ESTIMATING SOIL DROUGHT RISK IN ITALY USING THE EPIC MODEL AND A PEDOCLIMATIC GIS.

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Abstract

The Experimental Institute for Soil Study and Conservation has been endorsed of the realization of a new atlas of the desertification risk in Italy at 1:250,000 scale by the Italian Ministry of Environment. The methodology proposed is based on the use of indicators of pressures, state and response. Since soil stores water and mitigates drought risk and temperature excursions in the root zone, pedoclimatic regimes were considered as an useful state indicator. Aim of this work was to test a pedoclimatic GIS and the use of the EPIC model at the national and regional scales to assess soil drought risk. The pedoclimatic GIS stores data about 140 climatic stations, 207 soils and 259 elaborations. This data were elaborated to evaluate pedoclimatic regimes of the whole country. A series of 656 meteorological stations were elaborated to characterize aridity index. The aridity index was obtained applying the Hargreaves-Samani methodology (1982) on the long term mean monthly temperature and rainfall values and it was spatialized by means of the inverse distance weighed (IDW) tool of ArcGIS. Soil moisture regime was obtained using EPIC (Environmental Policy Integrated Climate, former Erosion-Productivity Impact Calculator, Sharpley and Williams, 1990) daily outputs, while soil temperature regime from the algorithm proposed by Costantini et al. (2001), which makes use of annual mean air temperature and soil water field capacity. Average cumulative days per year when the soil moisture control section is completely dry (DYSD) was tested as indicator to assess drought risk at a semi detailed scale. DYSD was estimated by means of the National Soil Database and long term climatic data. A multiple regression deriving DYSD from long term mean air temperature, annual rainfall and available water capacity (difference between soil water at field capacity and wilting point; AWC) was developed. The regression was applied to AWC of about 13,000 soils of the National Soil Database and to air temperature and rainfall of soil sites. Air temperature and rainfall of soil sites were obtained through ordinary kriging of the long term annual values of about 1000 reference meteorological stations. The algorithm proposed by Costantini et al. (2001) to estimate mean annual soil temperature was applied to 6377 soils as well.

The aridity index and the pedoclimatic maps were matched with the climatic regions of Italy (Finke et al., 1998; Righini et al., 2001). The evaluation of potentially vulnerable lands through the pedoclimatic indicators resulted far more accurate than that obtained with the traditional climatic indicator, the aridity index, and drought risk resulted in all climatic regions with a Mediterranean type of climate. The indicator DYSD was particularly useful at the regional scale for providing information about the land vulnerability in agricultural areas.

Introduction

The most widely accepted definition of desertification has been given by the United Nations Convention to Combat Desertification (http://www.unccd.int). Desertification is here defined as "*land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities*". Arid, semi-arid and dry sub-humid areas are the territories, other than polar and sub-polar regions, in which the aridity index, that is the ratio of annual precipitation to potential evapo-transpiration, falls within the range from 0.05 to 0.65.

Studies regarding mapping the desertification risk in Italy have already been carried out at global (Eswaran and Reich, 1998), continental (DISMED, 2003) and national scale (National Technical Services, 1998). More recently, using the MEDALUS approach (MEDALUS, Mediterranean Desertification And Land Use, Kosmas et al., 1999) the European Environment Agency (DISMED, 2003) worked out a new map of the desertification risk in Italy at 1:250,000 scale. Other maps of desertification risk have been drawn up/compiled at regional level, using modified MEDALUS approaches (UNCCD-CRIC, 2002). These projects define a unique index of desertification calculated assembling together many indicators. They use a model that assigns a score to the classes in which each indicator is subdivided and weights all the scores for the final evaluation. According to this approach the soil variable is considered only using soil maps and assigning a score to each taxonomic class of the cartographic units. Our methodology focuses on the realization of a desertification risk geographic information system. The primary role of soil characteristics in regulating desertification processes has been granted through the use of about 13,000 soils observations and related 40.000 records of the National Soil Database (Costantini et al., 2004). The methodology proposed is based on the use of indicators of pressures, state and response. State factors of land desertification are the environmental characteristics (measured by indicators) which regulate the occurrence of desertification processes. Pressure factors are the processes of desertification. The desertified, sensitive and vulnerable lands are the answer indicators. Since soil stores water and mitigates drought risk and temperature excursions in the root zone, pedoclimatic regimes were considered as an useful state indicator.

Aim of this work was to test a pedoclimatic GIS and the use of the EPIC model at the national and regional scales, to assess areas potentially affected by drought risk.

At the national scale, the potential drought risk provides the information about the geography of arid, semi-arid and dry sub-humid lands requested by the UNCCD definition of desertification . At the larger scale, the interest is focused in singling out territories where soil characteristics and local climate can induce a higher drought risk.

Materials and Methods

To determine the potential drought risk at the national scale, we elaborated the aridity index and the pedoclimatic regimes of Italy. The aridity index was obtained from a series of 656 meteorological stations (Fig. 1), applying the Hargreaves-Samani methodology (1982) on the long term mean monthly temperature and rainfall, and then spatialized, with the Inverse Distance Weighting method (Fig. 4).

Pedoclimatic regimes refer to soil classification according to Soil Taxonomy (Soil Survey Staff, 1999), which considers soil moisture and temperature regimes. In fact, “aridic”, “xeric”, “dry xeric” and “ustic” soil moisture regimes identify areas with varying degrees of potential water deficit (Costantini, 2004). Moreover, soils with “thermic” and “hyperthermic” temperature regimes refer to lands with high temperatures in the root zone, which can enhance the decaying of the organic matter, especially under agricultural land use. Soil moisture regime was obtained using EPIC daily outputs, soil temperature regime from the algorithm proposed by Costantini et al. (2001), which makes use of annual mean air temperature and soil water field capacity. EPIC was preferred to others models after a thorough comparison (Calì, et al. 1995).

The EPIC (Environmental Policy Integrated Climate, former Erosion-Productivity Impact Calculator, Sharpley and Williams, 1990) model (version 3090) was used on a daily time step. Daily inputs were minimum and maximum air temperature, rainfall, and radiation. Potential evapotranspiration was calculated according to Priestley-Taylor (1972). Monthly means came from long-term series of data, daily statistics from long-term or a limited number of years. The reference crop was a stable meadow, grown without irrigation and maintained at about 0.20 m high. Optimal temperature for plant growth was 20 °C for warmest climate and 15 °C for the others. Soil inputs were horizon depth, texture, rock fragments, bulk density, water content at field capacity and wilting point, and organic carbon. Field capacity and wilting point were measured in laboratory or estimated according to Baumer’s method (provided by EPIC). Soil bulk density was measured in the field or estimated by EPIC. Soil horizons depth was arranged to have four layers corresponding to the moisture control section of each studied soil. EPIC was initialized at field capacity and, using the weather generator, ran for a 50-year period of time. Daily soil moisture of the layers forming the control section was extracted from the output file of EPIC with a software created with visual basic language.

A set of linked spreadsheets of Excell were used to further elaborate EPIC outputs and in particular: i) draw graphs of the climate and soil water content of each layer; ii) elaborate daily data and classify soil moisture and temperature regimes of the 50 years generated by Epic, iii) calculate soil moisture and temperature regime and average cumulative days per year when the soil moisture control section is completely dry.

To determine vulnerable lands to drought at the regional scale, DYSD was obtained by EPIC outputs for about 259 elaborations.

This data has been applied with a multiple regression to the National Soil Database observations. The multiple regression derives the DYSD from long term mean air temperature, annual rainfall and available water capacity (difference between soil water at field capacity and wilting point; AWC; $R^2 = 0.55$; F<0.00001; n=260). It was applied to 13,000 soils AWC and to air temperature and rainfall of the soil sites, obtained through ordinary kriging of the long term annual values of 1067 (total rainfall) or 944 (mean temperature) meteorological stations. Soil information was generalized using land components of the land subsystems (1:250,000), linked to the National Soil Database. Land subsystems are geographical units with a characteristic pattern of lithologies, morphologies and land uses (Costantini et al., 2003). A land component is a part of a land system, not delineated in the GIS but stored in the database, formed by a combination of morphology, lithology and land use, with legends created on the basis of pedolandscape perception at the reference scale (Fig. 4).

Results and Discussion

The map of the aridity index is reported in figure 1. Semi arid and dry sub humid land (aridity index lower than 0.65) are limited to the major part of the Sicily and Puglia regions, and the southern part of the Sardinia island. The combinations of soil temperature and moisture regime which indicate a pedoclimatic drought risk are those were a “hyperthermic” or “thermic” soil temperature regime matches a “dry xeric” soil moisture regime. Among conditions of thermic temperature and dry xeric moisture regime, four classes were foreseen in function of the frequency of dry xeric years on the long-term period (figure 2). Sites with pedoclimatic drought risk were more widespread than areas with an aridity index lower than 0.65. In particular, most part of southern Italy and a large part of central Italy resulted potentially affected by soil drought risk. This was due to the large diffusion of thin, skeletal and eroded soils, which emphasised the climatic drought. The aridity index and pedoclimatic risk maps were then matched with the climatic regions of Italy (Finke et al., 1998; Righini et al., 2001) and the result was that areas with potential climatic and pedoclimatic drought risk coincided with Mediterranean climate regions (figure 3).

An example of the results obtained at the regional level is given for the Sardinia region (figure 4) where data of 792 profiles were queried to select soil characteristics used to qualify the state indicator DYSD. The threshold of 90 was proposed to highlight area that, following the criteria given by Soil Taxonomy (Soil Survey Staff, 1999) are more prone to drought risk. This layer, confronted with soil temperatures, gives a rather detailed picture of the lands where soils suffer from a prolonged lack of moisture and, at same time, have a high mean annual temperature.

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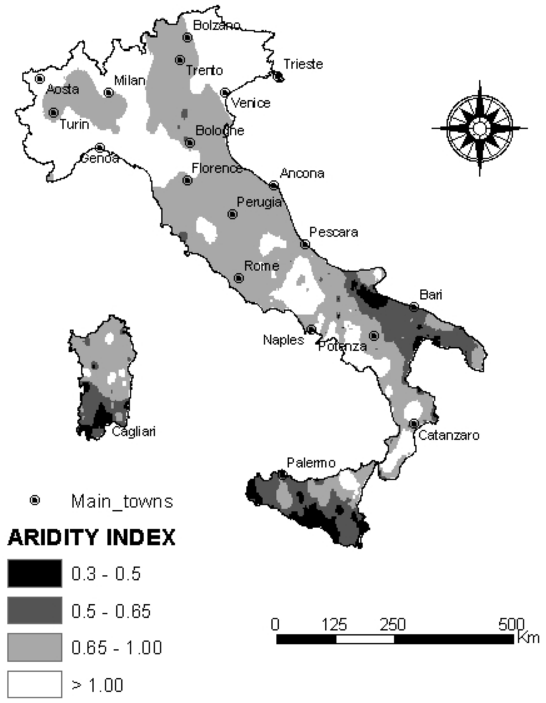

Figure 1. Aridity index.

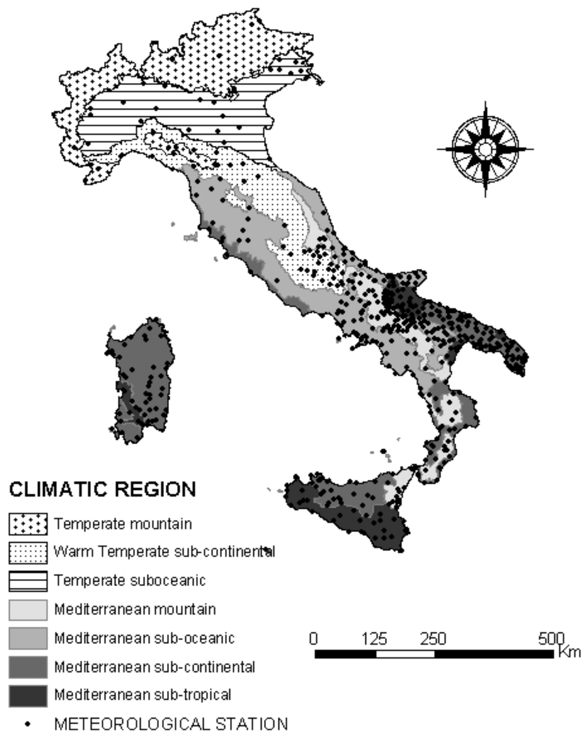

Figure 2. Climatic regions of Italy and meteorological stations.

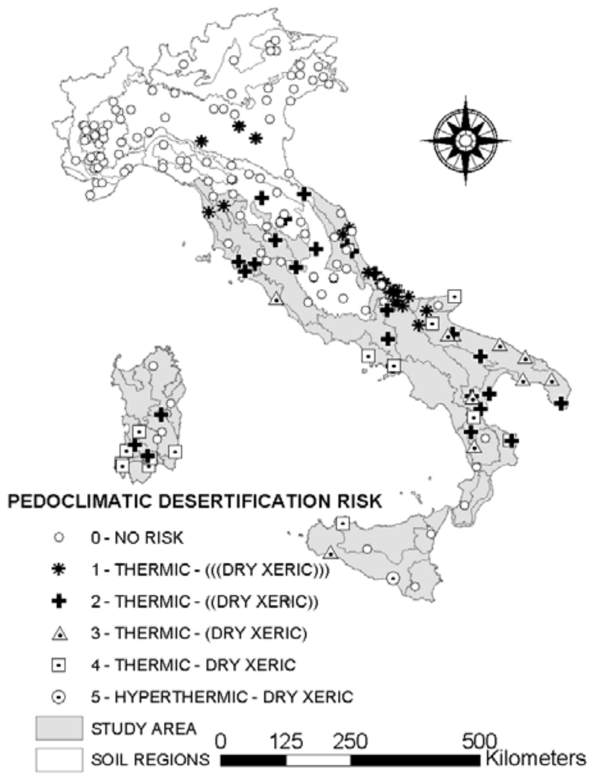

Figure 3. Areas potentially at risk of desertification (study area), soil regions and pedoclimatic desertification risk.

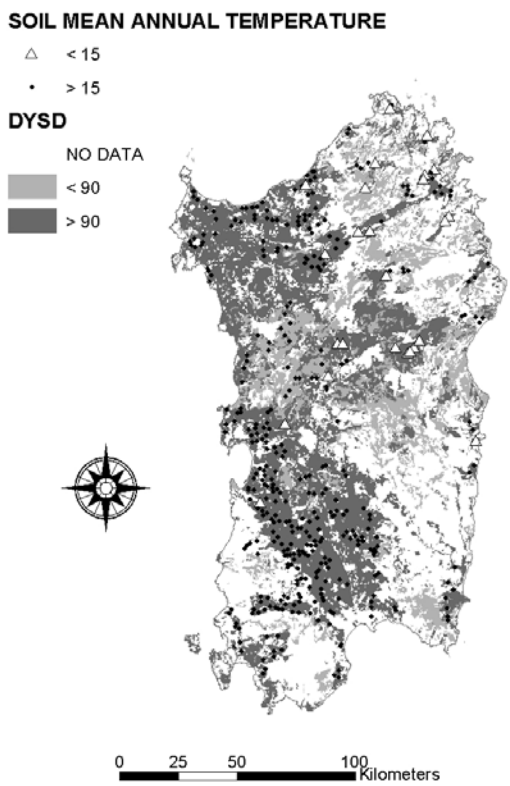

Figure 4. Lands vulnerable to drought. state indicator "mean annual number of days when the soil is dry" (DYSD) and soil mean annual temperature.