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A new approach to landslide geomorphological mapping using the Open Source software in the Olvera area (Cadiz, Spain)

Abstract This paper presents the preliminary results of a geomorphological survey of the Olvera area (Cadiz province, Betic Ranges, Spain) and the use of the Geographic Information System (GIS) Open Source (OS) software plus Database Management System (DBMS) for making available and distributing the landslide data over the Web. In the geomorphologic survey, different landforms have been identified in the area, including structural, anthropogenic, fluvial, karst, and slope forms. In particular, the majority of the slope forms are complex (from topple to rotational slides and falls), but there are also minor forms like debris flows and mudslides. To manage geomorphological data, an Open Source GIS was used, which contained the following components: QuantumGIS, System for Automated Geoscientific Analyses (SAGA), GIS and Geographic Resources Analysis Support System (GRASS), GIS for Digital Elevation Model (DEM) generation. A key aim was to make the project-derived data available over the Web. This was achieved using MapServer which allows for the representation of the derived geospatial data with pMapper providing the graphical Web interface. Our study highlights the process dynamics of run-off erosion in Olvera derived through the use of advanced computer-based mapping tools. The resulting map products and interpretations are available via the Internet. To date, derivative maps have been produced to improve maintenance of roads and transport and of the construction of new infrastructure.

Keywords Slope forms · GIS · Geomorphological mapping · Open Source software · Cadiz · Spain

Introduction

Landslide mapping has become an important tool for risk assessment, prediction, and management (Wu et al. 1996). Synthetic maps showing slopes at risk of movement have proven to be valuable for planning, risk analysis, and design of infrastructure. When geomorphological and geological surveys are imported into a Geographic Information System (GIS) environment, thematic maps can be generated to meet the needs of a wide variety of end users. Applications for products derived from these surveys include: thematic cartography implementation and improvement; creation of geological and geomorphological databases; thematic mapping aimed at mitigating geoenvironmental risks such as landsliding and flooding; remote sensing for geological and geomorphological mapping; land management and hazard mitigation; hydrological modeling; water resources protection and management; numerical modeling; environmental impact assessment; and managing environmental emergencies (Turner and Schuster 1996).

Traditional landslide mapping has undergone an evolution as a result of the attributes of GIS. These include data management, image processing, graphics production, spatial modeling, and visualization of many types of data. In this study, both modern and traditional methodologies of landslide analysis have been applied to obtain detailed geological and geomorphological data in and around Olvera. Techniques used have included detailed geological–geomorphological surveys, analysis of high-resolution remote sensing space data, Global Positioning System receiver measurements, and digital photogrammetry, all of which have been collated using the GIS Open Source software.

The GIS Open Source software is a well-developed and popular program that includes the Geographic Resources Analysis Support System (GRASS), PostgreSQL, and PostGIS for the Database Management System (DBMS) plus Mapserver for Web publications. For the present work, it was decided to examine each of these and use them as well as QuantumGIS (QGIS) and The Gimp. Within the earth sciences, the Open Source software has been used successfully to examine forest and landscape change detection (Ciolli et al. 2002b; Turda et al. 2004), atmospheric modeling (Ciolli et al. 2002a, b; Löwe 2004), geology (Masumoto et al. 2002; Kajiyama et al. 2004; Yonezawa et al. 2002), archaeological studies (Brovelli and Magni 2003; Baiocchi et al. 2005; Raghavan et al. 2002), and geomorphology and landslide mitigation (Clerici and Perego 2000; Clerici 2002; Fock and Rebolledo 2004; Paudits and Bednarik 2002). An advantage using the Open Source software to create geomorphological maps is the cost reduction if compared with purchasing proprietary software.

In the present work, a specific Open Source Database has been created and its thematic results made available online through a Geographical Information System on the Web (WebGIS) password-accessible site (http://webgis.unife.it/Olvera/map.phtml).

Geographical and geological setting

Olvera village is located in Andalucia, South Spain, on the northeastern sector of Cadiz province (Fig. 1). Regionally, the zone is formed by a series of low hills and plains ("Campiña de Olvera"), with elevations between 200 and 800 m above sea level, within the external zones of the Betic Ranges.

Streams are irregular and are generally at low flow conditions in the Alonso, Guadalporcún, Salado, and Trejo rivers. The area has a typical Mediterranean semicontinental climate, with annual average temperatures of around 20°C, spatially variable depending on the altitude. Precipitation is irregular, both in time and space, ranging between 700 and 1,000 mm/year (Lopez Geta et al. 2005). The gradient of spatial variation in precipitation is affected by topography and Atlantic winter humid fronts that track from W and SW (Gracia 2008). Rainfall is associated with local orography, which has a broad N–S orientation and thus intercepts the passage of Atlantic fronts.

According to the interpretative scheme proposed by Cano and Jerez (1990), the external zones of the Betic Ranges include

Fig. 1 Location of Olvera village

different geological units and complexes, mainly represented by (a) the Lower–Middle Miocene Aljibe unit, belonging to the Campo-de-Gibraltar flysch complex (Stromberg and Bluck 1998; Lujan et al. 2000; Vera and Martin-Algarra 2004); (b) Jurassic carbonates of the Subbetic Zone (García Dueñas 1967; Mauthe 1971; Vera and Martín-Algarra 2004); (c) undifferentiated Subbetic Triassic evaporites, or Germanic Trias; (d) Jurassic–Cretaceous Middle Subbetic turbidites (Cano Medina and Jerez Mir 1990), mainly characterized by marly facies (Vera et al. 2004); and (e) Upper Miocene and Pliocene postorogenic units.

Methods

Geological and geomorphological survey

Owing to their size, activity, lithology, and geomorphic forms, the processes and deposits can clearly be recognized on gray-scale aerial photographs at a scale of 1:30,000 and mapped with great detail at a scale of 1:10,000 on a topographic base map. The facies analysis and field surveys undertaken lead to partially reconsider the formal nomenclature of the stratigraphic units identified by previous authors in the zone (Table 1).

Pruna Castle yellow clays are uncertainly classified and are located below the relief formed by the Olvera limestones near the Castle of Pruna. Based upon stratigraphic coherence, field evidences supported its interpretation as a tertiary unit. Furthermore, we report the presence of a large outcrop of pillow lava-like structures and dolerites, characterized by ophitic texture, northwest of Olvera along the Vía Verde de la Sierra ("green way of the ranges," excavated along an old railway that was never constructed), in the undifferentiated Subbetic Triassic.

We have been able to distinguish structural, anthropogenic, fluvial, karst, and slope forms, processes, and deposits. Most of the slope forms are associated with complex mass movements (from topples to rotational slides and falls, currently affected by surface creep; Fig. 2) and conditioned by the different mechanical behaviors of the alternating clays and calcareous limestone layers of the postorogenic units. The biggest landslides are located near Torre Alhaquime village, at the contact between Setenil and Mina formations, with sandstone layers alternating with clay. Some characteristics of such movements are shown in Table 2 and in Fig. 2 (Fantini 2005).

Debris flows and mudslides are also present and appear to be related to anthropogenic causes, especially near local small villages and farms, where land use triggers and reactivates many of the above-mentioned flows, especially during the short but intense autumn rainfall episodes.

Image analysis

In this study, geomorphological mapping has been carried out through preliminary airphoto interpretation of panchromatic orthophotos dated 2004 provided by the regional government (Junta de Andalucia) at a nominal scale of 1:30,000. Photointerpretation of stereo images (black and white, color orthophotos, and color digital orthophotos) in conjunction with field work has provided fidelity of terrain and landforms. This has allowed for improved interpretation of geomorphological deposits and processes (Fig. 3) through discrimination of geometric, spectral, and temporal features contained within the images (Mantovani and Marcolongo 1992).

GIS and database management systems

Data of the Olvera area were inputted into a geodatabase we designed and organized. Figure 4 shows the steps made starting with literature, the field survey of the Olvera area, and the geotechnical laboratory analysis. As an example, in the landslides database, fields such as identity, location, length, width, average slope, area, slope exposure, size, shearing resistance, soil type, plasticity index, type of movement, depth of the surface, lithology, land use, current status, causes, damage, interventions, and notes were filled (Table 2). The geographical information collected

Table 1 Local lithostratigraphic formations vs regional stratigraphic units/age

Local lithostratigraphic formations	Regional stratigraphic units/age
Undifferentiated Subbetic triassic	Middle Subbetic
Limestones with ammonite (informal name)	Southern Middle Subbetic/Jurassic
Olvera limestones (informal name)	Lias–Dogger
White and gray marls and marly limestones of Las Harinas (informal name)	Cretaceous
Circumbetic flysch-like units (equivalent to Aljibe unit)	Inner Subbetic/Late Cretaceous–Early Neogene
Chaotic tectosedimentary unit, clays with blocks	Late Cretaceous–Early Neogene
White marls and calcareous sandstones of Monasterejo (informal name)	Oligocene
Numidic-like sandstones and marls (informal name)	Lower Miocene
Sandstones (Olvera formation) and clays (Mina formation)	Postorogenic units/Tortonian–Messinian
Pruna Castle yellow clays (informal name)	Tertiary

Fig. 2 Complex landslides developed at the Mina and Setenil formations contact, near Torre Alhaquime village. The movements include topples and falls in the upper escarpment and multiple rotational slides along the slope. The *upper left sketch* represents a detail of the geomorphological map of this zone

during the geomorphological survey was filtered through the QGIS and GRASS module database interfaces within the PostgreSQL (http://www.postgresql.org/) and PostGIS DBMS. This set of DBMS software programs controls the organization, storage, management, and retrieval of data in a database. The DBMS accepts requests for data from the application program and instructs the operating system to transfer the appropriate data. When a DBMS is used, information systems can be changed much more easily as the organization's information requirements change.

PostGIS and PostgreSQL were used as support for geographic objects and object-relational database derived for the Olvera area. PostGIS adds support for geographic objects to the PostgreSQL object-relational database. In effect, PostGIS "spatially enables" the PostgreSQL server, allowing it to be used as a backend spatial database for GIS, much like ESRI's SDE or Oracle's Spatial extension. PostGIS follows the OpenGIS "Simple Features Specification for SQL" and has been certified as compliant with the "Types and Functions" profile (http://postgis.refractions.net/).

QGIS 0.11.0 version Metis (http://www.qgis.org/) was selected to derive thematic information levels. This Open Source GIS system, licensed under the GNU General Public License, runs on Linux, Unix, Mac OSX, and Windows operating systems. It supports vector, raster, and database formats. Data could be ported into the GRASS GIS (http://grass.itc.it/) and PostGIS DB. Critically, QGIS manages both ESRI shape files and GRASS files, allowing the user to interact with data developed with proprietary software as well as those derived from the Open Source software. QGIS can work on GRASS mapset and data with GRASS module plugins.

Digital elevation model

To generate a Digital Elevation Model (DEM) of the Olvera area, taking into account relief and surrounding topography, GRASS and System for Automated Geoscientific Analyses (SAGA) GIS (http://saga-gis.wiki.sourceforge.net/) were used. Using these programs, slope, aspect and watershed maps of the Olvera study area were produced and stream analysis was conducted. DEM data were obtained from Junta de Andalucia cartographic products. Posting density of Andalucia DEM is 10×10 m, generated from the 1998 to 1999 survey flight.

Cartography layout

Graphical layout for thematic maps is not yet well developed in Open Source GIS layouts (QGis, GRASS, and SAGA GIS layouts) and, therefore, image elaboration was required. For this, we used

Table 2 Datasheet of Mina–Setenil clay and sandy materials properties of landslide contact

Location	**Length**	**Width**
S Torre Alhaquime	1,790 m	960 m
Particles size	**Shearing resistance**	**Soil type**
Sample 1: 76.91% sandy material	Sample 1: medium–low	Clay below: CL (lean clay)
Sample 2: 57.91% fine material	Sample 2: high	Landslide body: CL–ML
Sample 3: 75.65% fine material	Sample 3: low	
Lithology	**Land use**	**Current status**
Silty sand weakly clayey	Olive groves and croplands	Suspended
Average slope	**Area**	**Slope exposure**
11%	192,000 m^2	N–N–E
Plasticity index	**Type of movement**	**Causes**
Clay below: 22 (plastic medium); landslide body: 5.01	Topples to rotational in the top part; translational—earthslide below	Intense rain. Presence of deep clay layers facilitates the sand sliding
Damage	**Interventions**	
Rupture of outside ballast road. Cracks in private homes	Protective walls on the road facing the upslope margin	

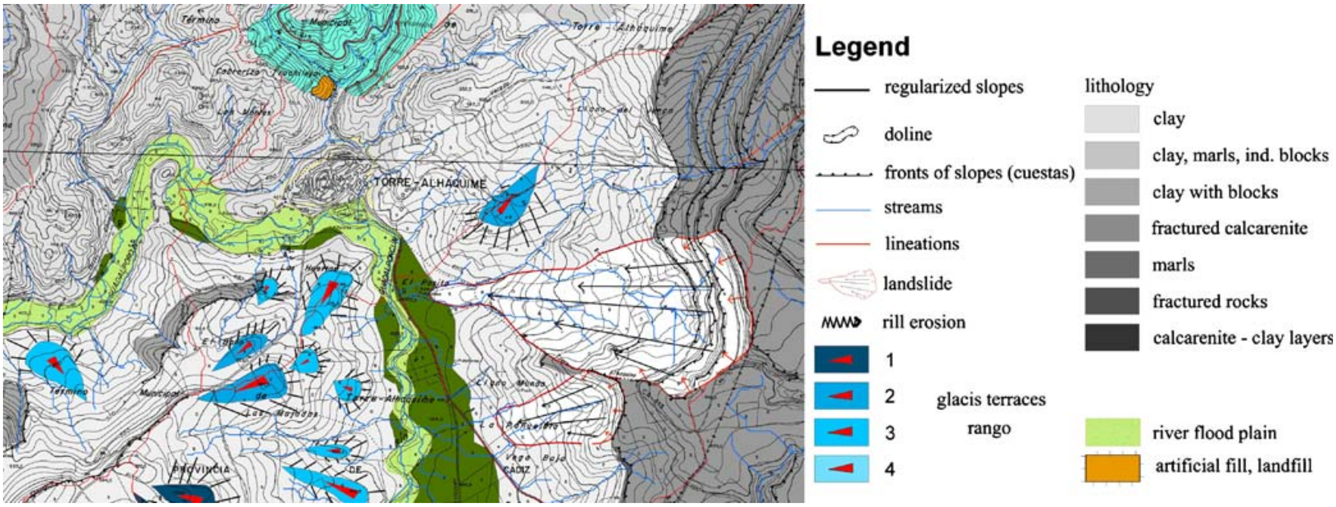

Fig. 3 Detail of the geomorphological map of the Olvera area (scale of 1:10,000)

the Open Source software The Gimp (http://www.gimp.org/). The first step was to export the raw output map directly from the QGIS and input it into The Gimp. Preparation of the map cartouche was undertaken to make sure that rendering occurred at the same scale as the QGIS export map. Extrapolation and positioning of single elements to generate the final map (Fig. 3) were crucial. Once this was achieved, improvements were then made to the text legend with font dimensioning, color, and any logos.

WebGIS

We used MapServer (http://mapserver.gis.umn.edu/) and pMapper (http://www.pmapper.net) for the graphical Web interface of the Olvera project data. The Linux Debian platform Web server Apache2 was used as the network server operating system with the

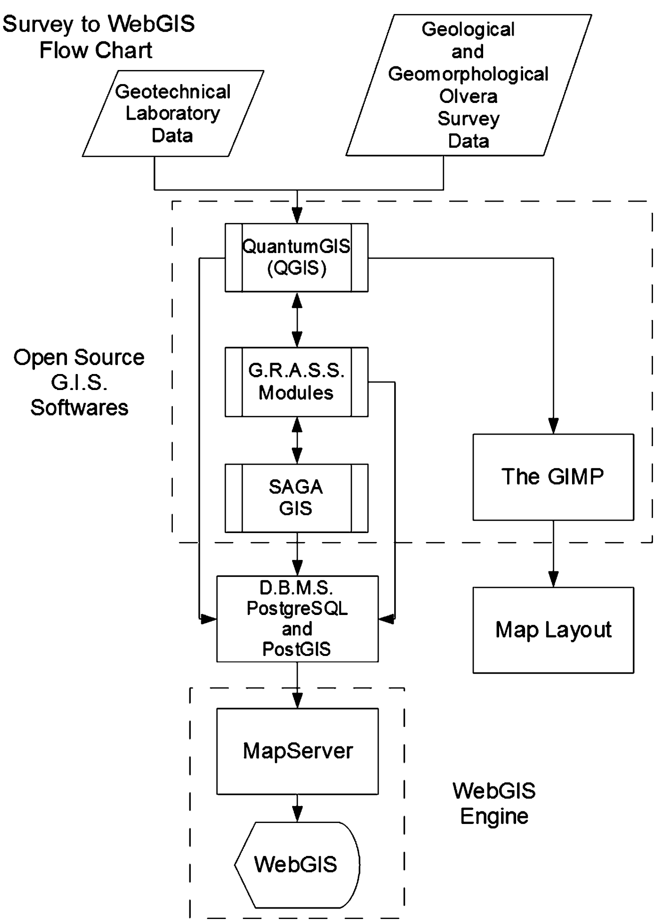

Fig. 4 Steps followed in the present work: from survey to WebGIS

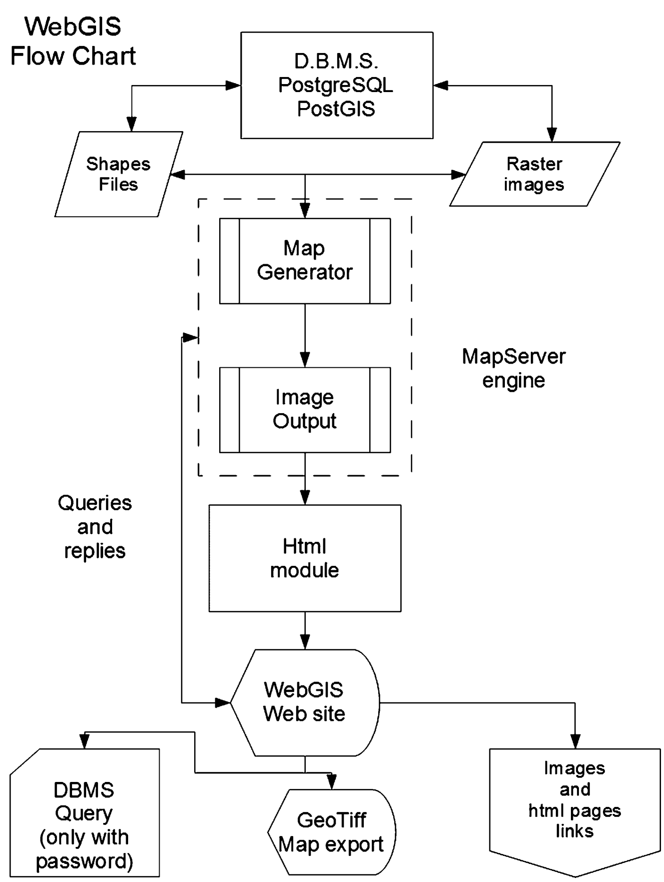

Fig. 5 The work flow from field survey to WebGIS output

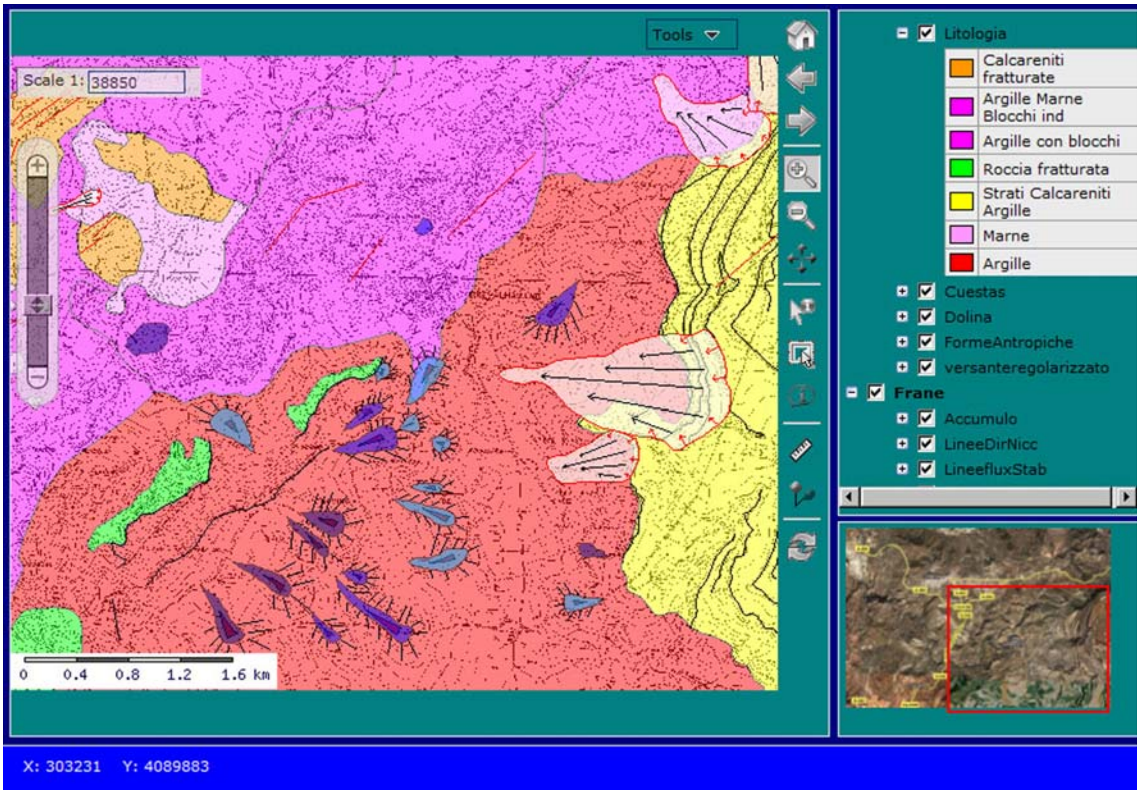

Fig. 6 Detail of the final product of the WebGIS applied to the Olvera area

PHP5 scripting language. These tools allow any user access to data, regardless their choice of computer, software, or other materials.

MapServer engines ingest PostgreSQL and PostGIS data files (Fig. 5) from which georeferenced map layout can be generated. Image output is in geoTIFF format which can be sent to an html module for visualization of the image on the Web. It should be remembered that requests for characteristics starts from the WebGIS website (choice of zoom of an area, layers visible or hide, scale of output, etc.). This site receives the output image (from a specific temporary folder, tmp) and shows it on the Web. The WebGIS graphic interface (pMapper) allows for many types of queries to be made and is based on two important files: the "config. ini" and the "Olvera.map file." The first takes the main basic characteristics of the website (for example, map size, scale, type of legend, fonts, etc.), while the second sets the values of every field and the characteristics of layers (for example, geology, streams, orthophotos, etc.). The vector and raster data are visible to any users on the website: http://webgis.unife.it/Olvera/map.phtml.

Results and discussion

To examine the geological and geomorphological problems around Olvera, a landslide map and derivative thematic products have been generated using a new approach based upon Open Source architecture which allows products to be accessed and shared over the Web (Fig. 6).

In Spain, there exists an Open Source GIS software called GvSIG, but it still needs important improvement to become a good product. This was achieved using Open Source software that was modified to suit the project aims. The Open Source software used in this work can be installed on almost any operating system (e.g., Linux, Windows, Mac OSX, Unix). The major problems encountered in the field of GIS were related to geodata formats which are often proprietary and require purchasing of a commercial software program to use them. Users of data derived from government agencies, public offices, and many private companies are often constrained by these formats and, therefore, the dissemination of potentially important information can be impeded. Both QGIS and GRASS foresee the management of proprietary file type. In particular, QGIS runs directly on proprietary format (create, edit, export to other formats, etc.), while GRASS manages, creates, and changes data still in its format and then returns it in shape format. This allows global data management with strong interoperability with all operating systems and software currently used.

Conclusions

Data obtained from field survey, image, and laboratory analysis have successfully been manipulated in the Open Source GIS that allow for data management, image processing, graphics production, spatial modeling, and visualization of many types of data. Map products derived from our study have highlighted the important role of run-off and erosion in the area and provide useful inputs to assist in environmental sustainability planning and land protection. The ability to undertake such mapping using the Open Source software is also significant because it shows that computer-based analysis can be undertaken without incurring the costs associated with purchasing proprietary software.

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