

DEVELOPING A GLOBAL DATABASE FOR COASTAL VULNERABILITY ANALYSIS: DESIGN ISSUES AND CHALLENGES

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ABSTRACT:

A global coastal database has been developed within the context of the DINAS-COAST project (**D**ynamic and **I**nteractive **A**ssessment of National, regional and Global Vulnerability of **C**oastal Zones to Climate Change and Sea-Level Rise). The database, which has been specifically designed to address the needs of researchers in the area of vulnerability assessment of coastal zones, integrates information on physical, ecological and socio-economic characteristics of the coast at various resolutions and covers the world's coastline, excluding Antarctica. Initially developed within a Geographic Information System, this global database forms an integral part of the DINAS-COAST system and one of the principal components of DIVA, the modelling and assessment tool that the project has produced. In order to comply with the physical and functional requirements of this tool, the database design has been based on a linear data model for the representation of the world's coast. According to this model, all the data in DIVA are expressed to linear coastal segments of variable length, thus giving the DIVA database a fundamentally different data structure to the more common raster datasets used in global studies. The decomposition of the world's coastline into segments has been based on a series of physical, administrative and socio-economic criteria and has resulted in 12,148 segments which represent homogeneous units in terms of impacts and vulnerability to sea-level rise and constitute the reference units on which all subsequent modelling and analysis are based. The selection of the data model and the representation of coastal space within DIVA have constituted two of the main challenges of the database design and have formed the basis for the compilation of a reliable, coherent and easy-to-use database that allows for consistent evaluations of coastal-zone vulnerability to sea-level rise at regional and global scales. It is expected that the DINAS-COAST database will provide researchers and modellers from various disciplines with an efficient and consistent basis for studying coastal systems, assessing coastal vulnerability and formulating broad policy responses to climate change.

1. INTRODUCTION

Human-induced global climate change and associated sea-level rise can have major implications for coastal populations and ecosystems. The results of global vulnerability assessments (GVAs) have been the main sources of quantitative information on the potential impacts of sea-level rise at regional and global scales and have been used extensively for further analysis (Hinkel and Klein, 2003). However, the consistency and reliability of GVAs have been compromised by several limitations, a principal one being the lack of appropriate data sources.

The EU project DINAS-COAST (Dynamic and Interactive Assessment of National, Regional and Global Vulnerability of Coastal Zones to Climate Change and Sea-Level Rise; <http://www.dinas-coast.net>) has developed an innovative interdisciplinary methodology in the form of a flexible assessment tool, DIVA (Dynamic Interactive Vulnerability Assessment), which will enable its users to produce quantitative information on a range of coastal vulnerability indicators and to

analyse a range of mitigation and adaptation policies (Hinkel and Klein, 2003). One of the main components of DIVA is a global database which contains information on various physical, ecological and socio-economic parameters of the world's coast. This component is accompanied by an integrated model and a graphical user interface (GUI). The development of a reliable and upgradeable database of relevant physical and socio-economic coastal parameters has been one of the principal objectives/innovations of the DINAS-COAST project and aims to provide coastal modellers and analysts with a coherent and consistent source of input for their models and analyses.

This paper discusses some of the issues and challenges faced during the design and compilation of the database. These issues include the selection of the data model, the representation of coastal space within DIVA and the functional requirements of the final product and the associated limitations of the database design within the context of the project.

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2. DESIGNING THE DATABASE-REPRESENTATION OF THE COAST

Many authors have emphasised the role of appropriate and reliable information and the importance of organized, planned and coherent coastal databases as essential prerequisites in decision making about the coastal zone (Bartlett *et al.*, 1997; Bartlett, 2000; Weyl, 1982). The decision on how information is represented in the system is an important factor for the organisation and reliability of a database. Within this context, the data model and structure have been identified by Bartlett (1997) as two of the major concerns to the developers of coastal information systems, the most immediate of which being the selection of an appropriate model of coastal space.

Representing coastal space however is notoriously complex. Despite being one of the most distinct features on earth's surface (Bartlett *et al.*, 1997; Shupeng, 1988) the coast has always been difficult to represent due to its dynamic nature and to the multi-dimensionality of information associated with it. This complex nature of the coastline presents a challenge in determining appropriate data structures to use when constructing a database to store coastal information.

Geographic Information Systems (GIS) have been used extensively in storing, processing and displaying coastal information. They offer significant advantages such as the ability to handle large databases and to integrate and synthesize data from a wide range of sources (e.g. remote sensing, cartography) and also the potential to convert and model data. However, coastal GIS also face problems in effectively representing and modelling the coast and have been described as a "tough issue" (Bartlett, 2000; Mueller *et al.*, 2002). This characterisation stems from various problems such as the lack of effective conceptual and data models of coastal objects and phenomena and the handling of the temporal and dynamic properties of coastal properties.

2.1 Representation of the coast in previous applications

Despite its complexity, the coastline is one of the most widely-used data elements in coastal research. Shoreline delineation is used, in some form, in almost every example of coastal or ocean resource mapping (Lockwood and Fowler, 2000). As mentioned earlier, the dissimilarity between the two main dimensions of the coastline and its complex nature are two of the principal reasons that raise fundamental issues regarding its representation. The representation of the coastline also affects GIS which are founded on the assumption that the two horizontal dimensions are essentially equivalent (Goodchild, 2000).

Sherin and Edwardson (1996) state that it is attractive to model the coast in one dimension. This approach has considerable appeal due to the common perception of the coast as a fundamentally linear entity (Bartlett, 1993). Coastal databases based on this simple notion include the RAMS database (Eberhart and Dolan, 1980) and GIS implementations using topologically structured systems (see Bartlett, 1993). One of the main limitations of this data model is that it fails to address problems of variable spatial resolution of coastal data. An alternative to this problem is suggested in the use of recursive methods of decomposition of space which involves breaking down a geometric unit into subunits in a hierarchical way until the desired level of detail has been attained. An example of the application of this technique was the Canadian Coastal

Information System which divided the coastline of Canada into smaller segments in an arbitrary fashion. These segments were "as long or as short, as comprehensive or as detailed as required" (Fricker and Forbes, 1988 p. 113). Debusschere *et al.* (1992) developed a similar technique for analyzing the changes on the coast of Louisiana. They mapped shoreline attributes on a linear representation of the coast which could then be decomposed and stretched out for the assessment of changes between different time periods. Leatherman *et al.* (1995) used a similar methodology employing aerial videotape-assisted vulnerability analysis (AVVA) and ground data. Based on the physical characteristics and human uses of the coast, the method partitioned the coastline into a series of linear sections. Shupeng (1988) suggested the use of the coastline as a basis for global databases. He partitioned the coastline of certain regions of China with points that represented the major coastal cities and ports, thus expressing the coast as a series of arcs intercepted with "dots". He argued that this model offers a necessary supplement to existing raster and polygon datasets.

A recent development in the linear representation of the coastline is a technique called dynamic segmentation. Dynamic segmentation measures distances from the beginning to the end of a coastal reference string (Sherin and Edwardson, 1996) and spatially references coastal features based on these measurements. With the dynamic segmentation, line objects are defined according to start and end nodes, attribute data are linked to segments within the line while associated distances are stored in separate relational tables.

2.2 The DIVA data model

The representation of coastal space in DIVA has been based on the general concept of the linear model, as described in the previous section. However, in addition to the existing difficulties in referencing coastal information, the adoption of a data model for the purposes of DIVA was further complicated by the specific requirements of the project and by the form of the final product. Firstly, DINAS-COAST aims to address primarily the needs of the climate change research and policy communities by providing a means to assess coastal vulnerability at regional and global scales. Therefore, this aim also needs to be addressed and reflected in the data model employed in DIVA. Secondly, one of the principal aims of the project is to ensure widespread applicability and maximum user-friendliness. DIVA will be provided on a CD-ROM that will include all its three components: the database, the algorithms and the GUI. As a result and in addition to the conceptual limitations, this fact generates physical and functional limitations (e.g. storage space, processing speed) which have an effect on the performance of the tool and may render it user unfriendly. These two issues were addressed with the selection of a specific linear model for the representation of coastal space and for referencing coastal information.

In order to address the first point, a method for an "intelligent" decomposition of the coastline was employed. In the context of this method, coastal space in the DIVA database has been structured to represent a meaningful expression of the variability in vulnerability. The world's coastline was divided into homogenous units (henceforth termed coastal segments) in terms of potential impacts and vulnerability to sea level rise. The boundaries of the coastal segments were decided according to a series of physical, administrative and socio-economic criteria. As DINAS-COAST is focused on sea-level rise, the range of critical values that define vulnerability within the

coastal zone should reflect the impacts and responses of the coastal system to this factor. Based therefore on the assumption that variations in vulnerability within the coastal zone are controlled by primary variations in the human and physical coastal interchange several critical parameters were identified. These parameters were (i) the geomorphic structure of the coastal environment, (ii) the potential for wetland migration, (iii) the locations of major rivers and deltas, (iv) population density classes and (v) administrative boundaries. According to these parameters, the world's coastline was segmented into homogeneous coastal segments on which all modelling and analysis in DIVA were based. The theory behind the segmentation methodology employed in DINAS-COAST is discussed in detail by McFadden *et al.* (2003).

The choice of the data model also addresses the physical and functional requirements of the project. The segmentation of the coastline was used as a means to provide a series of spatial reference units for the modelling tool of the project and to link it to the GIS database and to the graphical output. Considering the restrictions of storage space, imposed by the form in which the DIVA tool has been produced and will be disseminated, the database that would be included in the final product had to be as lean and as well-structured as possible, without however compromising the quality of the output results. A large database would not only be impossible to store on a single CD-ROM but would also substantially decrease the performance targets set for DIVA, thus rendering the tool inefficient and user unfriendly. Based on these facts and also due to the scale and size of the project, the selection of the segmentation criteria described in the previous paragraph was necessary for achieving the target of a manageable database. In this way it was ensured that the database would not be populated by “*an unmanageable profusion of impossibly small line segments ... and degenerate into an unmanageable and grossly overcomplicated assemblage*” (Bartlett *et al.*, 1997, p.141) which would have severe impacts on the analysis and graphical display performance of the tool.

3. GIS IMPLEMENTATION OF THE COASTLINE SEGMENTATION – THE DIVA DATABASE

Due to the explicit spatial nature of the data and of the type of operations required for populating the database, both tasks were performed as pre-processing steps within a GIS, externally to DIVA (Hinkel and Klein, 2003). For this purpose, a GIS database containing individual data layers that have been collected from various sources (table 1) was compiled. Due to the scale of the project, data collection primarily relied upon the contents of the vast archives of existing datasets. Datasets derived from remote sensing data have been an important data source as such data offer a globally coherent view of the earth, are largely unaffected by national data collection practices, can be aggregated comparatively easily and are readily available (Rhind and Clark, 1988). These datasets were complemented with analogue cartographic data from various sources which were converted into digital form and were incorporated in the database. According to Rhind and Clark (1988) the integration of remotely-sensed and analogue cartographic data offers the most promising approach to globally coherent, up-to-date and scientifically valid databases. Finally, tabular datasets collected from various organisations (e.g. UNESCO) as well as expert-judgement assessments were employed in cases where gaps in global coverage existed for certain parameters.

Dataset	Format	Source
Gridded Population of the World	Raster	CIESIN
World Elevation and Bathymetry	Raster	NGDC
Geomorphic type	Analogue map	McGill, 1958
Landform type	Analogue map	Valentin, 1952
Tidal Range	Raster	IGBP-LOICZ
Wetlands database	Tabular	CCRU
Second Level Admin. Boundaries	Polygon	DCW, ESRI

Table 1. Characteristic datasets, from different sources and in different formats, that were included in the database

After the compilation of the GIS database, the segmentation of the world's coastline was performed according to the criteria described in section 2.2. This process produced 12,148 coastal segments (Figure 1).

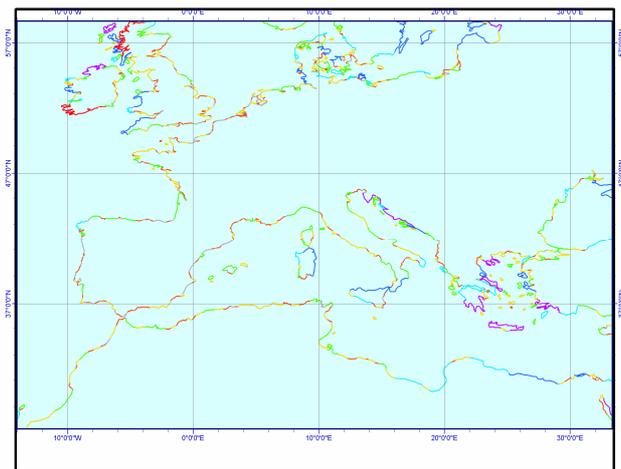


Figure 1: An example of the coastline segmentation. Display of segments for the European and North African coast.

Since the original data that were stored in the GIS database were in various formats (e.g. rasters, polygons, points), extensive GIS processing was undertaken in order to reference the existing data to the linear-representation model of the coast that was chosen for DIVA. The processing methodology varied for each dataset, depending on factors such as the source, the origin, the nature and the format of the data and the requirements of the DIVA model. The methodology used for each parameter is analytically described in the associated DIVA metadata files.

The final outcome of this referencing process was a database where each coastline segment has a unique numeric id and is associated with its attribute data in a table (Figure 2). Attribute data are included at different spatial levels (e.g. country, administrative units, regions) depending on the scale and accuracy of the original data and on the requirements of the algorithms incorporated into DIVA. The DIVA database is

therefore stored in a unified table structure, a form which has been found to facilitate the use of databases by multidisciplinary scientists (see also Mueller *et al.*, 2002).

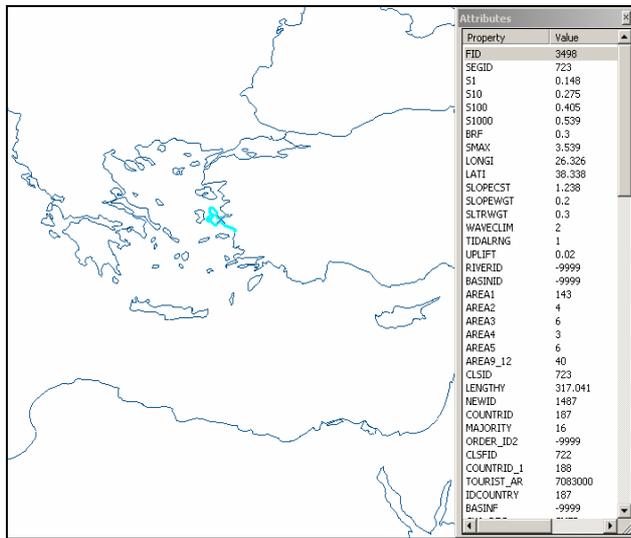


Figure 2: Example of coastline segment and associated attribute data

4. DISCUSSION

The representation of the coast in DINAS-COAST constitutes an improvement compared to other linear data models that have been used in the past for representing the coast. Firstly, the decomposition of space is not performed in an arbitrary way but is instead based on a series of scientific criteria. Secondly, this type of representation produces an organized and coherent data structure that reduces effectively the complexity of the reality to the minimum required. Moreover, it achieves all the above in a way that is compatible with the specific demands of the product of the project, the DIVA tool. One of the limitations of the employed methodology is the fact that the linear segments represent the coast in a static way. This limitation stems from the reliance of the technique on a particular linear feature. However, this is a general problem which is common to all linear data reference models of the coast, including dynamic segmentation (Sherin, 2000). It is noteworthy that most impact and vulnerability analyses have employed some form of coastal segmentation at an early stage of analysis. Such an example is the first Global Vulnerability Assessment where segmentation was essentially based on national boundaries, producing 192 segments (Hoozemans *et al.*, 1993).

The data model that has been used has played a fundamental role in achieving two of the main targets of DINAS-COAST, firstly the inclusion of the complete database within the DIVA tool that will be supplied to the end users and secondly the aim to address the needs of a wider community of researchers and policy makers. The first aim has been achieved without compromising the level of detail of the information contained in it. This is demonstrated by the fact that the coastline segmentation has produced two orders of magnitude more segments than Hoozemans *et al.* (1993). Nevertheless, due to its resolution, the information contained in the database is not designed for use at local scales and should be evaluated considering all the limitations that are associated with global

datasets. The second aim has been achieved by making the database available in an easily-accessible form as its use does not require specialized software and hardware. This makes the information included in the DIVA tool accessible to a wide range of coastal scientists who have been unable to utilize such information in the past. Within this context, the data model employed by DIVA and the methods used for transferring the GIS data to this model can be viewed as a methodological tool for making geodata available to the broader coastal science community and to a wider range of disciplines.

5. CONCLUSIONS

The methodology developed within the context of DINAS-COAST has led to the generation of a global coastal database for the purpose of vulnerability assessment. The structure and contents of the database reflect the priorities and perspectives of the project (Bartlett *et al.*, 1997) and in that sense these factors have been defined to a large extent by project-specific needs. However, the methodological and structural advances achieved can impact a wider range of applications in a more general context.

The DIVA database has a fundamentally different structure to all other global datasets, which are primarily based on raster data models. This includes the IGBP-LOICZ coastal typology which is raster based (IGBP-LOICZ, 2003). It is expected that the cross-disciplinary nature of the database developed and its consistency and user-friendliness will satisfy, to a large extent, current information needs of the wider coastal-research community and will assist coastal scientists in the modelling and analysis of coastal processes at regional and global scales. It is proposed to make the DIVA database publicly available via the International Geosphere Biosphere Program Land Ocean Interaction in the Coastal Zone (IGBP-LOICZ).

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