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Topsoil moisture mapping using geostatistical techniques under different Mediterranean climatic conditions

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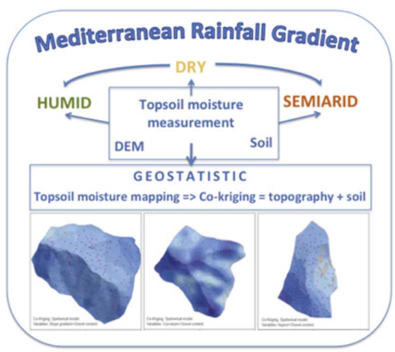
HIGHLIGHTS

- This study deals with topsoil moisture mapping in rangelands under different Mediterranean climatic conditions.
- Topsoil moisture is highly variable in space in the studied environments and controlled by topography and soil properties.
- Field survey and geostatistical techniques were combined for accurately mapping topsoil moisture.
- Topsoil moisture was mapped through kriging and co-kriging techniques considering topography and soil properties.

GRAPHICAL ABSTRACT



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ABSTRACT

Soil mapping has been considered as an important factor in the widening of Soil Science and giving response to many different environmental questions. Geostatistical techniques, through kriging and co-kriging techniques, have made possible to improve the understanding of eco-geomorphologic variables, e.g., soil moisture. This study is focused on mapping of topsoil moisture using geostatistical techniques under different Mediterranean climatic conditions (humid, dry and semiarid) in three small watersheds and considering topography and soil properties as key factors. A Digital Elevation Model (DEM) with a resolution of 1 × 1 m was derived from a topographical survey as well as soils were sampled to analyzed soil properties controlling topsoil moisture, which was measured during 4-years. Afterwards, some topography attributes were derived from the DEM, the soil properties analyzed in laboratory, and the topsoil moisture was modeled for the entire watersheds applying three geostatistical techniques: i) ordinary kriging; ii) co-kriging considering as co-variate topography attributes; and iii) co-kriging ta considering as co-variates topography attributes and gravel content. The results indicated topsoil moisture was more accurately mapped in the dry and semiarid watersheds when co-kriging procedure was performed. The study is a contribution to improve the efficiency and accuracy of studies about the Mediterranean eco-geomorphologic system and soil hydrology in field conditions.

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1. Introduction

In the Mediterranean region, rainfall gradients can be found in mountainous areas (Imeson and Lavee, 1998; Lavee et al., 1998; Ruiz-Sinoga et al., 2010a,b,c, 2011a,b, 2015). The hydrological and erosive response within the eco-geomorphologic system including climate, vegetation, soil and water as well as human activity are highly dependent on the annual rainfall (Lavee et al., 1998). This occurs due to those elements are modified with the rainfall variability which introduces changes in the abiotic and biotic factors but dependent on the scale approach: for instance, at catchment scale, both land use and vegetation patterns highly control soil erosion, whilst soil structure and spatial organization influence at patch scale (Cammeraat, 2004; Imeson and Lavee, 1998). Various studies have highlighted topsoil moisture as a key variable in the description of many hydrological and climatological processes (Pachepsky et al., 2003; Vereecken et al., 2007). In particular, regulation of matter and energy flow between the soil and the lower layer of the atmosphere is controlled by soil moisture, and is characterized by high spatial and temporal variability at finer scales (Bell et al., 1980; Brocca et al., 2007; Hupet and Vanclooster, 2005; Lin et al., 2006; Ruiz-Sinoga et al., 2011b; Schume et al., 2003). Likewise, its variations have substantial influence on nutrient losses and availability (Schmidt et al., 2011). Soil moisture is variable in space and time and, thus, the knowledge of their variability across spatio-temporal scales is important to the understanding of land surface processes, highly dependent on topography (Beven and Kirkby, 1979; Florinsky et al., 2002; Qiu et al., 2001; Western et al., 1999), soil properties, vegetation and climate (Koster and the GLACE Team, 2004; Bolten et al., 2010; Lin, 2011; Ruiz-Sinoga et al., 2010b).

Brevik et al. (2016) stated soil mapping have been important drivers in the advancement of our knowledge of soil since the beginnings of the scientific study of soils, indicating as well that, although many advances have been made since 19th century, there are still many unanswered questions and additional needs in soil mapping. Nevertheless, accordingly these authors, the geospatial revolution introduced tools and technologies such as geographic positioning systems (GPS), geographic information systems (GIS), remote sensing, GIS-linked proximal sensing, and spatial statistics. The techniques mentioned, greatly improve the ability to collect, analyze, and predict spatial information related to soils (McBratney et al., 2003; Scull et al., 2003; Lagacherie, 2008).

From recent decades, geostatistical techniques have been applied for soil modelling and mapping, which become an extremely useful tool in Soil Science (Sauer et al., 2006). Geostatistical techniques, e.g. kriging, let calculate the spatial autocorrelation between sample points and quantify uncertainty (Goovaerts, 1999). The prediction accuracy of these techniques may be improved applying spatial association via covariates (Odeh et al., 1995; Adhikari et al., 2013; Holleran et al., 2015). Also, it exits the so-called hybrid interpolation techniques which combine two conceptually different approaches to modelling and mapping spatial variability as the interpolation relying solely on point observations of the target variable with the interpolation based on regression of the target variable on spatially exhaustive auxiliary information (Hengl et al., 2007). One of these hybrid interpolation techniques, not very frequent used, is known as regression-kriging (Hengl et al., 2004), which first uses regression on auxiliary information and then uses simple kriging with known mean to interpolate the residuals from the regression model. This allows the use of arbitrarily-complex regression methods, including generalized linear models (Hengl et al., 2007). Another geostatistical technique is the cokriging, useful when there is availability of auxiliary information what is important to optimize sampling schemes (Minasny and McBratney, 2006; Shaner et al., 2008) and to serve as ancillary variable in the local prediction of a soil property (Vašát et al., 2010). Thus, cokriging can be applied whether there are two or more spatially interdependent variables, which incorporates those interdependent variables into spatial interpolation in order to obtain high prediction accuracy with limited sample data (Wang et al., 2013). Nonetheless, according to Brevik et al. (2016), spatial interpolation methods are by nature limited to the area between samples and often require a sampling density that is not practical for mapping large areas as well as the construction of stable semivariograms (the main tool on which geostatistics is based) requires considerable amount of geo-referenced data (Davidson and Csillag, 2003). All these geostatistical techniques have been applied to characterize the spatial distribution of soil moisture content and its variability (Vieira et al., 2008). During the last decades, great efforts were undertaken to detect spatio-temporal variability of soil moisture content by using geostatistics (Wang et al., 2001; Brocca et al., 2007; Schneider et al., 2011; Baroni et al., 2013; Korres et al., 2015; Yang et al., 2016).

In accordance with the previous statements, the hypothesis is the following: under contrasted Mediterranean climatic conditions, soil moisture is spatially dependent on i) rainfall supply, ii) topography and other iii) soil properties in watershed with no changes in geology and land use. The objectives are: i) characterizing the spatial variability of soil moisture in three watersheds located under different conditions of rainfalls; ii) mapping soil moisture through geostatistical techniques; and iii) selecting topography attributes and soil properties to improve the mapping of soil moisture. Accordingly, this investigation may provide an improvement of the soil sampling and mapping efficacy in Mediterranean eco-geomorphological environments.

2. Study area and field sites

This study was based on the climatic gradient approach which let compare sites with similar topography, geology and land use conditions but differing in climate (Imeson and Lavee, 1998). The study area covered a Mediterranean mountainous region and corresponds to three field sites located in South of Spain, Gaucín, Almogía and Gérgal watersheds as indicate in the Fig. 1. The rainfall gradient in the study area was defined by the analysis of a rainfall database (1960–2006) that included a total of 395 pluviometric stations distributed from the Straits of Gibraltar to Almería along the Bética Mountains (Ruiz-Sinoga et al., 2015). A rainfall gradient map was derived using cokriging through a model of linear coregionalization with two direct variograms and one cross variogram with two variables: annual rainfall and elevation. Afterwards, the three watersheds were selected according to the criteria of differences in rainfall regime and similarities in topography, parent material and land use, using aerial photography and fieldwork.

The main characteristics of the three watersheds were selected as experimental field sites are presented in the Table 1. These experimental sites were selected because of their similarity in topography, parent material and land use, what permits a suitable comparison of results: steep slope gradient (SG), metamorphic lithology and land use of rangeland. Gaucín watershed is the most humid field site (humid Mediterranean climate) where vegetation cover is high (>80%; evergreen oaks and scrubland) and enhances infiltration processes. The driest field site is Gérgal watershed whose climatic conditions correspond to semiarid Mediterranean, characterized by evident signs of water erosion, with very shallow soil, a high number of rock fragments on soil surface and rock outcrops. Almogía watershed is the field site located in intermediate climatic conditions (dry-Mediterranean climate) characterized by evergreen oaks and dense scrubland; bare soil areas are not abundant but can be characterized by rock fragment covers major than 50%. From Gaucín to Gérgal watersheds, we observed a reduction in the quality, fertility and resistance to degradation according to the soil properties of each study area, taking into account properties such as texture, organic matter (OM), aggregate stability and cation exchange capacity. More details from the field sites can be found in Ruiz-Sinoga and Romero-Diaz (2010), Ruiz-Sinoga et al. (2010b, 2011a,b, 2012).