DEVELOPMENT OF A GRASS-GIS APPLICATION FOR THE CHARACTERIZATION OF VINEYARDS IN THE PROVINCE OF TRENTO

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ABSTRACT

The physical factors that influence the grape ripening include elevation, slope, aspect, potential global radiation, sun hours and soil type of the vineyards.

Many of these features could be derived from Digital Elevation Models (DEM), using Geographic Information Systems (GIS). There are several commercial and open-source GIS-applications available and also the geodata are continuously increasing in amount, spatial resolution, frequency, but their use remains matter of specialists!

In the present work we developed an easy to use and open-source application, accessible on the web, exploiting the functionalities of GRASS-GIS in the analysis of geospatial data and PostgreSQL/PostGIS as geodatabase, allowing a rapid characterisation of the sites.

Each vineyard is identified through the compilation of a simple form on the web. The required fields are the cadastral codes of the zone as well as of the parcels, which composes it. After sending the request an automatic procedure starts, which extracts the geometry of the vineyard from the vector cadastral map of the Autonomous Province of Trento, provided by the PAT – S.I.A.T. office (**www.siat.provincia.tn.it**). The Digital Terrain Model at 10 m resolution (PAT – S.I.A.T.) was used in the open source GIS software GRASS 6.4 to derive the slope and aspect maps (*r.slope.aspect* function), whereas the cumulated global radiation, and mean insolation (sun hours) during the vegetative period (1^{st} April – 31^{th} October) were calculated at 20 m resolution using the *r.sun* command. In the following step GRASS GIS performs the query of all the available raster maps (digital elevation model, slope, aspect, etc.) within the limits of the vineyard and returns the correspondent mean values.

Moreover three bioclimatic indices (Winkler, Huglin, and Gladstones) are automatically calculated, based on modelling of 10-years of meteorological data from 64 weather station distributed over the Province, and the elevation of the site.

The data are automatically stored in the 'vineyards' table of the database and result immediately available on the web. The procedure is written in php and can be adapted to every region and purpose, modifying the vector and the raster layers. The input of the cadastral data can occur also by means of a comma separated values (.csv) sheet, allowing the characterisation of hundreds of vineyards in few minutes.

KEYWORDS

GRASS – GIS – Digital Elevation Model – Winkler – Huglin – Gladstones

INTRODUCTION

Wine grape ripening and therefore quality is the result of the interaction of different main factors: grape and rootstock variety, climatic conditions, geomorphometric attributes of vineyards, soil type and properties and agricultural practices (Jones *et al.*, 2004). Physical factors that influence the grape ripening include elevation, slope, aspect, potential global radiation, sun hours and soil type of the vineyards.

Many of these features could be derived from Digital Elevation Models (DEM), using Geographic Information Systems (GIS), and used for the selection of suitable vineyard sites (Jones *et al.*, 2004; Kurtural *et al.*, 2007; Reynolds *et al.*, 2007). There are several commercial and open-source GIS-applications available and also the geodata are continuously increasing in amount, spatial resolution, frequency.

The Digital Elevation Model is a digital representation of ground surface topography or terrain. It is also widely known as a Digital Terrain Model (DTM). A DEM can be represented as a raster (a grid of squares) or as a triangular irregular network. DEMs are commonly built using remote sensing techniques, but they may also be built from land surveying (Wilson, Gallant, 2000). Digital elevation models may be prepared in a number of ways, but they are frequently obtained by remote sensing using interferometric synthetic aperture radar on satellites (SARS) or by Airborne Light Detection And Ranging (LIDAR) systems, rather than by direct survey or stereo photogrammetry (Wilson, Gallant, 2000).

The Shuttle Radar Topography Mission (SRTM) was the first international research effort that obtained digital elevation models on a near-global scale from 56° S to 60° N, to generate the first most complete high-resolution digital topographic database of Earth (Farr *et al.*, 2007). Digital elevation models (DEM) at 90 m resolution for the entire globe, covering all of the countries of the world, are freely available for download on the site **http://srtm.csi.cgiar.org/**.

The Global Digital Elevation Model (GDEM) was created by stereo-correlating the 1.3 million scene ASTER VNIR archive, covering the Earth's land surface between 83 °N and 83 °S latitudes. The GDEM is produced with 30 meter postings, and is formatted in 1 x 1 degree tiles as GeoTIFF files, available at no charge for download from NASA's EOS data archive (**http://asterweb.jpl.nasa.gov/gdem-wist.asp**) and Japan's Ground Data System (**http://www.gdem.aster.ersdac.or.jp/index.jsp**).

The most commonly calculated surface derivatives are slope and aspect. Slope measures the steepness of the surface at any particular location; it is often measured in degrees or in percent rise. A flat region has zero slope. The steeper the surface, the higher the slope. Slope is an important variable for many analyses, such as drainage patterns on digital elevation models (DEMs), environmental modelling, site selection, cross-country movement models.

Aspect measures the direction of steepest slope for a location on the surface. It is usually measured in degrees, where 0 degrees is due north, 90 degrees is due east, 180 degrees is due south, and 270 degrees is due west.

Potential global radiation and sun hours can also be derived from digital elevation model using GIS applications. Direct radiation is the largest component of global radiation; diffuse radiation is the second largest component, whereas reflected radiation generally constitutes only a small proportion.

Topography can greatly affect the direct radiation and for this reason a key component of the calculation algorithm of potential global radiation include the generation of an upward-looking hemispherical viewshed for every location in the digital elevation model (DEM).

The generation of potential solar global radiation and insolation maps involves four steps:

- The calculation of an upward-looking hemispherical viewshed based on topography.
- Overlay of the viewshed on a direct sunmap to estimate direct radiation.
- Overlay of the viewshed on a diffuse skymap to estimate diffuse radiation.
- Repeating the process for every pixel to produce an insolation map.

In the present work derivative maps of the Trento Province (slope, aspect, potential solar global radiation and insolation) have been calculated from digital elevation model at 10 m and 20 m resolution and implemented in a open-source application accessible on the web, allowing a rapid characterisation of the vineyards.

Moreover three air temperatures based bioclimatic indices, developed for classifying grape growing areas, were calculated from the data collected hourly by 63 weather stations throughout the Trento Province:

- Winkler Index – WI (Amerine, Winkler, 1944) is based on cumulative degree-days of heat temperature, defined as the total summation of average degrees above 50 ºF (10 °C) during the typical growing season from April to October in the Northern hemisphere (Eq. 1).
- Huglin Index – HI (Huglin, 1978) The Huglin index (HI) is calculated from April 1st to September 30th in the Northern hemisphere. This index enables different viticultural regions of the world to be classified in terms of the sum of temperatures required for vine development and grape ripening. Specifically, it is the sum of mean and maximum temperatures above +10 °C, the thermal threshold for vine development. The index also includes a correction factor (k) for the length of the day in higher latitudes (Eq. 2).
- Gladstones Index – GI (Gladstones, 1992). The author proposed the adoption of an index known as Biologically Effective Day Degrees. This index similarly sums the heat experienced over ten degrees. However, Gladstones suggested that there is no further advance in phenological development with temperatures above 19 °C. He therefore included a cut-off at 19 °C (Eq. 3).

MATERIALS AND METHODS

GIS-data

The Digital Terrain Model at 10 m resolution was provided by the S.I.A.T. office (**www.siat.provincia.tn.it**) of the Autonomous Province of Trento (6.255 km^2) and used in the GIS software GRASS 6.4 (Neteler, Mitasova, 2008) to derive the percent of slope and degree of aspect maps (*r.slope.aspect* function), whereas the cumulated global radiation, and mean sun hours during the vegetative period (1st April – 31th October) were calculated at 20 m resolution using the *r.sun* function. The 10 and 20 m resolution rasters consist respectively of 62.546.236 and 15.898.592 pixels; the projected coordinate system is WGS 84/ UTM zone 32N. The size of the files is about 480 Megabytes for the higher (elevation, slope, aspect) and 114 MB for the lower resolution maps (potential global radiation, insolation).

The vector cadastral map of the Province of Trento, was also provided by the PAT–S.I.A.T. office. The ArcGIS shapefile (.shp) consists of 1.621.280 polygons and the spatial reference is also WGS 84/ UTM zone 32N. The size of the file is about 680 MB.

Meteorological data

The main meteorological data (air temperature and humidity, solar global radiation, wind speed and direction, soil temperature) were collected hourly by 63 automatic weather stations throughout the Trento Province, whose altitudes ranged from 83 to 1035 m a.s.l. Complete weather data are stored back to 2000 and are accessible on the web (**http://meteo.iasma.it/meteo/**).

Bioclimatic indices

Three bioclimatic indices (Winkler, Huglin, and Gladstones) were calculated for 64 weather station distributed over the Province of Trento, over a period of 10 years (2000-2009).

$$Winkler\ Index\ (WI) = \sum_{1th\ April}^{31th\ October} \max\left[(T_{avg} - 10^{\circ} C);0\right] \qquad \text{Eq. 1}$$

$$Huglin\ Index\ (HI) = \frac{\sum_{1st\ April}^{30th\ September} \max\left[(T_{avg} - 10);0\right] + \sum_{1st\ April}^{30th\ September} \max\left[(T_{\max} - 10);0\right]}{2} \cdot k \qquad \text{Eq. 2}$$

$$Gladstones\ Index\ (GI) = \sum_{1st\ April}^{31th\ October} \min\left[9, \max\left(T_{avg} - 10;0\right)\right] \qquad \text{Eq. 3}$$

where:

max = function used to find the largest or maximum number in a given list of values

min = function used to find the smallest or minimum number in a given list of values

T_{avg} = mean daily air temperature (°C)

T_{max} = maximum daily air temperature (°C)

k = day length coefficient, varying from 1,02 to 1,06 between 40° and 50° latitude.

Spatial interpolation of bioclimatic indices

Bioclimatic indices show a clear decreasing trend with altitude. The best fit was obtained by an expolinear function (Goudriaan, Monteith, 1990; Lakso *et al.*, 1995; Lee *et al.*, 2003; Eq. 4)

$$Expolinear\ \ function = \frac{b_0}{b_1} \cdot \ln\left\{1 + \exp^{\left[b_1 \cdot (elevation - b_2)\right]}\right\} \qquad \text{Eq. 4}$$

where:

b_0 = maximum relative decrease rate in the linear phase

b_1 = maximum relative decrease rate in the exponential phase

b_2 = determines the position of the curve on the elevation axis

elevation = height of the sites above sea level

The best-fitting curves for each bioclimatic index and year have been obtained using a least squares method, based on the Levenberg-Marquardt algorithm, where the sum of the squares of the residuals were minimized by changing interactively b_0, b_1 and b_2.

Annual maps of IW, IH and IG were calculated adding the residuals maps, obtained by universal kriging, to the expolinear trend surface.

Automated GIS query

The first step requires to fill a form, to assign a univocal code to the vineyard and to select the cadastral zone and parcels. After that, the GRASS-GIS procedure written in php, performs automatically the query of all the available raster maps (digital elevation model, slope, aspect, etc. – Fig. 1) within the limits of the selected cadastral parcels and returns the correspondent mean values. The data are automatically stored in the 'vineyards' table of the database and result immediately available on the web. The input of the cadastral data can occur also by means of a comma separated values datasheet (.csv), allowing the characterisation of hundreds of vineyards in few minutes.

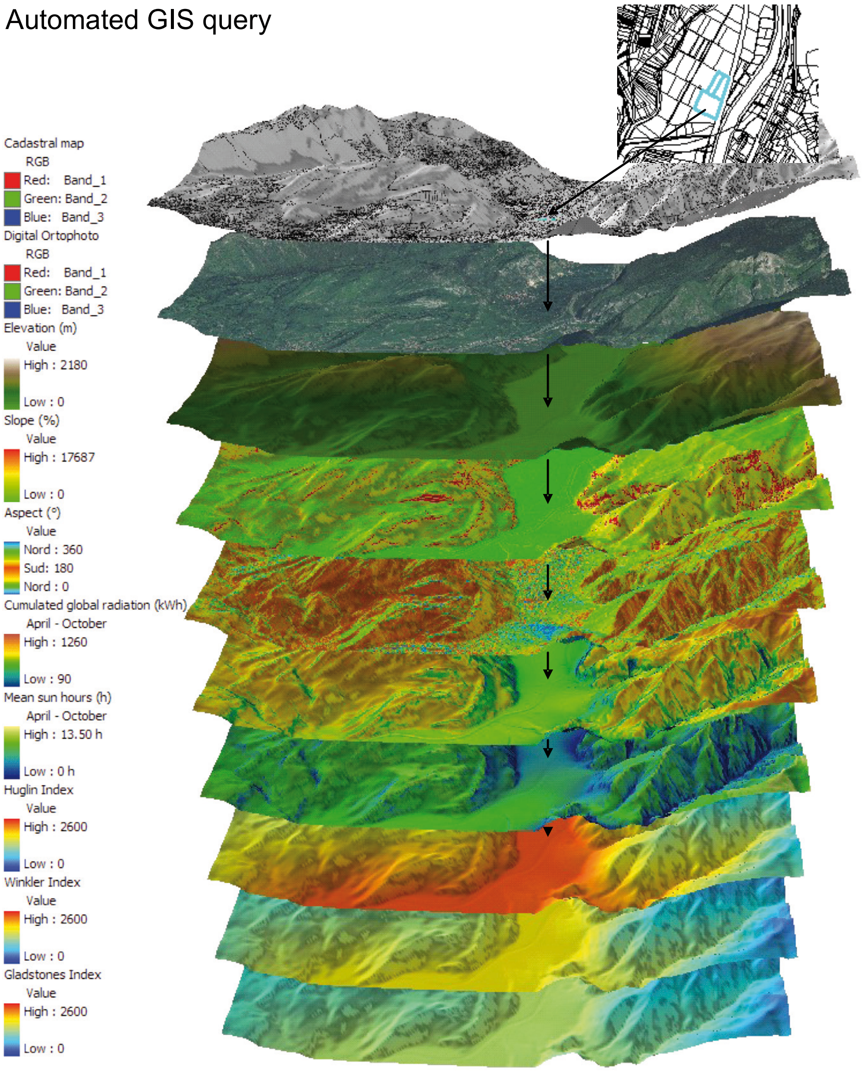

Fig. 1 – Automated query of GIS data. After selection of cadastral parcels a GRASS-GIS script performs the query of all available raster layers and stores the results in a geodatabase.

RESULTS AND DISCUSSION

The GRASS-GIS procedure was successfully implemented in the website **harvassist.fmach.it** and allowed the characterisation of 130 vineyards in few minutes; the application is usable for all the 10.000 hectares of the wine grape region of the Province of Trento. The availability of global high resolution Digital Elevations Models could extend this service worldwide. A critical point was represented by the availability and the exact knowledge of the cadastral data. We are planning to develop a web processing service (WPS) in order to allow the selection of the parcels by clicking on maps.

CONCLUSIONS

The increasing availability of GIS data must be accompanied by software easy-to-use applications. The new GRASS-GIS script offers the spatial analysis functions of the GIS-applications on the web in a very simple way, allowing the characterisation of the environment also to non-specialist users.

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