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Use of Directional Derivatives in the Study of Estuarine Sedimentation Process on Konkan Coast of Maharashtra

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Abstract

The process of estuarine sedimentation on Konkan coast of Maharashtra is very complex and leads to the development of complex bed forms and sedimentary structures on bed of estuaries, creeks and smaller tidal inlets. Attempts to bring out the variations in these bed forms are necessary to understand the nature of sedimentation process in Konkan creeks and estuaries. An attempt is made here to describe and discuss how a technique of directional derivatives could be used to understand the morphological details of such accumulation forms indicative of process of sedimentation.

Introduction

Tidal inlet sedimentation on Konkan coast of Maharashtra is still poorly understood. Seasonally changing hydraulic condition in the tidal creeks, estuaries and smaller tidal inlets have produced exceedingly complex patterns of sedimentation. The contribution of monsoon discharge to tidal sectors of the rivers, sediments created and supplied by waves on the coast and material from the margins of creek or estuarine basin itself are the major sources of sediments in these tidal inlets (Karlekar *et al.*, 1993). The quantum and nature of sediments varies from north to south and adds to the complexity of tidal inlet sedimentation (Karlekar, 1993). Konkan estuaries, like others in the world, are tidal basins of non-marine origin that have been invaded by sea after sea level rise in Holocene (Carter, 1990).

The sediment input is responsible for the development of a variety of bed forms in the inlets (Dyer, 1979). The inlets, especially estuaries and creeks, show a mix of unidirectional and bidirectional bed forms such as tidal inlet dunes, sand waves, sand lenses, sand bars and mega ripples (Carter, 1990). In Konkan these bed forms are also associated with cuts and scoops in the tidal channel. Sediments on these bed forms range from fine to medium sand and gravels. Clays constitute the major part of sediments in the northern estuaries where tidal range is greater than 4m, mainly to the north of Mumbai. Suspended sediment matter is more important in the sedimentation process in the northern estuaries and creeks. The tidal environments here are more turbid as compared to those south of Mumbai (Karlekar, 1993). Here, coarse and fine sandy material predominates the bed load.

Down estuary zonation in the sediment size is distinctly visible in the creeks and estuaries of Raigad, Ratnagiri and Sindhudurg coast (Karlekar, 1996). Fine sediments are found deposited in the upper and middle reaches of the tidal sectors. Coarse fraction, gravels and pebbles usually

characterize the tidal mouth. This variation in size is indicative of fluvial origin of bed forms in upper reaches and tidal origin in lower reaches. In the funnel shaped estuaries typical of this coast, where inlet widens in lower reaches, bed forms are exclusively tidal in nature.

Most of the bed forms have preferred orientation associated with tidal currents and velocity vectors. A substantial portion of suspended sediment is found to be deposited within the creeks and estuaries (Rajmanickam 1990). In macro tidal estuaries with a tidal range exceeding 4m., a large proportion of suspended matter settles on mud flats and other areas outside the main tidal channel (Karlekar, 1996, Karlekar *et al.* 1993, Yargop 2005). The average tidal range on this coast, ranges from 1.2 m in south near Redi to about 5.1 m in the north near Dahanu.

This general trend, however, deviates slightly due to shoreline configuration (Karlekar 2002). The estuaries are bar built, or coastal plain, well mixed as well as partially mixed depending on tidal range, tidal incursion and the size.

Although a strong seasonal salinity front develops in major creeks and estuaries, tidal energy in macro tidal estuaries destroys whatever stratification exists between saline and fresh water.

Strong flood currents in macro tidal estuaries on this coast lead to scouring of bed material and development of sinks on the bed (Karlekar 1997).

A detailed account of spatio-temporal variations in the morphology, hydrodynamics and sedimentation of Konkan estuaries provided by Karlekar (1996 a) concludes that the sedimentation of a specific tidal inlet on this coast is unique in terms of its hydrodynamics.

The process of estuarine sedimentation on Konkan coast of Maharashtra is very complex and leads to the development of complex bed forms and sedimentary structures on bed of estuaries, creeks and smaller tidal inlets. It is necessary to bring out the variations in these bed forms are necessary to understand the nature of sedimentation process in Konkan creeks and estuaries. An attempt is made here to describe and discuss how a technique of directional derivatives could be used to understand the morphological details of such accumulation forms indicative of process of sedimentation.

It is obvious that the patterns of sediment movement are different in different types of inlets, estuaries and creeks (Awasthi 1994, Belgalli 1990, Shrikhande 1996). These patterns are not easy to recognize and estimate quantitatively. The variations in morphology displayed on the derivative maps can give clues to the patterns and sedimentation process.

Methodology

The directional derivatives of first and second order were attempted to understand the complexity in the morphology of estuarine bed forms. Bed contours on the hydrographic charts of certain creeks were used to obtain their gridded surfaces.

Sounding datum in Indian hydrographic charts coincides with the local levelling datum with reference to a benchmark. The mean sea level is also provided. Using level datum and mean sea level the depths were reduced to constant level and used as Z in X, Y Z domain.

Estuaries of Konkan

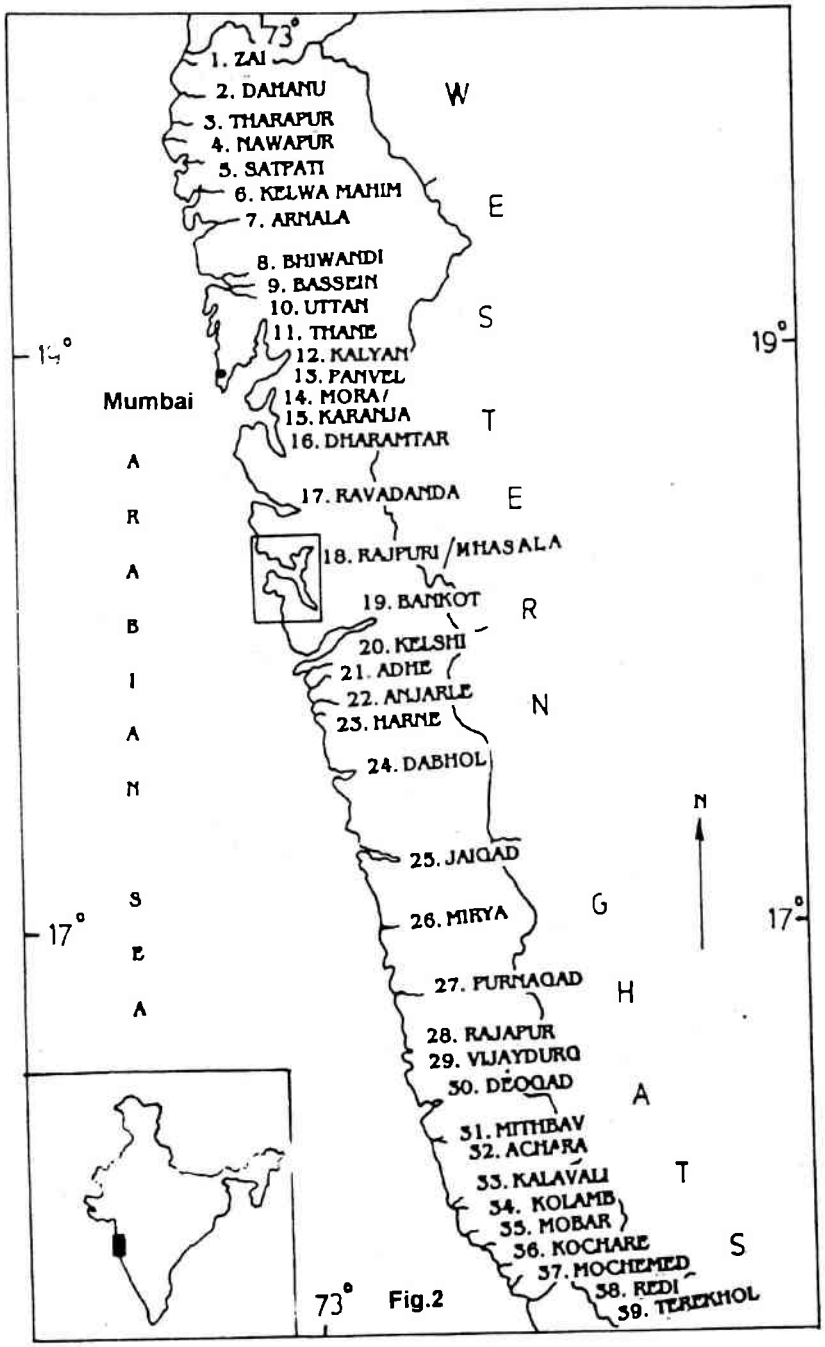

Fig. 2: Estuaries of Konkan

The depth values on the hydrographic charts after reducing to datum level were digitized and gridded using surfer software. The directional derivatives were obtained and as surfaces created software. The hydrographic charts for Dabhol, Kajali, Mithbav, Anjarle and Karli creeks and estuaries were used to calculate directional derivatives based on depth contours.

The contour map of any form gives a clear idea about its geometry. If these contours are gridded in an X, Y, Z domain, at the location of each node, magnitude and direction of the steepest slope can be calculated to generate its slope map. The result is based on the direction of the general gradient. The directional derivative of the contours calculates rate of change of slope along a predetermined direction. The result is a contour map that shows isolines of constant slope along this direction. The rate of change of slope along predetermined direction is obviously zero. The rate of change of slope is reported as rise over run and approaches negative or positive infinity as it approaches vertical in a downhill or uphill direction. The rate is positive in uphill direction and negative in downhill direction. First directional derivatives can be obtained along various predetermined lines. Second derivative produces contour maps that show isolines of rate of change of slope not along the line but across the surface.

Discussion

For the application of such derivatives to creek bed contours, knowledge of sedimentation process leading to bed forms is necessary. The bed forms in the upper reaches of creek or estuary are usually produced due to fluvial control and hence their downhill slopes face lower reaches. They are thus oriented towards mouth of the creek. Similarly the downhill slopes of bed forms in the middle and lower reaches as well as those just inside the entrance of creek, face upper reaches of the creek due to tidal component that pushes sediments in the creek. This knowledge of the sedimentation process in marine and fluvio-marine environment helps in fixing the specific direction along which directional derivatives are calculated.

The derivative surface thus obtained and overlaid with isolines of constant change gives an idea about the microforms developed on the creek bed. Fig. 2 is the digital elevation model of the part of Kajali creek bed obtained by digitizing bed contours shown on hydrographic map of the area. The contour overlay is shown in Fig. 3 A. The model clearly shows that the sand accumulation forms in the creek are oriented east-southeast to north-northwest. Since the sedimentary features are developed in the mid creek section, their downhill slopes face upper reaches of the creek that is towards east. Obviously the directional derivative in north-northwest to south-southwest direction is therefore most suitable to indicate various sedimentary forms. The first derivative isolines of constant rate of change of slope calculated and superimposed on the derivative surface are shown in Fig. 2 B. It can be seen that all the values east of derivative line, indicated by zero slope, are negative and those to the other side are positive.

Sedimentary microforms along with other features like sand bar (covered by mangroves), scoop, ridge of sediment deposition along the creek bank then can be clearly identified.

The DEM created from digitized gridded data gives a generalized view of bed forms in estuaries and creeks. This view helps in displaying the major forms, especially sand bars and scours. The details of infill activity cannot be ascertained from such views. The first derivative surface takes into account rate of change of slope along the preferred direction and the second derivative across the area. Both the derivatives enhance the micro details of the bed configuration. One can easily identify elongated ridge like structures, micro infill, sediment lenses, small size scours and tidal dunes on the bed.

The preferred orientation of such microforms indicated by derivatives is in perfect tune with the existing tidal flow patterns and velocities (Psuty 1995). The derivative enhanced bed configuration of lower reaches shows bed forms that are characteristic of forms developed in coarse sediments. Estuarine banks and middle reaches show smooth, convex lenses developed in silts and clays. An additional advantage of such derivatives is that they help in demarcation of major sub environments such as marsh edge, high tide flats, low tide flats, scoured channels and creek banks which are the products of site specific sedimentation process (Fig. 4).

The trends obtained by directional derivatives are however indicative and one should not try to read more from the patterns produced and deduce final conclusions regarding the sedimentation process in that estuary or creek.

Ground truthing of mud flats, sub tidal zones and sand bars at low tide confirms the indicative power of this technique. It can therefore be used effectively to understand the process of tidal inlet sedimentation, the thing which is not easy to monitor quantitatively on Konkan coast.

Note: See Artplate on page nos. 157-158.

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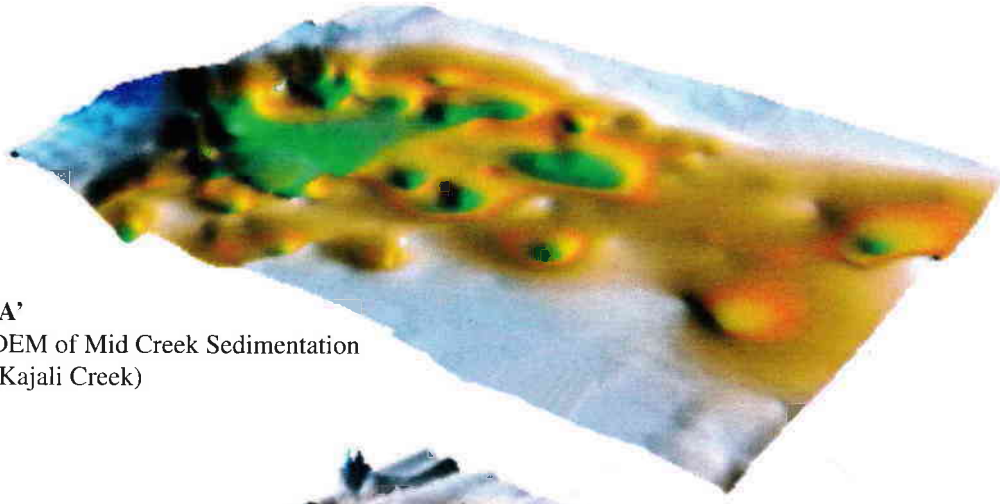
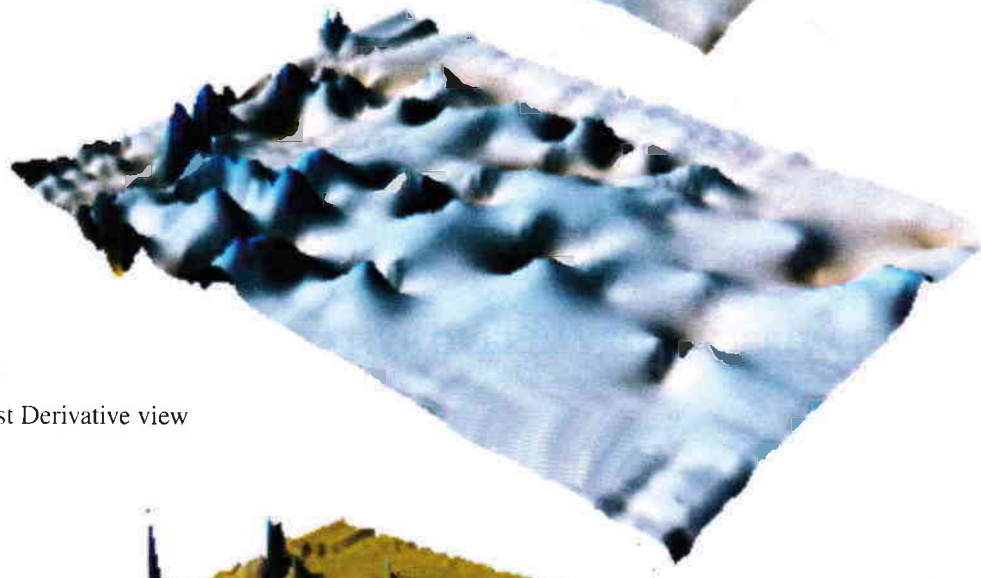
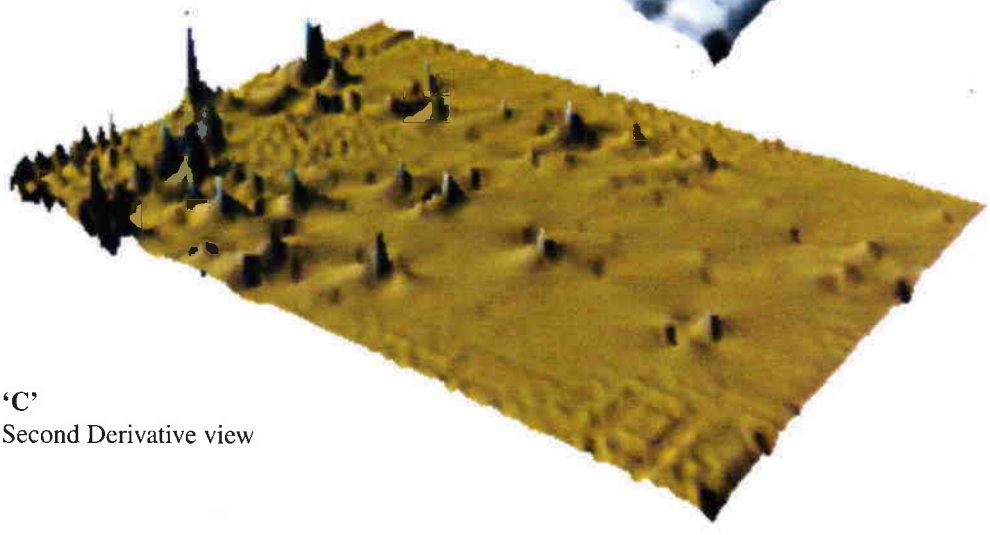


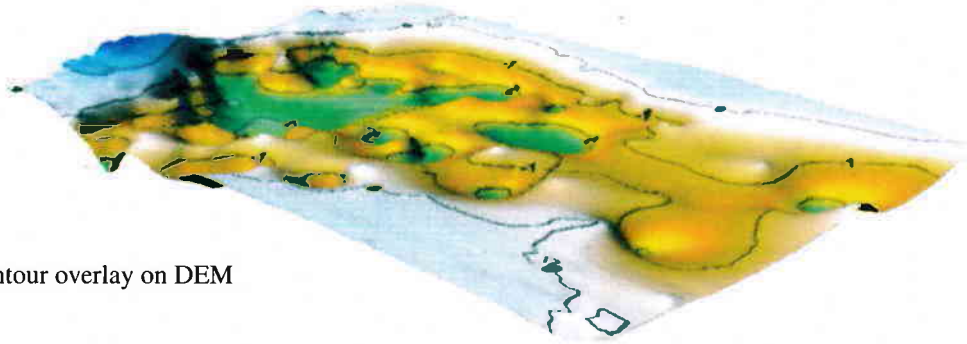
'A'
DEM of Mid Creek Sedimentation
(Kajali Creek)



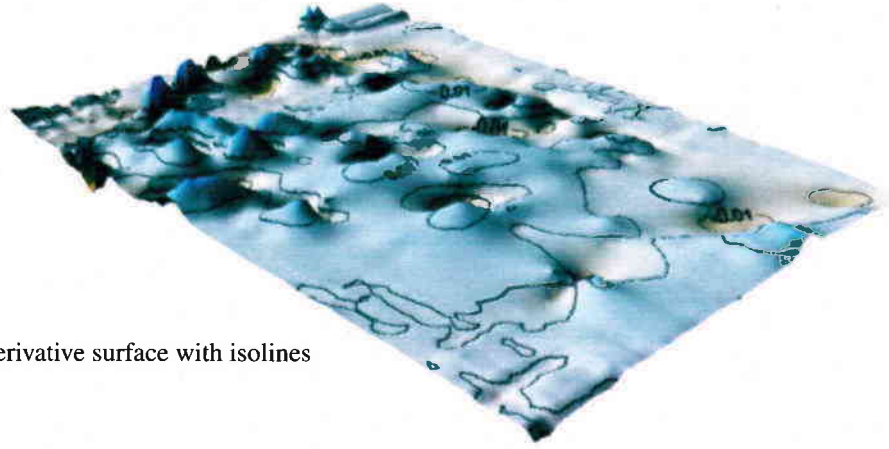
'B'
First Derivative view



'C'
Second Derivative view



'A'
Contour overlay on DEM



'B'
First derivative surface with isolines

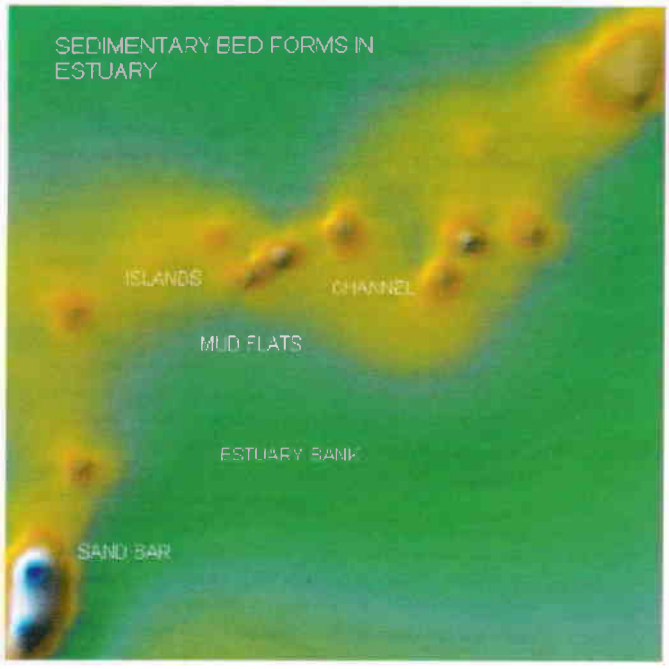


Fig. 4: Sedimentary bed forms