A LAND-COVER BASED APPROACH TO THE STATISTICAL ANALYSIS OF PRECIPITATION FOR INTEGRATING CLIMATE IN THE ASSESSMENT OF LAND DEGRADATION VULNERABILITY

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ABSTRACT

The international community has definitively recognized the urgent need for a holistic understanding of land systems in the context of Global Change. Our approach to the integration of climate information in the assessment of sustainability and land degradation vulnerability is based on the analysis of climate data within the geographical constraints imposed by the land cover heterogeneity. This study uses the CHIRPS dataset (Climate Hazards Group InfraRed Precipitation with Station data) to evaluate potential rainfall impacts in Basilicata (Italy), a very complex Mediterranean area. Two indices, accounting for rainfall erosivity and, by contrast, for the local degree of dryness are integrated in a unique rainfall exposition layer. For each land cover, this information layer enables us to detect the areas most exposed to rainfall erosion risk or to water scarcity and drought. This layer can be profitably used within multivariate analyses for the estimation of land degradation vulnerability.

***Index Terms* — Rainfall, Land degradation, CHIRPS, erosivity, aridity.**

1. INTRODUCTION

The 2030 Agenda for Sustainable Development, signed in 2015 by all the 193 Members of the United Nations, has set out an ambitious paradigm of specific goals to address a multitude of global challenges. Specifically, Goal 15 concerns “Life on Land” and is directly committed to the promotion of a sustainable management of ecosystems [1]. The main challenge of the scientific research in this framework is to understand the diversity of the natural and anthropic factors that drive land dynamics and the multiple effects this dynamics feeds back, with potential global consequences and impacts on climate.

The development of successful strategies to combat land degradation is therefore a complex problem, which critically depends on the ability to identify early degradation signs and improve our understanding of causes, impact, degree and links with climate, soil, water, land cover and socio-economic factors. The complexity of land degradation implies that its features can differ from area to area and that there are not universal parameters and thresholds to define it. For this reason, there are plenty of different strategies for assessing land degradation worldwide [2].

The primary driver of land degradation is the inappropriate use of land but climate factors can be decisive to establish the sustainability of specific uses because local climate conditions could be detrimental regardless any other threating factor, especially in synergy with inappropriate management. In complex biogeographic regions, any evaluation has to consider local heterogeneity both in land cover and local climate. According to this premise, our approach to the integration of climate information for the assessment of land degradation vulnerability is based on the analysis of climate data within the geographical constraints imposed by the land cover heterogeneity (e.g., [3]). Major detrimental effects due to rainfalls are linked to aggressive rain events that can trigger soil erosion or, by contrast, to dryness and water scarcity. This study uses the CHIRPS dataset (Climate Hazards Group InfraRed Precipitation with Station data, [4]) to build up a rainfall exposition layer in the case study of Basilicata (Italy), a complex Mediterranean area where there are both zones at hydrogeological risk and areas at desertification risk [5]-[6]. We computed the Modified Fournier Index (MFI), which is an estimator of rainfall erosivity [7], to detect the zones in the region that are subjected to aggressive rainfalls. The MFI map was then integrated with the Aridity Index defined by De Martonne [8] to identify areas characterized by imbalance in the water availability consisting in low average annual precipitation.
These indices were used to construct a single rainfall exposition layer to evaluate the size of areas at risk per each agricultural cover in the region.

2. MATERIAL AND METHODS

2.1. Study area

Basilicata is a region (according to the NUTS2 - Nomenclature of Territorial Units for Statistics) of the Southern Italy (Fig. 1) characterized by a diffused rurality (less than 2% of artificial surfaces) with a strong presence of agricultural areas (57%) and natural covers (41%). Among the valuable agricultural districts, the Metapontum Plain on the Ionian Coast and the Vulture-Melfese in the north-western part of the region show overt signs of intensification in a semi-arid or Mediterranean climatic context, where the driest periods are contextual with the hottest periods of the year [9].

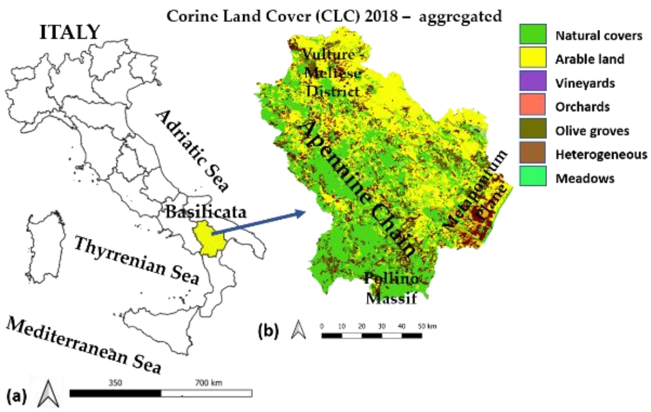

Fig. 1. Italy subdivided in 20 administrative units (regions); (b) Corine Land Cover map 2018 grouped in six classes and main toponyms of the study area.

Forests and other natural covers are mostly located along the Apennine Chain where the thermoregulatory effect of the sea is negligible, thus the western part of Basilicata experiences sub-continental climatic conditions while the area facing Thyrrenian Sea and the Pollino Massif can be considered humid with a considerable amount of annual rainfall [10]. Humid and sub-humid areas are mostly prone to erosional processes [11], semi-arid and Mediterranean zones suffer drought episodes [12].

Due to the biogeographical complexity of this region, it represents a good case study to elaborate successful strategies for the assessment of land degradation.

2.2. Data

CHIRPS is a 40-year (1981 to present) quasi-global (50◦ S–50◦ N) daily, pentadal, and monthly rainfall gridded dataset produced at 0.05 × 0.05 degree spatial resolution by incorporating satellite imagery with in situ station data [13].

Temperature data were provided by the meteorological network of ALSIA (Regional Agency for Development and Innovation in Agriculture). The selected dataset of monthly precipitation and temperature covers the period 2000-2020.

A 20m DEM (Digital Elevation Model) of Basilicata was provided by the Basin Authority of the Basilicata Region, while the land cover adopted is the 2018 CORINE Land Cover (CLC2018, [12]). For the purpose of this work, from the original CLC2018 - level 3 artificial and natural areas were excluded and were considered only five agricultural classes: Arable land, Vineyards, Orchards, Olive groves, Meadows and Heterogeneous agricultural areas.

2.3. Methods

In this study, trends and other indices useful to evaluate negative effects of rainfalls, such as the Modified Fournier Index (MFI) that is linked to rainfall erosivity, are estimated and the statistics of the estimates is provided per land cover class [13].

$$MFI = \frac{\sum_1^{12} p_i^2}{P_a} \qquad (1)$$

where p_i are the monthly and P_a the annual precipitation.

The MFI is usually classified according to different levels of erosivity risk (Tab. 1). In our rainfall layer, we considered the classes characterized by moderate, high, and very high risk of erosion.

Table 1. Classification of the MFI.

Erosivity risk	MFI Value
Very low	0 - 60
Low	60 - 90
Moderate	90 - 120
High	120 - 160
Very high	>160

In our rainfall information layer, we considered only the three worse classes (Moderate, High, and Very high). The Very high erosivity class included only few pixels that were merged in the High erosivity class,

The De Martonne Aridity Index (AI) [14] was estimated according to the equation:

$$AI = \frac{P_a}{Ta+10} \qquad (2)$$

where P_a is the annual rainfall (in mm) and Ta is the annual average of temperature (Celsius degrees) estimated by regression on elevation, which is the main factor determining spatial heterogeneity in the data provided by the ALSIA meteorological stations. The usual classification of the AI leads to the definition of different climates (Tab.2).

Table 2. Classification of the De Martonne Aridity Index (AI).

Climate type	AI
Semi – arid	AI< 20
Mediterranean	20 ≤AI<24
Dry sub-humid	24 ≤AI < 28
Humid	28 ≤AI <35
Very humid	35 ≤AI ≤ 55
Extremely humid	AI> 55

In our rainfall information layer, we considered only the first three climates (Semi-arid, Mediterranean, and Dry sub-humid) as humid areas are not subjected to aridity risk.

A final layer was then constructed integrating the two classified indices in an exposition layer that was used to separate each investigated land cover in areas differently affected by rainfall impacts.

3. RESULTS

The MFI estimated for all the Basilicata region is shown in Figure 2a. Critical areas (high MFI) are circumscribed to the zones located on the Tyrrhenian coast and on the neighboring of the mountain complex of the Pollino Massif. These areas are characterized by a high amount of annual precipitation, often asymmetrically distributed along the year. On the other hand, areas most devoted to agricultural uses (Metapontum Plain on the Ionian Coast and the Vulture-Melfese district in the north-western part of the study area) show low or very low MFI values indicating a reduced incidence of rainfall on the possibility of detachment of soil particles from the surface. In these areas the main source of climate vulnerability is due instead to water scarcity. The De Martonne index (Figure 2b) is particularly high in areas including agri-food activities of national importance, specialized primarily in fruit and vegetable production.

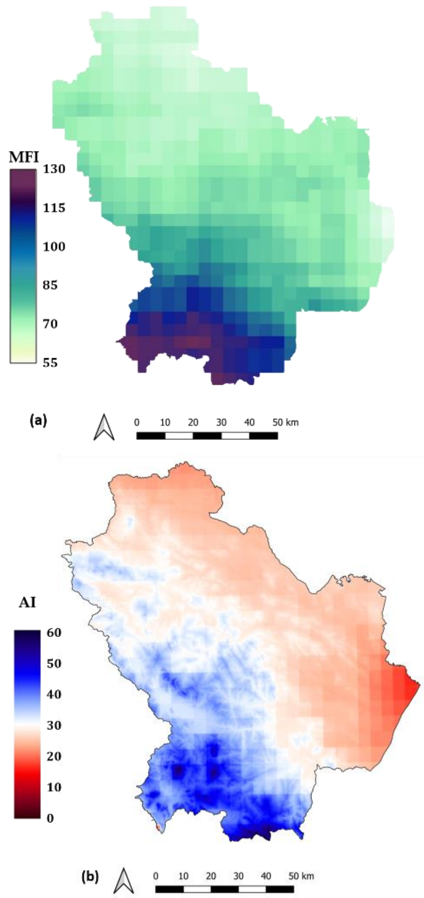

Fig. 2. MFI and De Martonne Aridity (AI) indexes computed for the study area.

The final Exposition Layer (Fig. 3) synthesizes very well this scenario. Most of the agricultural areas are not particularly exposed to rainfall erosivity and aridity seems to be the main vulnerability factor (Tab. 3). A large percentage of vineyards (54%) and orchards (70%) fall in Mediterranean and Dry sub-humid zones; about 29% of vineyards are even located in semi-arid zones. These covers can be considered the most vulnerable to global warming and to precipitation decrease. In particular, drought and heat waves can have very negative impacts in these zones, especially considering that the hottest summer period coincides with the driest period of the year.

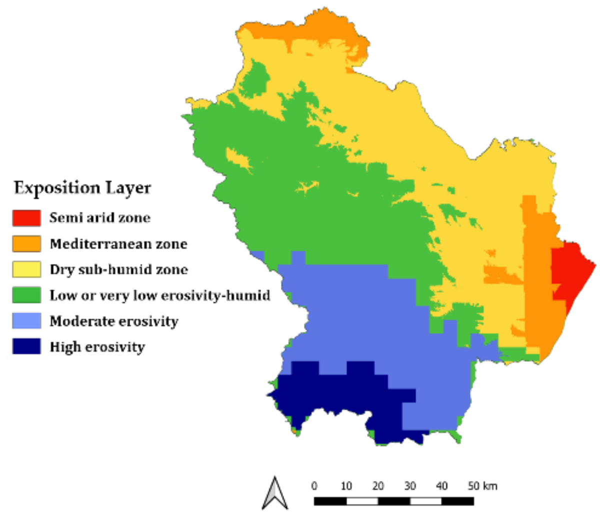

Fig. 3. Exposition layer based on the combination of the MFI and De Martonne Aridity indexes.

Table 3. Statistics of the exposition layer (rows) per land cover (columns).

%	artificial + natural areas	Arable land	Vineyard	Orchard	Olive grove	Meadow	Heterog. Agric.areas
semi-arid	0,5	2,7	29,3	18,6	0,4	0,9	2,1
Mediter.	3,6	10,6	14,9	32,1	15,3	0,1	12,6
dry sub-humid	16,5	51,5	39,0	38,5	52,4	27,6	24,6
low - humid	37,5	26,2	4,5	8,4	18,2	52,7	30,1
moderate	29,5	8,3	12,3	2,4	13,3	18,3	22,2
high erosivity	12,4	0,7	0,00	0,00	0,4	0,4	8,4
Tot	*100*	*100*	*100*	*100*	*100*	*100*	*100*

4. CONCLUSION

The proposed analysis gives selective information in terms of the potential rainfall impacts on the sustainability of specific land uses. The information layer integrating MFI and AI can be profitably used within multivariate analyses for the estimation of land degradation vulnerability.

In addition, the CHIRPS dataset offers the possibility of a direct integration of rainfall data and satellite-derived land cover data in land degradation assessments, thus limiting the arbitrariness of assessments based on spatial interpolations performed with different methods and data.

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