Ecological Indicators 48 (2015) 599–604

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Short communication

Assessing trends in climate aridity and vulnerability to soil degradation in Italy

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ARTICLE INFO

Article history:
Received 24 March 2014
Received in revised form 16 September 2014
Accepted 19 September 2014

Keywords:
Climate change
Agro-forest systems
Territorial disparities
Italy

ABSTRACT

The present study illustrates a framework to analyze changes in climate aridity and soil degradation on a country scale in Italy. The spatial distribution of an indicator of soil vulnerability to degradation (the SQI, soil quality index) was compared with an aridity index (the ratio of annual rainfall to annual reference evapotranspiration) estimated on a decadal basis during 1951–2010. The aridity index decreased by 0.38% per year indicating increased aridity and a non-uniform spatial distribution of soil vulnerability to degradation. Changes in the aridity index were found associated with the lowest SQI classes, suggesting that the largest increase in climate aridity affects land with high-quality soils. Territorial disparities in the aridity index between high-quality and low-quality soils decreased over time indicating a more homogeneous and dry climate regime prevailing in the more recent decades. Results may inform sustainable land management policies and National Action Plans to combat desertification in the Mediterranean region. Areas classified at increased aridity and high vulnerability to soil degradation should be identified as a key target for climate change mitigation policies. Sustainable land management strategies are required to address the dependency between climate variations, land-use changes and soil degradation processes.

1. Introduction

The mismanagement of drylands coupled with climate variations may lead to unsustainable socioeconomic development and desertification (Briassoulis, 2011). Climate change is a key driver of soil degradation especially in arid and semi-arid regions (Olesen and Bindi, 2002; Sivakumar, 2007; Verstraete et al., 2008). While soil is considered a key natural resource (European Commission, 2006), soil degradation accelerated on the global scale due to unsustainable human activities (European Environment Agency, 2009). Changes in the use of land have led to severe soil degradation processes including erosion, decline in organic matter, sealing, compaction and salinization (Montanarella, 2007).

Both research and policy are engaged in providing strategies to reduce the impact of climate change and soil deterioration on agro-forest ecosystems. Research contributed to define decision support systems enabling the assessment of long- and medium-term climate variations and their impact on soil (Fussel and Klein, 2006). However, up to now relatively few studies proposed diachronic approaches to analyze changes in selected climate and soil degradation variables over large areas on fine-grained spatial scales.

The Mediterranean region is a paradigmatic case for studying the implications of changes in climate, soils and agro-forest landscapes over time and space (Garcia Latorre et al., 2001; Moriondo et al., 2006; Rodriguez Diaz et al., 2007). Mediterranean climate includes a considerable rainfall uncertainty (Dünkeloh and Jacobeit, 2003) together with ample variations in thermometric regimes along defined gradients such as elevation or the urban-rural gradient (Brunetti et al., 2000). In southern Europe evidence for climate variations is characterized by temperature rise (e.g. Piervitali et al., 1997; Brunetti et al., 2004; Martínez et al., 2010), longer drought episodes especially during winter (e.g. Brunetti et al., 2002), high rainfall variability in time and space

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http://dx.doi.org/10.1016/j.ecolind.2014.09.031
1470-160X/

(Reiser and Kutiel, 2008) with a moderate decrease of total precipitation e.g. for winter (Martínez et al., 2004; Altava-Ortiz et al., 2011), spring (Brunetti et al., 2006a) or both (De Luis et al., 2010) – but with some controversial results at the local scale (e.g. Philandras et al., 2011) – as well as climate aridity (Costa and Soares, 2012) and extreme events (Brunetti et al., 2004) such as hot waves (Baldi et al., 2006; Founda and Giannakopoulos, 2009). These changes affect water budget inducing an increase of soil aridity with land productivity decline (Olesen and Bindi, 2002; Maracchi et al., 2005; Rodriguez Diaz et al., 2007; Mavromatis and Stathis, 2011).

The IPCC report (International Panel for Climate Change, 2013) shows that a shift towards sub-tropical climate has been recorded in the Mediterranean region during the last twenty years determining a rise in temperature especially in coastal areas, where increased vegetation stress caused by climate aridity was observed (Moriondo et al., 2006; Incerti et al., 2007; Salvati et al., 2008; Salvati and Mavrakis, 2014). Moreover, southern European coastal areas threatened by climate change are generally affected by high anthropogenic influence which lead to soil salinization, sealing, compaction and important landscape transformations (Garcia-Latorre et al., 2001; Salvati and Bajocco, 2011; Salvati et al., 2013).

Climate regimes in Italy were demonstrated to be largely variable in time and space (Piervitali et al., 1997; Brunetti et al., 2004; Salvati et al., 2008) due to different factors acting on a local and regional scale. A decrease by 5% per century in the annual precipitation amount was observed over 1865–2003 and is accompanied with a generalized increase in both minimum and maximum temperature (Brunetti et al., 2006). Central Italy is the region with the most evident negative trends in total precipitation, showing decreasing rates even larger in spring and summer (Brunetti et al., 2006). At the same time, northern Italian land experienced a relevant increase in climate aridity due to the concurrent action of warming and rainfall decline (Salvati and Bajocco, 2011).

Based on these premises, the present study investigates the relationship between indicators of soil vulnerability to degradation and climate aridity in Italy. According to a previous study (Salvati et al., 2013), changes in the aridity regime may impact sub-humid and dry land in a different manner. To verify this hypothesis, the spatial distribution of an indicator of soil vulnerability to degradation in Italy was analyzed together with an aridity index over six time windows between 1951 and 2010. Results may inform sustainable land management coping with a changing climate. The contribution to the practical implementation of an integrated policy strategy against climate change in Italy and, possibly, in other southern European countries, was finally discussed.

2. Methods

2.1. Study area and soil data

The analysis undertaken here is based on a climate analysis covering Italy (301,330 km^2) between 1951 and 2010 combined with the assessment of the level of soil vulnerability to degradation. Topography, latitudinal extension and proximity to the sea account for a great deal of variation in climate, soil and landscape types in Italy (Salvati and Bajocco, 2011). Soil vulnerability to degradation is considered a multidimensional concept representing the ability of a soil to sustain agricultural production and/or natural vegetation (Sposito and Zabel, 2003). Due to the national coverage of the present study, homogeneous data layers made available at a detailed resolution scale and derived from official data sources were considered as candidate indicators. The soil quality index (SQI) proposed by the European Environment Agency (2009) was adopted in this study and calculated using the information contained in the European Soil Database (Joint Research Centre, Ispra). The index was made available in a raster file covering the whole southern Europe and is disseminated at 1 km^2 resolution based on the spatial resolution of the composing variables (Salvati and Bajocco, 2011). Territorial coverage is complete (Perini et al., 2008) except for small, not evaluated surfaces areas (e.g. lakes, rivers, glaciers). The SQI is a composite index based on four variables (parent material, soil depth, texture and slope angle) derived from the European Soil Database that were combined to assess the level of vulnerability to soil degradation (Basso et al., 2000). A vulnerability score ranging from 1 to 2 (see Salvati et al., 2013) was assigned to every variable's value observed in each spatial unit with the aim to homogenize soil variables (European Environment Agency, 2009). The vulnerability score system was derived from statistical analyses and the fieldwork performed by previous authors (Basso et al., 2000; Perini et al., 2008; Salvati and Bajocco, 2011). The SQI was estimated for each spatial unit as the geometric mean of the scores attributed to each value of the four selected variables and ranges from 1 (the lowest soil vulnerability) to 2 (the highest soil vulnerability). Five vulnerability classes were identified in the SQI distribution observed in Italy (very low: $SQI < 1.4$; low: $1.4 < SQI < 1.5$; intermediate: $1.5 < SQI < 1.6$; medium-high: $1.6 < SQI < 1.7$; high: $SQI > 1.7$).

The layers considered in the analysis were regarded as the most reliable and referenced data currently available for use at the regional and national scale in Italy and, possibly, in the whole Mediterranean Europe (European Environment Agency, 2009). As a matter of fact, the national coverage of this study prevented us from using diachronic soil mapping whose availability is restricted to small areas and specific soil types in Italy. Although other physical, chemical or biological variables may provide important indications dealing with soil quality, they are generally mapped on a local scale or in larger areas but at a lower spatial resolution (Marzaioli et al., 2010) and for this reason they were excluded from the analysis. The coverage of the present study makes the results potentially more interesting than a pilot study confined to a limited test area. However, data material used in the study has obvious shortcomings. For example, soil depth can vary along prolonged time intervals and in places with site-specific characteristics possibly due to the effect of soil erosion (Salvati et al., 2013). Despite its acknowledged importance as a tool to detect soil quality, the SQI was hence regarded as static during the investigated time interval (Salvati and Bajocco, 2011). This may be acceptable when the purpose is to study a large area, since the cost of mapping is insurmountable for an individual research survey.

2.2. Climate data

We used an official dataset belonging to the Italian Ministry of Agriculture, Food and Forestry Policies (MiPAAF) and provided by the Agriculture Research Council, Research Unit of Climatology and Meteorology applied to Agriculture (CRA–CMA). The dataset refers to about 2000 weather stations and contains daily time series of precipitation, temperature, wind, air humidity and solar radiation that overall cover the period 1951–2010. The original data come from national weather networks belonging to the Italian governmental offices, like the Meteorological Service of Italian Air Force, the National Hydrological Service and the National Agro-meteorological service (technical details provided in Perini et al., 2008). Meteorological data were previously checked and validated in order to verify, according to WMO's operational criteria, the internal, temporal and spatial consistencies (Beltrano and Perini, 2004). The dataset is considered an adequate resource for scientific