Geomorphology 214 (2014) 436–451

Contents lists available at ScienceDirect

Geomorphology

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

Coastal processes and longshore sediment transport along Kundapura coast, central west coast of India

P.R. Shanas, V. Sanil Kumar *

CSIR-National Institute of Oceanography (Council of Scientific & Industrial Research), Dona Paula, Goa 403 004 India

ARTICLE INFO

Article history:
Received 1 September 2012
Received in revised form 24 February 2014
Accepted 28 February 2014
Available online 12 March 2014

Keywords:
Longshore currents
Sediment transport
Nearshore waves
Nearshore processes
Littoral drift

ABSTRACT

Longshore sediment transport (LST) is one of the main factors influencing coastal geomorphology. This study examines the variation in the LST estimate using four well known formulae and the sensitivity of wave parameters on LST determination. The study was done along the Kundapura coast, central west coast of India. The Delft3D-wave module was used for obtaining the nearshore wave characteristics from the wave data measured using Datawell directional wave rider buoy at 12 m water depth for a period of one year. Diurnal change and seasonal variation in LST were examined. The study shows that the net LST was toward north for most of the time (non-monsoon period) during the year when predominant wave direction was between SWS and SW, whereas the LST was toward south during the monsoon season when the wave direction was from the west. It was found that the influence of breaker height was more during the non-monsoon period whereas during the monsoon period, breaker angle shows more influence on LST. Estimated annual net LSTR for the region is 3.6, 3.0, 1.6, and 2.6×10^5 m^3 based on the CERC, Walton and Bruno, Kamphuis and Komar formulae. The LSTR estimate based on the Kamphuis formula, which also includes the wave period, beach slope, and sediment grain size, was found to be a reliable estimate for the study region. The variation in LSTR estimate considering different data intervals was also examined and found that the difference in monthly LSTR for data intervals of 6, 12 and 24 h with respect to the 3 h interval was up to 11, 13 and 24%. For better and more accurate estimates of LSTR, the data interval should be 3 h or less.

1. Introduction

The coastal environment constitutes a fragile and complex ecosystem that is an important resource for most nations. The littoral drift or longshore sediment transport (LST) is one of the main factors influencing the coastal geomorphology (CERC, 1984). Quantitative understanding and thorough knowledge of LST in the littoral zone are essential for the design of coastal protection measures and operational maintenance of navigation channels. In the normal course, if some beach material is washed away during a rough weather season, the lost material is re-deposited during the next fair weather season and the beach equilibrium is maintained (Komar, 1998). However, when there is an obstruction to littoral drift due to the presence of natural headlands, shoals and/or artificial structures, the equilibrium profile of the natural beach is disturbed (Komar, 1998). Quantitative prediction of coastal processes and coastal evolution through numerical modeling is now possible due to the major advances that have been made in understanding the physical processes and mathematical modeling techniques over the last few years (e.g. Jiang et al., 2010). Because of the complexity of the nearshore processes, accurate estimation of longshore sediment transport rate (LSTR) is still a task for the coastal engineers (Mafi et al., 2013). The accuracy of the prediction depends on the environmental conditions at the nearshore zone, the governing physical processes, and the quality of the data used to calibrate the formulation (Güner et al., 2013).

Generally there are two fundamental approaches for the estimation of LSTR. One is with the bulk formulation which is based on the assumption of simplified physical processes and the other one is the process-based models which include the effects of large number of complex physical processes. The process-based models require a large number of input parameters (Mil-Homens et al., 2012). In the surf zone of sandy beaches, the LSTR is controlled by the waves through wave breaking and wave-induced currents (Van Rijn, 2002) and hence are mainly related to breaking wave parameters. So the bulk formulation requires wave characteristics in the breaker zone. Also, due to the difficulty of acquiring extensive data in the complex nearshore region using instruments, a commonly used approach is to estimate LSTR through empirical bulk formulation.

LSTR empirical formulations largely dependent on the field measurements and moreover they remained site specific. Hence, it is important to test these formulations in different coastal regions which are subjected to different wave conditions. In the eastern Arabian Sea, during June–September, a time generally referred to as the summer

* Corresponding author. Tel.: +91 832 2450 327; fax: +91 832 2450 602.
E-mail address: sanil@nio.org (V. Sanil Kumar).

http://dx.doi.org/10.1016/j.geomorph.2014.02.027

monsoon or SW monsoon or monsoon, the general direction of winds is south-westerly and its strength is significantly larger than that during the rest of the year (Kumar et al., 2012). During November–March, winds over the region have an overall north-easterly direction. October and April–May are times of transition (Shetye et al., 1985). This seasonal cycle of winds leads to a cycle in wave field off the west coast of India, both over the open sea and over coastal areas (Kumar and Anand, 2004; Semedo et al., 2011). During the monsoon period the maximum significant wave height along the west coast of India is 6 m and during the non-monsoon period it is less than 1.5 m (Kumar et al., 2003; 2006). Hence, a location off the central west coast of India was selected for the study since the wave conditions of the region vary with the seasons.

Along the west coast of India, quantitative estimation of LSTR was reported at different localities. Prasannakumar (1985) studied sediment transport in the surf zone along certain beaches in Kerala. Chandramohan et al. (1994) estimated LSTR along the south Karnataka coast based on 1-year visual observation of breaking parameters and the longshore currents. In order to examine the various physical processes affecting the different coastal environment of Kerala, an investigation of LSTR was completed by Sajeev et al. (1997). Veerayya and Pankajakshan (1988) have reported longshore sediment transport pattern along the Mangalore coast. Hanamgond (1993) investigated the sediment movement on Aligadde beach, Uttara Kannada and stated that the beach morphology undergoes cyclic seasonal changes in response to the changing wind and wave climate. Other studies on selected coastal segments along the west coast of India for the estimation of annual LSTR include Jayappa (1996) and Kurian et al. (2009). These studies revealed that the LSTR is variable, bi-directional and season dependent.

Variation in geomorphologic condition can cause large uncertainties in the estimated LSTR and hence field measurements are very important to assess the wave characteristics. Only a few field studies have reported the measurement of LSTR along the central west coast of India. Kumar et al. (2003) studied the LSTR based on measurements along the surf zone of a 4 km-long beach in the central west coast of India over a 4-month period.

LSTR estimates in the above-mentioned studies were largely based on predictive empirical formulations calibrated from field measurements or laboratory physical models (Bayram et al., 2001; Bayram et al., 2007). Most of the studies along Indian coastline were based on ship reported wave data (Chandramohan and Nayak, 1991) or visually observed wave and littoral environmental observations (Chandramohan et al., 1994; Sajeev et al., 1997), and numerical modeling to quantify LSTR has not been attempted in many studies. Most of the LSTR estimates were based on single formulae, and one year-long measured nearshore wave data were not used in these studies for the estimation of LSTR.

Neither long-term nor short-term information on nearshore waves and LSTR were available for the study area in question. Hence, a study was carried out to identify the nearshore wave characteristics and quantify the LSTR from well-known formulation with nearshore wave parameters obtained from the numerical model Delft3D-wave module (Delft Hydraulics, 2011). Measured directional wave data at 3 h intervals for a period of one year were used as input to the numerical model.

The research questions addressed in the study were i) what is the variation in the LSTR estimate using four well known LST formulae, ii) how sensitive are the LSTR estimates to wave height, peak wave period and breaker angle during monsoon and non-monsoon periods, iii) what is the diurnal change in LSTR, and iv) what is the influence of data intervals on the LSTR estimate?

2. Study area

Coastline of Karnataka extends over a length of 280 km (Kumar et al., 2006). It is the one of the most indented shorelines with numerous rivers, lagoons, bays, creeks, promontories, cliffs, spits, sand dunes and beaches. Unlike the east coast of India, the coastal stretches of Karnataka have no major delta formation. Also, the coastal zone of Karnataka is one of the better developed regions of the State, with a high degree of economic development and density of population. Areas near the river mouths along the coastline of Karnataka state suffer permanent erosion due to natural shifting and migration of the river mouths (Dattatri, 2007). Erosion becomes severe during monsoon season (June–September) due to high floodwaters in the river and strong wave action (Hegde et al., 2004).

The selected area for study is Kundapura, geographically located at 13°40′0″N 74°38′30″E–13°36′0″N 74°42′0″E on the confluence of Kollur, Chakkara and Haladi rivers and Arabian Sea (Fig. 1). Sandy beaches, lateritic plain, alluvial plain, tidal flat and Channel Islands are the characteristics of Kundapura.

The coastline at Kundapura is inclined 8° to the west with respect to true north, with the depth contours aligned approximately parallel to the coastline. The depth contours of 10, 20 and 30 m occur at 3, 11 and 20 km from the coast. The mean spring tide range is 1.3 m and the mean neap tide range is 0.61 m (Kumar et al., 2011) indicating that the study area falls in a micro-tidal (tidal range < 2 m) coast.

To understand the offshore wave characteristics of the region, long-term climatology of the study area was examined with ERA-Interim reanalyzed data (Dee et al., 2011) from 1979 to 2012 at deep water location (water depth ~100 m) (Fig. 2). Waves of this region contain both locally generated wind seas and swells from the southern Indian Ocean. It was observed that about 39% of the waves were approaching from SW to SSW directions and these waves were generally of lower energy (significant wave height, H_s < 1 m) and were observed during the non-monsoon seasons. Waves in the height range of 1–2 m contribute 36% and were evenly distributed in S–W direction. With the onset of the monsoon season, waves from 255 to 270° become prominent and were similar to the observation of Sajiv et al. (2012) for the central west coast of India. Relatively higher waves (H_s ~ 2–3 m) were approaching from W to WSW and occurred for 16% of time. Higher waves (H_s > 3 m), which were due to the strong winds during the peak monsoon season and storm events, were from the direction between W and WSW and occurred for 4% of the time.

Based on the analysis of beach profiles and textural characteristics of beach sediments, Dora et al. (2011, in press) observed that during 2008 to 2011, the beaches at Kundapura experienced a slow rate of sediment accretion over an annual cycle. Quantitative study on coastal changes along the study area for the period from 1973 to 2008 was undertaken by Vinayaraj et al. (2011) and reported that the area which covered by the tidal flat, decreased by 0.531 km^2 during 1973 to 1998 and increased by 0.967 km^2 during 1998 to 2008. In addition, sand bar environments diminished by an area of 0.227 km^2 from 1973 to 1998, but during 1998 to 2008 the sand bars show an increasing trend. Few studies have reported LSTR along the central west coast of India (Chandramohan and Nayak, 1991; Kunte and Wagle, 1993; Chandramohan et al., 1994; Kumar et al., 2003) and the LSTR along the study area has not been investigated in the past.

3. Data and methodology

3.1. Measurements

The directional wave data was collected at 3 h intervals using a Datawell directional wave rider buoy at Kundapura (13.61746°N, 74.62234°E) from January to December 2011 at 12 m water depth. Since the waves were measured at 12 m water depth, the measured waves are expected to experience some depth influence and are thus transformed waves. The measured wave height and the wave direction are, therefore, expected to be different from that in the deep water offshore.