Ocean & Coastal Management xxx (2015) 1–10

Contents lists available at ScienceDirect

Ocean & Coastal Management

journal homepage: www.elsevier.com/locate/ocecoaman

Determination of risk to users by the spatial and temporal variation of rip currents on the beach of Santiago Bay, Manzanillo, Mexico: Beach hazards and safety strategy as tool for coastal zone management

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A R T I C L E I N F O

Article history:
Received 1 February 2015
Received in revised form
8 June 2015
Accepted 10 July 2015
Available online xxx

Keywords:
Rip currents
Beach management
Risk assessment
Coastal zone management tool

A B S T R A C T

Beaches are one of the most popular sites used for recreation and spare time by people, being a zone with a constant evolution due to the combined effects of coastal currents, waves and tides. Sometimes, interaction of these processes with local bathymetry causes formation of rip currents (RCs), which are related with accidents to swimmers that even cause drownings. These accidents are strengthened by the lack of information and awareness of RCs, in addition to poor and insufficient beach surveillance. Santiago Bay (SB) (Manzanillo, Mexico), has beaches with great recreational value visited by many tourists every year. Unfortunately SB is not exempt of having potentially dangerous RCs (there is not an official number of accidents reported), and their spatial and temporal variation has not been extensively studied. Due to this lack of data, several research campaigns have been made since 2013 to identify, register and characterize RCs in order to use the information for elaborating new strategies of risk assessment, beach management and assure safety regulations in recreational beaches. In the field survey different data were collected: position, width and RCs intensity, using mobile devices such as a GPS Ashtech Mobile Mapper 10, and two self-made buoys equipped with internal GPS Garmin DC 40. After processing the data, six RCs were constantly identified in the area of study, with intensities ranging from 0 to 1.5 m/s approximately, and widths from 20 to 60 m, and were found to be more recurrent and strong on later spring and summer, as because these period more energetic waves (swell) generated by storms (located as far as the South Pacific) arrive and interact with local bathymetry and tides, favoring the generation and intensification of the RCs. The collected data will be especially useful for the implementation and validation of numerical hydrodynamic models that will be used for spatial and temporal forecasting of potentially dangerous RCs at SB.

1. Introduction

Coastal environments fulfill several functions, emphasizing their use as recreational area. These places have particular characteristics, which make them singular and complex due to the intensity of mass and energy fluxes between land and sea, as well as interactions between physical, chemical and biological processes present (Cabrera, 2009).

There is a special interest to understand these complex processes in order to manage coastal areas properly. A lack of information may be reflected in an increase of risk for beach users, as there are physical phenomena as rip currents (RC) which have a probability of incidence with certain intensity in specific sites and variable time periods, producing adverse effects for swimmers (Afanador and Ruíz, 2009).

RCs are a response to water that has reached the beach mainly due to waves, which try to go back offshore as a cross-shore current that typically dissipate behind surf zone, at distances around 100 m

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http://dx.doi.org/10.1016/j.ocecoaman.2015.07.009
0964-5691/

from shore. Some RC are cuasi-permanents, but other could transiently appear at almost everywhere along coast, especially where two different alongshore currents interact. Their width varies from 15 to 30 m, with superficial velocities up to 2 m s^{-1}, characterized by presence of turbulence and thin suspended sediment (Woodroffe, 2002). Size, intensity and particular RCs characteristics may vary from place to place, due to tide cycles, wave and climate conditions (MacMahan et al., 2006).

1.1. Rip currents genesis

The bigger the waves, the stronger the rip- Think of them as “rivers of the sea” (Brander, 2010).

Rips currents (RCs) are shore-normal, narrow, seaward-flowing currents (Dalrympe et al. 2011) that originate within surf zone and extend seaward of the breaking region (rip head), and can obtain relatively high velocities (MacMahan et al., 2006).

They occur on many types of beaches under a variety of wave conditions and tidal levels. The RCs flow behavior within the surf zone is often masked by breaking waves, whereas, offshore of the surf zone, the rip current jet moves into relatively quiescent waters, where the jet diffuses into a rip current head. Beach type is a key component in rip current scale. Open-coast beaches that are far away from coastal structures or headlands have a plethora of rip current shapes (Dalrympe et al., 2011).

Shepard et al. (1941) pointed out that rip currents are most visible on long sandy beaches were the sediment- and bubble-laden rip currents exiting the surf zone are more easily identified, as the case of Miramar beach in the study area (Fig. 4).

As an example, a theoretical scenario was simulated in a CFD hydrodynamic model called FLOW 3D (Version 11.0.4, Flow Science, USA), in order to show how a RC is formed. A mild slope beach with a broken submerged bar was used in the setup (Fig. 1), with regular wave trains imposed in the inlet boundary, which propagated towards the beach. Results obtained showed that the interaction between waves and the submerged bar formed two well defined rip currents, with velocities around 20 cm/s (Fig. 2).

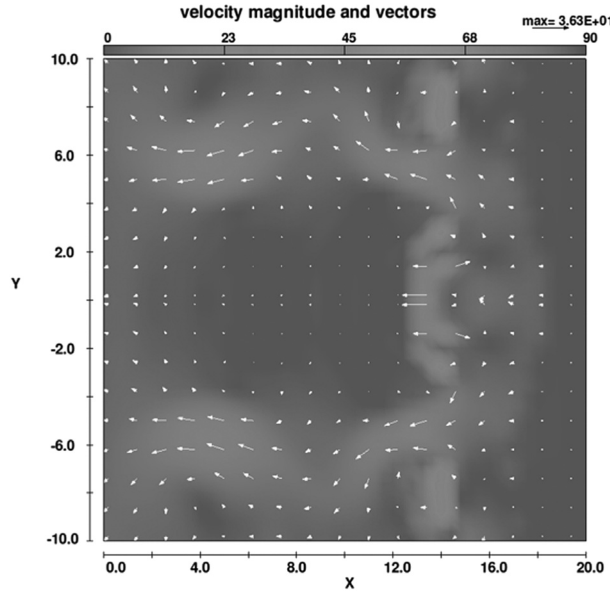

Fig. 2. Results obtained from numerical simulation. It can be seen that the interaction between waves and the submerged bar forms two well defined rip currents, with velocities around 20 cm/s.

1.2. Risk and rip currents

Although rip currents are useful for surfers and lifeguards because they accelerate their journey across the surf zone, lack of education and awareness about these natural flows allows these important surf-zone circulations to become one of the most lethal natural hazards worldwide, taking swimmers of all ability levels into deeper water within minutes.

In an international panorama, they are the main cause of drowning and rescue campaigns at beaches (Leatherman and Fletemeyer, 2011). At Australia, 89% of more than 25,000 rescues were due to presence of these currents (Short and Logan, 1994); with a rough estimate of 40–50 annual drownings (Short and Logan, 1994; Sherker et al., 2008; SLSA, 2009). Other sites with RCs related accidents are Europe, New Zealand, Asia, Israel, South Africa, as well as Central (highlighting in Costa Rica) and South America (Klein et al., 2003; Carey and Rogers, 2005; Hartmann, 2006; Short, 2007; McCool et al., 2008; Scott et al., 2009; Leatherman and Fletemeyer, 2011; Woodward et al., 2013; Arozarena et al., 2015).

Mexico is not the exception, with no reliable official RCs registrations that makes real annual drowning estimates to remain unknown. The lack of awareness from beach users about RCs, as well as data shortage that would allow spatially and temporal evolution understanding, are main factors that are reflected in a raise of hazards due to a scarcity of strategies for risk assessment and beach management. Between 2011 and May 2015 in at Manzanillo, local and regional newspaper reported 27 drownings on Manzanillo Beaches (Fig. 3), highlighting the months of July and August with more reports related to holiday periods and greater energy on the coast because it is the period of ocean storms (SMN, 2012).

In this paper, a comprehensive review of the RC dynamics is presented, as a result from several research campaigns that have been made since 2013 to identify, register and characterize the RCs. Scientific information derived from this characterization can be used to elaborate new strategies of risk assessment, beach management and assure safety regulations at Manzanillo and other recreational beaches.

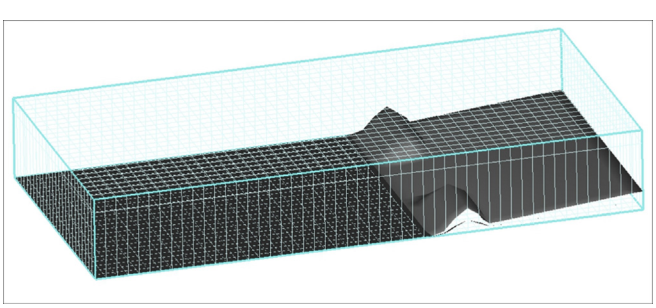

Fig. 1. Bathymetry of a mild slope beach with a broken submerged bar. This setup (bathymetry and mesh) was used in a numerical simulation example using the CFD model FLOW-3D. A regular wave train was imposed in the inlet boundary, which propagated towards the beach.

1.3. Study area

Santiago Bay (SB) is located at the central zone of the Mexican tropical Pacific (19°05′ N – 104°23′ W), is semicircular in shape and open to the ocean. Bathymetry of Bahía Santiago indicates an average depth of about 6 m; it is connected with the Julualpan lagoon (Fig. 1) and has beaches with a high number of visitors due to its recreational features during all year. Unfortunately SB is not

Please cite this article in press as: Cervantes, O., et al., Determination of risk to users by the spatial and temporal variation of rip currents on the beach of Santiago Bay, Manzanillo, Mexico: Beach hazards and safety strategy as tool for coastal zone management, Ocean & Coastal Management (2015), http://dx.doi.org/10.1016/j.ocecoaman.2015.07.009