ARRIBA: DESIGNING A GIS FOR COASTAL MANAGEMENT

Paula Redweik[a], Rita Matildes[b], Fernando Marques[c]
[a] Dep. Eng. Geogr. Geof. Energia e Centro de Geologia, Faculdade Ciências Universidade Lisboa, Campo Grande 1749-016 Lisboa, Portugal
predweik@fc.ul.pt
[b] Faculdade Ciências Universidade Lisboa, Campo Grande 1749-016 Lisboa, Portugal
rmmatildes@fc.ul.pt
[c] Dep. Geologia e Centro de Geologia, Faculdade Ciências Universidade Lisboa, Campo Grande 1749-016 Lisboa, Portugal
fsmarques@fc.ul.pt

KEY WORDS: GIS, Landslides, Inventory, Multitemporal, Coast, Database, User.

ABSTRACT:

Well designed Geographic Information Systems (GIS) are a very useful tool for the analysis of coastal dynamics phenomena. Coastal monitoring involves large quantities of data from several types and sources, which converge to a better description of the coastal dynamic. In order to model coastal behaviour it is also necessary to perform a multi-temporal study. The heterogeneity of the data and their complex correlation demand a well structured GIS. Series of vertical aerial photos are a pillar in every multi-temporal approach of this kind. An example of such a GIS, named ARRIBA, is being implemented for the cliffy coast of the Algarve region in Portugal. There, a significant quantity of mass movements of all types, taking place in different time periods, originated by a set of circumstances can be found, making the GIS a very rich but complex system to develop. In this paper, it will be described not only the structure from ARRIBA, but also how several information levels were produced.

1. INTRODUCTION

A well designed Geographic Information System (GIS) is nowadays a tool of unquestionable utility for the analysis of coastal dynamics phenomena. Geologists, engineers, land managers, archaeologists and geographers are potential users of such a GIS as they are mainly concerned with the spatial and time distribution of coastal changes like landslides and sediment drift, their possible causes and consequences. In order to model coastal behaviour it is not only necessary to assess the time component, which means performing a multi-temporal study, but also to include large quantities of data from several types and sources, which converge to a better description of the coastal dynamics. A reliable inventory defining the type and activity of landslides and the definition of their spatial distribution is of great importance, before any analysis takes place (Duman, 2005).

The heterogeneity of the data and their complex correlation demand a well structured GIS in order to allow an efficient analysis of phenomena. The use of an organized GIS allows a more efficient collection, manipulation and analysis of data, as well as being more cost-effective (Carrara, 1999).
Also, providing visual and reliable information about the coast at several time points, series of vertical aerial photos set up the pillar of every multi-temporal approach of this kind since they go back to the thirties in most countries. Information about position, shape and geometric features of landslides can be obtained from these materials (Yalcin, 2006).

An example of such a GIS, named ARRIBA, is being implemented for the cliffy coast of the Algarve region in Portugal. Along the cliffy coastal segments, a significant quantity of mass movements of all types, taking place in different time periods, originated by a set of circumstances associated with geology, lithology, slope, pluviosity, etc, can be found, demanding a rich and complex to develop GIS. As stated by Carrara (1999), a well structured and rich in useful data GIS is of paramount importance when investigators attempt to evaluate the total landslide hazard of a region where more than one type of landslide is frequent. ARRIBA constitutes the final result of a project aiming the evaluation and quantification of cliff changes in the Algarve coast ordered and supported by Comissão de Coordenação e Desenvolvimento Regional do Algarve (CCDR Algarve).

2. ARRIBA DESIGN

2.1 General structure

Landslides occurrence and behaviour are controlled by a set of spatial factors, being the most important the ones related to geology (retrieved from geological maps), topographic maps; digital elevation models (DEMs), aerial photo and satellite imagery (Yalcin, 2006).

Therefore, ARRIBA presents a base structure, designed in ArcGIS 9 (ESRI), composed of a set of 10 distinct levels of raster and vector information to support the spatial analysis (Figure 1). The raster levels are: geologic maps, orthophotos, DEM, difference digital elevation models (DDEM) and pluviometry maps. The vector levels consist on: contours maps in scale 1:2000, manmade structures (buildings, roads, etc.) in scale 1:2000, landslides, cliff top and base lines and oblique aerial photos location. Metadata has been defined for each of the layers specifying origin, date and spatial reference.

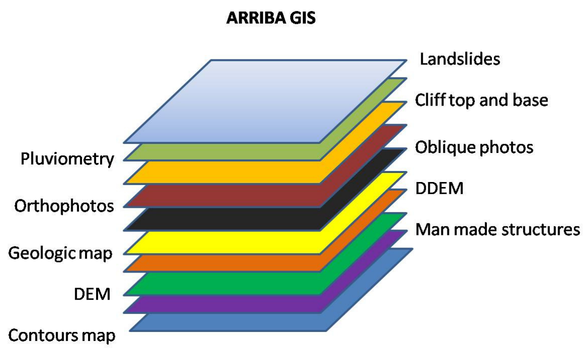

Figure 1. Structure of ARRIBA.

2.2 Description of information levels

Due to the amount of information involved, the diversity of sources and feature characteristics, it is necessary to specify the contents of each level. They will integrate Arriba not only as basic information layers as input data for more complex analyses.

Contours map and manmade structures - This information was extracted from the 1:2000 coast cartography elaborated 2002 by Instituto Nacional da Água (INAG). Contours present an interval of 1m and a ±200m m wide strip is represented. The spatial reference system of these layers is the Portuguese Datum 73 and the vertical Datum of Cascais.

All the subsequent generated information shares the spatial reference of this cartography. Furthermore, the layer of manmade structures is composed by several levels, relevant for risk analysis: accesses to beaches, roads, single-storey and multi-storey buildings, and private maintenance beach sections.

Digital elevation models - For each epoch considered, a DEM is generated through automatic stereo image correlation using the aerial photos available. The resolution of such DEMs is controlled by most elevated values of the planimetric RMSE in all flights. In this case, the DEMs must be generated with a resolution of 1m, in order to guarantee data homogeneity and compatibility.

Difference digital elevation models - DDEMs generated by the difference between two DEMs of different epochs are available and can, afterwards, suffer any spatial analysis the user may need. Obviously, it is taken into account that resolution and errors are inherited from the DEMs used in its generation.

Geological map - These layers show the geologic cartography of the region of interest in two degrees of detail: the official geologic map of Portugal in scale 1:50000 and several geologic surveys.

Oblique photos - Three oblique aerial surveys of the coast of the Algarve, performed in 2001, 2003 and 2006 are included in ARRIBA. In this layer, oblique photos, although not geo-referenced, are represented by a symbol located at the center of the photographed costal segment. A hyperlink to each image is associated to the correspondent symbol, together with date, author, name of the photographed place on the coast and reference to file.

Orthophotos - A set of orthophotos with a GSD (Ground Sample Distance) of 0.5 m dating from 2005 is available in this layer. These were elaborated by Instituto Geográfico Português.

Cliff top and base - These layers consist on 3D lines representing cliff top and base in each epoch. These lines were acquired systematically by stereo plotting, using PCI's Geomatica v.10 software. The elements considered were constantly target of geomorphological evaluation as, in a first glance, and especially the cliff top feature, they can cause some digitizing errors caused by misinterpretation.

Pluviometry - Several pluviometry maps showing the 5 year mean pluviosity since 1947 are gathered in this layer. The basic data of pluviometry and other weather parameters are available in the official SNIRH - Sistema Nacional de Informação de Recursos Hídricos database (http://snirh.pt). The pluviometry surfaces are obtained by Kriging, based on the available stations for a determined period.

Landslides - This is the core layer of ARRIBA. It consists on the representation of all detected cliff top changes between epochs caused by landslides. Each landslide consists of a polygon involving the lost area at cliff top and, for each, a panoply of attributes regarding location, geology, geometry and time of occurrence is defined. Associated with every landslide is a detail of the area portrayed in oblique photos.

3. DATA ACQUISITION

A complex data acquisition stage preceded the integration of several of the levels in ARRIBA. In fact, the data acquisition phases are always the most time consuming and costly components of a GIS, although the most important ones (Carrara, et al, 1999). In the case of ARRIBA, such phases regarded the acquisition of cliff top and base elements, DEM, DDEM, and landslides and its characterization.

According to Yalcin (2006), quoting Kraus (1993), landslides and land cover change detection can be effectively determined using aerial photographs with digital photogrammetric techniques. For this purpose, 5 sets of aerial photos covering completely the coastal section, dating from 1951, 1991, 1995, 2002 and 2007, were collected (Table 1). From all available flight, these fulfill the relevant criteria: widest time window, best ground control, best scale or GSD and best radiometry, simultaneously.

Flight	Scale	GSD (m)
1951	1:18000	0.41
1991	1:33000	0.67
1995	1:15000	0.34
2002	1:8000	0.18
2007	1:46000 (Digital)	0.50

Table 2. Scale and Ground Sample Distance (after scanning of analog images) of each flight (Matildes, et al, 2008).

Altogether, a total of 304 aerial photographs were processed and interpreted. Although not being processed by means of photogrammetry, another set of several aerial photos of different intermediate epochs were visually inspected in order to better sample the date of occurrence of each landslide.

Spatial orientation of all flights had to be determined by aerotriangulation, using the specific software BLUH (http://www.ipi.uni-hannover.de), based on ground control points (GCP) used to produce the INAG 2002 cartography. In fact, there was a set of well documented GCPs, identifiable in the 2002 flight, that could be used in the aerotriangulation. As no ground control for the other flights was available, well distributed common points between the five surveys had to be identified and collected. Having passed 56 years, the task of registering common points was especially hard to accomplish for the 1951 flight, since the landscape changed considerably in this region. Moreover, there was an important lack of information regarding the older flight (no camera information, only paper prints available that had to be scanned). This fact required additional processing in order to recover the internal orientation of these photos, by defining a pseudo-camera (Redweik, 2008).

The results of the aerotriangulation processing were highly satisfactory (Table 2), presenting RMSE inferior to 0.25m in the 2002 flight and inferior to 1.5m in the 1951 flight. These values are inferior to the landslides' dimension values of lost area presented in a previous study (Marques, 1997), which validates the suitability of the method to the study of landslides in this region.

RMSE (m)	Flights				
	1951	1991	1995	2002	2007
X	0.892	0.706	0.351	0.119	0.300
Y	0.578	0.942	0.336	0.119	0.339
Z	1.456	1.537	0.586	0.465	0.756

Table 2. Results of the aerotriangulation of the 5 flights.

The aerotriangulation results enabled stereo plotting and generation of DEMs for the five epochs. These were produced using automatic stereo correlation of the images supported by stereo plotted break lines of the top, ridges and toe of the cliffs.

The segments corresponding to cliff top and base were selected and integrated in ARRIBA to build the layer "Cliff top and base".

Using ArcGIS 9, difference DEMs between each pair of epochs were derived, revealing the height changes in the coast and their distribution in planimetry. A thorough interpretation of the results allowed separating the changes due to human activity from those corresponding to actual landslides in the coast.

To define the horizontal areas lost at cliff top the stereo plotted lines corresponding to cliff top in each epoch were superimposed in the XY plane. The discrepancy polygon materializes the lost area, allowing affected cliff top length and width to be measured. These polygons and their geometric attributes feed the layers "Landslides", and constitute the most relevant information for hazard assessment and definition of set back lines based on the coastal dynamics.

A different approach can be made using DDEMs. The lost material at the top of the cliff builds a deposit at the base which is afterwards removed by beach dynamic processes. Based on this fact, DDEM are built, for example DDEM [2002-1951]. For a user not familiar with digital imaging or DEMs, a chromostereographic color is applied, enabling an automatic detection of possible cliff instabilities and a 3D perception of the relief changes. Within ARRIBA, a buffer can be applied along the coast line in the chromostereographic representation. Possible landslides appear enhanced as small areas of lost material, sometimes neighbored by similar small areas of gained material (Figure 3).

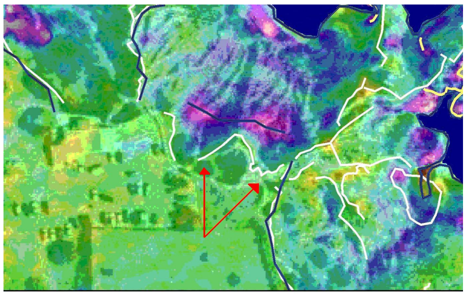

Figure 3. Chromostereographic representation of changes (in this case material loss), superimposed to the stereoplotted lines of different time periods and orthophoto.

Finally, pluviometry data was collected for all weather stations in the Algarve, from 1947 to 2007. In fact, despite having weather stations registering since the 19th century, not all the stations for the Algarve region have mean annual pluviometry data for all years. Therefore, the different pluviometry surfaces are obtained with different sets of stations. Pluviometry surfaces were generated by kriging for each 5 year period, considering the average annual pluviosity values. These results are relevant in a context of relating landslide dimension and frequency, geology and weather conditions (Figure 4).

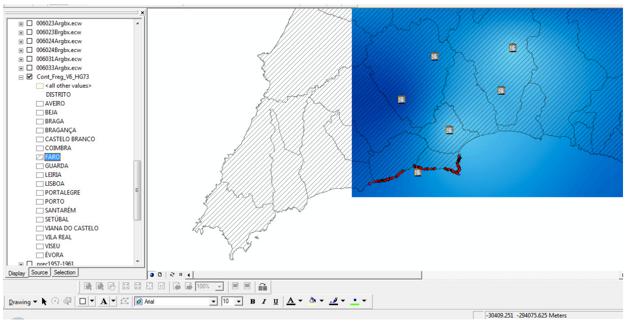

Figure 4. Relating pluviosity maps and landslide events.

4. EXPLORING ARRIBA

Once the information is compiled and well organized, it is possible to perform spatial analysis on the several levels of information made available. Updates of changes inventories become easier, particularly when the stereoplotting output from a later flight has to be integrated.

Each landslide is defined in ARRIBA by a large set of attributes; some may result from spatial analysis. They are date or time interval of occurrence, affected cliff length, lost area at cliff top, displaced volume, lithology, geology and type of landslide (Figure 5).

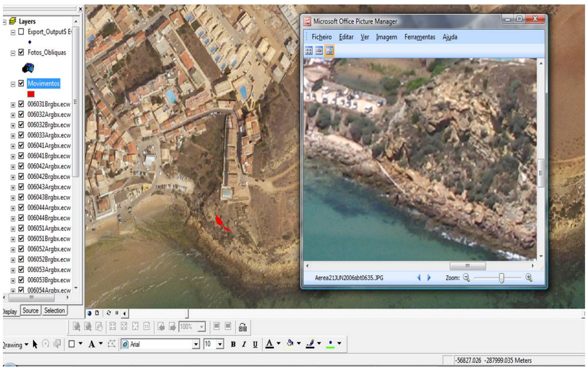

Figure 5. Landslide and the correspondent zoom in with the help of an oblique photo.

The crossing of information such as a landslide occurring in a given time window with a pluviometry map may allow the narrowing of that time window, assuming that a higher mean annual value of pluviosity influences the occurrence of a landslide. Although existing 36 weather stations working in all the Algarve today (hydrographic basins of Arade and Algarve water courses), SNIRH lacks stations in the coast: apart from one exception, the nearest station is place about 2km from the coast (Figure 6). Consequently, some pluviometry surfaces do not cover the entire studied coastal segment.

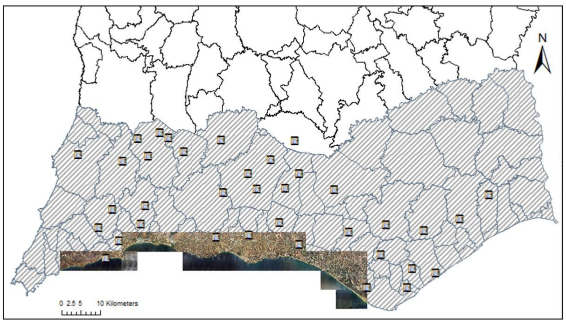

Figure 6. Distrbution of weather stations in the Algarve region.

As any efficient GIS, the several possible analyses take the form of queries to the database, such as “How many landslides occurred between 1951 and 1991?”, “In which geology occurred toppling landslides?”, “Which landslides produced a loss superior to 100 m^2?”, “How many landslides occurred between a given $(x,y)_{min}$ and $(x,y)_{max}$?”, and so on.

Also oblique aerial photos will be associated to each movement (Figure 7), in order to facilitate visual interpretation and as an auxiliary when searching for a determined landslide.

With the information described above, multiple queries will be implemented and made available for users who want to research the data. This phase will be especially important when a remote access system to the database is implemented.

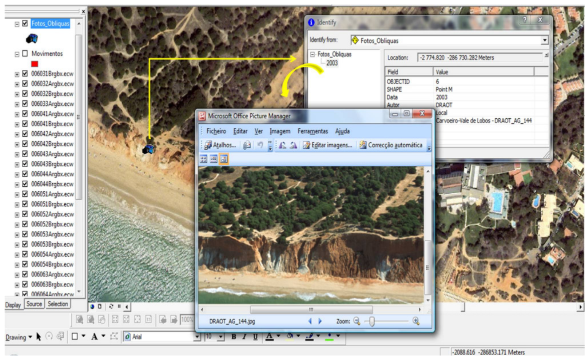

Figure 7. Association of oblique photos to coastal sections (detail zoomed in).

5. CONCLUSIONS

Landslide inventories is a fundamental base of knowledge, as well as a basic tool for land planning (Colombo, 2005), and, implemented in a GIS platform, allows a more effective mitigation and risk management.

Instead of appearing as a traditional way of simply displaying interesting maps, the design and the exploitation of ARRIBA has proven to be a useful tool to gather, manipulate and extract new information. As a GIS technology (Carrara, 1999), it may even be useful in the future to build and test different models or simulations.

This GIS structure is of great interest for all institutions with some level of jurisdiction over the coast and allows, at any time, accessing precise and extensive information providing the knowledge needed to correctly and efficiently understand and manage coastal regions. Also, it has been stated (Yalcin, 2006) that central and regional planners and decision makers should take into consideration this kind of research in order to minimize damage in determined regions.

The integration of digital photogrammetry and GIS provide more accurate results and allows manipulation of data and subsequent analysis in a shorter time and less costly (Yalcin, 2009), meeting the goals described by several studies as the main advantages of GIS (Colombo, 2005): definition and analysis of a landslide inventory; achievement, update and maintenance of GIS, cartography and working tools; realization of studies, research and experiment; diffusion of knowledge by means of internet services, etc.

In this line of thought, an interesting further development of this project would be the implementation of a service of dynamic analysis and data access through an user-friendly interface on an internal network (or via internet), allowing sharing knowledge and data by the scientific community and interested users of this kind of information. Nevertheless, such a progress would require careful planning and evaluation of hardware and server capabilities in order to retrieve full potential, as the response times to remote users should be as small as possible (Carrara, 1999).

REFERENCES

Carrara, A., Guzzetti, F., Cardinali, M., Reichenbach, P., 1999. Use of GIS Technology in the Prediciton and Monitoring of Landslide Hazard. *Natural Hazards (1999)*, 20, pp. 117-135.

Colombo, A., Lanteri, L., Ramasco, M., Troisi, C., 2005. Systematic GIS-based landslide inventory as the first step for effective landslide-hazard management. *Landslides (2005)*, 2, pp. 291-301.

Duman, T., Çan, T., Emre, Ö., Keçer, M., Dogan, A., Ates, S., Durmaz, S., 2005. Landslide inventory of northwestern Anatolia, Turkey. *Engineering Geology (2005)*, 77, pp. 99-114.

Marques, F., 1997. The sea cliffs of the coast of Algarve. Dynamics, processes and mechanisms. University of Lisbon, Ph.D. thesis, 556 p.

Matildes, R., Redweik, P., Marques, F., Santos, L., 2008. Detecção e medição de recuos nas arribas no litoral do Algarve para integração em SIG. *X Encontro de Utilizadores de Informação Geográfica* (Oeiras, Portugal), pp. 759-771.

Redweik, P., Marques, F., Matildes, R., 2008. A strategy for detection and measurement of the cliff retreat in the coast of Algarve (Portugal) by photogrammetry. *EARSeL eProceedings*, 7 (2), pp. 92-104.

Yalcin, A., Bulut, F., 2007. Landslide susceptibility mapping using GIS and digital photogrammetric techniques: a case study from Ardesen (NE-Turkey). *Natural Hazards (2007)*, 41, pp. 201-226.

ACKNOWLEDGEMENTS

The authors would like to thank the Comissão de Coordenação e Desenvolvimento do Algarve for the financial support of the project and INAG for providing several of the fundamental data for this work. Appreciation is also due to Instituto Geográfico Português who provided scanned aerial images under the FIGIEE program.