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# Effect of long-term wave climate variability on longshore sediment transport along regional coastlines

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ABSTRACT

Long-term changes in wave climate have potential impacts on the evolution of regional coastlines. This study investigates the impact of variable wave climate on the temporal dynamics of longshore sediment transport (LST), which plays a major role in defining the overall coastal geomorphology of regional coastlines. The central west coast of India is considered as the study region. ERA-Interim wave hindcast dataset over the period of 1979–2015 is used to derive the contemporary wave climate in this region. The annual average significant wave height, period, and direction are computed and used to estimate LST of the study region. This region experiences oblique waves from the W-SW direction with an annual average significant wave height and wave period of 1.32 m and 8.10 s, respectively, that induces a gross northerly transport of approximately 450,000 $m^3$/year. It is found that the total LST is driven by swell waves and wind waves and shows a decreasing trend of about 5% over the analysis period. The decay in LST is found to be linked with decreases in wave activity in this region. The swell wave induced sediment transport is an order of magnitude higher than the wind wave induced LST. It is observed that the swell generation in the lower latitudes has decreased, resulting in reduced swell wave induced LST in the study area. Both swell and wind wave induced LST show seasonal variation. Finally, a link is established between the seasonal variation of swell induced LST and the cyclogenesis periods. In addition, the wind wave induced LST is observed to have a direct link with the latitudinal position of the inter-tropical convergence zone (ITCZ).



## 1. Introduction

The coastal environment forms a complex but important ecosystem and is one of the most important resources needed for the development of any nation. The vulnerability of tropical coastlines is increasing with an increase in the twin pressures of increased frequency in natural hazards under a changing climate and unchecked human activities. The situation is worse in developing countries like India where the majority of the population lives in coastal areas and participates in marine resource exploitation. The coastal evolution, mainly driven by longshore sediment transport, of the west coast of India has become a major area of investigation due to the rapidly growing socio-economic development in this region. This coastline hosts a large number of harbors and river deltas/estuaries, which, together with the changing climate, are responsible for the modified nearshore wave-current climate and consequent longshore sediment transport (LST) pattern. Scanty knowledge is available on the effects of changing climate on nearshore wave characteristics and the resulting regional LST in the tropical region (Short, 2012). It is, therefore, necessary to investigate the dynamics that affect and govern the evolution of tropical coasts under variable climate change scenarios (IPCC, 2014; Stive, 2004).

The central west coast of India is comprised of open sandy beaches that are exposed to a wave climate controlled by energetic swells from the west Arabian Sea and northern Indian Ocean, as well as the locally generated wind waves (Anoop et al., 2015). The large-scale variability in the wave climate of the Arabian Sea and northern Indian Ocean alter the nearshore wave climate along the central west coast of India and, in turn, the long-term longshore sediment transport. The littoral drift or the LST along the central west coast of India has been investigated by various authors and reported to be between 250,000 $m^3$/year and 450,000 $m^3$/year directed northward (Chandramohan and Nayak, 1991; Kumar et al., 2003; Shanas and Kumar, 2014). These estimates of LST are based on different methods, such as the use of

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empirical models, ship reported data, and satellite imagery and the measurement of sand volume using mesh traps (Chandramohan and Nayak, 1991; Kumar et al., 2003; Nayak et al., 2010; Shanas and Kumar, 2014). Most of these studies were undertaken for small periods (from a few months to one year). These large quantities of LST control the morpho-sedimentary evolution of the central west coast of India. In addition to the large sediment flux, the natural and anthropogenic interventions (natural headlands, shoals, and man-made structures) also disturb the natural equilibrium of the coasts. Kurian et al. (2009) observed that the LST in this region is bimodal in nature. In this given scenario, even minor and temporary alongshore in-equilibrium in sediment transport rates may be expected to result in huge coastal erosion/accretion. Therefore, there is a need to investigate the effect of seasonal and annual climatic forcing on LST over this region to provide feedback to coastal managers and policy makers for current as well as future developmental projects.

The LST in tropical and sub-tropical regions is driven by the long-term seasonal and inter-annual fluctuations of wind and wave conditions (Almar et al., 2015). However, due to lack of long-term observational wind and wave data, the relationship between the morpho-sedimentary evolution of coastlines and regional climate drivers has not been investigated or established for the central west coast of India. Recent studies demonstrated that the effects of the El Niño Pacific mode and the occurrence of storms have direct correlation with the rate of LST and coastal evolution (Komar et al., 2000; Allan and Komar, 2002, 2006). Ranasinghe et al. (2004) and Splinter et al. (2012) demonstrated the effect of inter-annual variability on wave climate and its potential impact on coastal evolution. They indicate that the effect of long term wave climate variability on coastal processes is inevitable and needs our immediate attention to unfold the complex response of coastal environment to climate change driven wave characteristics. The Indian coastline has not received enough attention due to scarce wind and wave observation datasets, which are now being addressed using more accurate model hindcasts and satellite altimetry (Young et al., 2011). The present study aims to provide overall insight on the historical evolution of the selected study area by investigating the correlation between the LST regime and the governing wave climate using wave hindcast data. However, the contribution of anthropogenic activities towards the evolution of this coast has not been dealt with in this study. A hybrid empirical model with an empirical breaking wave predictor formula and a bulk LST estimation formula are used to estimate the long-term LST of the study area.

## 2. Study area

### 2.1. Central west coast of India

The study area is located in the central west coast of India (Fig. 1) between 13 °N – 17 °N and 73 °E – 75 °E, which consists of numerous headlands, river deltas, cliffs, bays, creeks, lagoons, sand spits, and sandy beaches (Shanas and Kumar, 2014). It is oriented at about 10° to the west with respect to true north. This region is exposed to an energetic wave climate with swell waves travelling from the far west Arabian Sea and Indian Ocean and locally generated wind waves. The southern Indian Ocean winds get deflected at the equator and form the strong cross-equatorial winds in the northern Indian Ocean called the Somali Jet (Findlater, 1969). The Somali Jets are responsible for the high energy swell and wind sea conditions along the west coast of India (Anoop et al., 2015). The west coast of India is exposed to significant changes in seasonal to annual wind and wave pattern. Winds are southwesterly and significantly high in strength during the south-west monsoon (June-September); whereas, winds are north-easterly during the north-east monsoon (November-February). The beaches in this region are mainly reflective to intermediate in nature with a tidal regime varying from 0.25 to 2.3 m for neap and spring tidal ranges, respectively (Kumar et al., 2003; Manoj and Unnikrishnan, 2009). Therefore, it is classified as a meso-tidal region (Short, 1991). The region experiences a tropical climate with heavy rainfall and high humidity. Most of the rainfall (87%) occurs during the south-west monsoon (Chempalayil et al., 2014), resulting in huge river runoff. The presence of numerous river mouths in the study region makes the sediment interaction process complicated. The situation is worse during monsoon, when most of the rivers bring huge amounts of inland sediments to the coast. The varying nature of sediment influx in the coastal environment complicates the distribution of sediments in the nearshore and foreshore areas close to estuaries and tidal inlets. The inflowing sediments are usually distributed along the coast by coastal processes driven by waves and tides. The influx sediment grain size

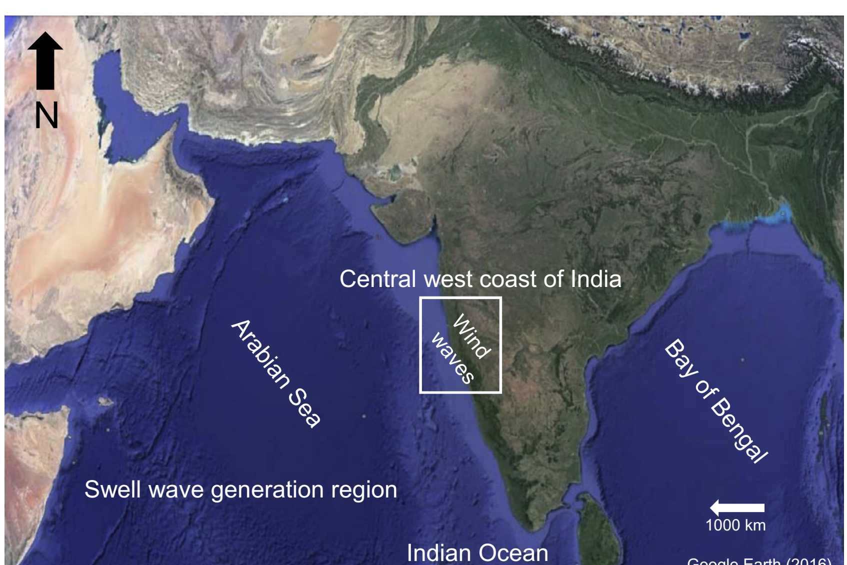


**Fig. 1.** Map showing the study area (central west coast of India) along with the Arabian Sea, Bay of Bengal, and northern Indian Ocean.