Exploring coastal morphodynamics of Ameland (the Netherlands) with remote sensing monitoring techniques and dynamic modelling in GIS
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SUMMARY

PART 1 Introduction

Introduction
Coastal landforms are constantly changing. An understanding of these changes is required for proper present-day management and for the prediction of future changes. This research aims to describe and predict the morphological development of a sandy coast under the influence of natural processes and human impacts on a time scale of months to years, the meso-scale. There are no suitable methods available for such a study. A new approach had to be developed to meet this objective. An additional aim is therefore, to develop a method for qualitative and quantitative prediction of the morphodynamics, based on suitable elevation and remote sensing data input and on the application of dynamic modelling and GIS techniques. Ameland was chosen as the study area. It is one of the Dutch coastal barrier islands. These islands exhibit a large variation in morphodynamic systems over a relatively short distance; at some sites erosion and at other locations accretion dominates.

PART 2 Development of methods

Surveying with remote sensing

Multiscale monitoring techniques versus multiscale morphodynamics
Ameland has been used as a test area to evaluate the use of various remote sensing techniques for coastal zone management. These techniques are discussed, and some selected data were used for a geomorphological scale study. Each remote sensing technique has its own characteristics concerning, for example, spatial and temporal resolution of the data. Since geomorphological forms and processes also act on different spatial and temporal scales, each remote sensing technique will have certain advantages in the analysis, mapping and monitoring of a particular phenomenon. The data were evaluated for geomorphological purposes. This resulted in a table with multiscale monitoring techniques listed versus multiscale morphological features. The table shows that different techniques produce different information. The 1:18,000 aerial photographs scored best, because they provide an overview and a perception of height of the study area.

Multitemporal radar satellite imagery illustrates coastal dynamics in their spatial context
The study of coastal morphodynamics requires an expression of dynamics. Recently, several techniques have been developed to express dynamics. Attention was paid to one of these techniques, pixel based image fusion, and to the resulting image map. Remote sensing data provide an overview of dynamic coastal areas without interfering with the system, and allow the mapping and monitoring of changes. C-band radar remote sensing allows continuous data acquisition both day and night and is practically independent of weather conditions since it penetrates cloud. Three images, collected during different tidal stages and at different dates, formed a colour composite. The changes, or actually, the differences between the images,
appear as colourful features on the image map. Such maps can be of interest to coastal managers because they illustrate coastal dynamics: they can show the areal extent of tidal influence and of geomorphological processes (erosion and accumulation). The images used to construct this particular image map of Ameland were selected according to the tidal differences during image acquisition; this selection obscured possible geomorphological differences. The large number of images that has recently become available will facilitate the analysis because it allows a reduction of variables: it will be possible to focus on either tidal or geomorphological changes.

The derivation of digital elevation models from aerial video data
Coastal morphological research benefits from digital elevation models. Videography, a cheap, simple and flexible airborne remote sensing technique, was used to extract such elevation models. A hand-held Hi 8 camera and a small airplane were used to collect video data of a 1300x320 m strip of beach and foredune area on Ameland. Simultaneously, the coordinates of the ground control points (GCPs) were collected with laser electronic distance measurement (EDM) equipment. A series of overlapping frames was grabbed, contrast-stretched and corrected for interlacing effects. The resulting images were processed with software that has some photogrammetric options, R-WEL's Desktop Mapping System (DMS). The images and the positions of the GCPs enabled computing of the camera orientation, and allowed for image rectification and stereo correlation. Stereo pairs form the basis for anaglyphs, which give a perception of height. In addition, the parallax in the stereo pairs allows derivation of quantitative height information. In this case, the information comprised semi-quantitative relative terrain heights; the absolute height values calculated by DMS are incorrect. This was due to inaccuracies in the camera technology and the use of photogrammetric software that was not principally designed for the use of video imagery.

Modelling with GIS

Systems approach on coastal morphology allows modelling
Models are formulated based on perception and understanding of the real system. The approach necessary to study and predict coastal morphological changes is described. Many efforts are directed towards disentangling of the driving forces behind morphological changes. Models that are based on a detailed description of the elementary physics of fluid and sediment particle motion require detailed knowledge of the physics of many interacting processes. This approach has increased knowledge on to short-term hydrodynamics, aerodynamics and sediment transport processes. It has provided insight into the role of these processes in geomorphological change. There are still some problems, though, in their application to long-term prediction of morphology because of the chaotic (stochastic) character of the morphodynamics of coastal systems, and the increasing inaccuracy of the prediction with scale. Therefore, there is an awareness that prediction of yearly morphological changes of coastal stretches would benefit from additional large-scale research (in time and space) that focuses on these morphological changes themselves. Modelling of the complex geomorphological processes and interactions involved in geomorphological change in the coastal zone requires a systems approach. Three sand-sharing systems have
been defined on Ameland. Trends in the evolution of sand mass (or volumes) were used for prediction of the future morphology of the three systems.

**Spatio-temporal modelling of coastal morphodynamics in GIS**

In addition to a new approach, new tools have been used for the study of morphodynamics. Earth-surface forms can be analyzed with 3-D impressions generated by 2.5-D GISs. The study of their dynamics challenges the new possibilities of GIS in fields of change detection, storage of temporal attributes and presentation of temporal changes. The integration of models and GIS allows spatio-temporal modelling and facilitates the prediction of morphological developments. These tools are introduced in relation to their use in a geomorphological study of the coastal systems reported in the part 3. Two GISs have been applied for the phenomenological description of the behaviour of geomorphological systems, IEMGA, an object-oriented GIS, and PCRaster, a field-based GIS. The morphodynamic models were written in PCRaster. The input consists of elevation data and their derivatives. The models have been built from mathematical, modelling, and GIS functions, and describe geomorphological processes. The output consists of prediction maps.

**PART 3 Geomorphological investigation**

The evolution of the northwestern beachplain as a result of the migration of channels and shoals of the ebb-tidal delta

The Wadden islands are partly protected by ebb-tidal deltas. The spatial pattern of channels and shoals of these deltas is important for the coastal morphological development of the extremes of the islands. An extensive beachplain with a large swashbar occurs at the head of Ameland. Recent changes of Ameland’s northwestern beachplain are cause for concern for management. Yearly elevation data for the past 11 years (1985-1996) were interpolated to create elevation maps. Two spatio-temporal GISs have been used to describe the long-term development of this beachplain: a field-based GIS and an object-oriented GIS. The description resulted in the differentiation of three phases in the morphological development of the beachplain. The beachplain shows a regular development within these three phases, although it is irregularly cyclic in the long-run. Prediction based on long-term historical trends is therefore difficult. However, in the last phase a decrease in activity was noted, because of a lack of erodible sand; in the past, Ameland’s west coast has been stabilised with groynes. This state of inactivity might come to an end when a new phase begins, e.g. by the amalgamation of a shoal to the beachplain. A sequence of storm floods could change the stable situation for the swashbar, causing the landward migration of the swashbar and the filling of the lagoon.

Morphological behaviour of central Ameland’s North Sea coast

The development of a continuous sandy shoreline under the influence of natural processes (e.g. storms) and human impacts (i.e. nourishments) is described and predicted, based on suitable remote sensing data input and the application of dynamic modelling and GIS techniques. On time scales ranging from several months to several years, major changes can be observed on the boundary between beach and dunes, as well as within the nearshore zone.
The actively changing interdependent landscape units, the foreshore, beach and foredunes were studied by volumetric analysis of sediment budgets. The changes observed in the nearshore zone as a result of the behaviour of bars have also been described. Storm floods and nourishments are related to sediment exchange between landscape units, but not to the behaviour of bars. Breaker bars seem to display autonomous behaviour and their influence on the cross-shore sediment exchange is mainly limited to the nearshore zone. These results were used to construct a model for predicting future topography with and without nourishments. According to the model, without nourishment the dunefoot will display retreat in 2000, and the beach will be lower compared to the morphology in 1996. Had nourishments been applied in 1996, then these effects would have been compensated for.

Modelling washover landscape development with airborne remote sensing data

An important and genetically controversial geomorphological phenomenon observed on the eastern ends of the Wadden islands is the occurrence of washovers. Through their present geomorphological function in aeolian and marine sand transport from the beach and foredunes to the saltmarsh and tidal flats, washovers also have a major ecological impact. They influence, i.e., the species composition of the saltmarsh. The study aims to describe and predict the development of a washover landscape. Several airborne sensors were used to monitor the washovers. Information on developments in the formation and stabilisation of the washovers by vegetation was extracted from multitemporal airborne videography and aerial photographs. Based on the trends derived from these sequential images, digital elevation data and morphological parameters derived from laser altimetry, dynamic modelling in a GIS environment was applied. This resulted in the prediction of a (future) washover and saltmarsh landscape. The approach taken and the results produced were tested in several ways. The approach seems to be promising, but some of the assumptions in the model should be rejected. This means that the model could still be refined. Both sea and wind are active agents in the formation and the development of the eastern washover and saltmarsh landscapes. The presence of washovers causes environmental heterogeneity, resulting in high species diversity. Multitemporal airborne remote sensing data are not only useful for monitoring the landscape but these data also support spatio-temporal modelling.

PART 4 Synthesis

Synthesis

Remote sensing data and elevation data can be useful for the study and management of coastal areas. Present and previous morphodynamics can be monitored. Models in GIS can be used to make a prediction of coastal behaviour so that, if required, management decisions can be made in time. The importance of this study for process-geomorphology is, the identification of the factors that are important for the understanding and prediction of the meso-scale morphodynamics of three different sand-volume sharing systems. The knowledge of interaction of forms and geomorphological processes in relation to other parameters is presented in conceptual models and is elaborated by interactive modelling in GIS.