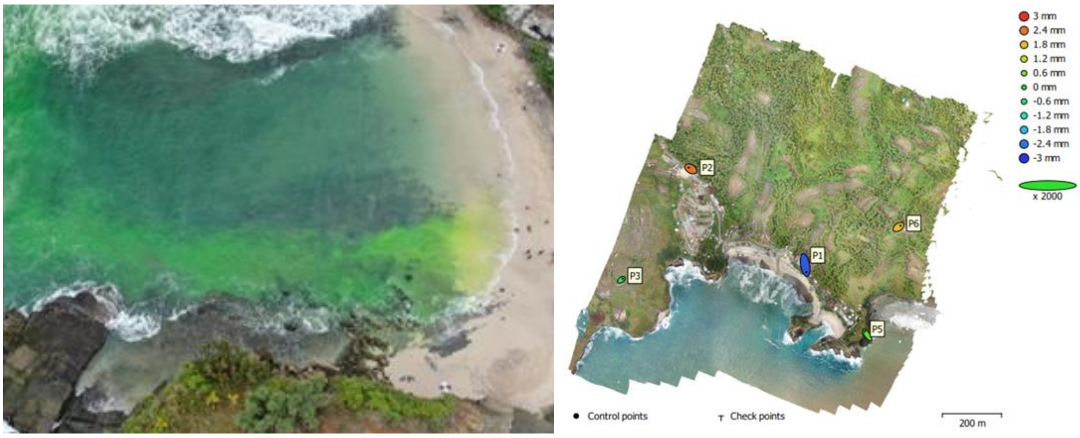

Figure 3. Geo-references used in this study, two markers (left) and five Ground Control Points (right)

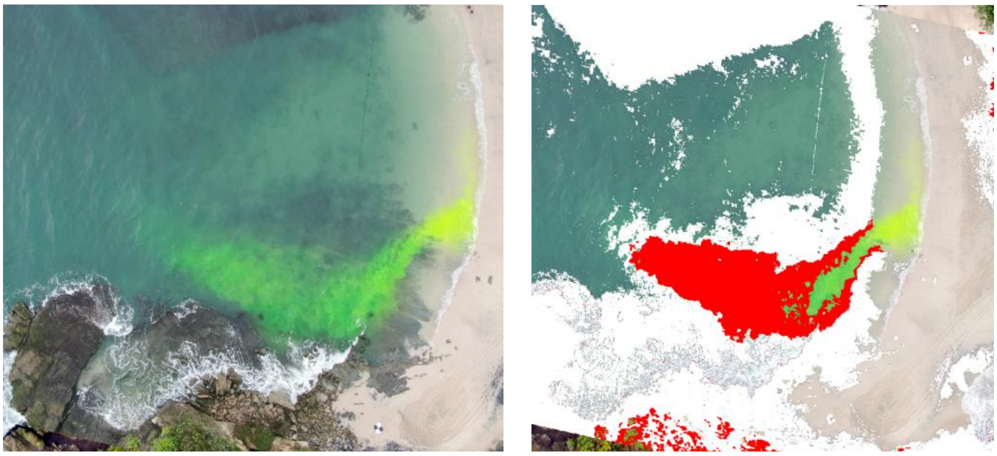

Figure. 4. Pigmented sea water (left) and its segmentation of fluorescent dye areas and non-fluorescent dye areas (right)

interest. In this study, the flying height is set at an altitude of 150 m above ground level, with a coverage area of 112 hectares. Front overlap is set at 80% and side lap at 75%. This is to ensure that photos can be processed perfectly through Agisoft.

The calculation of rip current speed is done by converting drone video into a sequence of images at 15 second intervals using the Python Library, namely Open CV. The selected image is then georeferenced using the coordinates measured on the marker. Beside the marker coordinates, geo-reference points also refer to orthophoto results that have been processed and have a clear coordinate and reference system (Fig. 3). The process of identifying tracer fluorescent dye is carried out by means of semi-automatic segmentation using ENVI software. The tool used is object identification based on Region of Interest (ROI) which will semi-automatically classify fluorescent dye areas and non-fluorescent dye areas (Fig. 4).

After all image sequences have been processed, the velocity is determined by calculating the distance of the fluorescent dye movement in each image sequence. The measured distance is then divided by a time interval of 15 seconds to obtain the dye flow velocity. The velocity is measured in several segments, including starting from the dye injection to the wave breaking zone, from the rip feeder, the rip neck ends at the rip head. For each image sequence, the average rip current width, feeder and neck length, and total rip length are also calculated.

III. Results and Discussion

Rip Currents Dimension

Uranine fluorescent dye was injected at two selected locations of the study area, at the center of the bay and beside headland, on 13 October 2022 and 15 October 2022, respectively. In order to make footage of the rip currents flow, we combined fluorescent dying with a video camera mounted on the drone. Rip current observations were carried out through analyses of photographs and video footage of the pigmented sea water movement by rip currents. Current velocity was measured through the conversion of video into picture sequences with an interval of 15 seconds for each sequence. The selected pictures were then referred to the two markers and five GCPs (Figure 3).

Figures 5 and 6 show the results of rip current characteristics observations based on the measured movement of each sequence from the measurement on 15 October 2022, at 10.50 and 11.08, respectively. The yellow color indicates the feeder area until it starts to enter the rip neck area. The rip neck measurement starts from the red point and goes to the rip head. Each dot indicates the tip of the fluorescent dye identified in each sequence at 15 second intervals. The results of calculating rip current characteristics at 10.56 am are as follows. Total rip length is 99.95 m, the average rip width is 10.99 m, the maximum velocity reached as high as 0.81 m/s, and minimum velocity is 0.116 m/s with average velocity of 0.44 m/s. While the result of the measurements at 11.08 are the following: total rip length is 85.06 m, the average rip width is 11.76 m, the maximum velocity up to 0.69 m/s, and minimum velocity is 0.270 m/s with average velocity of 0.44 m/s. The detailed result of the observations is presented in Table 1.

Rip Current Characteristics

This is interpreted that KB is categorized as erosional rather than accretional beach. Therefore, according to [29], KB rip currents could have been classified as erosional rips. However, since the morphology of the embayment including the size of the embayment is relatively small, its geometry as shown by the sea bottom valley and direction of the east headland tends to refract and block the incident waves, respectively, then eventually, any direction of incident waves almost always perpendicular to the shoreline and are blocked by the east headland. Therefore, the above-mentioned classification of rip types for the study area is applicable.

More specifically the existence of east headland which is playing an important role in blocking the incident waves that lead the down waves area as a shadow zone that is very susceptible for shadow rips to take place. KB, especially at the east headland looks calm as protected from incident waves and breaking waves, also looks attractive and beautiful since very close to the headland, despite that attractiveness, structural (headland) boundary shadow rip current in KB persistently occurs and could be very fast in velocity. Concerning the condition, it is suggested to formulate mitigation measures to lower the risk due to this deadly hazard, not only in the KB but also along the southern coast of Java Island.

TABLE 1.
RIP CHARACTERISTICS MEASUREMENTS OBSERVED FROM THE SEQUENTIAL PICTURES EXTRACTED AT EVERY 15 SECOND INTERVAL OF THE PIGMENTED RIP VIDEO FOOTAGE TAKEN FROM THE DRONE ON OCTOBER 2022 15TH AT 10:50 AM AND AT 11.08 AM.

Rip Anatomy	Injection at 10:50 am			Injection at 11:08 am		
	Distance between consecutive points observation (m)	Width (m)	Velocity (m/s)	Distance between consecutive points observation (m)	Width (m)	Velocity (m/s)
Point of uranine injection	0	-	-	0	-	-
Rip feeder				7.76	6.8	0.517
	8.01	3.59	0.534	8.66	7.75	0.577
	9.66	6.52	0.644	5.63	12.17	0.375
	8.02	5.82	0.535	5.71	14.06	0.381
	7.03	13.07	0.469	7.57	13.32	0.505
Rip neck	8.10	12.46	0.540	10.44	14.37	0.696
	12.15	12.16	0.810	5.73	12.66	0.382
	4.85	11.67	0.323	6.32	14.04	0.421
	5.47	12.95	0.365	4.06	12.76	0.271
	4.79	11.15	0.319	5.46	12.55	0.364
	4.44	11.85	0.296	5.48	12.6	0.365
	4.40	11.40	0.293	7.04	11.74	0.469
	2.66	11.43	0.177	5.20	11.01	0.347
	4.01	11.87	0.267			
	5.00	11.71	0.333			
	5.55	13.82	0.370			
	4.07	12.42	0.271			
	1.74	13.06	0.116			
Rip head	-	-	-	-	-	-
Average		11.00	0.345		11.99	0.443
Feeder length (m)	32.72			35.33		
Neck length (m)	67.23			49.73		
Total rip length (m)	99.95			85.06		

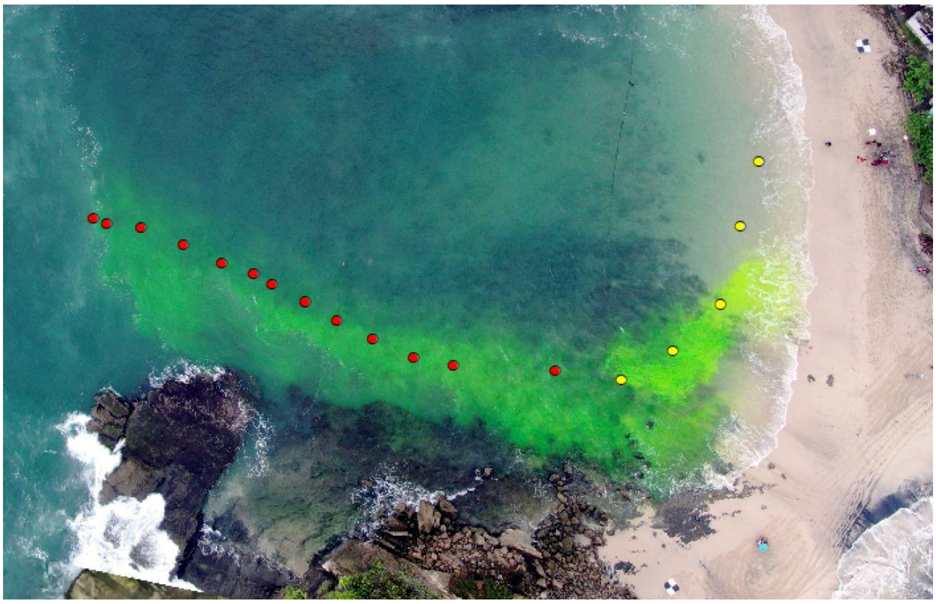

Figure 5. Measurements of rip current from uranine pigmented seawater on October 15th 2022 at 10:50 am (local time); yellow and red dots represent feeder and neck, respectively, with interval time observation between adjacent dot is 15 second.

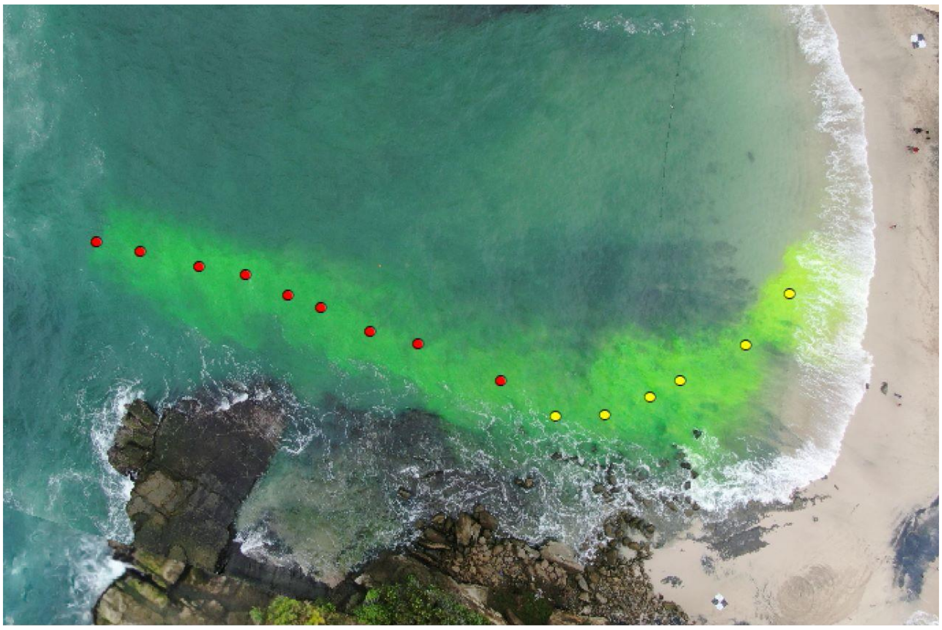

Figure. 6. Measurements of rip current from uranine pigmented seawater on October 15th 2022 at 11:08 am (local time); yellow and red dots represent feeder and neck, respectively, with interval time observation between adjacent dot is 15 second.

IV. Conclusion

We have conducted field observation for rip currents identification using fluorescent dye and UAV in Klayar Beach Pacitan East Java Indonesia. We used UAV multirotor DJI Mavic 2 Zoom with video camera to take and monitor aerial photo and video of rip current flows. The result of this study proves that there is rip currents in KB. It also reveals that the maximum velocity reaches 0.8 m/s, with average width of 11 m, and total length 99.99 m. The type of rip current in the KB is structural boundary controlled and predicted as a permanent rip. Therefore, this evidence should be considered for promoting beach safety in this area.

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