International Journal of Geosciences, 2014, 5, 341-345
Published Online March 2014 in SciRes. http://www.scirp.org/journal/ijg
http://dx.doi.org/10.4236/ijg.2014.53033

Coastal Erosion Studies—A Review

Durusoju Hari Prasad, Nandyala Darga Kumar

Department of Civil Engineering, JNTU, Hyderabad, India
Email: jntu.hari@gmail.com, ndargakumar@yahoo.com

Received 17 January 2014; revised 16 February 2014; accepted 12 March 2014

Abstract

The land ward displacement of the shoreline caused by the forces of waves and currents is termed as Coastal Erosion. The Coastal areas have become more prone and vulnerable to natural and human made hazards which lead to Coastal Erosion. The Shoreline retreat is recognized as a burgeoning threat because of global climate change and other anthropogenic activities that alter the natural processes of sustaining beaches and coasts. Coastal Erosion mainly occurs when wind, waves and long shore currents move sand from shore and deposit it somewhere else. The sand can be moved to another beach, to the deeper ocean bottom, into an ocean trench or onto the landside of a dune. The removal of the sand from the sand sharing system results in permanent changes in beach shape and structure. The impact of the event is not seen immediately as in the case of Tsunami or Storm Surge but it is equally important when we consider loss of property. It generally takes months or years to note the impact of Erosion; therefore, this is generally classified as a "Long Term Coastal Hazard". The present paper attempts to describe a Review on Coastal Erosion Process, Parameters' affecting, and methodologies are adopted to identify the erosion and recommend a solution.

Keywords

Coastal Erosion; Waves; GIS; Remote Sensing

1. Introduction

Shoreline or coastline, the boundary between land and sea, keeps changing its shape and position continuously due to dynamic environmental conditions. Various developmental projects are made in shoreline areas, placing great pressure on it, leading to diverse coastal hazards like soil erosion, sea water intrusion, coral bleaching, shoreline change; etc. Considering Coastal erosion, it is a global problem affecting almost every country around the world having a coastline. It's a hazard effecting the shoreline or coastline pertaining to several changes in the climate, atmospheric disturbances and constant changes in the water bodies.

How to cite this paper: Prasad, D.H. and Kumar, N.D. (2014) Coastal Erosion Studies—A Review. *International Journal of Geosciences*, **5**, 341-345. http://dx.doi.org/10.4236/ijg.2014.53033

However, globally it is estimated that about 60% of the population is dwelling in the coastal environments. Although the coastal environment can retain some degree of natural character, increased human modification reduces the "naturalness" (Dahm, 2000). The accelerated release into the atmosphere of Carbon dioxide and other greenhouse gasses has resulted in a projected global warming of about 3˚C by the year 2030 (Davis & Fitzgerald 2010) [1].

This increase would be enough to raise the global sea level by as much as 5 m in a few centuries (Davis & Fitzgerald 2010), which is a short time in terms of human occupation of the coast.

This phenomenon has the tendency to expose a significant proportion of vulnerable coastal areas to flooding and destruction of habitats for migratory birds and other endangered species. Occurring in synchrony with these continual changes is the recession of shorelines, estimated to occur on coastal population and infrastructure of major economic and cultural importance in almost all coastal regions globally.

The location of the shoreline and changing position of this boundary through time are of elemental importance to coastal scientists, engineers and managers (Douglas & Crowell 2000). Relief and development agencies also depend on such information to facilitate development of effective measures to prevent, mitigate or manage disasters. Both sustainable coastal management and engineering design require information about where the shoreline is, where it has been in the past, and where it is predicted to be in the future. Such information is required in the design of coastal protection (Coastal Engineering Research Centre 1984), to calibrate and verify numerical models (Hanson *et al.* 1988), to assess sea-level rise (Leatherman 2001) and to develop hazard zones.

Remote Sensing helps to replace the conservative survey data by its rhythmic and less cost-effectiveness. Several studies using satellite data have proven its efficiency in understanding various coastal processes (Wagner *et al.* 1991; Ahmed and Neil 1994; Anbarasu *et al.*, 1999; Makota *et al.*, 2004; Mani Murali *et al.*, 2009; Boutiba and Bouakline 2011) [2]. Space technologies have the capability to provide information over a large area on a repetitive basis, and therefore, it's very useful in identifying and monitoring various coastal features. Douglas, Crowell & Leatherman 1998, formulate policies to regulate coastal developments (National Research Council 1990), and to assist with legal property boundary definition (Morton & Speed 1998) as well as coastal research and monitoring (Smith & Jackson 1992).

2. Causes and Impacts of Coastal Erosion

A coastline is a complex series of interlinked physical systems in which both offshore and onshore processes are involved. Coastal Erosion is one of these physical processes, wearing away and redisturbing solid elements of the shoreline as well as sediment, normally by such natural forces as waves, tidal and littoral currents and deflation. The coastal sediments, together with those arising from inland erosion and transported seaward by rivers, are redistributed along the coast, providing material for dunes, beaches, marshes and reefs.

Coastal Erosion is usually the result of a combination of factors both natural and human induced operating on different scales. Erosion is defined as the encroachment of land by the sea after average over a period which is sufficiently long to eliminate the impacts of weather, storm events and local sediment dynamics (such as Sand Waves) [3].

Coastal Erosion results in three different types of impact like: Loss of land with economical value (such as the beaches) or with ecological value; a specific mechanism is the collapse of properties located on the top of cliffs and dunes.

3. Models for Predicting Shoreline Change

A wide variety of numerical models and methods have been proposed to detect the shoreline change and also to model the change mathematically.

In many cases the parameters such as surf zone turbulence, effect of frequency, variations in directional spread and other wave transformations are also calculated and the solutions are formulated. Therefore some of the models are been briefly discussed in this paper.

3.1. Equilibrium Model

Shoreline Change is affected by a multitude of complex processes operating at a various time and length scales (Larson & Kraus, 1995). At shorter time scales on energetic coastlines wave dominated cross-shore transport, long shore transport gradients, wave set-up and storm surge are the dominant processes driving shoreline change. Coastal managers, scientists and engineers have long sought a robust and practical methodology for the prediction of shoreline change along sandy coastlines, over time-scales spanning several years to decades. The equilibrium model [4], which at the present time come closest to satisfying theses requirements generally include a considerable level of empiricism and may be termed top-down or data-drive models. Probably the best known and most widely used example is the GENESIS model which is applicable to predicting generalized platform shoreline evolution for the special case where alongshore gradients in sediment transport dominate.

A variety of measures are used here to objectively assess model skill. The first is linear squared-correlation (r2) between the measured (x) and modeled (x_m) shoreline position. Whilst this method is useful for exploring correlations between the measurements and predictions it is possible that the series may be well correlated but have large residual. For this reason more rigorous comparative methods are also used, which compare the model residuals with a suitable baseline (x_b). The choice of baseline is somewhat arbitrary. Here, both a linear fit to the shoreline series and the prioir DLT10 model for shoreline position are used to assess improved model performance. The first comparative method, the Brier Skill Score (Sutherland and Soulsby, 2003), also has the advantage of considering measurement error Δx.

$$\mathrm{BSS} = 1 - \sum \left\{ \left| x - x_m \right| - \Delta x \right\}^2 \Big/ \sum \left(x - x_b \right)^2 \tag{1}$$

3.2. AHP Model

The Analytical Hierarchy Process [5] (Saaty, 1980) is a multi criteria decision method that solves decision making problems by ranking alternatives according to several criteria. The main steps in the method involve –

- Representing a decision making problem by organizing its criteria into a hierarchical structure.
- Evaluating the relative importance of the criteria (within a hierarchical tree) and then the alternatives with respect to each criteria on; this is done by constructing pair wise comparison.

To estimate coastal shoreline change, we generally apply simplified models and the associated scaling of uncertainties, taking into account the susceptibility of the coast to erode.

The simplified model of beach erosion is the formula suggested by the Eurosion (2004) project, which combines expected erosion due to sea level rise (Brunn, 1962) with shoreline change due to ongoing processes, as calculated from past shoreline observations

$$\mathrm{R}_{\text{future}} = \mathrm{R}_{\text{historical}} + \mathrm{S}_{\text{future}} - \mathrm{S}_{\text{historical}} \big/ \tan\left(\alpha\right) \tag{2}$$

where tan(α) is the beach slope and S is the sea level rise. For cliff erosion we combine spatially continuous knowledge of past erosion, local knowledge of erosion rates calculated for a few representative sites and expert opinions. The use of these models is arguable, so we consider a scaling of uncertainties in potential future erosion instead of a single future shoreline position.

3.3. Model Using SPH Method

Smoothed Particle Hydrodynamics Method (SPH) [6] is a relatively new method for examining the propagation of highly non-linear breaking waves. The SPH method can be considered as computing the trajectories of particles of fluid which can interact according to the Navier-Stokes equations. An alternative view is that the fluid domain is represented by the nodal points that are scattered in space with no definable grid structure and move with the fluid. Each of these nodal points carries scalar information, density, pressure, velocity components, etc.

$$f\left(x\right) = \sum f_{jj} W\left(x - x_j\right) V_j \tag{3}$$

Taking the conservation of Mass and momentum written in particle form are taken into account (Monaghan, 1992), we finally derive an equation that relates the pressure in the fluid to the local density.

$$P = B\left[\left(p/p_o\right)^{\gamma} - 1\right] \tag{4}$$

The factor Gamma is taken as 7. This equation implies that the fluid is compressible.

In this way different equations are derived for other components such as velocity, viscosity, which also incorporates the numerical modeling of large and small turbulent eddies and the trajectories with which the wave strikes the shore. Finally, the derived equations are interpolated with the standard values and conclusions are drawn.

3.4. Model Formulating Sand Transport

Sand transport becomes crucial parameter while estimating the coastal erosion. Practical sand transport formulae for the coastal marine environment are generally semi-empirical formulae which can be classified as time-averaged, quasi-steady or semi steady. Based on approaches used for fluvial sediment transport, time averaged formulae predict sand transport at a timescale that is much longer than the wave period, using wave-averaged values of velocity and sand concentration. The bijker (1971) [7] formula is an example of a widely-used time-averaged transport formula where the total net transport is always in the direction of the mean current and the wave-related transport component is not taken into account. Thus, taking the above quantities into account the new formula is based on a modified version of the semi-unsteady "half cycle" concept originally proposed by Diajnia and watanabe (1992). In this concept, the wave-averaged total net sand transport rate as taking place in the oscillatory boundary layer is essentially described as the difference between the two gross amounts of sand transported during the positive "crest" half-cycle and during the negative "trough" half-cycle. Unsteady phase lag effects are taken into account. In addition to this the formula uses 1) bed shear stress rather than near-bed velocity as the main forcing parameter; 2) the phase lag effects are considered; 3) the effects of acceleration skewness are incorporated 4) it also covers graded sands and 5) the formula distinguishes between oscillatory flows and progressive surface waves.

4. Applications using GIS & Remote Sensing

The shoreline is one of the rapidly changing coastal landforms. Shorelines are the key element in coastal GIS and provide the most information on coastal landform dynamics. Therefore, accurate detection and frequent monitoring of shorelines are very essential to understand the coastal processes and dynamics of various coastal features. Nevertheless, the researchers and engineers have been studying the several levels of the increasing complexities of wave information from offshore to near shore, the role of different technology strategies have always been helpful in drawing important conclusions and also to make their job easier. The usage of Remote sensing devices, satellite data, topographical maps and electronic devices operating in the microwave frequency bands such as RADARS [8] are extensively used nowadays. Precisely, the Synthetic Aperture Radar (SAR) images are being used more often than ever before for geosciences applications in the moist tropics.

The airborne GEMS 1000 X-HH radar images acquired in 1972 during the RADAM Project was also used for evaluating coastal changes occurring over last three decades. In application perspective, orbital and airborne SAR data proved to be fundamental source of information for both geomorphological mapping monitoring coastal changes in moist tropical environments. At present remote sensing spatial resolution has achieved even 1 cm or better in the coastal zone. The current in-orbit satellites of oceans include NOAA series satellites, Landsatseries satellites, MOS-1, JERS-1, China meteorological satellites FY-N, SPOT, ERS, MODIS, Sea WiFS, [9] China resource satellite ZY-1, etc. By using large-scale and precision positioning macro image information provided by varies satellites, coastal scientist can monitor various coastal geomorphology types as well as their spatial distribution information about estuarine delta, tidal flat, coastal dunes, shell ridges, barrier lagoon, mangrove and coast coral reefs, etc. Image data can also be acquired from multi-spectral scanners or radar sensors aboard aircraft.

5. Conclusions

The review paper presents an overview of the significant work done in the geosciences field, wherein a new efficient three-dimensional model is introduced to calculate the water wave intermediate velocities for the advection and diffusion by imposing the divergence-free velocity field condition. The 3D model is shown to well resolve vertical velocity profiles of nonlinear wave deformation over a submerged bar.

The SPH technique, with its Lagrangian formulation, provides a methodology for the detailed examination of water vorticity. It is particularly suited to those cases where there is splash or flow separation.

Moreover, determination of extreme beach erosion involves integrating a five to six parameter probability density function of wave parameters (height, period, direction and storm duration), surge and timing. The wave details are often recorded well offshore or taken from global wave models well offshore where the hindcast wave parameters are considered free from near shore bathymetry that is coarsely represented or assumed deep water in these models due to their scale.

In addition to this, RADARSAT's capability to provide unique geomorphological and land cover mapping of the Coastal Plain and the integration of information provided by the orbital C-HH imagery with the airborne XHHSAR [10] has allowed detecting and mapping coastal changes related to the shoreline retreat and accretion, during the 26-year period of both SAR acquisitions. Sedimentary dynamic, tidal current, wave action and estuarine and tidal channel displacements have played an important role in controlling these coastal changes. Based on results obtained from SAR data analysis, we can conclude that SAR imageries have provided valuable, rapid and accurate information on coastal features recognition, coastal land-use assessment, monitoring of shoreline changes and base maps' updating, which are basic components for an integrated management program in this coastal zone. SAR data provide greater details of the coastal environments and configuration of the shoreline and its changes. Extensive research has also been done using different interpolation techniques leading to the optimum convergence of the solutions. Thus, the basic causes, impacts and solutions regarding the natural hazard Coastal Erosion have been briefly discussed.

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