VULNERABILITY ASSESSMENT OF SOIL SALINIZATION BY IRRIGATION WITH SALINE WATER. APPLICATION IN THE COASTAL AREA OF RHODOPE, NE GREECE

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1. INTRODUCTION

The water scarcity, mainly caused by droughts and overexploitation of the available groundwater recourses used for irrigation and domestic use has led to a significant decline of water table in many coastal aquifers of the Mediterranean basin. This phenomenon is anticipated to be further impacted by the foreseen climate change in the forthcoming years (Stigter et al., 2014; Martín-Arias et al., 2020). As a result of the water scarcity in coastal areas, the salinization of groundwater reserves due to seawater intrusion and/or other potential factors (e.g. trapped saline lenses, evaporitic formations etc) will eventually affect the soil resources of the irrigated agricultural land due to salt accumulation by irrigation. The use of brackish/saline water for irrigation creates consequent threats for agricultural soils due to the increase of their salinity-sodicity, which could eventually be a step towards a consequent desertification of Mediterranean agricultural lands (Okur & Örçen, 2020).

In the context of MEDSAL Project (www.medsal.net), which aims to provide holistic approaches for securing the availability and quality of groundwater reserves in the Mediterranean coastal areas, the additional component of soil quality is also highly regarded, since the afore described pressures and the imminent climate change has already led in some cases and will eventually lead to further use of brackish/saline water resources for irrigation. To efficiently cope with the adverse effects of this phenomenon, a suite of methodological steps and actions should be carefully developed structuring proactive management approaches, which could prevent and/or minimize the impact of soil salinity. The first step of such approaches, which is the subject of this work, is to propose **a method for evaluating the intrinsic ability of agricultural land to leach salts via water percolation below the root zone with the aid of precipitation. This approach is based on the assumption that the less water is percolated below the root zone due to precipitation, the less salt is leached below the root zone and therefore the more vulnerable is the soil to salt accumulation due to irrigation with brackish/saline waters.** The specific approach is based on the existing formula LOSW-P (Aschonitis et al., 2012), which was developed to assess the intrinsic vulnerability of agricultural land to water losses by percolation below the root-zone of 30 cm of a theoretical reference crop (Penman-Monteith concept) considering soil physical properties, topography and mean long-term climate conditions.

2. MATERIALS & METHODS

The proposed LOSW-P methodology considers a uniform surface of actively dense cover with clipped perennial grass, whose rates of evapotranspiration under non-water stress conditions are equivalent to the reference crop evapotranspiration of American Society of Civil Engineers (ASCE)-standardized/Food Agriculture Organization of the United Nations (FAO)-56 concept (Allen et al., 2005). The use of grass as a reference surface is used to remove the effect of different land uses. The LOSW-P index was calibrated based on the inputs and outputs of simulation scenarios performed by the Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) model (Knisel and Davis, 2000). The LOSW-P index describes the annual water losses by percolation below the 30 cm according to the Equations 1,2 (Aschonitis et al., 2012; 2013):

$$LOSW\text{-}P = \left\{\begin{matrix} \mathbf{0.0941}\sqrt{K_s} - \mathbf{0.761}\sqrt{SL} + \mathbf{0.4185}\sqrt{P} \\ - \mathbf{0.0487}\sqrt{ET_o} + \mathbf{0.0903}\sqrt{IR} \end{matrix}\right\}^2 \quad (1)$$

$$IR = \sum_{1}^{12} IR_i \text{, where } IR_i = ET_{o,i} - P_i \text{ when } ET_{o,i} > P_i \text{ else } IR_i = 0 \quad (2)$$

where LOSW-P is the annual water losses by percolation under the 30 cm of a reference grass (mm year^{-1}), K_s is saturated hydraulic conductivity (mm day^{-1}), SL is soil surface slope (%), P is annual precipitation (mm year^{-1}), ET_o is the annual reference evapotranspiration (mm year^{-1}), IR is the annual irrigation to cover the deficit of reference evapotranspiration (mm year^{-1}), IR_i is the monthly irrigation for covering the deficit of reference evapotranspiration of the month i (mm month^{-1}), $ET_{o,i}$ is the monthly reference evapotranspiration (mm month^{-1}) (estimated in this study by FAO-56 method), P_i is the monthly precipitation and i is the month. It has to be noted that when the formula inside the brackets of Eq.1 leads to negative values, the value of LOSW-P is set equal to 0. The above equation can be used either for IR = 0 or IR ≠ 0. The use of larger IR values from the values of Eq.2 for over-irrigation analysis using Eq.1 is not indicated. In this study Eq.1 was applied for IR=0 in order to assess the amount of precipitation water (clean water) that percolates below the root zone and is responsible for salt leaching.

The application of LOSW-P formula was performed for the Rhodope pilot area of MEDSAL project, as well as all for the total of irrigated lands in Greece for performing comparisons at national scale based on the following databases:

- The database of Hijmans et al. (2005) provides gridded data of mean monthly precipitation P and mean monthly temperature T for the period 1950–2000 (WorldClim version 1.2) at 30 arc-sec (~1×1 km) spatial resolution. Their mean annual values are given in Fig.1a,b, respectively.
- The database of Aschonitis et al. (2017) (10.1594/PANGAEA.868808) provides gridded data of mean monthly reference evapotranspiration ET_o of the period 1950–2000 at 30 arc-sec (~1×1 km) spatial resolution (Fig.1c) (this database is built using temperatures from the WorldClim version 1.2 database). Using the ETo and precipitation, the irrigation map of the reference crop IR is built according to Eq.2 (Fig.1d).
- The surface slope (Fig.1e) was obtained by the digital elevation model of GTOPO30 (pixel analysis of 30 arc-sec, ~1×1 km) as it is given by the USGS (United States Geological Sur-vey).
- The European Soil Database provided by the European Commission Joint Research Centre (Hiederer et al., 2013) provides soil data (% sand, % silt, % clay, % gravel, % organic car-bon) with spatial analysis (~1×1 km). These data are used to estimate the saturated hydraulic conductivity Ks according to the respective pedotransfer function (PTF) of Saxton and Rawls (2006), taking into account the gravel and organic matter effect (Fig.1f).
- The Corine Land Cover 2018 (https://land.copernicus.eu/pan-european/corine-land-cover/clc2018) was used to derive irrigated lands.

3. RESULTS & DISCUSSION

The LOSW-P ranged between 21-241 mm·year^{-1} (mean annual water losses by percolation only by precipitation) with an average value of 82 mm·year^{-1} at country level, based on all irrigated lands of Greece. The respective values of LOSW-P for the coastal region of Rhodope ranged between 31-91 mm·year^{-1} with an average value of 81 mm·year^{-1}, which approximates the average value of LOSW-P at a country level. The respective irrigation requirements for covering the reference crop evapotranspiration after removing precipitation ranged between 320-1122 mm·year^{-1} at country level and 645-676 mm·year^{-1} for Rhodope region (Fig.2).

The results of the study showed that ~80% of irrigated lands of Greece (including Rhodope) present LOSW-P values <100 mm·year^{-1} (Fig.2), which are relatively low considering that these regions require irrigation rates >600 mm·year^{-1} (Fig.1d). This indicates that the use of high salinity waters at amounts larger than 500 mm·year^{-1} would increase the soil salinity due to the inadequate salt leaching by precipitation water. The problem of inadequate salt leaching is expected to be more intense in soils with higher percentages of clay and lower values of saturated hydraulic conductivity. For these regions, the LOSW-P maps should also be combined with current soil salinity maps and water salinity monitoring of available water sources for irrigation (groundwater and reclaimed wastewater) in order to build integrated water resources management for combatting soil desertification by the salt accumulation by irrigation.

4. CONCLUSIONS

In this study, the LOSW-P methodology was proposed in the context of MEDSAL project for evaluating the intrinsic ability of agricultural land to leach salts via water percolation below the root zone with the aid of precipitation. At least for the case of Greece, the proposed methodology indicated that the use of water with relatively higher salinity may not be a solution to most irrigated lands (including Rhodope coastal area) due to the low LOSW-P values and further solutions shall be evaluated.

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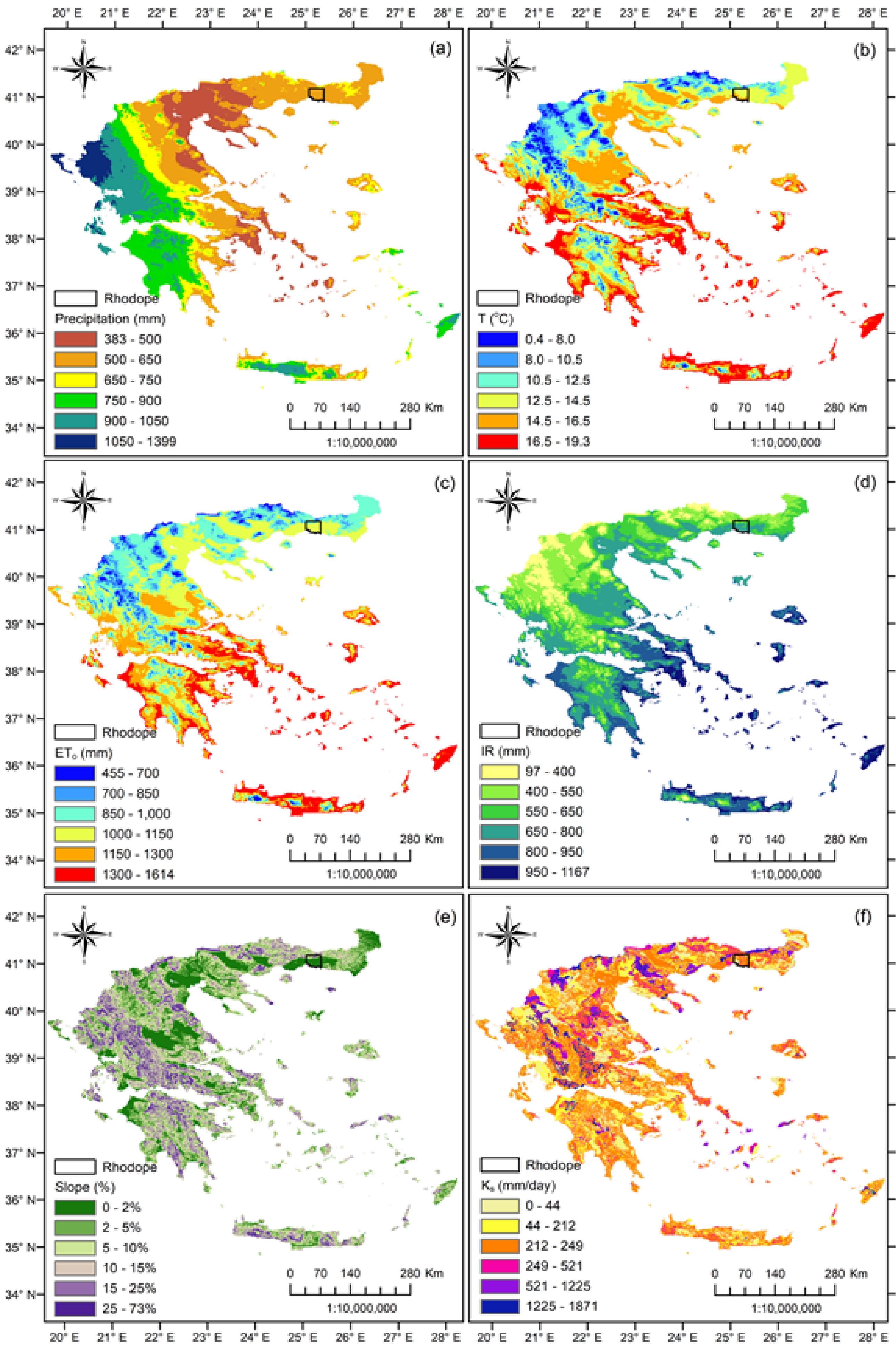

Figure 1. Mean annual values of (a) precipitation, (b) temperature, (c) reference evapotranspiration according to ASCE-standardized for short reference crops, (d) irrigation required for covering the deficit of annual reference evapotranspiration for the period 1950–2000, (e) surface slope and (f) saturated hydraulic conductivity in Greece.

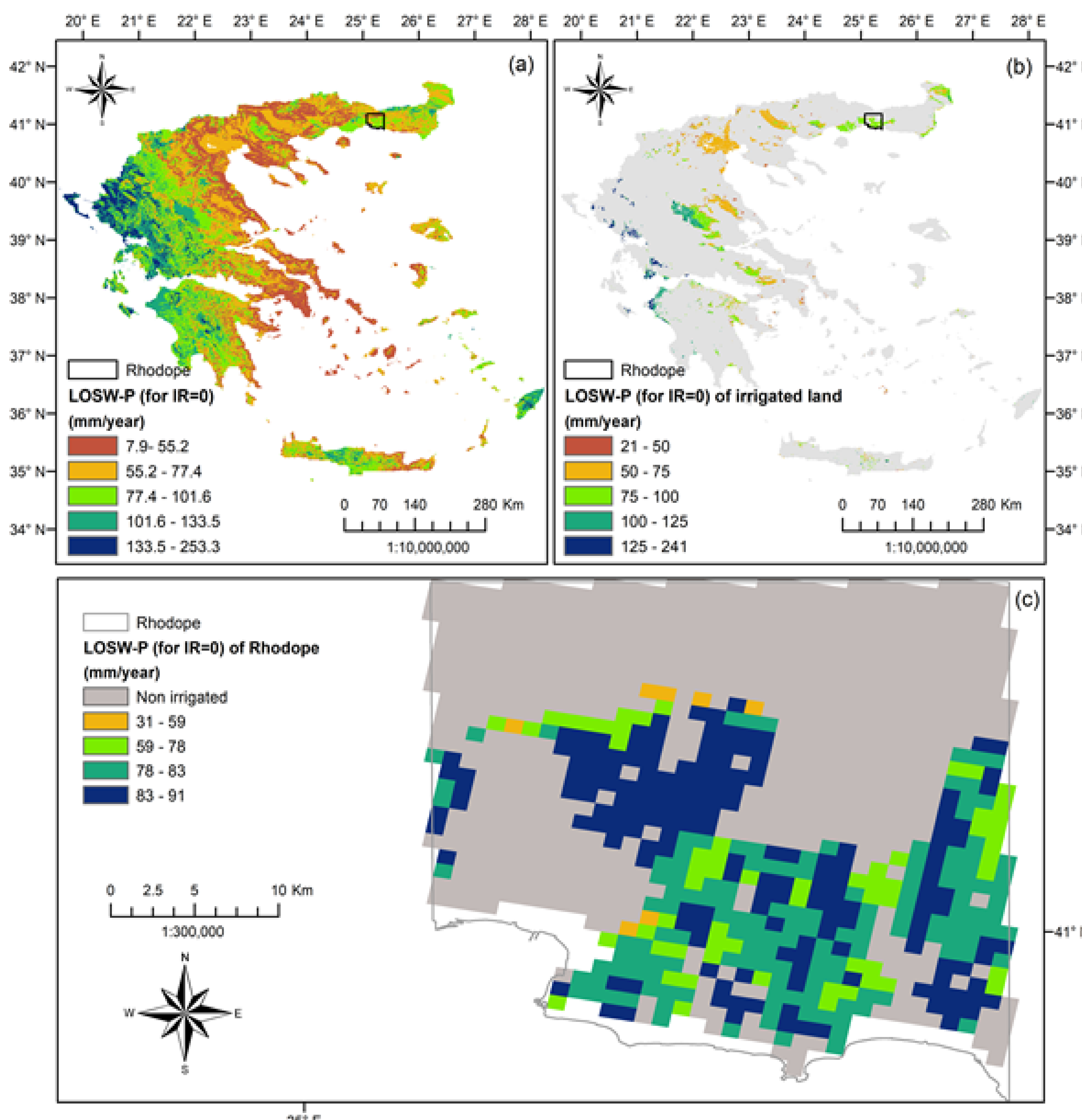

Figure 2. Mean annual values of (a) LOSW-P (for IR=0) for the whole Greece, (b) LOSW-P (for IR=0) for all the irrigated lands of Greece, (c) LOSW-P (for IR=0) for all the irrigated lands of Rhodope.