

Joint report

Drought vulnerability estimates based on climatological and geomorphological data

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Final

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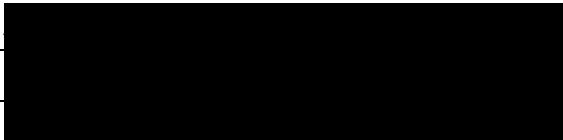
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1. INTRODUCTION

1.1. DROUGHT VULNERABILITY

The knowledge of drought vulnerability is a necessary condition in the optimisation of protection against drought. If the drought vulnerability of a given territory is known, action plan can be developed to mitigate the damages (even to prevent the damages in an ideal case).

Determination of drought vulnerability and the adopted decisions accordingly can result cost reductions in the agriculture, a sector with important financial problems, in the land management and many other sectors in connection with sustainable development.

Developed approach of Wilhelmi and Wilhite (2002) was used for determination of vulnerability. The drought vulnerability maps were calculated from category maps which are made of different selected parameters.

1.2. OUTPUT STANDARD

OMSZ made an output standard for the partners to standardize the methods to prepare vulnerability maps for the SEE region.

In this output standard the following topics were detailed:

- what parameters have to or may be used for vulnerability calculations
- method of classification
- preparing the final vulnerability map from the category maps

In the following parts of the report the results of partners can be read.

2. CROATIA

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2.1. INTRODUCTION

Following the recommended procedure within WP4 in the project "Drought Management Centre for South East Europe" (DMCSEE-OMSZ, 2011), the map of vulnerability to drought for Croatia is prepared using the maps of necessary parameters: slope, irradiation, and precipitation as well as available optional parameters: soil type and land use, as inputs.

Compared with the OMSZ proposal some modifications are introduced that are going to be described in the document. The input maps are presented and discussed at first, followed by the three versions of the vulnerability map, the first one dependent on climatological inputs only, the second one modified by soil type and the final one based on the necessary and the two optional parameters of soil type and land use class.

2.2. SLOPE

The slope map presents the slope angle based on the digital elevation model (DEM). The SRTM DEM of 100 m resolution is used. Calculated angles range from 0° on the flat terrain to 74° in some river canyons and on the mountain slopes (Fig.1), but mostly the slope belongs to the lowest category classes of 0.2 and 0.4 (Tab. 2).

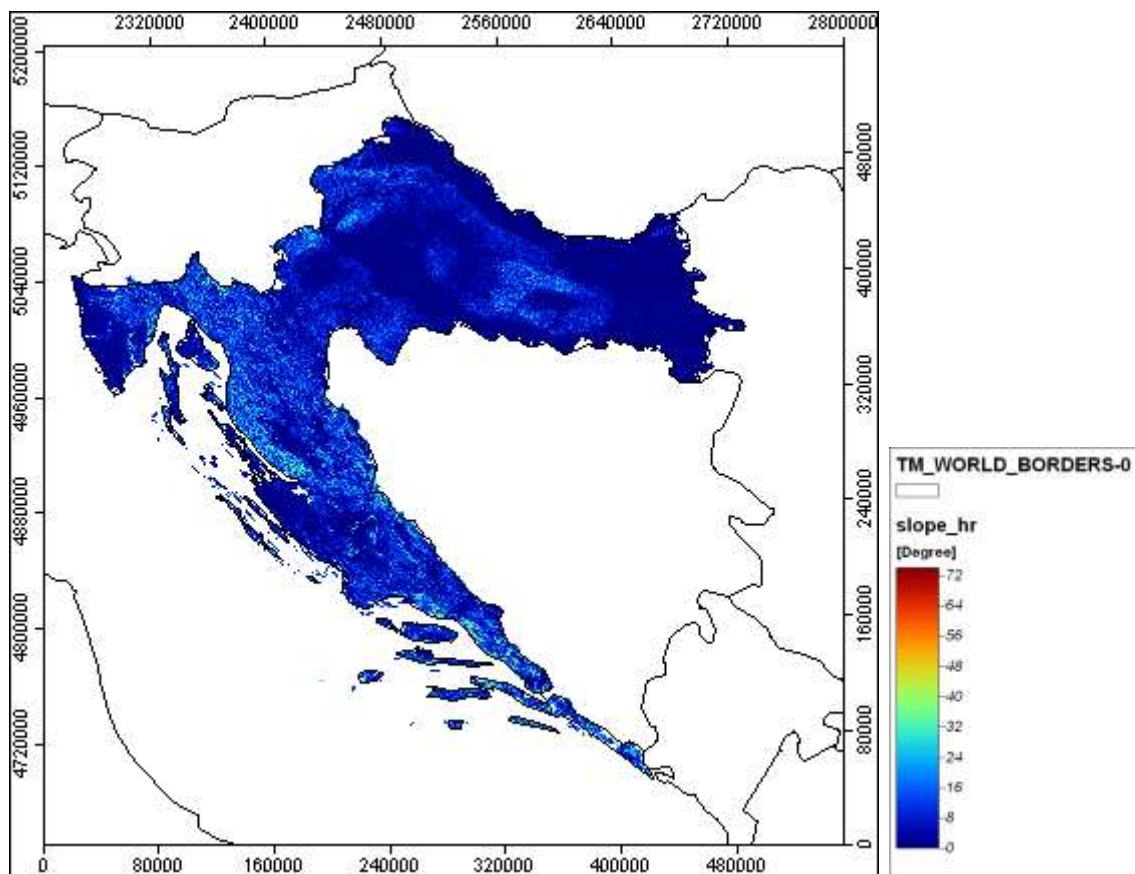


Fig. 1: The slope map of Croatia.

2.3. SOLAR IRRADIATION

The potential solar irradiation map (PISR) for the vegetation period calculated with RSAGA rsaga.pisr module (Brenning, 2011) is presented for Croatia in Fig. 2. This algorithm is implementation of the Saga GIS module Potential Incoming Solar Radiation (Conrad, 2010) for R statistical computing and visualisation framework (www.r-project.org). PISR was calculated for one year with four hours temporal resolution and clear sky conditions.

It can be seen that maximum values are predicted for the southern slopes while minima are on the northern slopes. Furthermore, the range of values is greater (126.7–1552.6 kWh/m²) compared to the irradiation map from the observations (Fig. 3) since there is a number of pixels with very low irradiation values (<500 kWh/m²). With the proposed classification procedure, with five equidistant classes, the resulting category map is dominated with the higher vulnerability classes. The map was filtered to reduce this problem but suggestion is that this irradiation vulnerability classes should be connected with some vegetation related thresholds.

The proposed methodology from OMSZ to use the potential solar radiation, calculated by the SAGA GIS module and for the vegetation period, as an input parameter in determining vulnerability to drought in Croatia, gave the results that were inconsistent with the physical characteristics of Croatian climate which could cause drought.

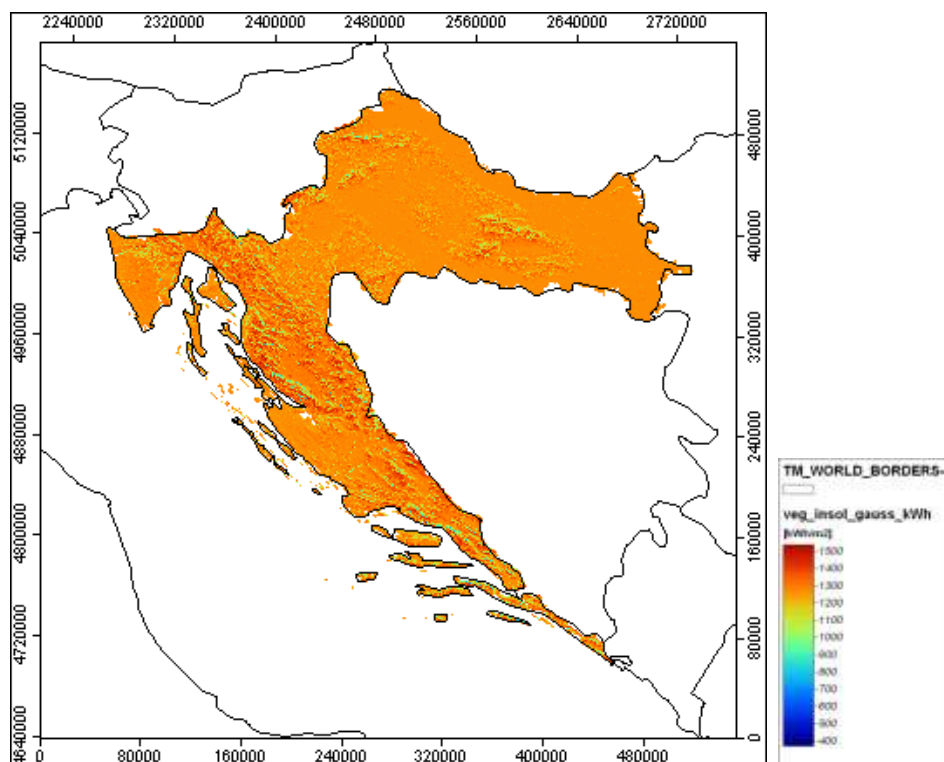


Fig. 2: Map of potential solar irradiation for the vegetation period for Croatia.

Namely, the irradiation on the territory of Croatia depends significantly on the cloudiness regime and relief. It ranges from 1164.9 to 1635.3 kWh/m² (Fig. 3) as estimated from the Croatian solar irradiation map for the available 1961–1980 period (Perčec Tadić 2004, Zaninović et al. 2008). The irradiation rises from the north to the south and it is larger on the coast than inland. Also, the values are lower on the mountain tops due to the increased cloudiness in summer. This is opposite to the distribution of potential irradiation which shows maximum values on the mountain summits (Fig. 2). It could not be expected that the vulnerability to drought in the vegetation period, due to solar radiation, would be the highest on the mountain tops.

For these reasons the irradiation map, calculated from the measured data in the 1961-1980 period, was used as input parameter that influence vulnerability to drought. Most of the territory belongs to the lowest category classes of 0.2 and 0.4 (Tab. 2).

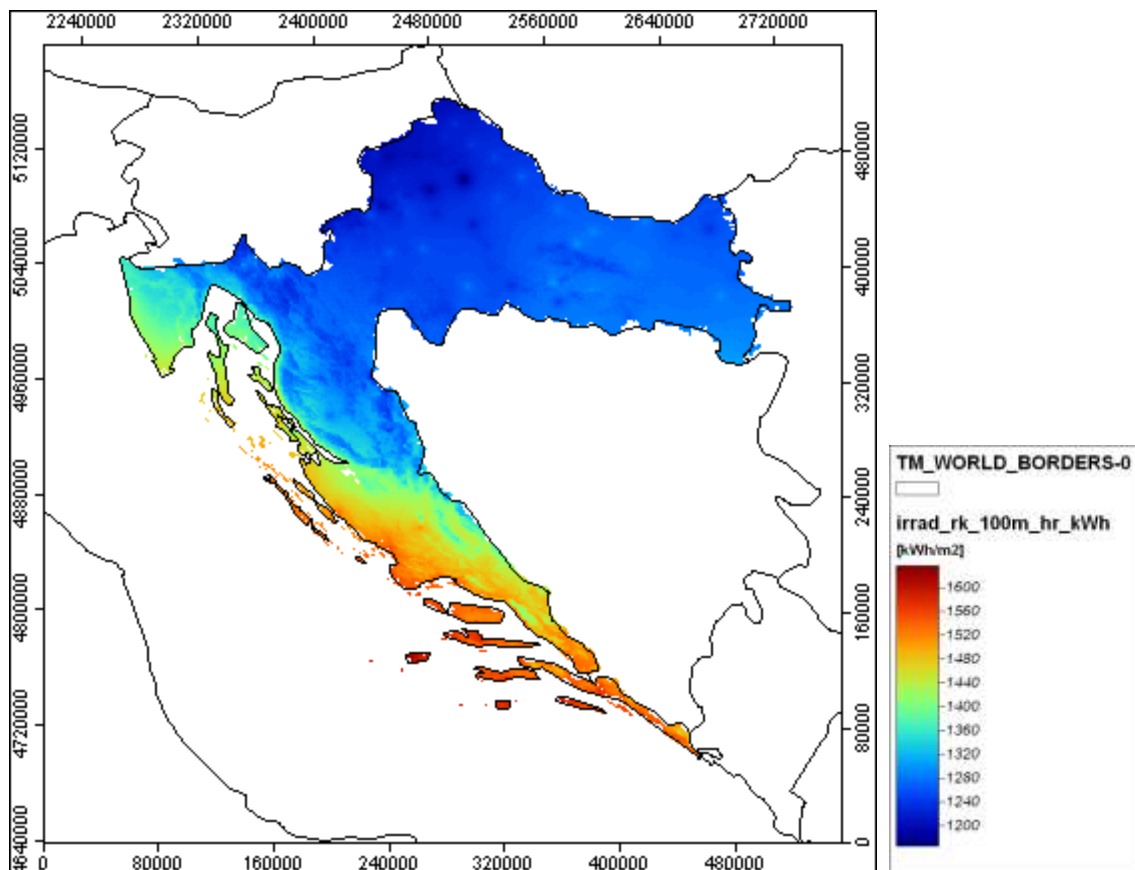


Fig. 3: Solar irradiation map of Croatia based on the measured irradiation data in the 1961-1980 period.

2.4. PRECIPITATION

2.4.1. Mean annual precipitation for the 1971–2000 period

Average annual precipitation in Croatia for the period 1971–2000 ranges from about 3900 mm on the summits of the southern Velebit Mountain located along the northern Croatian Adriatic coast to about 300 mm on the outlying islands in the middle Adriatic. The quite dry areas are also the eastern lowland (Slavonia), the middle and southern Adriatic islands and the coastal flat zone of the western Istrian peninsula and middle Adriatic coast. The mountainous hinterland of the Kvarner bay in the northern Adriatic (Gorski kotar) and of the southern Dalmatia as well as the southern Velebit Mountain, are the areas with the highest precipitation amounts in the country.

This map was created by applying the regression kriging framework, as described in Perčec Tadić (2010). Average annual precipitation data from the period 1971–2000 collected on 562 meteorological stations have been used in the geostatistical analysis. The correlation with the climatic factors such as altitude, weighted distance to the sea, latitude and longitude has been established and the residuals (differences of observation and regression prediction) were modelled for the spatial correlation. Final prediction of the average annual precipitation was calculated as a raster map in 1 km resolution. This map was resampled to 100 m resolution for the estimation of the drought vulnerability map.

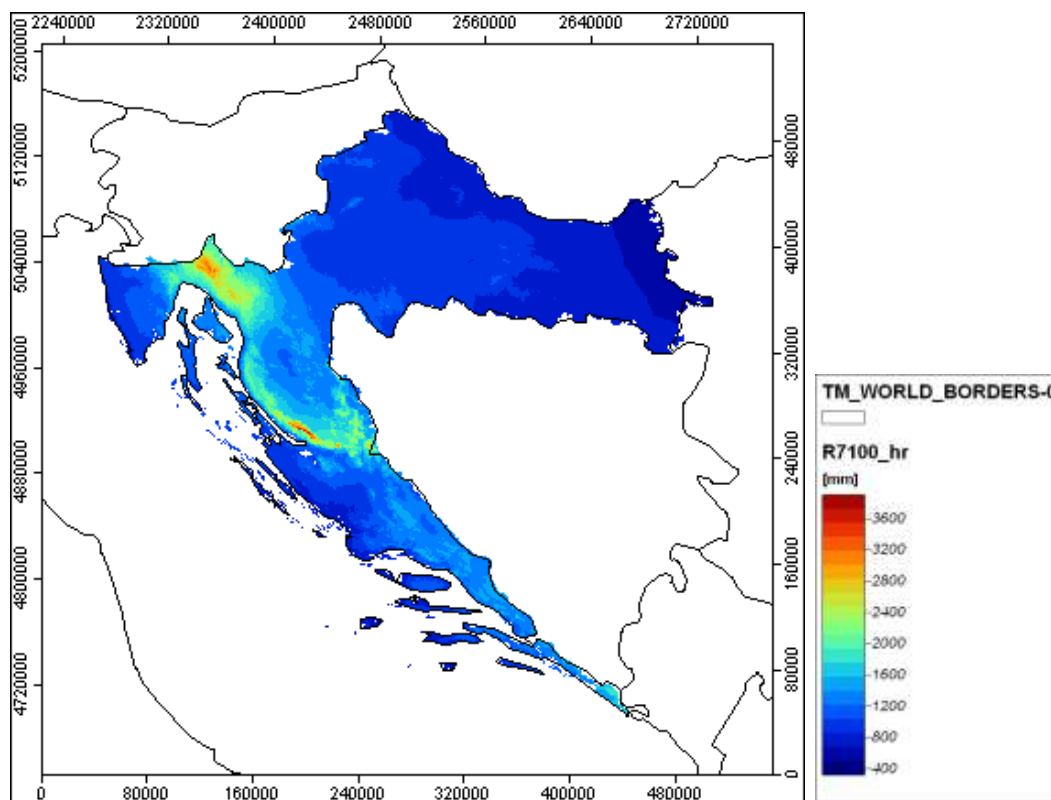


Fig. 4: Average annual precipitation for the 1971–2000 period.

2.4.2. Standard deviation of precipitation for the 1971–2000 period

Standard deviation of precipitation was calculated with the same method as precipitation (and solar irradiation), that is regression kriging. Values of standard deviation range from 99 mm to 455 mm. The lowest values are on the western continental part of the country, on the lowland of the eastern continental region and on some coastal areas (western Istria peninsula in the northern Adriatic and the plain Ravni kotari beyond the middle Adriatic coast). Precipitation is the most variable on the mountain areas.

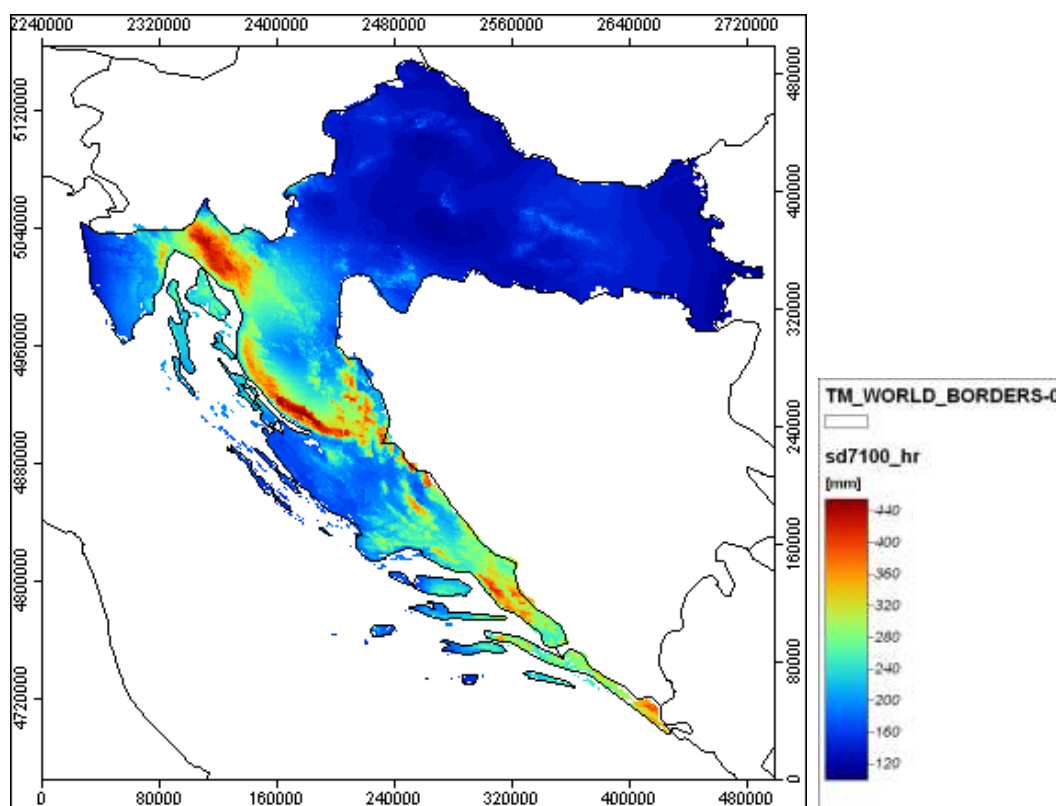


Fig. 5: Standard deviation of the annual precipitation for the 1971–2000 period

2.4.3. Ratio of precipitation and standard deviation

The last version of output standards for drought vulnerability (DMCSE-OMSZ, 2011) proposed the ratio of precipitation and standard deviation as the parameter that was intending to represent the extremity of precipitation. The map of this parameter (Rsd) for Croatia is presented in Fig. 6. According to this map, the lowest values of this parameter, that correspond to the least vulnerable areas to drought, would be in the areas with the lowest annual precipitation. This is hard to accept. Firstly, it was the discussion about modifying the proposed precipitation parameter by reversing the definition of vulnerability classes. Finally, the coefficient of variation (c_v) (the inverse of the suggested Rsd parameter)

was used to define the extremity in precipitation amounts while the vulnerability classes were left as proposed.

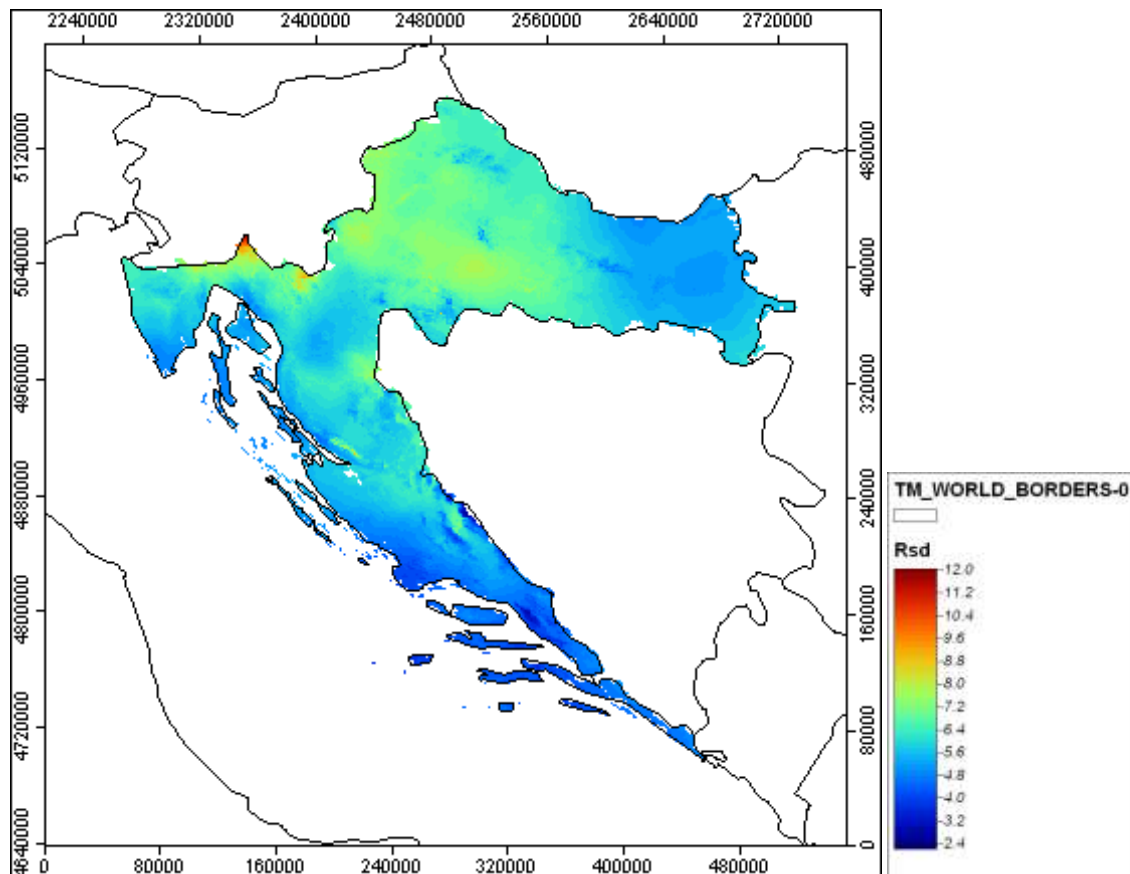


Fig. 6: Ratio of precipitation and standard deviation for the 1971–2000 period.

2.4.4. Coefficient of variation

Coefficient of variation, c_v , is defined as the ratio of standard deviation and precipitation. Higher values of c_v are connected with the higher vulnerability to drought (Fig. 7). For Croatia, the most sensitive areas are on the southern coast. Coefficient of variation ranges from 8% to 48% of the average annual precipitation amount. With the proposed classification procedure with five equidistant classes the resulting category map is dominated with the lowest category classes of 0.2 and 0.4 (Tab.2).

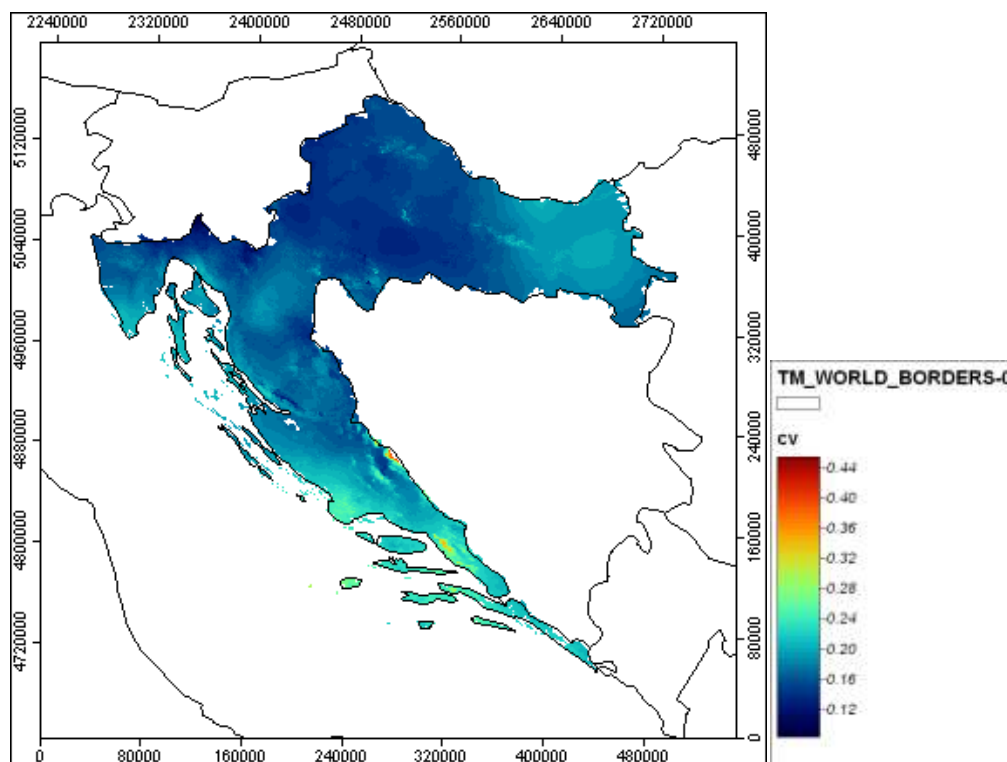


Fig. 7: Coefficient of variation of precipitation for the 1971–2000 period.

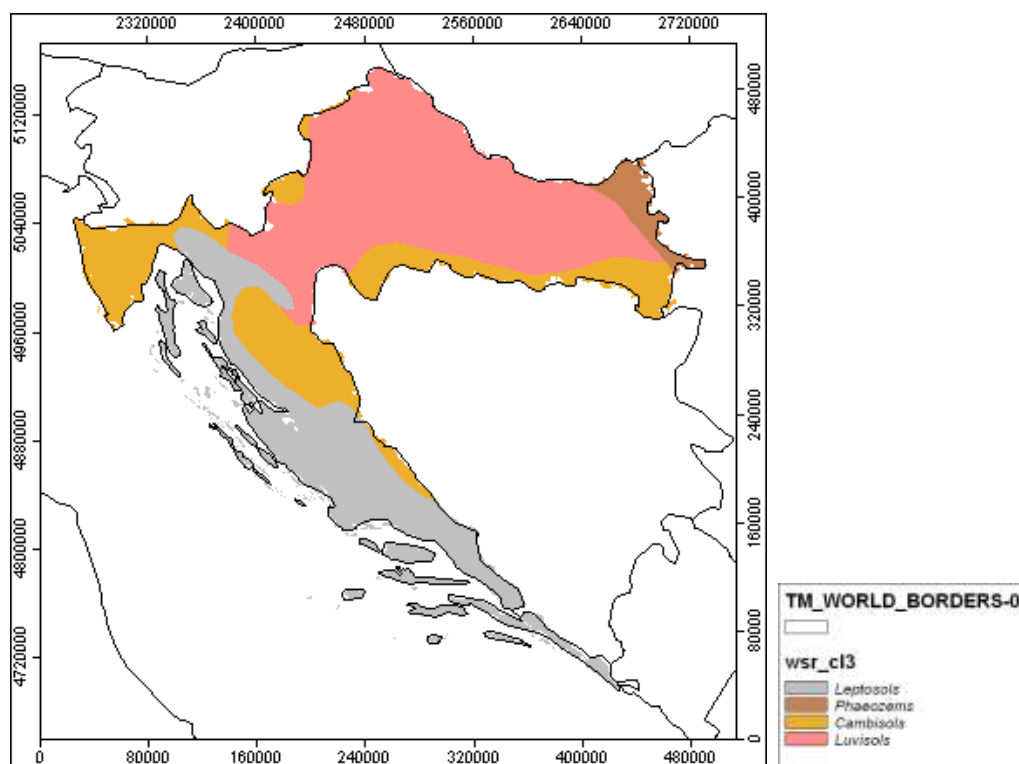


Fig. 8: Soil classes (adapted from the Map of World Soil Resources (WSRC))

2.5. SOIL CLASS MAP

The Map of World Soil Resources (WRB) is available from the FAO web page at the scale 1:25.000.000 as a World Soil Resources Coverage (WSRC). It was completed in 1990 from the FAO/UNESCO Soil Map of the World at the scale 1:5.000.000 (FAO, 1971-1981) and from some additional information (WRB). There are 32 soil classes for the world and four of them can be found in Croatia. Luvisols dominate in the continental part of the country, with some Cambisols and Phaeozems. Cambisols dominate in Istria peninsula and the mountainous Lika region, while the rest of the coastal area is covered with Leptosol soils (Fig. 8). Widespread are the Luvisols (category 0.4), then Leptosols (category 1.0) and Cambisols (category 0.6) while the rarest are Phaeozems (category 0.8) (Tab. 2).

Luvisols (LV) are most common in flat or gently sloping land in cool temperate regions (Central Europe) and in warm regions (e.g. Mediterranean) with distinct dry and wet seasons. Most Luvisols are fertile soils and suitable for a wide range of agricultural uses. They are characterized with a clay-rich subsoil (IUSS Working Group WRB, 2006).

Cambisols (CM) generally make good agricultural land and they are used intensively. Cambisols with high base saturation in the temperate zone are among the most productive soils on earth. Because of the generalisations made on the WSRC, it can be suspected that in the northern part of the mountainous district of Gorski kotar, the WSRC Cambisols are misclassified as Leptosols (Bakšić et al, 2008) while on Medvednica mountain in NW Croatia, beside Luvisols, the Cambisols are also present (Pernar et al, 2009).

Phaeozems (PH) are more common in America and Asia. In Europe, mostly discontinuous areas are found in Central Europe, notably the Danube area of Hungary and adjacent countries. Wind and water erosion are serious hazards. There can be periods in which the soil dries out (IUSS Working Group WRB, 2006).

Leptosols, LP are the world's most extensive soils (IUSS Working Group WRB, 2006). They are very shallow soils over continuous rock and soils that are extremely gravelly and/or stony (IUSS Working Group WRB, 2006).

2.6. LAND USE MAP

Land use classes for the part of the Croatian territory covered with vegetation have been analysed from the Corine Land Cover raster data (CLC 2006). There are 50864.3 km² (90%) of the Croatian territory that is covered with some kind of vegetation.

The largest part of the Croatian land (56.4%) is mostly covered with forest and transitional woodland-shrub or occupied by agriculture that has significant areas of natural vegetation belonging to the lowest category class of 0.2. These types of vegetation are not so vulnerable to drought. Vineyards occupy 0.5% of the area and they are slightly more sensitive to drought. Complex cultivation patterns, natural grasslands and sclerophyllous

vegetation are the second most spread land cover types that occupy 26.2% of the territory. They belong to the 0.6 vulnerability class. Fruit trees and berry plantations are quite sensitive to drought but grow on only 0.2% of the land. Most sensitive to drought is arable land (6.7%) and unfortunately in Croatia it is mostly non-irrigated (6.5%) according to the CLC 2006 data (Tab. 1).

When available, the CLC 2006 data were compared with the national sources. According to the CBS (2011), forests occupy 39.5% of the territory. According to the National Agricultural census Report (CBS 2003), Croatia has 0.5% of vineyards, 0.6% of orchards, 14.2% arable land and gardens and only 0.2% of irrigated arable land.

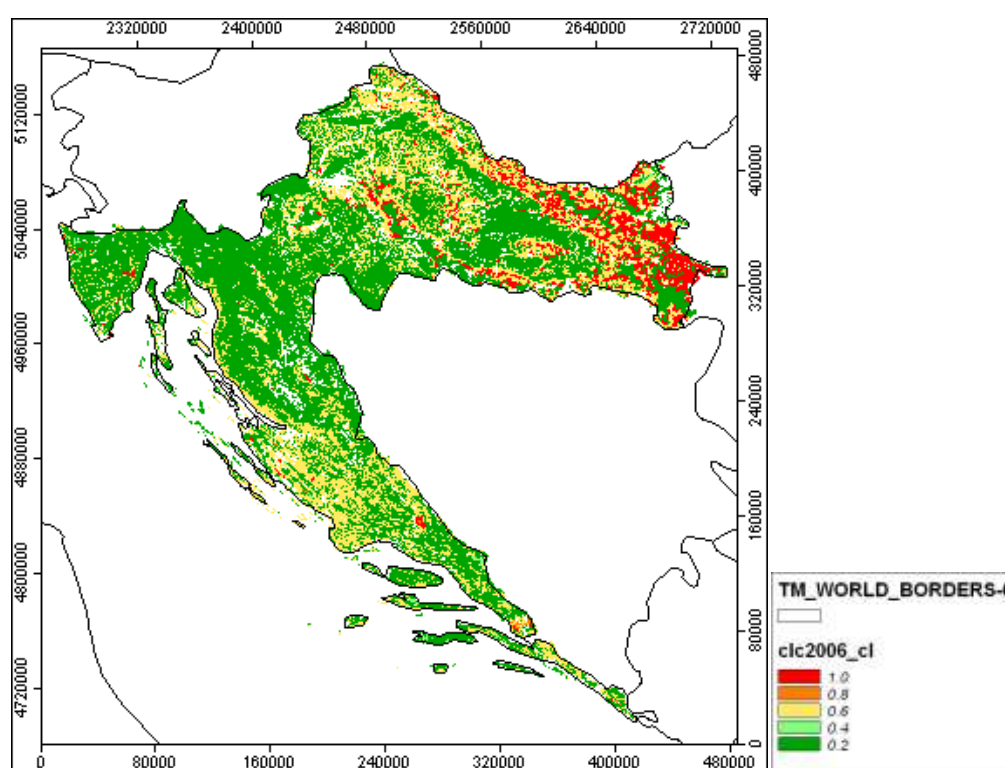


Fig. 9 Land use map

Vulnerability class	Description	Code	Area [%]
0.2	Olive groves, Land principally occupied by agriculture, with significant areas of natural vegetation, Broad-leaved forest, Coniferous forest, Mixed forest, Transitional woodland-shrub	223, 243, 311, 312, 313, 324	56.4%
0.4	Vineyards	221	0.5%
0.6	Complex cultivation patterns, Natural grasslands, Moors and heathland, Sclerophyllous vegetation, Sparsely vegetated areas	242, 321, 322, 323, 333	26.2%
0.8	Fruit trees and berry plantations	222	0.2%
1.0	Non-irrigated arable land, Permanently irrigated land	211, 212	6.7%
	Without vegetation, water area		10.1%

Table 1: Description of the classes for the land use map

2.7. DROUGHT VULNERABILITY MAP

The first version of the drought vulnerability map (Fig. 9) is calculated from the category maps of slope, irradiation and coefficient of variation of precipitation. It is dominated with the lowest vulnerability classes of “not vulnerable” and “slightly vulnerable” since the lowest class categories of 0.2 and 0.4 are the most common on the category maps of slope, coefficient of variation of precipitation and solar irradiation.

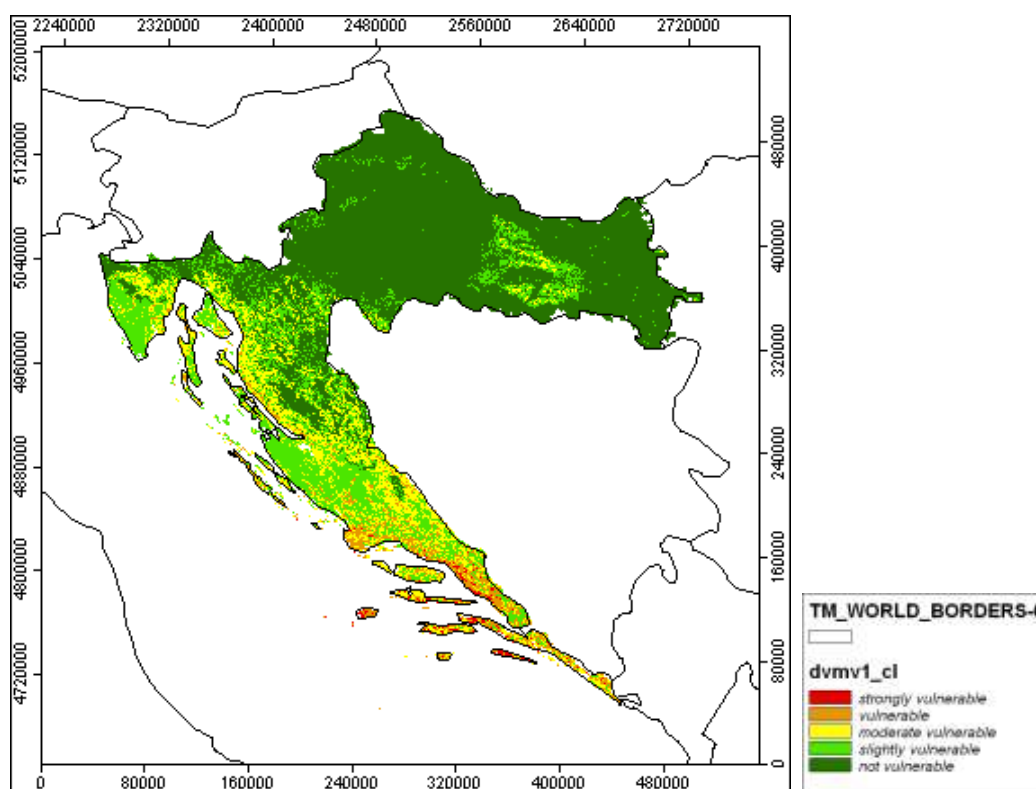


Fig. 9: Categorical drought vulnerability map calculated from the category maps of slope, irradiation and coefficient of variation of precipitation.

Inclusion of soil information rises the drought vulnerability most evidently on the coast and on the Dinaric mountains as well as in the very eastern lowland of Slavonia (Fig. 10). Coastal zone is dominated by the Leptosols (class 1.0, tab. 1). The excessive internal drainage and the shallowness of many Leptosols can cause drought even in a humid environment (IUSS Working Group WRB, 2006).

Continental part of the country mostly belongs to the vulnerability class “not vulnerable”. Only dryer (east of Croatia) or steeper mainland (Slavonian Mountains) can be “slightly vulnerable”. “Slightly vulnerable” are also the Istria peninsula and the mountainous Lika region where only some smaller parts are in the classes “not vulnerable” or “moderately vulnerable”. Along the coast vulnerability rises to the south, from “moderately vulnerable” and “vulnerable” on the northern Adriatic coast and over the nearby Velebit Mountain, to

the predominant class “vulnerable” on the southern Adriatic coast. “Strongly vulnerable” can be on some steeper slopes with higher irradiation and/or higher precipitation variability.

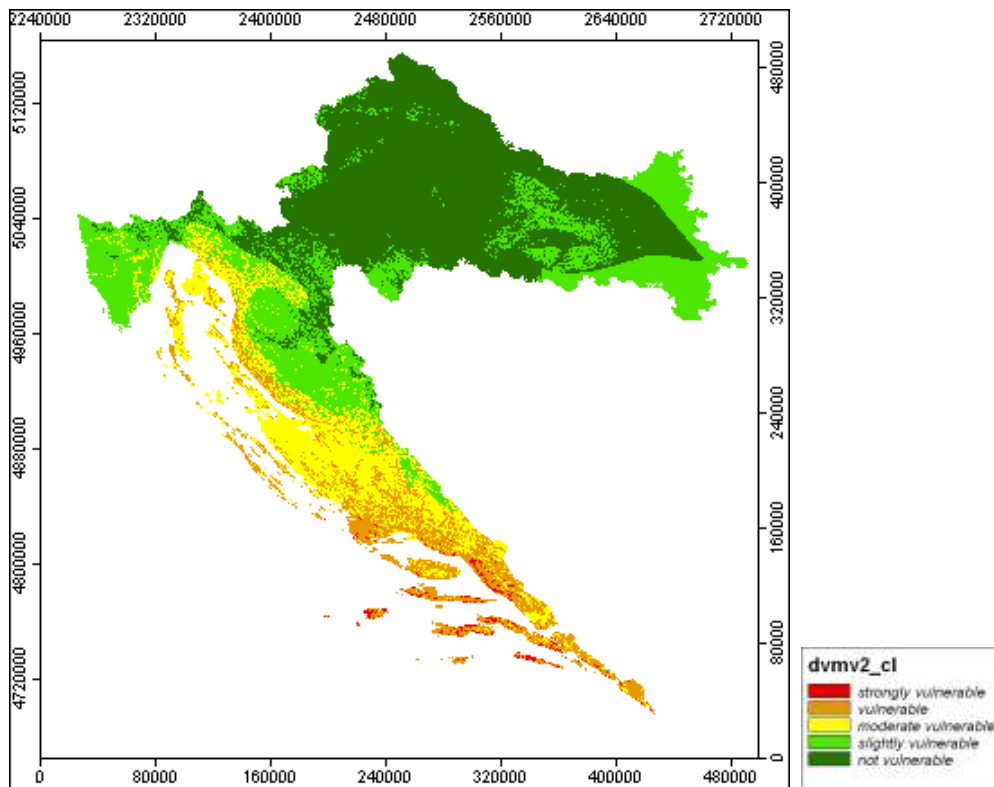


Fig. 10: Categorical drought vulnerability map calculated from the category maps of slope, irradiation, coefficient of variation of precipitation and soil type.

Final version of the drought vulnerability map (Fig. 11) is calculated from the category maps of slope, irradiation, coefficient of variation of precipitation, soil classes and the land cover classes.

It has been calculated for the areas with vegetation.

The most eastern inland part of Croatia is considered the “moderately vulnerable” to drought. That area is mainly associated with arable land or complex cultivation patterns. Forests in this area belong to the classes “not vulnerable” and “slightly vulnerable”. On the north-western inland area the woods are mainly “not vulnerable”, while the arable land and cultivated areas are “slightly vulnerable”. “Slightly vulnerable” are also the Istria peninsula and Lika region where only some smaller parts are in the classes “not vulnerable” (mixed forests) or “moderately vulnerable” (cultivated land or pastures). On the northern Adriatic coast vulnerability rises, and becomes “moderately vulnerable” (forests) and “vulnerable” (cultivated areas, sparse vegetation or shrub). On the middle Adriatic coast the “moderately

vulnerable” are mostly transitional woodlands while grassland and cultivated areas are “vulnerable”. Some smaller areas can be also “strongly vulnerable”

Inclusion of the land use map in the analysis, modified the vulnerability map compared with the second version of the map. The vulnerability increased mainly on the cultivated land, natural grassland and arable land, but decreased mainly in the forests and on olive groves which are adapted to the dryness.

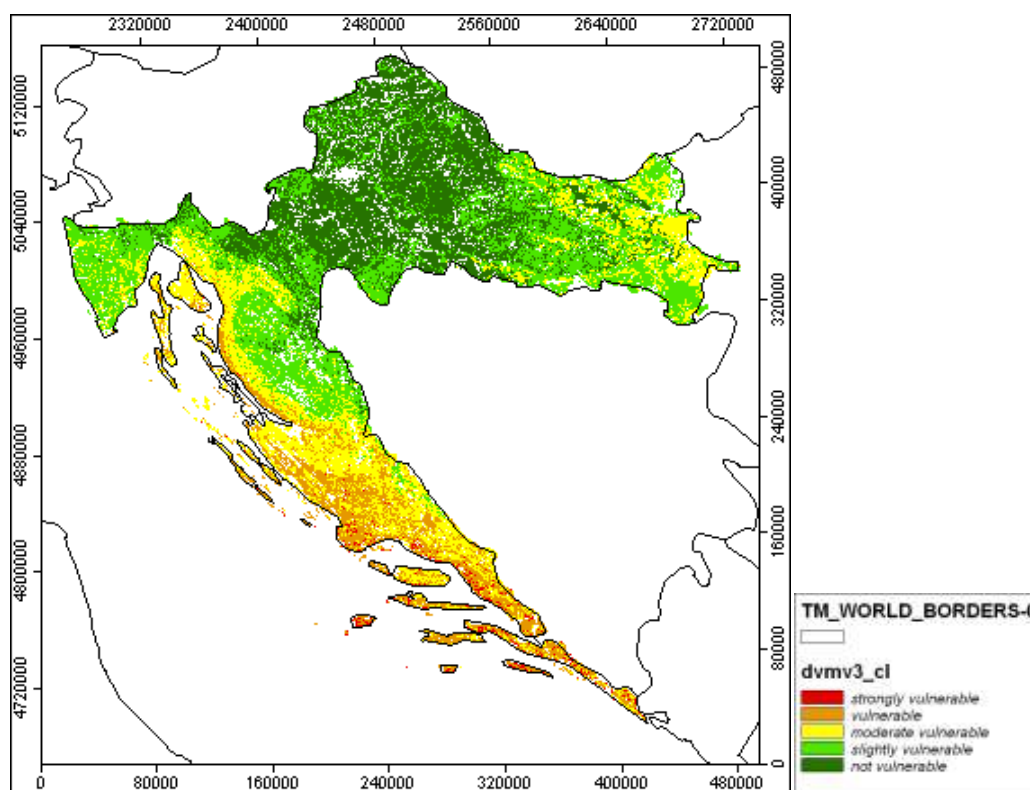


Fig. 11: Categorical drought vulnerability map for the areas covered with vegetation. It is calculated from the category maps of slope, irradiation, coefficient of variation of precipitation, soil type and land cover type.

1.8. STATISTICAL ANALYSIS OF THE MAPS

One of the attempts to summarize complex interactions of terrain, soil and climatological properties in only one parameter that would be capable to describe the sensitivity to drought is the calculation of the drought vulnerability map. According to these preliminary results, 28.1% of the territory of Croatia is not vulnerable to drought (Tab. 3). Slightly vulnerable is 29.5% of the area, and 21.1% is moderately vulnerable. Vulnerable to drought is 10.3% and only 1% of the territory is strongly vulnerable. The 10% of the land without vegetation or water bodies has not been classified.

The major concern in this kind of analysis is how to set the limiting values for the vulnerability classes. Beside the already mentioned problem of the skewed distribution, there can also be the disadvantage in setting the equal intervals for the classes on the input maps as well on the vulnerability map. The equal intervals can tell where the values are smaller or larger. Further research should be oriented to the definition of the actual vulnerability classes that would have to be established on some real drought data. Solving these relations could also allow for an expert decision on how to treat a land that belongs to a certain vulnerability class.

Vib. class	Slope		Irradiation		Coeff. of variation c_v		World soil		Land cover	
	Limits [°]	Area [km ²]	Limits [kWh/m ²]	Area [km ²]	Limits	Area [km ²]	Type	Area [km ²]	Code	Area [km ²]
0.2	0–5	32325.6	1164.9–1259.0	18609.2	0.08–0.16	21582.5	-	-	223,243,311,312,313,324	31879.2
0.4	5–12	14482.4	1259.0–1353.1	22763.5	0.16–0.24	33802.6	LV	24923.5	221	289.0
0.6	12–20	6699.3	1353.1–1447.2	6526.7	0.24–0.32	1130.2	CM	13508.0	242,321,322,323,333	14803.6
0.8	20–35	2875.2	1447.2–1541.3	7485.7	0.32–0.40	37.6	PH	1824.6	222	95.5
1.0	35–90	172.2	1541.3–1635.4	1169.6	0.40–0.48	1.9	LP	16298.8	211,212	3797.0

Table 2: Proportion of the necessary and optional parameter classes related to the vulnerability classes over the territory of Croatia expressed in km². Soil classes: LV - Luvisol, CM - Cambisol, PH - Phaeozem, LP – Leptosol. Land cover code according to Tab. 1.

Vulnerability class	Drought Vulnerability Fig 9		Drought Vulnerability Fig 10		Drought Vulnerability Fig 11		
	limits	area [km ²]	limits	area [km ²]	limits	area [km ²]	area [%]
NV	0.6–1.0	33015.3	1.00–1.52	24744.9	1.2–1.8	15891.7	28.1
SIV	1.0–1.4	12445.1	1.52–2.04	16016.1	1.8–2.4	16678.3	29.5
MV	1.4–1.8	7852.8	2.04–2.56	9095.5	2.4–3.0	11925.1	21.1
V	1.8–2.2	2784.3	2.56–3.08	6241.7	3.0–3.6	5797.2	10.3
StV	2.2–2.6	457.3	3.08–3.60	456.5	3.6–4.2	571.9	1.0

Table 3: Proportion of drought vulnerability classes over the territory of Croatia expressed in km² and percents. Drought vulnerability classes: NV - “not vulnerable”, SIV - “slightly vulnerable”, MV - “moderately vulnerable”, V - “vulnerable” and StV - “strongly vulnerable”.

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WRB Map of World Soil Resources 1:25 000 000 - January 2003
<http://www.fao.org/ag/agl/agll/wrb/soilres.stm>

WSRC World Soil Resources Coverage <ftp://ftp.fao.org/agl/agll/faomwsr/wsrl.zip>

3. GREECE

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3.1. INTRODUCTION

Greece is located at the southeast end of Europe among several countries and seas. Namely, in the north it borders with Albania, FYROM, and Bulgaria. To the east Greece borders with Turkey. To the south and west Greece is surrounded by the Mediterranean Sea (the Ionian Sea is west and the Libyan sea to the south). The country is comprised of the Greek peninsula as well as of the adjacent approximate of 3,000 islands archipelago. The terrain is predominantly mountainous with 27 peaks higher than 2,033 m.

Greece has a total area of 131957.4 km² from which 28.71% is plains, 29.01% is semi mountainous and the rest 42.28% is mountainous (ESYE, 1991). The arable lands in Greece possess 50684.6 km² which is the 38.4% of the total, while the water bodies area is only 1790.1 km² (1.4%). Pastures (grasslands) in Greece take 14451.6 km² (11.0%) and forests take 57968.9 km² (43.9%). Urban areas cover 2307.5 km² (1.7%) and 4779.6 km² (3.6%) are covered by other land uses (ESYE 2000).

The climate is typical northern Mediterranean with most of the precipitation falling during the winter months and increasing from southeast to northwest. The average annual rainfall ranges from 350 mm/yr to 2,150 mm/yr, with an approximate average of 760 mm/yr (Karavitis, C.A., 1999). The climate of Greece is classified as Csa Climate (Koeppen-Geiger classification); a warm temperate Mediterranean climate with dry, warm summers and moderate, wet winters with the warmest month above 22°C on the average. However, the climate in Greece varies greatly from region to region. The north-western part of Greece is usually cold during the winter and snowfalls are not uncommon, especially in the higher elevations. For the southern Greece and the islands, the winters are milder. Summers are usually hot, and in July and August temperatures reach 30 to 35°C and sometimes even more. The islands have smaller differences of temperature during the day than the mainland. Western Greece is receiving more precipitation than the eastern part. The Ionian islands and southern Crete have very small differences between winter and summer temperatures. The Aegean islands have less rainfall and they experience strong winds in summertime known as the Etesies (Meltemia).

The greatest rivers in Greece are located in the northern regions of Macedonia and Thrace. Greek territories form the lower parts of the watersheds. The upper and greater parts of the watersheds fall into the neighboring countries. Nevertheless, the management of these common water resources needs to be implemented by the principles of international cooperation, and is still pending.

The water quality can be generally described as satisfactory (Karavitis, C.A., 1999). However, pollution exists in some places due to the high use of fertilizers and pesticides, as well as municipal and industrial effluent. Problems might escalate as the rate of exploitation increases.

The coastal waters of Greece are primarily devoted to tourism. The quality of such waters is generally considered excellent, but high pollution exists in some areas (Athens and Thessaloniki metropolitan regions). European Union legislation for water and pollution control has also to be fully implemented in Greece as by all member states.

3.2. DROUGHT VULNERABILITY FACTORS

In order to develop the drought vulnerability map of the activity 4.2.1, six factors were taken into account according to the provided guidelines:

1. Slope
2. Irrigation
3. Solar Radiation
4. Land Use
5. Precipitation
6. Soil Type

3.2.1. Slope

For the calculation of slope angle a TIN file was created using 100m contours of Greece in ArcGIS 10 3D Analyst. Continuing, a Raster Layer that pictures the slope angle (Figure 1) was created from the previous TIN file. Table 1 shows the classification of the slope factor used for the development of the Digital Map of Slope Factor (Figure 1).

3.2.2. Irrigation

The Map of Irrigation Factor (Figure 2) was created from a Raster Layer that presents the Irrigated and non-Irrigated areas of Greece. The classification of the irrigation factor is indicated in Table 2.

Factor	Classification	
	Angle [°]	Vulnerability Class
Slope	(0-5)	0.2
	(5-12)	0.4
	(12-20)	0.6
	(20-35)	0.8
	(35-90)	1

Table 1. Classification of Slope Factor.

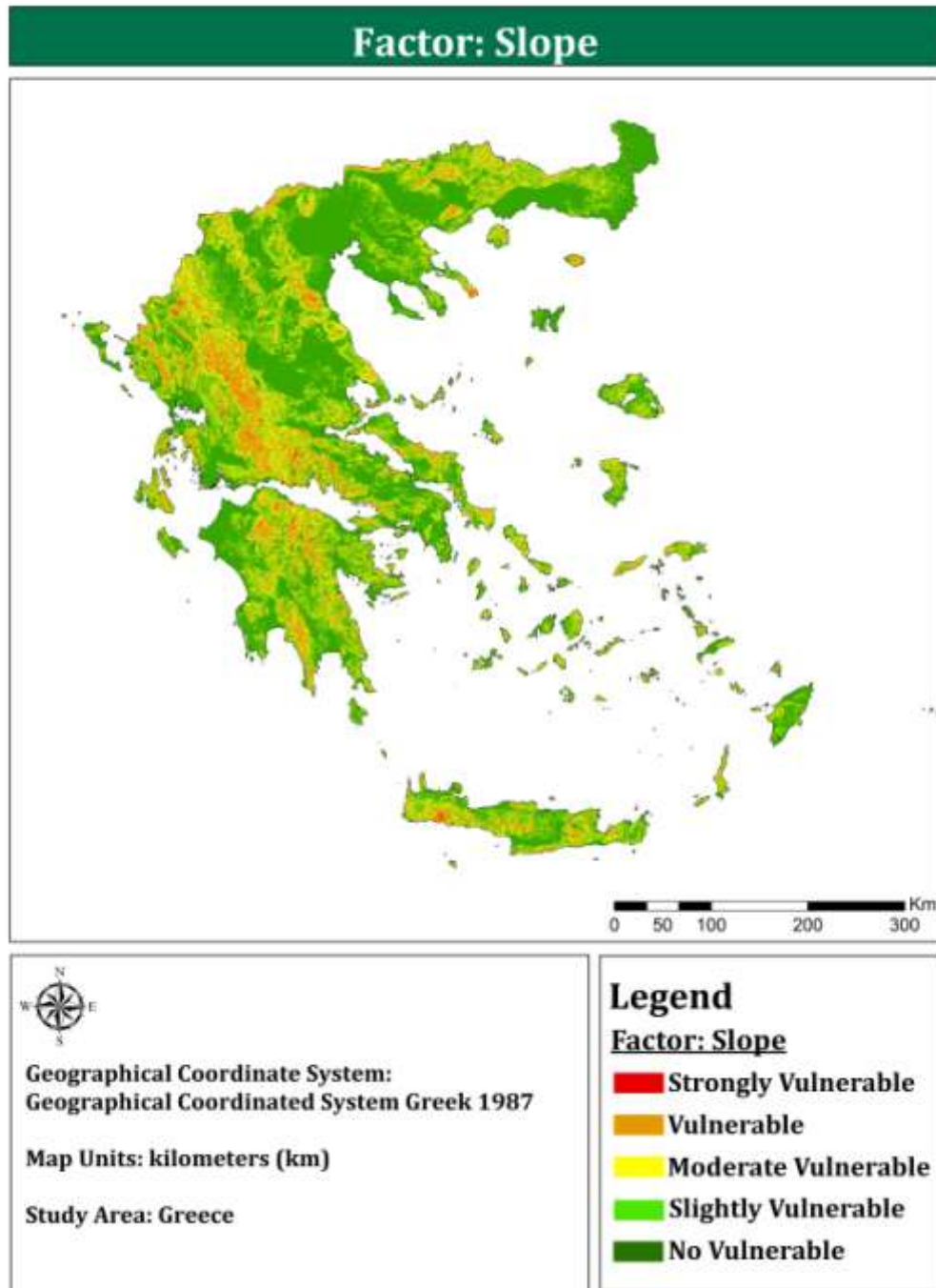


Figure 1. Digital Map of Slope Factor.

Factor	Classification	
Irrigation	Irrigation	Vulnerability Class
	YES	0
	NO	1

Table 2. Classification of irrigation Factor.

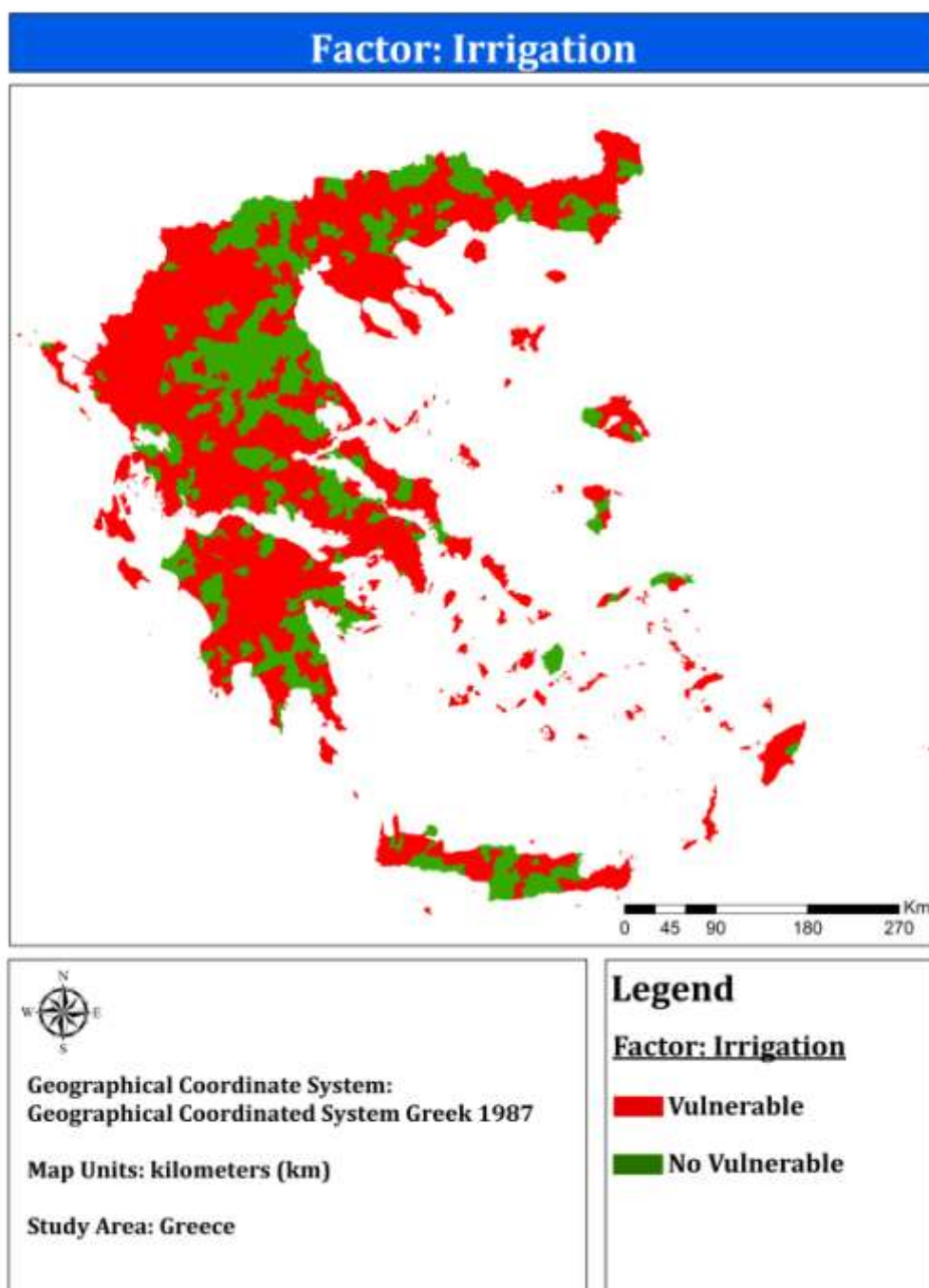


Figure 2. Digital Map of Irrigation Factor.

3.2.3. Solar Radiation

Solar Radiation Factor was calculated using measured values of Solar Radiation from 35 meteorological stations all over Greece for the period 1971-2000. According to the output standards Solar Radiation for this activity is referred to the vegetation period (v.p.) and it is given in MJ/m²v.p. In Greece during the vegetation period (April-September) Solar Radiation varies from 3500 MJ/m²v.p. to 4750 MJ/m²v.p. These measurements were classified (Table 3) and used for the development of the map of Solar Radiation Factor (Figure 3).

Factor	Classification	
Solar Radiation	Solar Radiation (MJ/m ² v.p.)	Vulnerability Class
	3500-3750	0.2
	3750-4000	0.4
	4000-4250	0.6
	4250-4500	0.8
	4500-4750	1

Table 3. Classification of Solar Radiation Factor.

3.2.4. Land Use

In order to create the map of Land Use Factor (Figure 4) the Corine 2000 Type of land use (CLC100) was used. The Raster Layer that pictures the Land Use Factor was created in ArcGIS 10 and was classified using the output standards classification (Table 4)

Table 4. Classification of Land Use Factor.

Factor	Classification	
Land use	Type of land use (CLC100)	Vulnerability Class
	223, 243, 244, 311, 312, 313, 324	0.2
	221	0.4
	241, 242, 321, 322, 323, 333	0.6
	222	0.8
	211, 212, 213	1

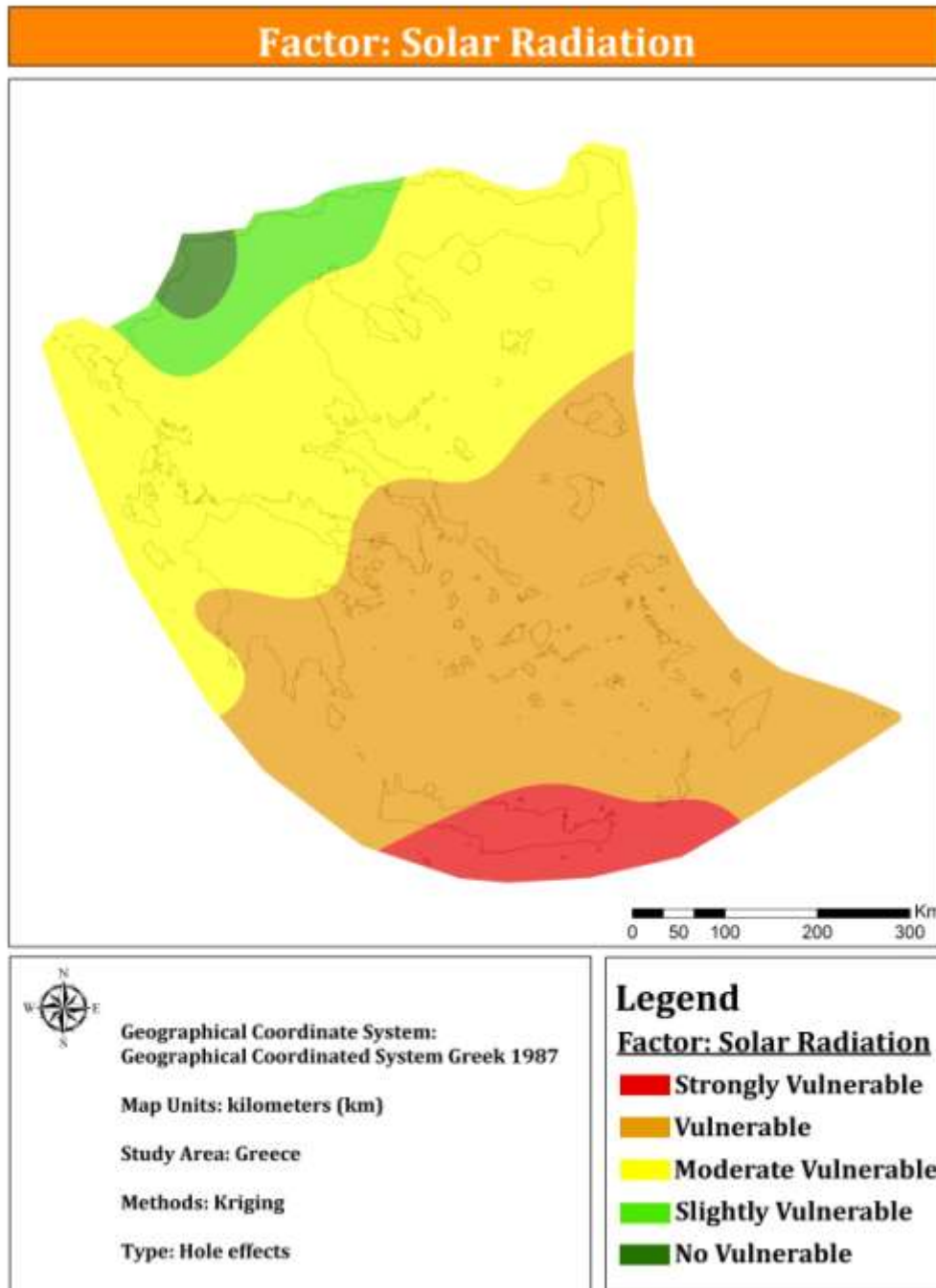


Figure 3. Digital Map of Solar Radiation Factor.

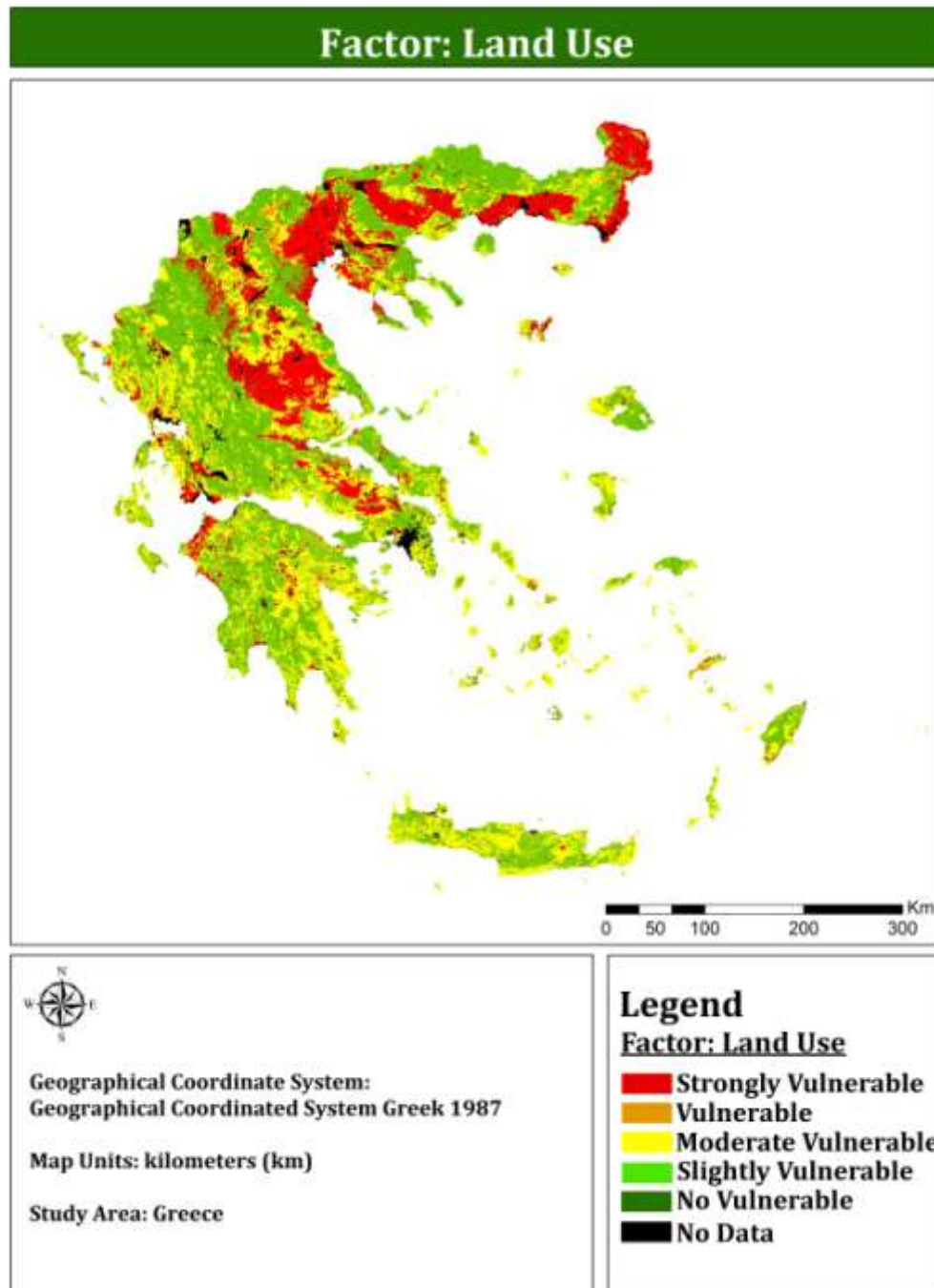


Figure 4. Digital Map of Land Use Factor.

3.2.5. Precipitation

Precipitation Factor was calculated using measured values of Precipitation from 48 meteorological stations all over Greece for the period 1971-2000. In Greece precipitation varies from lower than 400mm per year to upper than 1000mm per year. These measurements were classified in equal classes of 200mm (Table 5) and used for the design of the map of Precipitation Factor (Figure 5).

Factor	Classification	
Precipitation	Annual Precipitation mm	Vulnerability Class
	min-400	0.2
	401-600	0.4
	601-800	0.6
	801-1000	0.8
	1001-max	1

Table 5. Classification of Precipitation Factor.

3.2.6. Soil Type

The map of Soil Type factor (Figure 6) was created using the soil type classes of Greece (Yassogloy, N.J., 2004) and has been visualized, by using the vulnerability classification of the output standards (Table 6), in Raster Layer in ArcGIS 10 environment.

Factor	Classification	
Soil Type	Soil Type	Vulnerability Class
	Histosols (HS)	0.2
	Gleysols (GL), Luvisols (LV)	0.4
	Cambisols (CM), Chernozems (CH), Fluvisols (FL)	0.6
	Phaeozems (PH), Solonetz (SN)	0.8
	Arenosols (AR), Leptosols (LP), Solonchaks (SC), Vertisols (VR)	1

Table 6. Classification of Soil type Factor.

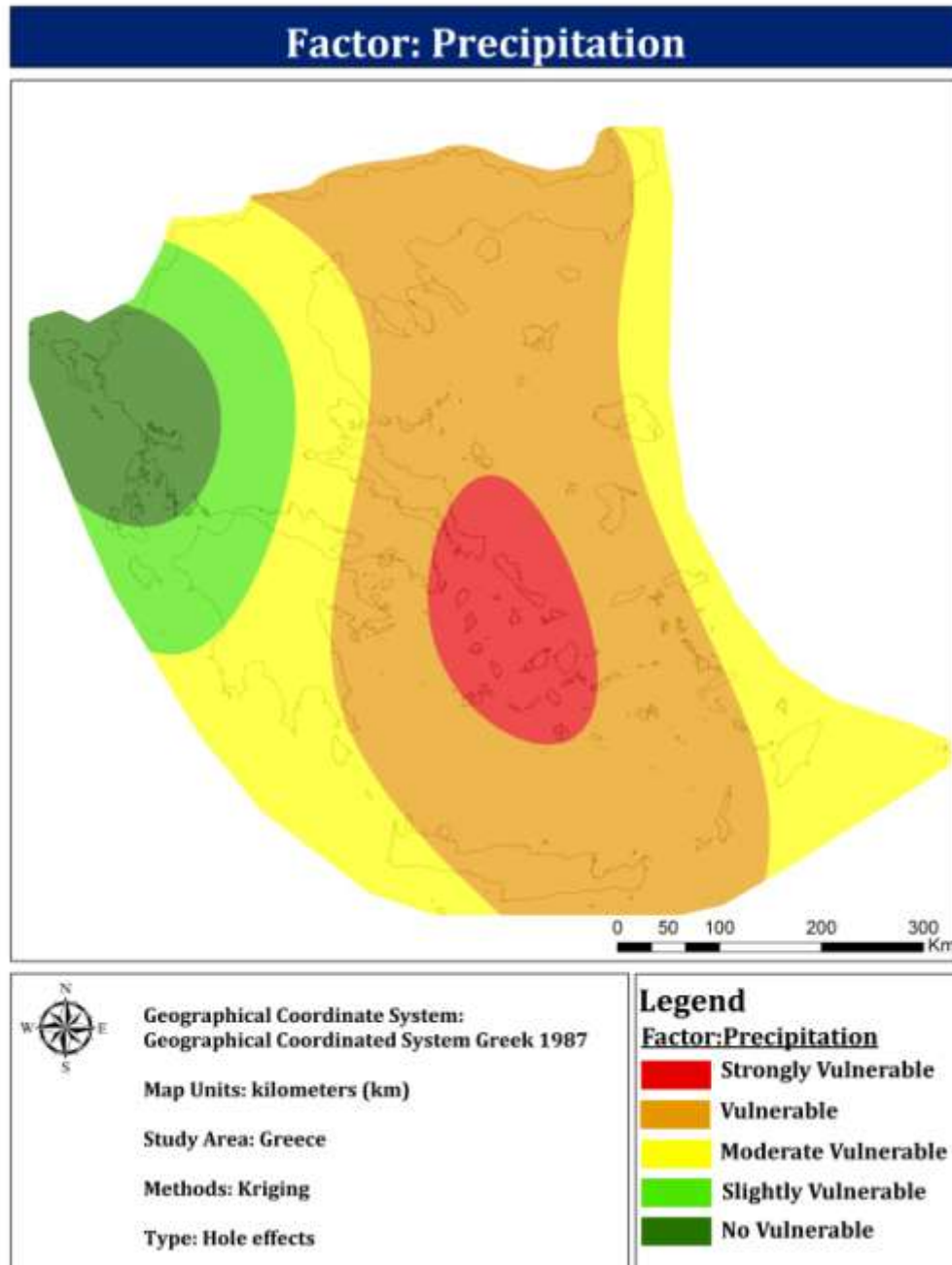


Figure 5. Digital Map of Precipitation Factor.

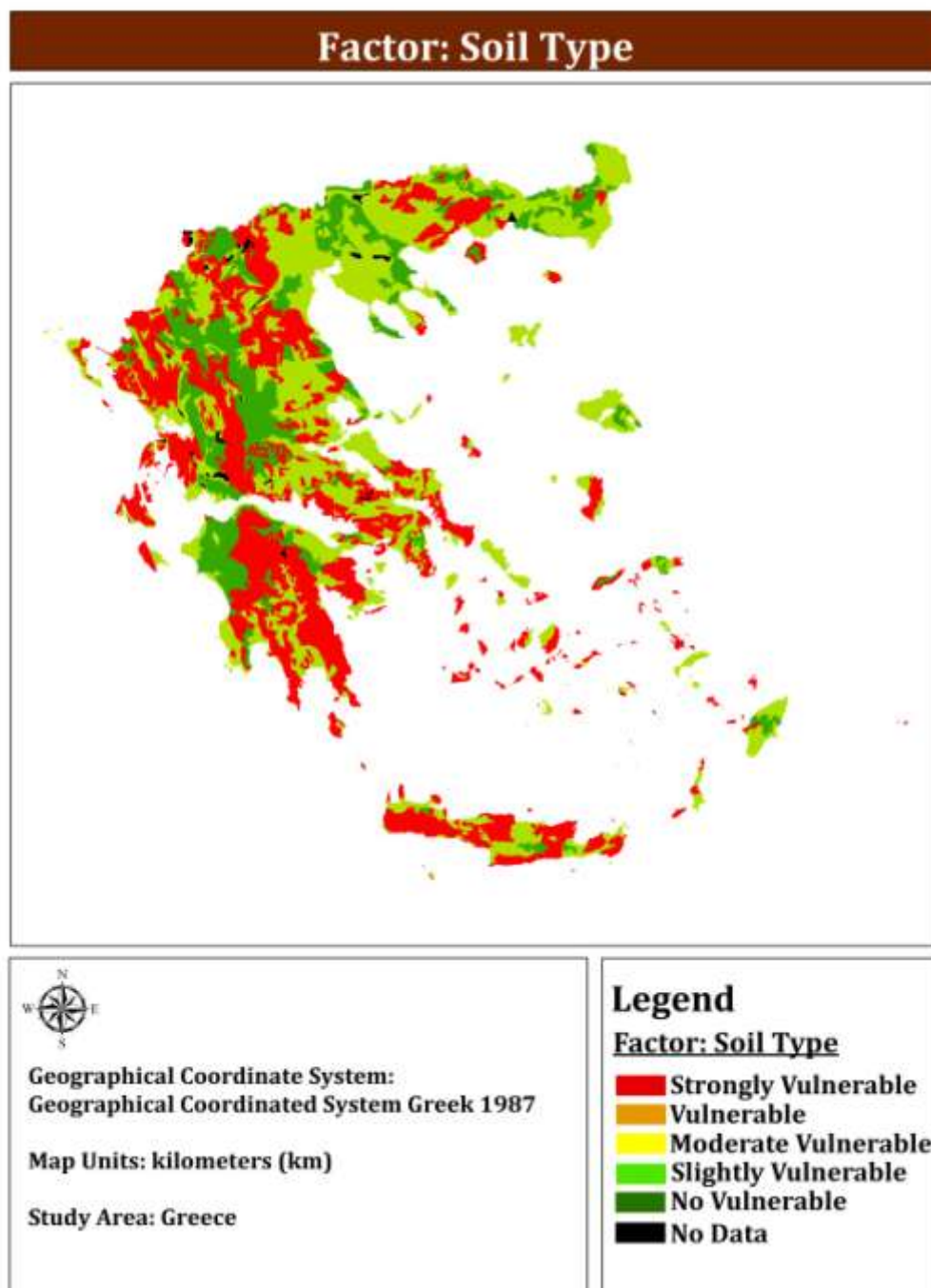


Figure 6. Digital Map of Soil Type Factor.

3.3. DROUGHT VULNERABILITY MAP BASED ON CLIMATOLOGICAL AND GEOMORPHOLOGICAL DATA

The six maps of the factors, Slope-Irrigation-Solar Radiation-Land Use-Precipitation-Soil Type, were combined into the final Drought Vulnerability Map based on climatological and geomorphological data. Vulnerability classes were set according to the output standards. In the present effort, equal weighting for all factors has been selected.

The final Drought Vulnerability score was calculated according to the following equation (Equation 1) for equal weights using map algebra raster calculator in Spatial Analyst tools in ArcGIS 10.

$$D.V = \sum_{i=1}^6 F_i \cdot W_i \quad \text{Eq.1}$$






Where:

F_i = Factor Performance

W_i = Factor Weight

The outcome of all this procedure was the Final Drought Vulnerability Map of Greece based on climatological and geomorphological data (Figure 7).

Table 7. Classification of Drought Vulnerability based on Climatological & Geomorphological data.

Colors	Vulnerability Class
	No Vulnerable
	Slightly Vulnerable
	Moderate Vulnerable
	Vulnerable
	Strongly Vulnerable

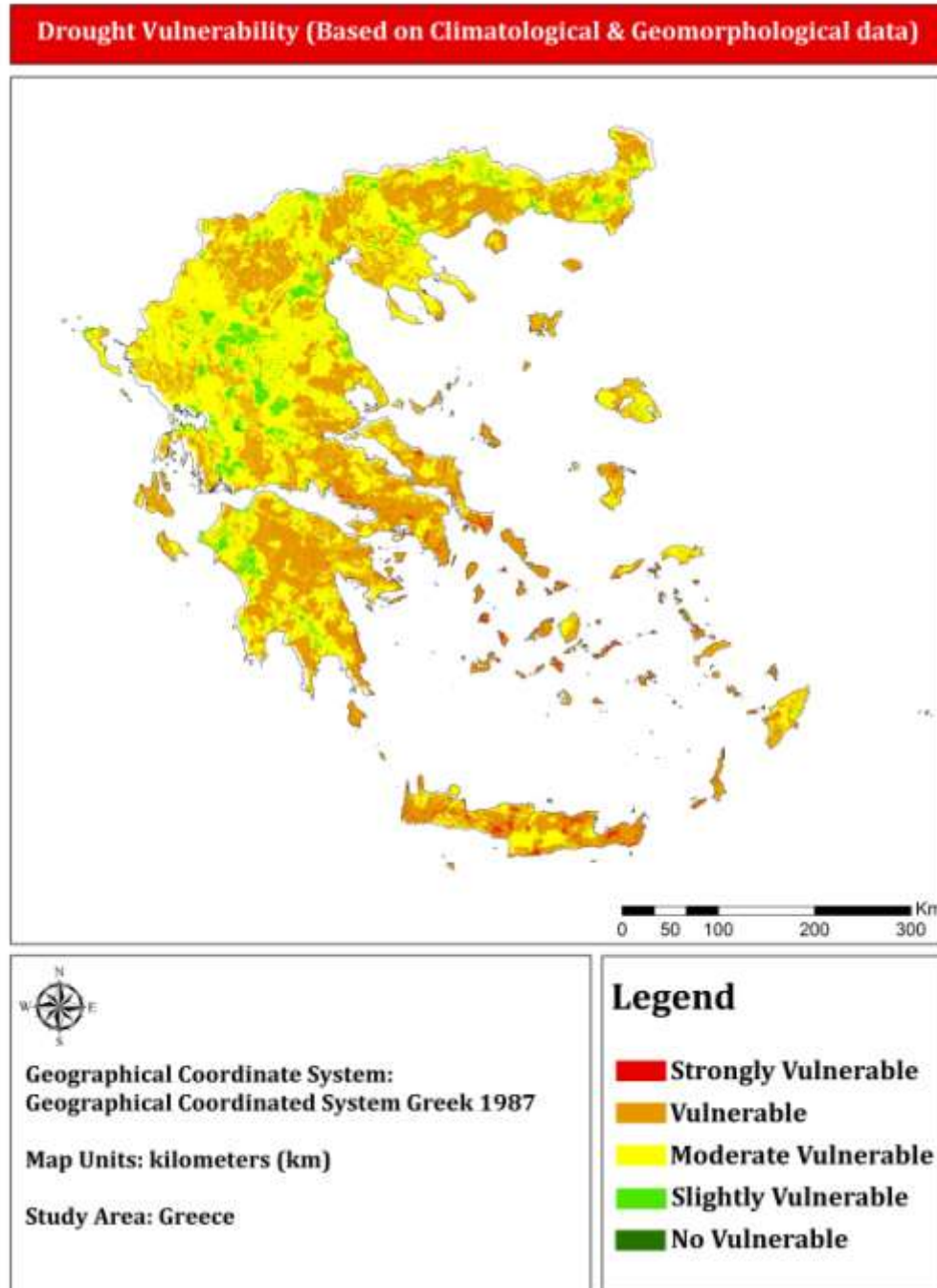


Figure 7. Drought Vulnerability Map based on climatological and geomorphological data.

3.4. CONCLUSIONS

The territory of Greece is mostly mountainous or hilly. More specific, Greece is the third most mountainous country, after Norway and Albania, in Europe with more than 60% of its territory to be classified as mountainous and several mountain peaks to exceed 2000 m.a.s.l. Consequently, steep slopes dominate the country's terrain, which is also scared by numerous ravines and canyons that make it seem even rougher. According to that description, and regarding the slope factor that is included in the applied drought vulnerability assessment, Greece should be classified as highly vulnerable territory. Nevertheless, such a classification would overestimate the country's vulnerability leading to false results. That can be explained by the following facts since the majority of the country's mountainous areas:

- are mostly covered by natural vegetation (forests, grasslands etc) which is not vulnerable to drought and hold a great amount of runoff water as well as,
- they present low or no economic activities and therefore are no impact prone to drought events.

The majority of economic activities, and mostly agricultural ones, are located in lowlands (low or no slopes), that cover almost 20% of the country's territory, and coastal zones that present low (slope factor) and high (vegetation and impact proneness) levels of vulnerability simultaneously.

Therefore, the slope factor is acting as a buffering (both positive and negative) actor that can create confusion and lead to unclear results and conclusions. The factor's weight in the present methodology of drought vulnerability assessment should be limited. An additional problem may be the irrigation vulnerability in Greece. The agricultural activities depend on irrigation during the dry summer period. If a drought comes then irrigation usually minimized having as a result catastrophic losses in agriculture all production. In this regard, the irrigated areas in Greece are the most vulnerable to drought and not the other way around as it is constrain in the pertinent vulnerability map which in this regard could be misleading.

3.5. REFERENCES

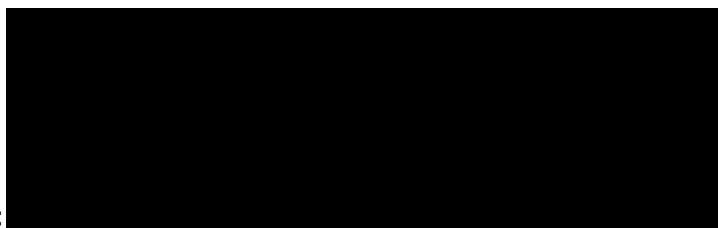
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Hellenic National Meteorological Service <http://www.hnms.gr/hnms/greek/index.html> (last access: 15-11-2011)

4. REPUBLIC OF MACEDONIA

Authors:



Contact person:

Organization: Hydrometeorological Service of Republic of Macedonia

4.1. INTRODUCTION

Scarcity of water is an increasing problem in the southern parts of Europe, especially the Mediterranean region and neighboring countries. Droughts are estimated to become worse and more frequent in the light of global climate change. Therefore, essential shifts in policy are required to be prepared for drought events and prevent situations of chronic water scarcity. Current management response however, calls for actions for capturing and preserving the water in order to guarantee water supply for an ever increasing demand.

Drought is a natural hazard that differs from other events in that it has a slow onset, evolves over months or even years and affects a large spatial region. Its onset and conclusion, and the severity of drought are often difficult to determine. Drought typically causes substantial economic, environmental, and social impacts in large regions or entire countries. It occurs in virtually all climatic zones, but the vulnerability of the area and the grade of impact vary significantly from one region to another.

On the other hand vulnerability is the degree to which a system will respond to a given change in climate including beneficial and harmful effects (IPCC Working Group II, 2001). Or, vulnerability is the degree to which a system is susceptible to or unable to cope with, adverse effects of climate change including climate variability and extremes.

Therefore vulnerability to drought is the effect of the drought on the normal state of the environment and social activities. The impact on the plants depends on the environmental amplitude or how much pressure they can take in order to survive. The crops are different matter altogether because the planting on the crops depend on economic reasons (growth and yield). The choice of the future crops will depend on the development of the vulnerability maps for the region. The development of the vulnerability maps were done in multicriteria GIS environment according to the established methodology.

4.2. STUDY AREA AND DATASET DESCRIPTION

4.2.1. Geographic features of the country

Republic of Macedonia is located in the central part of the Balkan Peninsula. It is a landlocked country with a total area of 25.713 km and approximately 80% of the entire territory is represented by hilly and mountainous regions. About 2% of the land area is covered by water, comprising 35 large and small rivers, three natural lakes (Ohrid Lake, Prespa Lake, Dojran Lake), and over 100 artificial reservoirs.

The population of the country is around 2 million people, of which about 60% reside in urban areas and the overall population density is 81 inhabitants per square kilometer. Although Macedonia is small in area, it shows a great diversity of relief forms, geological formations, climate, plants and soils. The difference in altitude is from 40 to 2764 m above sea level.

The territory of the country belongs to three basins:

- Black Sea basin (44 km² or 0,17%);
- Adriatic Sea basin (3359 km² or 13,07%)
- Aegean Sea basin (22310 km² or 86,76%)

4.2.2. Climate

The climatic conditions vary according to the altitude. In the valleys on the lower altitudes the climate is continental with long, hot and dry summers and cold winters. The average temperature drops gradually with a rise in altitude and converts to mountain climate on the highest altitudes. From national meteorological network during the period 1951-2010 were measured the following extremes (Table1).

Element	Value	Date	Meteorological station
Tmax (°C)	45,7	24.07.2007	Demir Kapija
Tmin(°C)	-31,5	27.01.1954	Berovo
max r24 (mm)	154,4	24.10.1981	Lazaropole

Table 1: Meteorological data extremes

In general, Macedonia is vulnerable to desertification processes. Because of this the forecasted climate changes will contribute to worsening of the situation, i.e.

- Increase of the drought periods,
- Decrease of vegetation cover,
- Increase of frequency of heavy rainfalls,
- Increase risks of wildfires,
- Increase of soil erodibility,
- Increase of frequency of flash floods.

All of these factors have contributed towards changes in land cover and land use practices and increasing need of constant monitoring of the land cover change is required.

4.2.3. Dataset description

For the purpose of this study the following dataset was used:

DEM (Digital elevation model) acquired from the Ministry of Environment and Physical Planning. Spatial resolution 80 m, with spatial accuracy of 18, 9 m. The DEM was subsequently used to extract the slope of the terrain.

- Corine land cover/use map 2000. This land cover map was developed according the methodology of European Environmental Agency on the scale 1:100.000, minimal mapping unit of 25 ha and with 3 hierarchical levels.
- Map of Irrigated land (source: Public Enterprise for spatial and urban plans of Republic of Macedonia)
- Soil map of Macedonia (source: Agriculture Institute-Skopje)
- Rainfall data (source: Hydrometeorological Service of Republic of Macedonia)
- Solar radiation (source: Hydrometeorological Service of Republic of Macedonia)

4.3. METHODOLOGY AND DEVELOPMENT OF THE SEPARATE PARAMETERS

All of the aforementioned data was used as an input of the GIS based model for estimating the drought vulnerability of the area. The mapping unit of the developed model is 80x80 m with approximation of the scale 1:100.000.

4.3.1. Slope

For the development of the parameter slope the acquired DEM was used. The DEM had 80 m spatial resolution and spatial accuracy of 18, 9 m. The DEM was used as an input in the GIS algorithm creating slope output in degrees. Further on the slope was reclassified in five vulnerability classes (0, 2 -1) Table 2. Finally a slope map was produced Figure 1.

Slope	Angle [°]	Vulnerability class
	(0-5)	0,2
	(5-12)	0,4
	(12-20)	0,6
	(20-35)	0,8
	(35-90)	1

Table 2: Slope vulnerability classes

4.3.2. Irrigation

This map was created by the Public Enterprise for spatial and urban plans of our Republic and it was acquired in hardcopy format. First the map was scanned and georeferenced according the state reference system. Next, the irrigated land was vectorized and reclassified according the classification. Finally an irrigation map was produced Figure 2.

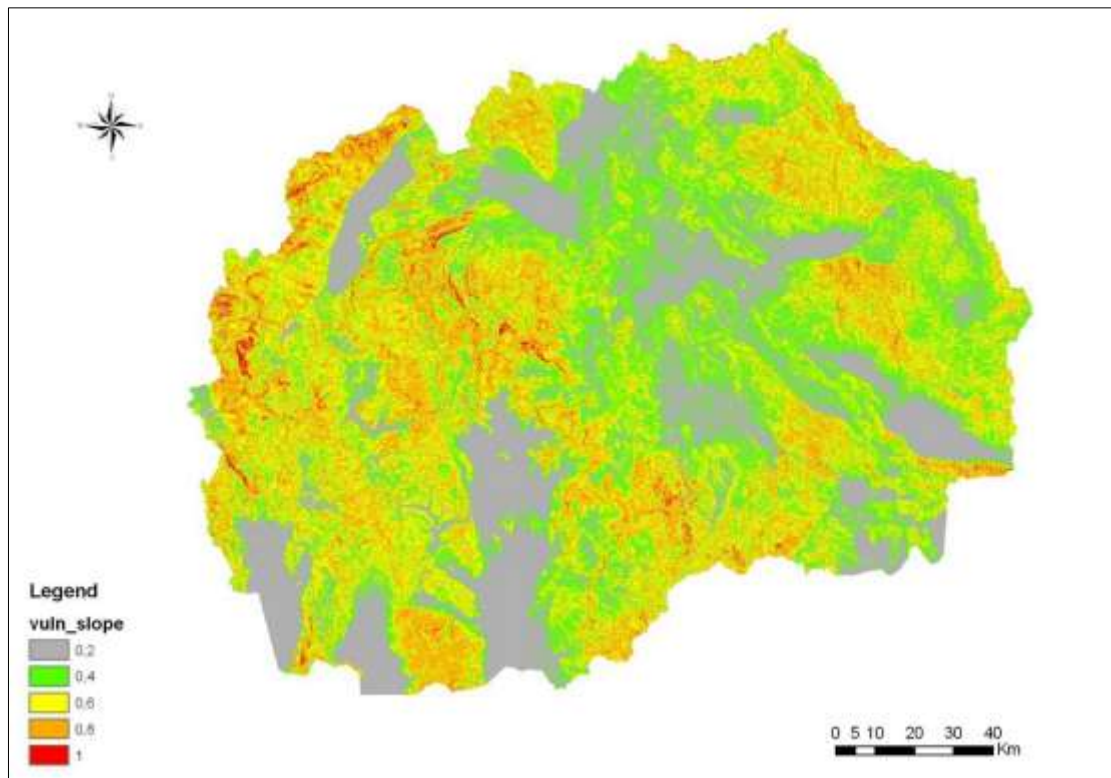


Figure 1: Slope vulnerability map

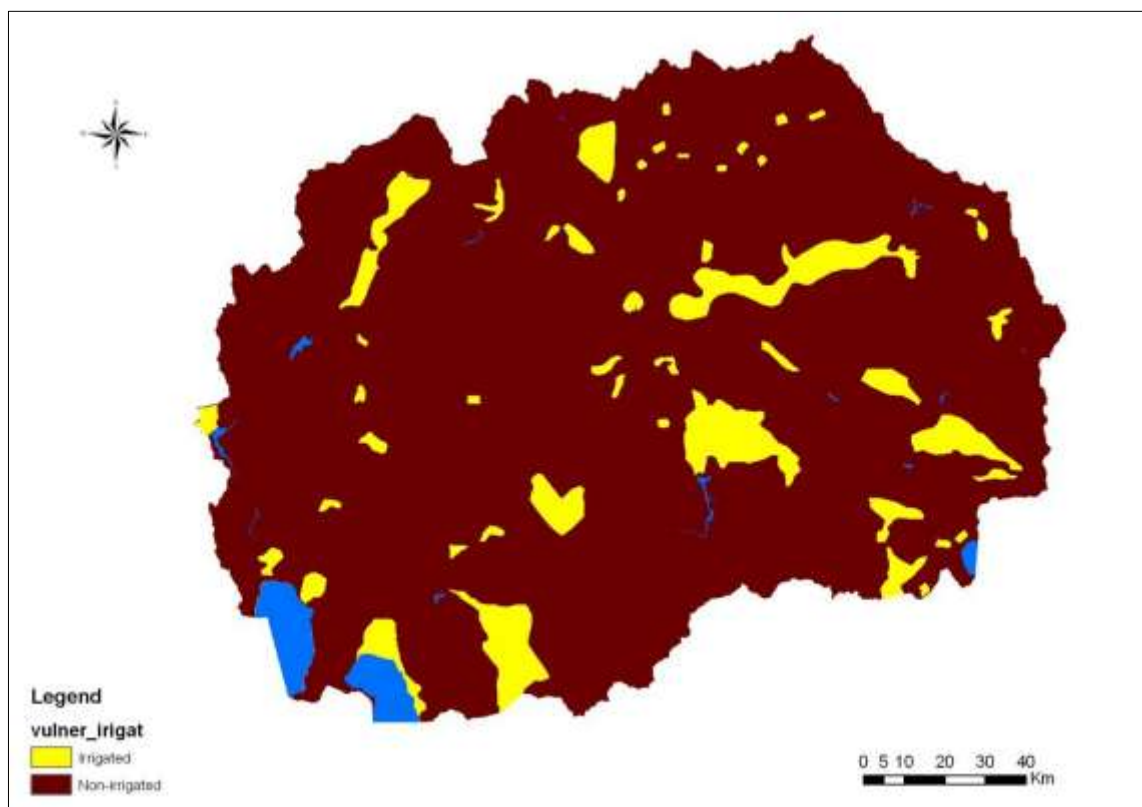


Figure 2: Irrigation vulnerability map

4.3.3. Solar radiation

This parameter was acquired from the Hydrometeorological Service of Republic of Macedonia. The data was provided in table form. Most of the meteorological station had continuous measurements for 30 years (9 out of 13). According the provided methodology only the solar radiation from the vegetation months was taken (April through October).

This database was then transferred in GIS environment. Each meteorological point was updated with the parameter for solar radiation. Using the data in the meteorological points an interpolated map of the whole territory of Macedonia was created using the IDW (Inverse Distance Weighting) algorithm. Finally this map was reclassified according the given methodology in order to produce the vulnerability map for solar radiation.

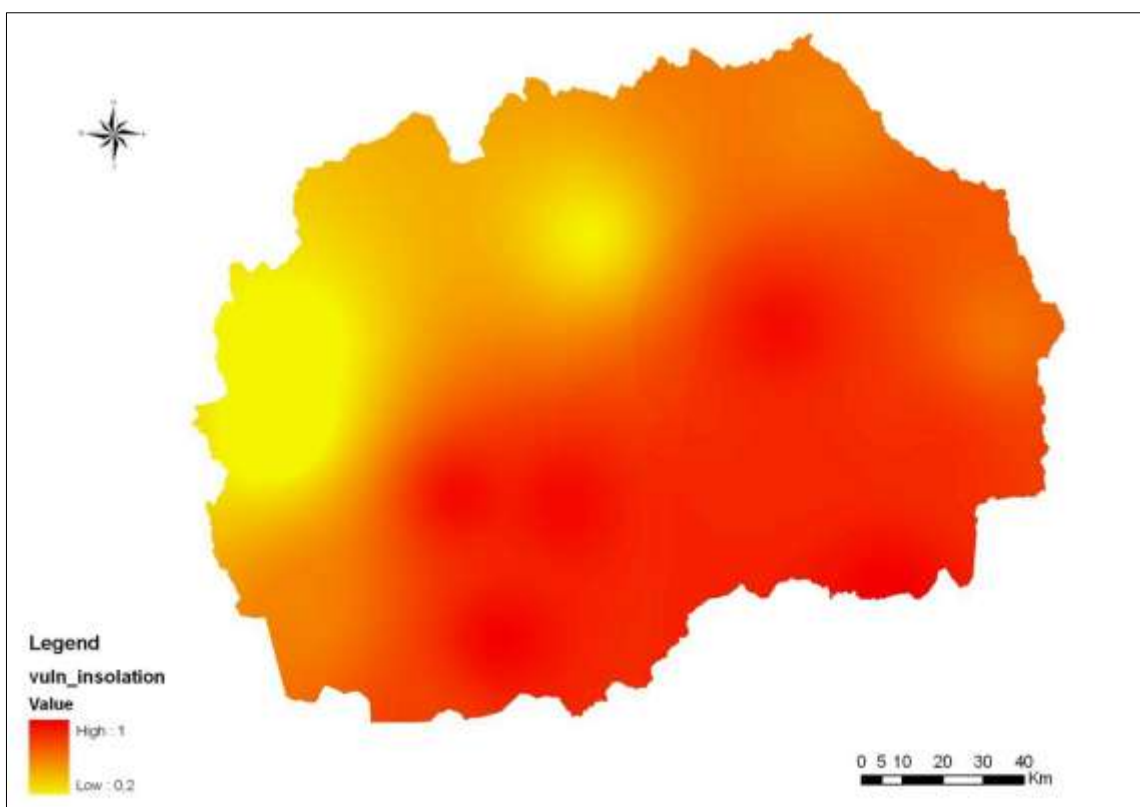


Figure 3: Solar radiation vulnerability map

4.3.4. Land cover/use

For the development of the parameter Land cover/use the Corine land cover/use map 2000 was used. This land cover map was developed according the methodology of European Environmental Agency on the scale 1:100.000 with minimal mapping unit of 25 ha and with 3 hierarchical levels.

Landuse	Type of landuse (CLC100)	Vulnerability class
	223, 243, 244, 311, 312, 313, 324	0,2
	221	0,4
	241, 242, 321, 322, 323, 333	0,6
	222	0,8
	211, 212, 213 + hierarchical class 1	1

Table 3: Landuse vulnerability classes

The provided methodology for classification of the vulnerability of the land use covered only the classes: agricultural areas, forest and semi natural areas. In order to obtain a map of the whole territory of the country also the other classes were included. Namely the class artificial surfaces were classified in the highest vulnerability class (1) and the classes water bodies and wetland were classified in the lowest vulnerability class (0,2).

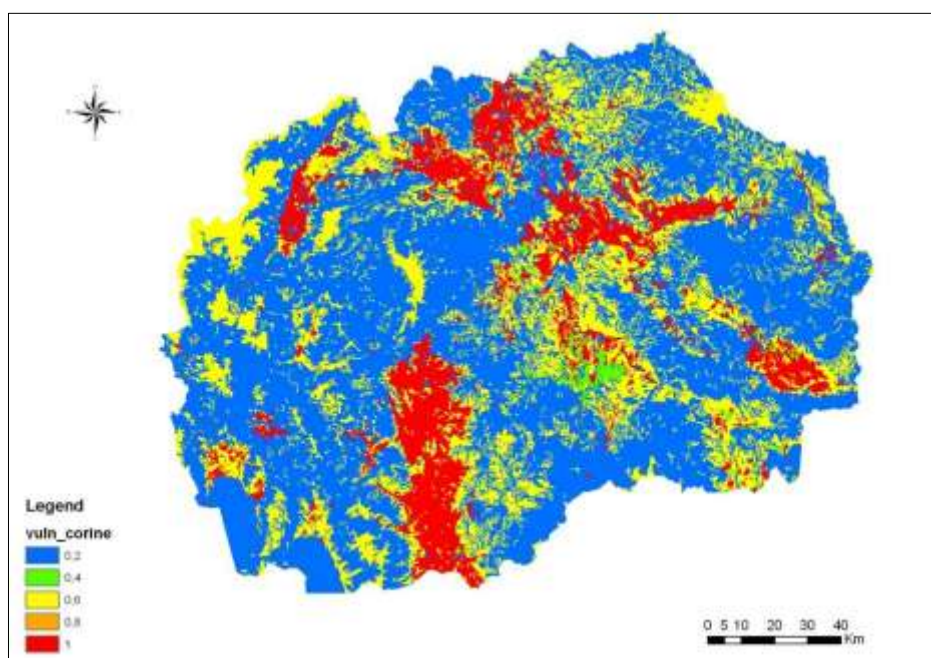


Figure 4: Landuse vulnerability map

4.3.5. Precipitation

This parameter was acquired from the Hydrometeorological Service of Republic of Macedonia. The data was provided in table form. For this model, from the national network were used 51 meteorological stations, which had continuous measurements for 30 years

(1971- 2000). The precipitation from each month was summed up in order to get the annual precipitation. Further on, average precipitation was calculated from the annual precipitation. Also this was done for the standard deviation for each meteorological station. Then the precipitation was divided with the standard deviation. This took care of creation of the database. This database was then transferred in GIS environment. Each meteorological point was updated with the parameter for precipitation. Using the data of the meteorological points, an interpolated map of the whole territory of Macedonia was created using the IDW (Inverse Distance Weighting) algorithm. Finally this map was reclassified according the given methodology in order to produce the vulnerability map for precipitation (Figure 5).

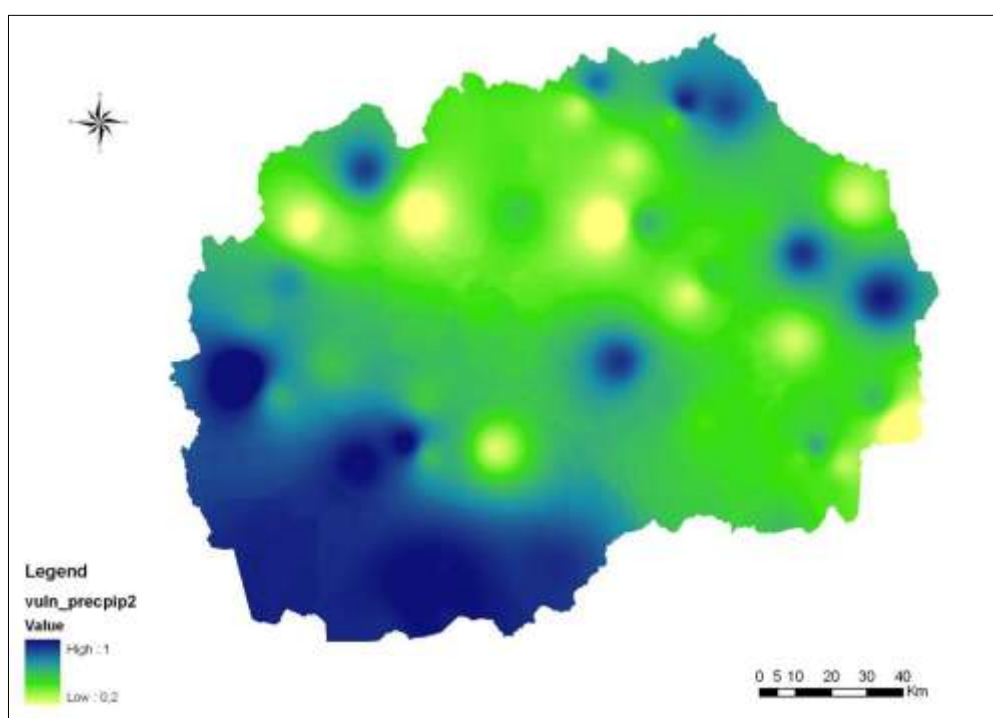


Figure 5: Precipitation vulnerability map

Soil type	Soil type	Vulnerability class
	Histosols (HS)	0,2
	Gleysols (GL), Luvisols (LV)	0,4
	Cambisols (CM), Chernozems (CH), Fluvisols (FL)	0,6
	Phaeozems (PH), Solonetz (SN)	0,8
	Arenosols (AR), Leptosols (LP), Solonchaks (SC), Vertisols (VR)	1

Table 4: Soil type vulnerability classes

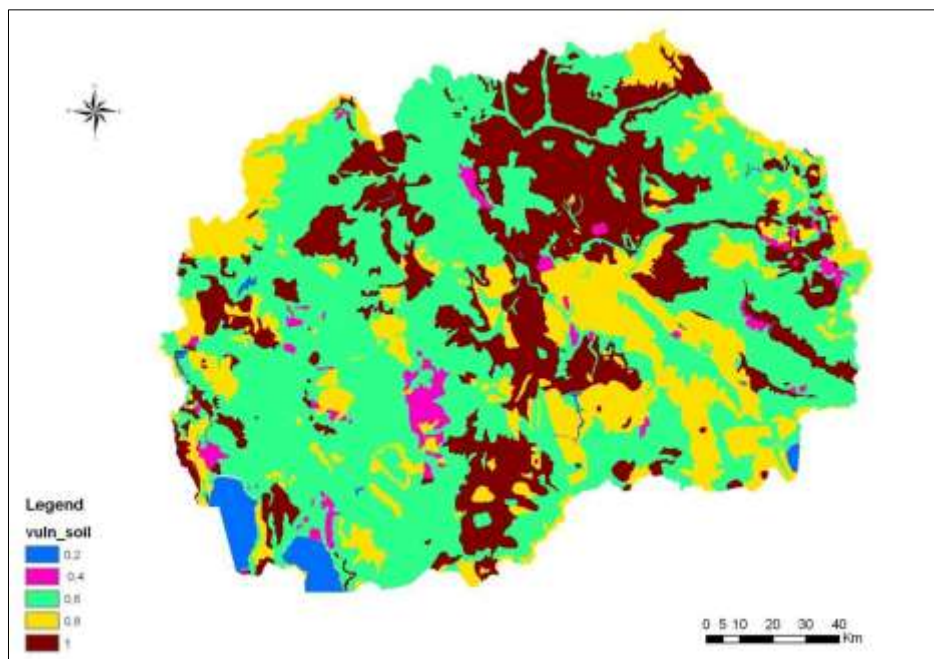


Figure 6: Soil vulnerability map

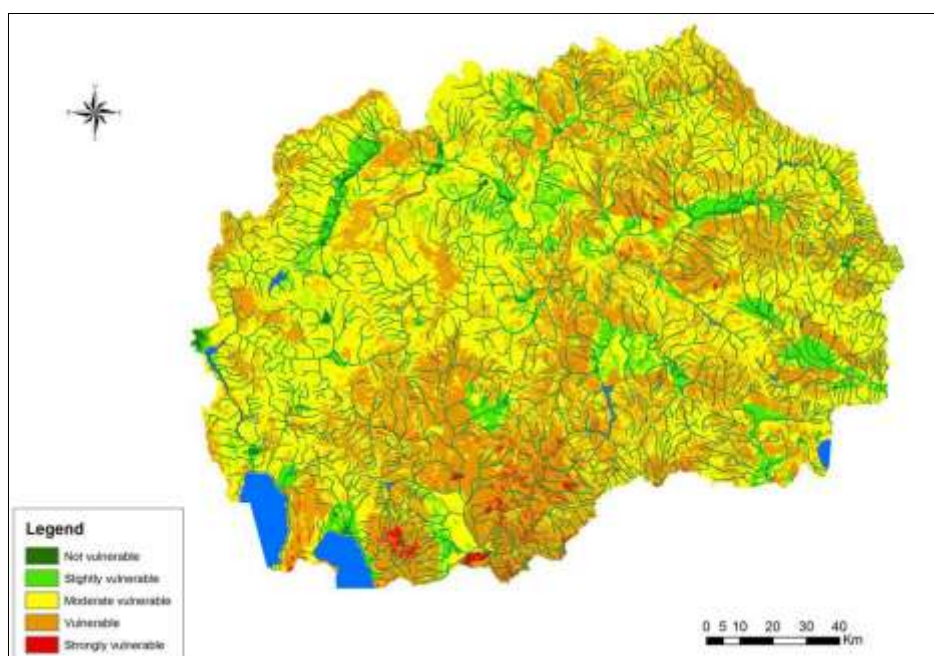


Figure 7: Drought vulnerability map

4.3.6. Soil type

The Soil map (Figure 6) of Republic of Macedonia was acquired from the Agriculture Institute-Skopje in vector format. The soil type classes were reclassified according the provided methodology (Table 4).

4.3.7. Preparation of the final vulnerability map of the area

After the creation of the separate criteria/parameters the final vulnerability map of the area was developed. According the provided methodology, the separate parameters were summed. Finally the map was reclassified creating five equidistant vulnerability classes (Figure 7).

4.4. CONCLUSIONS

The developed model for estimation the drought vulnerability is good starting point for estimation of large scale studies for our territory. Also it is a guideline for estimating the vulnerability.

4.5. REFERENCE

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Drought in the Mediterranean: WWF Policy Proposals; WWF report 2006

5. MONTENEGRO

Authors:

Contact person:

Organization: Meteorological and Hydrological Service of Montenegro

5.1. INTRODUCTION

Pursuant to the methodology in the output standards for this activity, the drought vulnerability maps were calculated from the category maps created of necessary parameters (slope angle, sunshine duration, precipitation) and optional parameters (land use and soil type).

5.2. SLOPE

This layer presents the slope map where the inclination was calculated from the digital elevation model (DEM) of 250 m resolution. The data was obtained from the UNDP in Montenegro.

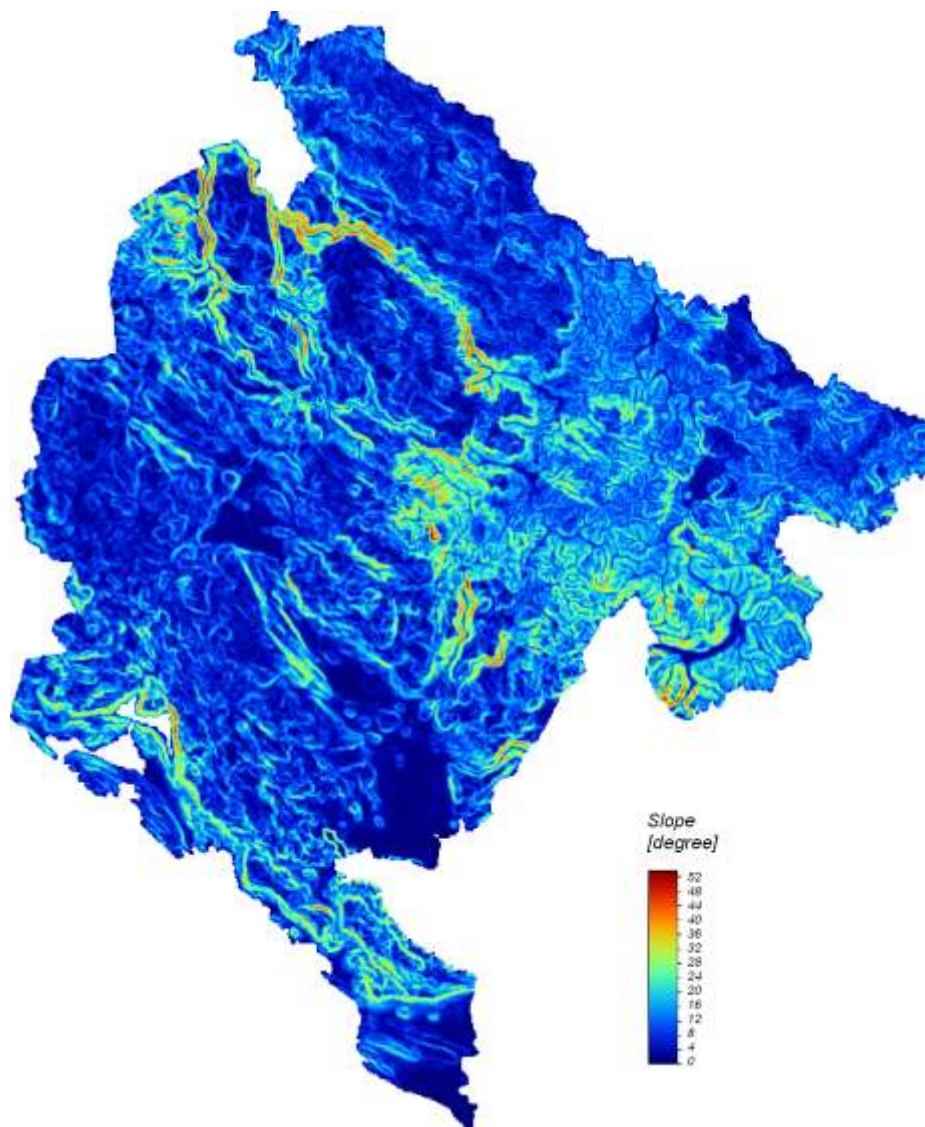


Fig. 1: The slope map of Montenegro.

According to the relief of Montenegro, the average height of the land is around 1050 m above sea level (asl). Approximately, 70% of the total surface is between 500 m and 1500m asl, while less than 10% is below 200 m asl. The lowest heights are along the narrow coastal belt and in the surrounding of Podgorica city, Ćemovsko field, Crmnica field and the valley of the river Zeta up to Danilovgrad town.

Considering the runoff and exposure, three dominant slopes are marked off:

- The slopes that belong to the lowest vulnerability class from 0.2 and 0.4;
- The slopes that belong to the vulnerability class 0.6, and
- The slopes that belong to the vulnerability class 0.8.

In the figure 1, orange to red colors of the slope angle (35° - 54°) refers to the river canyons (Tara, Piva, Komarnica, Morača, and their tributaries) and the mountain slopes too in the central to eastern parts as well as in the vicinity of the coast.

5.3. SUNSHINE DURATION

This layer presents the sunshine duration data for the vegetation period from April to September, 1991-2011. This layer presents combination of 2 maps. First map was calculated from the measured observed data of sunshine duration from 10 meteorological stations with Kriging method and second map of potential solar irradiation also for period April-September calculated with SAGA.

The region of Montenegro, especially its southern parts are abundant with sunshine hours. As it could be seen from the figure 2, the highest sunshine duration is on the coastal area (particularly in the Ulcinj's field), and in the valley of the rivers Zeta and Morača.

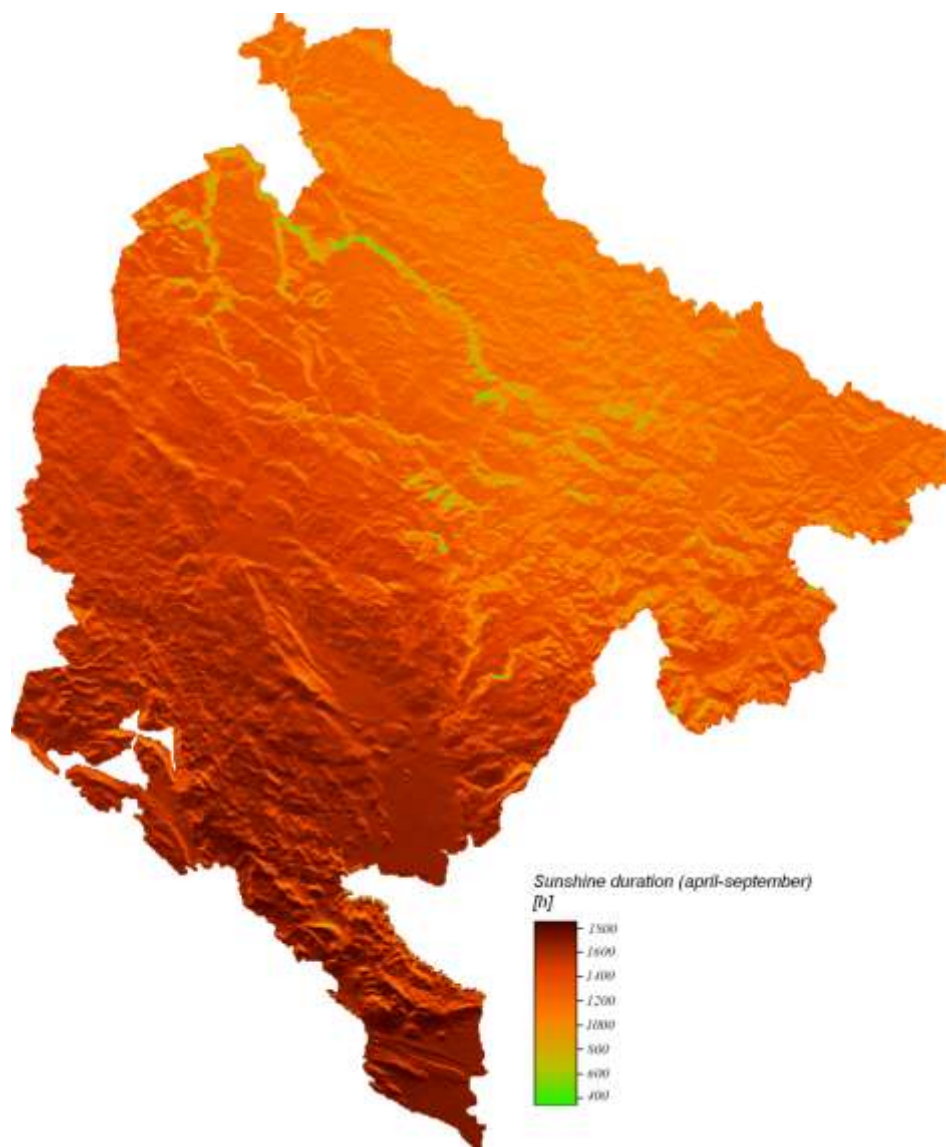


Fig. 2. The sunshine duration map of Montenegro based on the measured data in the period 1991-2011.

5.4. PRECIPITATION

5.4.1. Mean annual precipitation for the 1971–2000 period

The data from 59 stations were used to create the layer of mean annual precipitation for the period 1971–2000. For mapping, Kriging method was used.

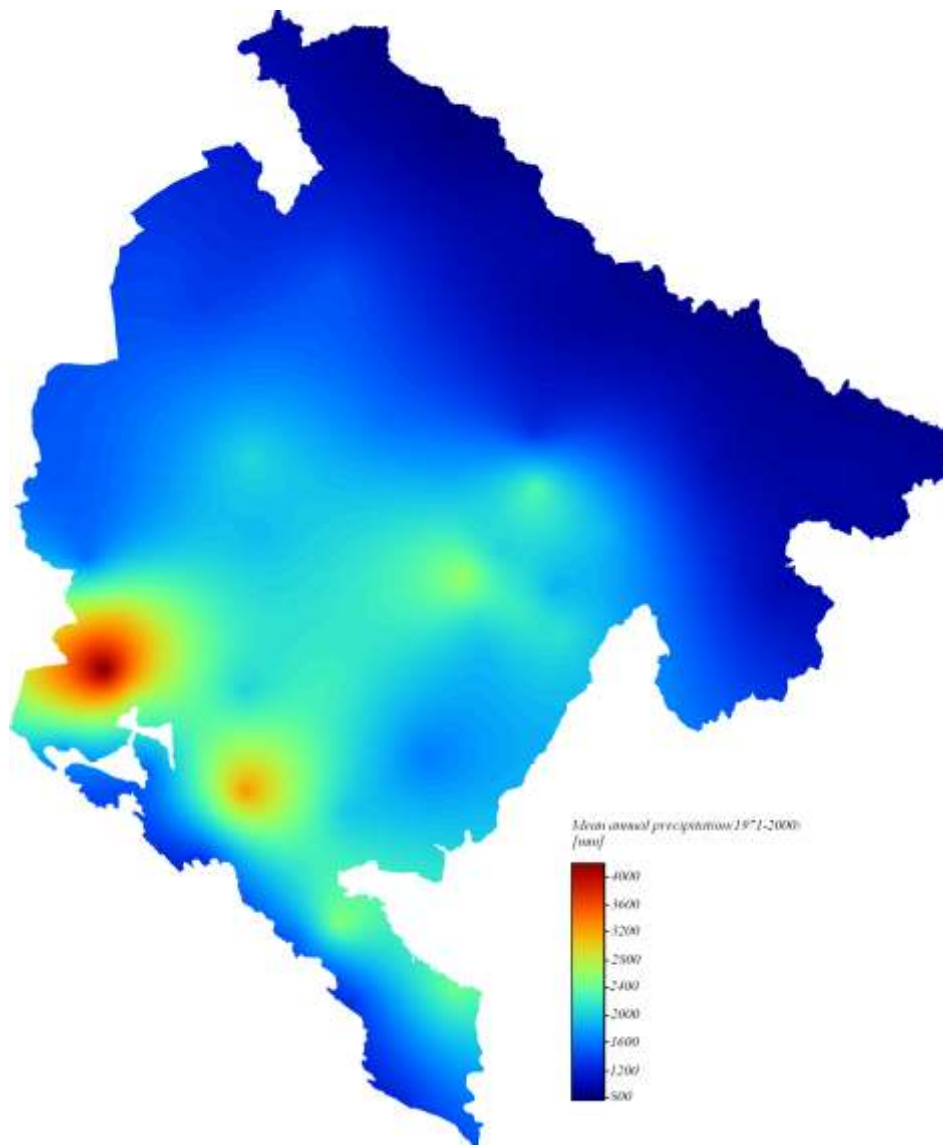


Fig. 3. The mean annual precipitation for the period 1971–2000.

The average annual precipitation has non-steady spatial character, figure 3. Due to the impact of orography, average annual values of precipitation range from around 800 mm on the north to around 5000 mm on the southwestern region (the slopes of the mountain Orjen), figure 3.

5.4.2. Standard deviation of precipitation for the 1971–2000 period

The standard deviation of annual precipitation is presented in figure 4. For mapping, Kriging method was used.

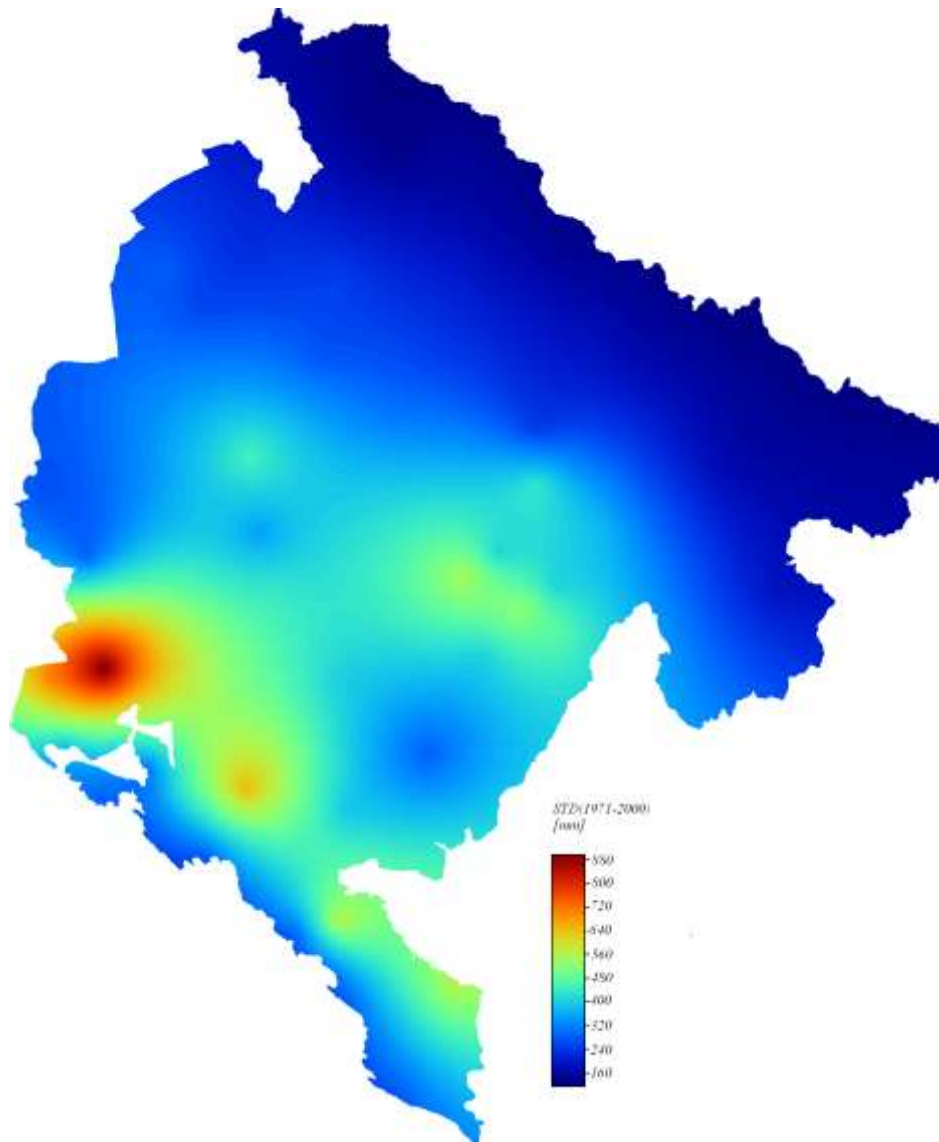


Fig. 4: The standard deviation of annual precipitation for the period 1971–2000

5.4.3. The ratio of precipitation and standard deviation

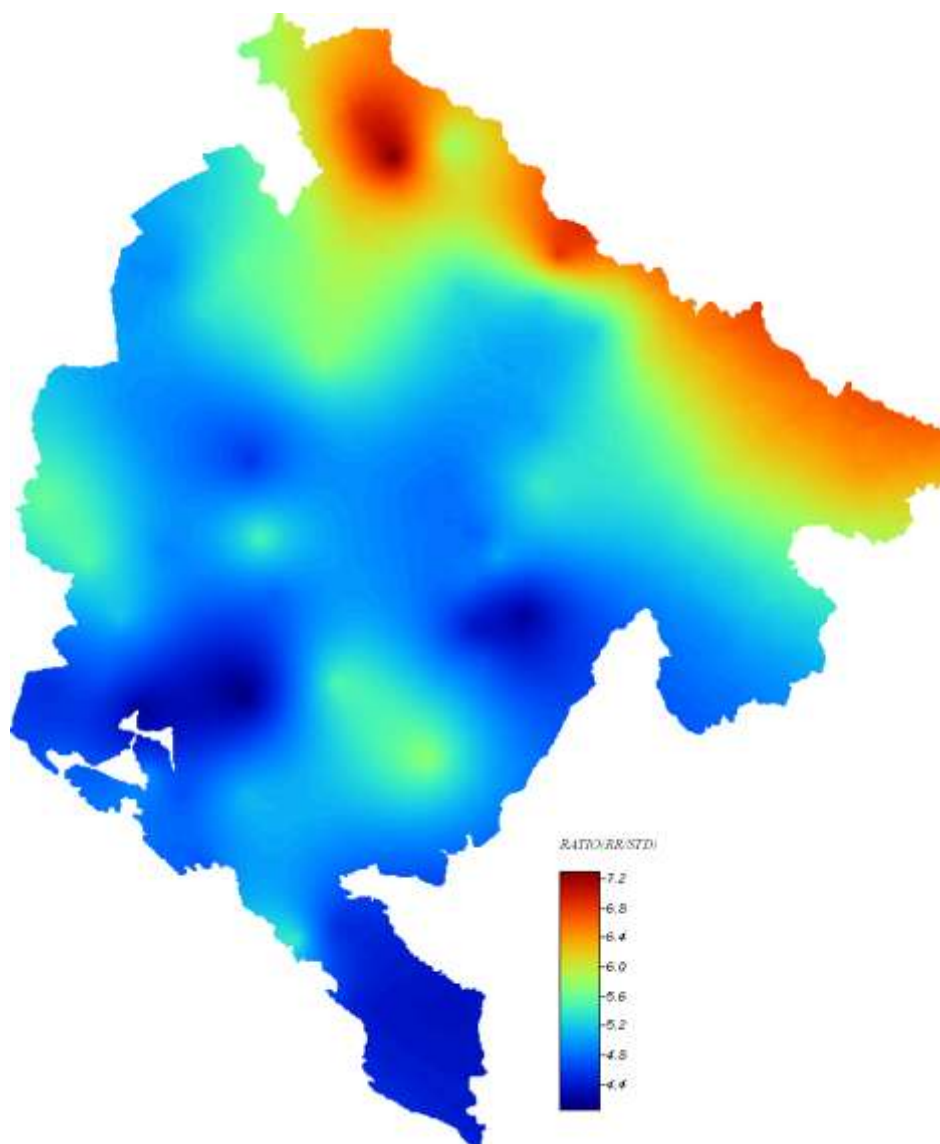


Fig. 5: The ratio of precipitation and standard deviation for the period 1971–2000

5.4.4. Ratio of standard deviation and precipitation

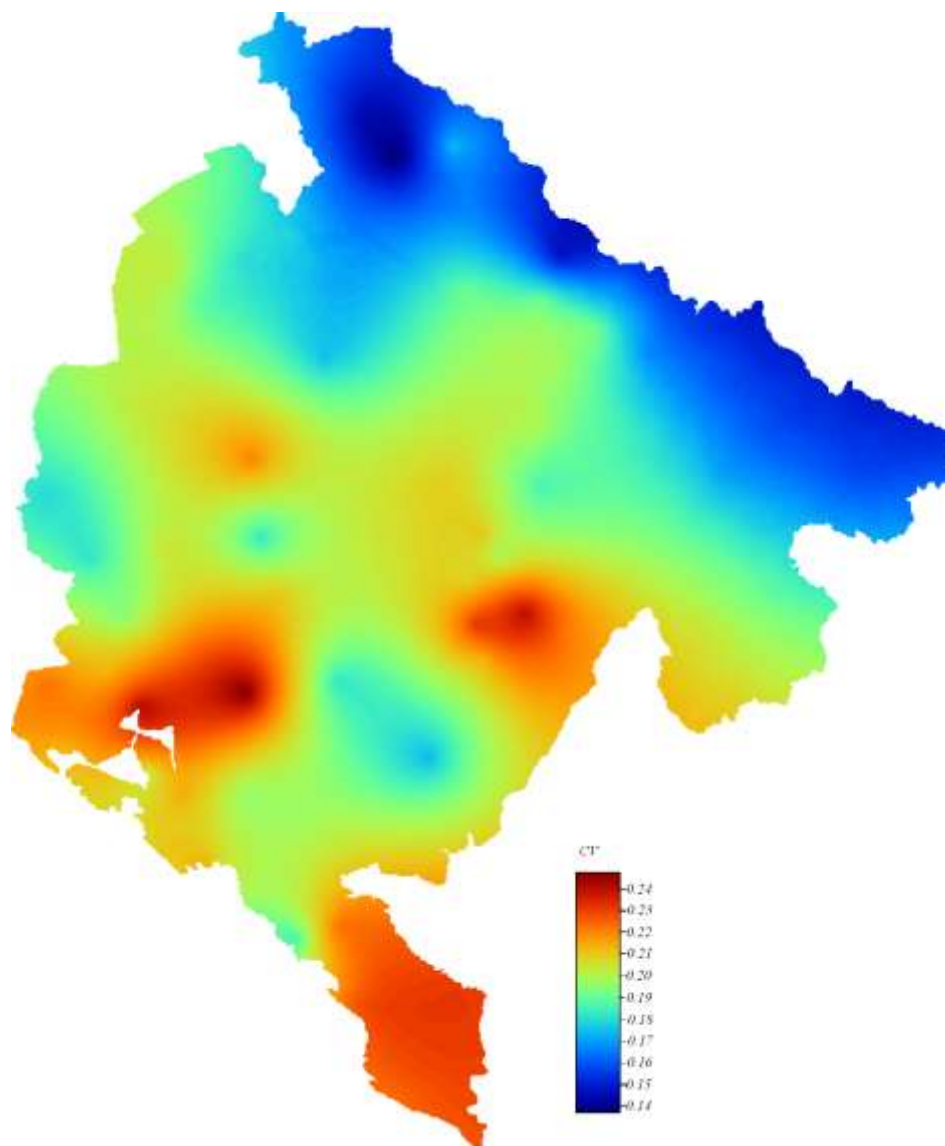


Fig. 6: The coefficient of variation to precipitation.

5.5. LAND USE MAP

To map land use, the Coreine Land Cover 2000 vector database was used.

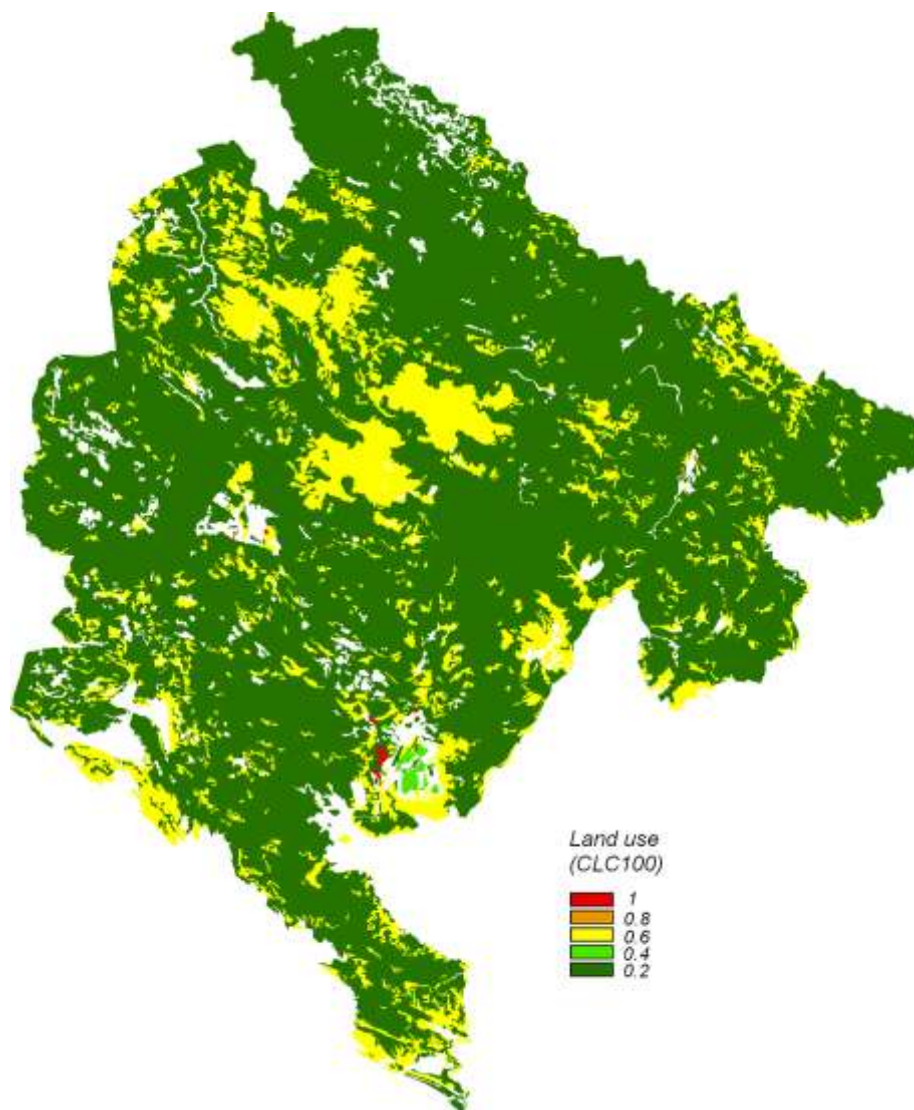


Fig. 7 Land use category map

Vulnerability class	Description	Code
0.2	Olive groves, Land principally occupied by agriculture, with significant areas of natural vegetation, Broad-leaved forest, Coniferous forest, Mixed forest, Transitional woodland-shrub	223, 243, 311, 312, 313, 324
0.4	Vineyards	221
0.6	Complex cultivation patterns, Natural grasslands, Moors and heathland, Sclerophyllous vegetation, Sparsely vegetated areas	242, 321, 322, 323, 333
0.8	Fruit trees and berry plantations	222
1.0	Non-irrigated arable land	211
	Without vegetation, water area	

Table 1: Description of the classes for the land use map

5.6. SOIL MAP

The Map of World Soil Resources (WRB) at the scale 1:25.000.000 as a World Soil Resources Coverage (WSRC) was used for soil data.



Fig. 8: Soil classes based on WRB (FAO) soil categories

5.7. DROUGHT VULNERABILITY MAP

Pursuant to instructions in output standards, the procedure of reclassifying was applied.

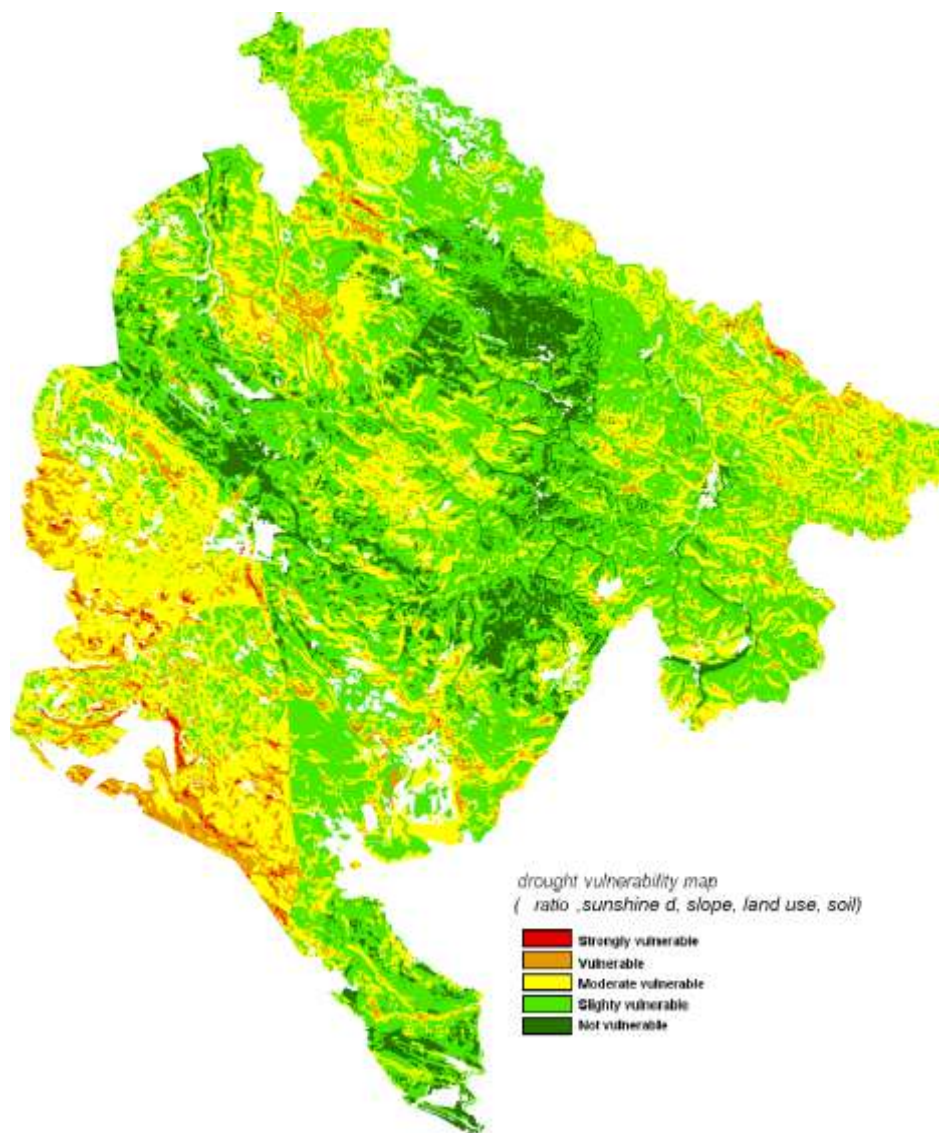


Fig. 9: Categorical drought vulnerability map calculated from the category maps of slope, sunshine duration, ratio of precipitation and standard deviation, land use and soil.

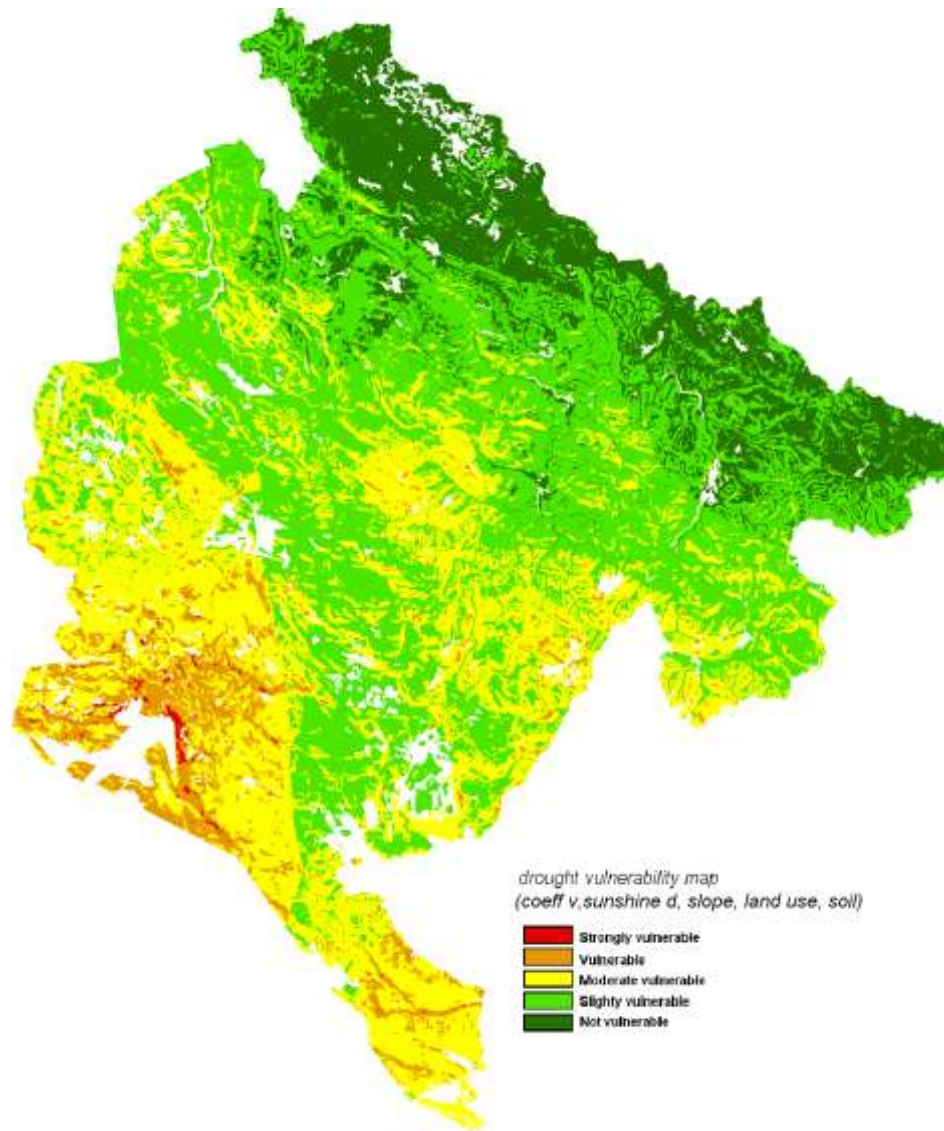


Fig. 10: Categorical drought vulnerability map calculated from the category maps of slope, sunshine duration, coefficient of variation of precipitation, land use and soil.

From the figure 10, it could be concluded that the agricultural areas are mostly moderate vulnerable to the droughts.

5.8. THE DATA SET DESCRIPTION

The following dataset was used:

- Digital elevation model obtained from the UNDP in Montenegro
- The Corine land cover/use map 2000
- The Map of World Soil Resources (WRB) at the scale 1:25.000.000
- Precipitation data and solar radiation

5.9. REFERENCES

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The climate reports and analysis of Hydrometeorological Institute of Montenegro

Spatial Plan of Montenegro

6. SERBIA

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6.1. INTRODUCTION

According to proposal of WP4 - Drought risk assessment; Activity 4.2.1 – Drought vulnerability estimates based on climatological and geomorphological data, drought vulnerability map is obtained using: slope angle, sunshine duration, annual precipitation and its' standard deviation, land use and soil type.

6.2. SLOPE ANGLE

Slope angle is derived from SRTM-DEM digital elevation data (100m resolution) using Local morphometry module from SAGA-GIS software. Because slope angle is in radian, Grid Calculator is used to get slope angle in degrees, multiplying original grid values by 57.2958.

The range of slope angle is between 0° (lowlands and river valleys) and 85° (mountains) which means that all five categories of vulnerability classification are present.

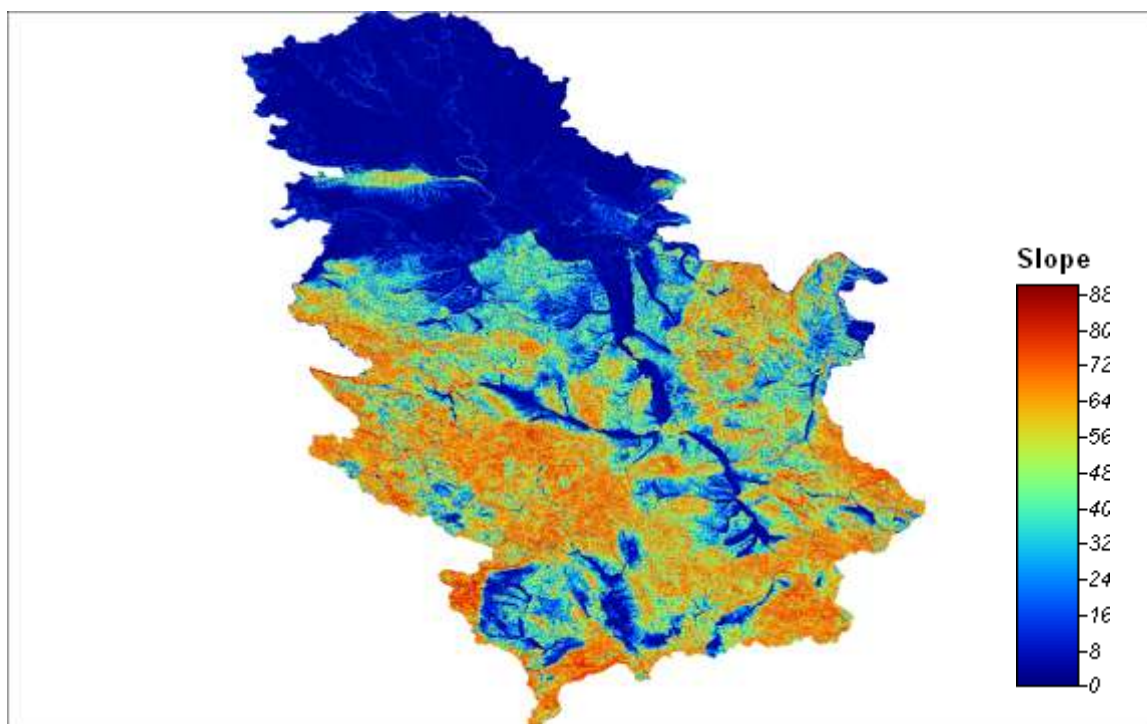
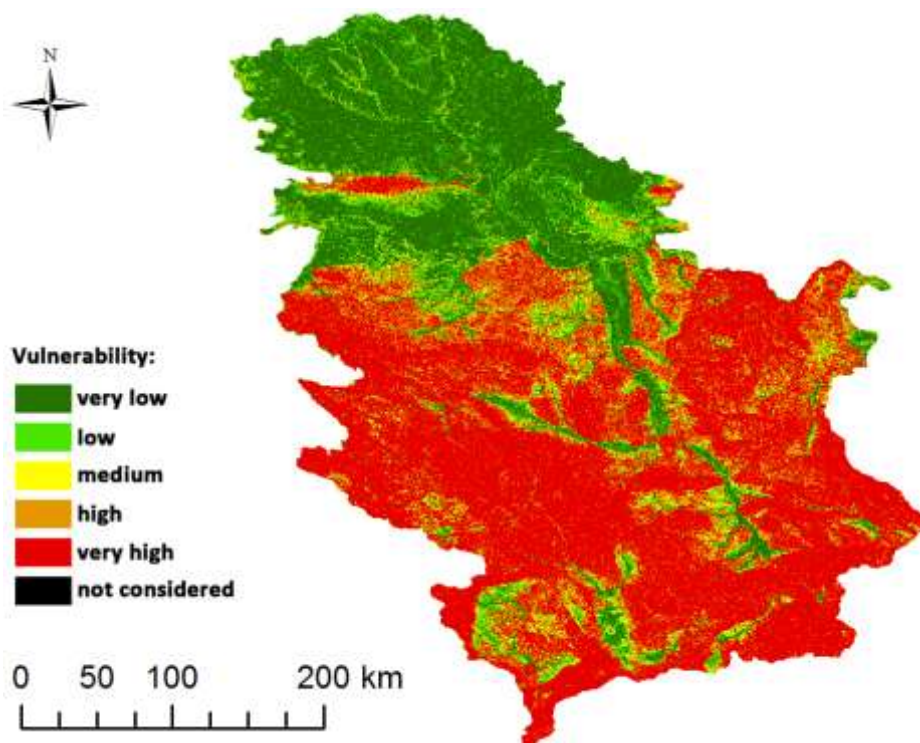


Figure 1. – Map of slope angle (in degrees)



Angle (°)	Vulnerability class	Area (%)
0 - 5	0.2	24.4
5 - 12	0.4	9.3
12 - 20	0.6	5.4
20 - 35	0.8	11.1
35 - 90	1.0	49.8

Figure 2. – Vulnerability map of slope angle

6.3. SUNSHINE DURATION

Data from 26 stations are used for geomorphological map of sunshine duration. Source of the data is RHMSS. Data are the mean of sunshine duration during vegetation period, from March till November, for the period 1971-2000. Universal kriging is used as method of interpolation.

Northern and Eastern Serbia have the longest sunshine duration, and thus the highest vulnerability, while the shortest is in southwest. NE-SW gradient of insolation is evident.

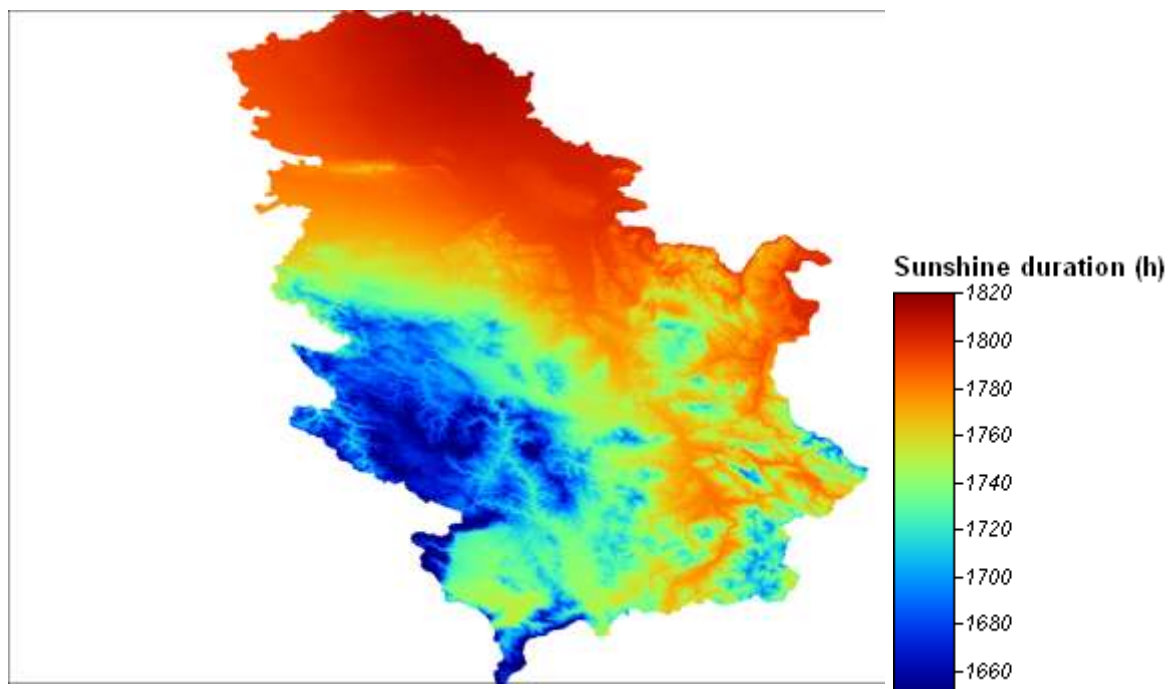


Figure 3. – Map of sunshine duration during vegetation period (in hours)

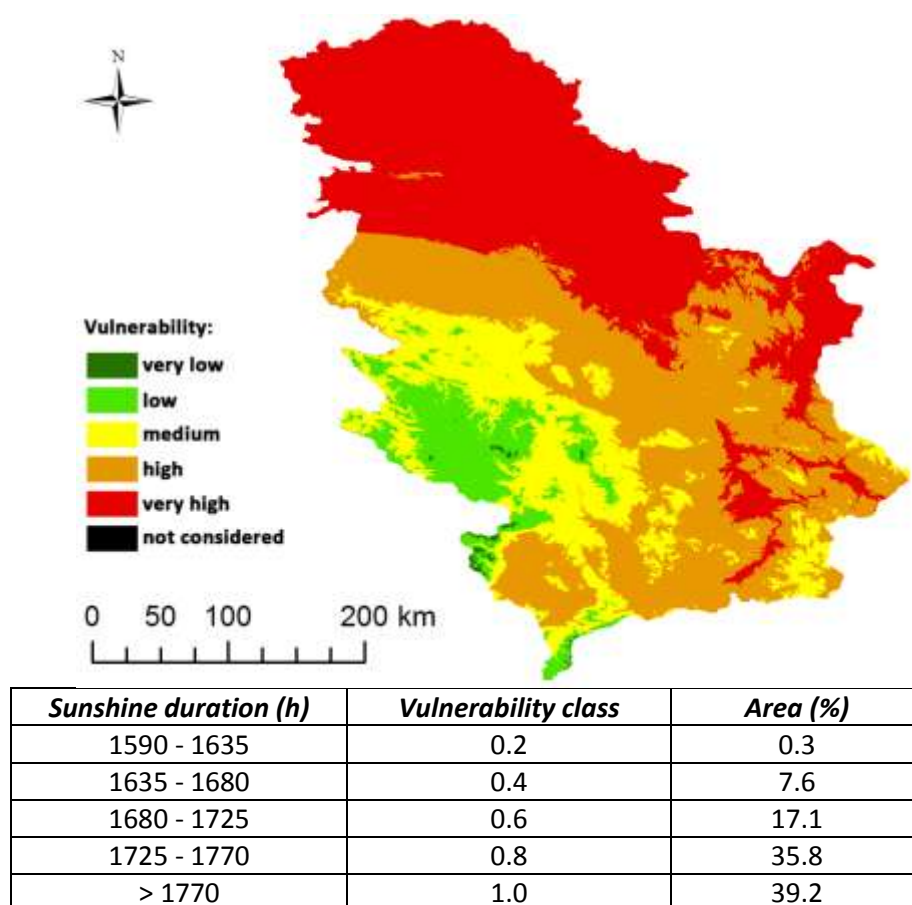


Figure 4. – Vulnerability map of sunshine duration during vegetation period

6.4. PRECIPITATION

Data source of precipitation and its' standard deviation is RHMSS. In both cases for interpolation of station values universal kriging method is used.

6.4.1 Mean annual precipitation

Mean annual precipitation for period 1971-2000 ranges from 550 to 1000mm. The highest amount of annual precipitation can be observed in the far west and south of Serbia. Northern Serbia, where the longest sunshine duration is, has the lowest precipitation amount (less than 600mm) and the highest vulnerability.

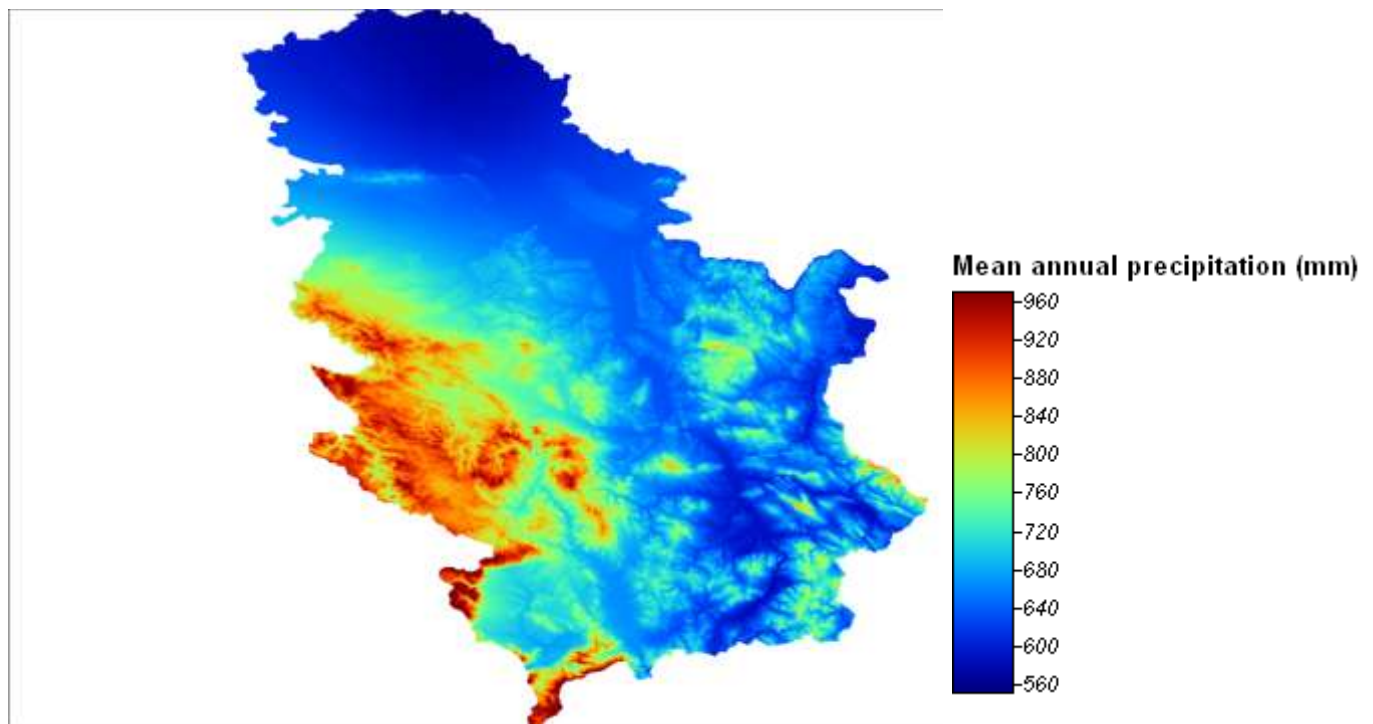


Figure 5. – Map of mean annual precipitation (in mm)

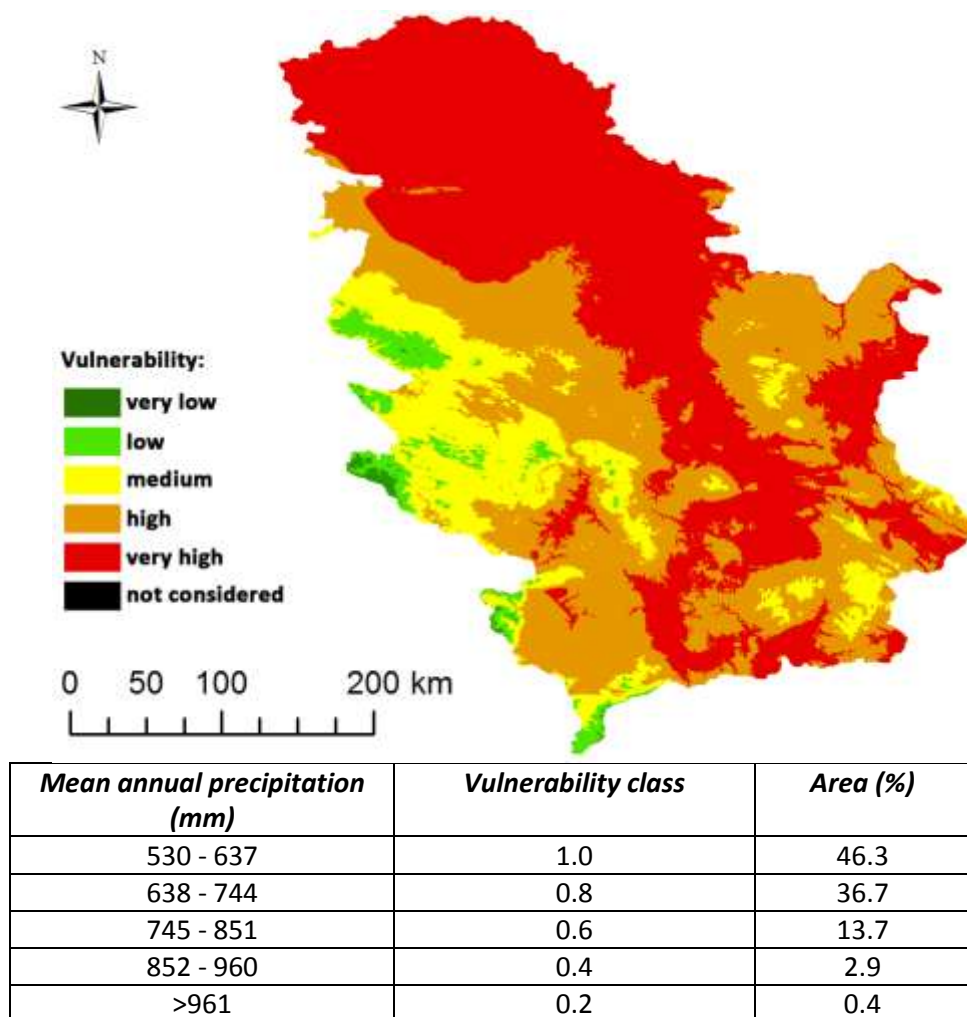


Figure 6. – Vulnerability map of mean annual precipitation

6.4.2 Standard deviation of the annual precipitation

East Serbia and mountain regions (up to 150mm) have the largest variation in annual precipitation, while the lowest is in region around South Morava river. In general, values of standard deviation range from 100 to 150mm.

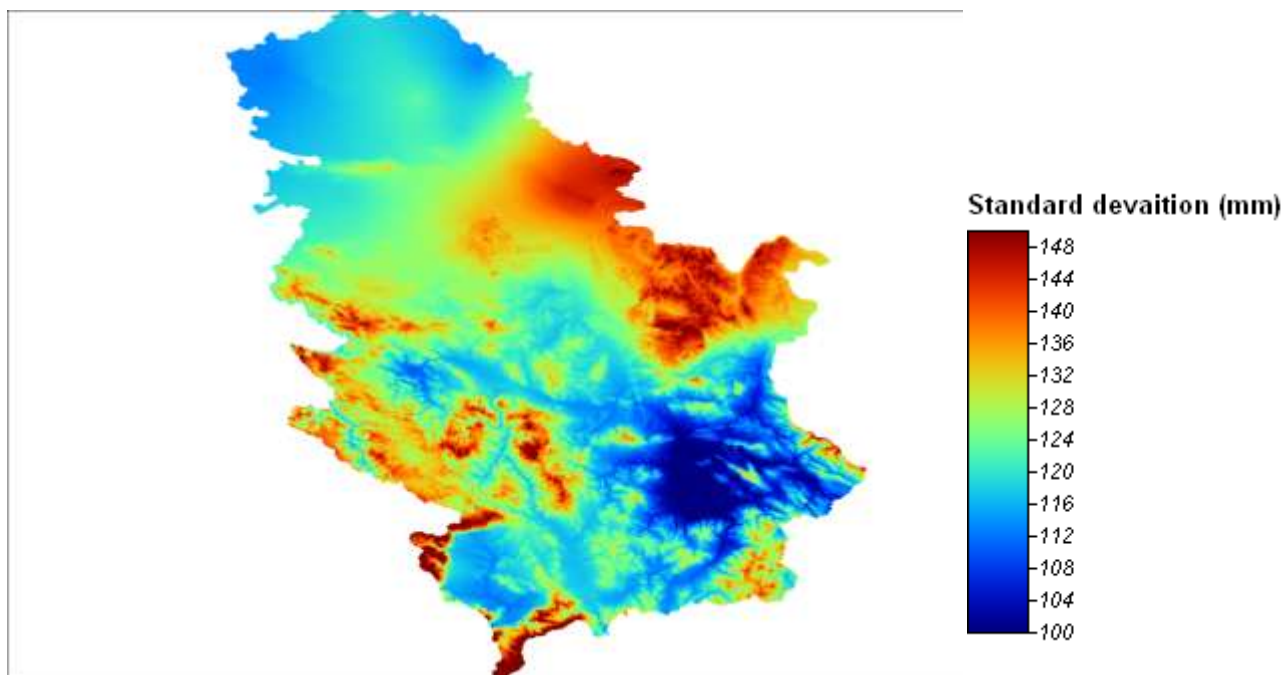


Figure 7. – Map of standard deviation of annual precipitation (in mm)

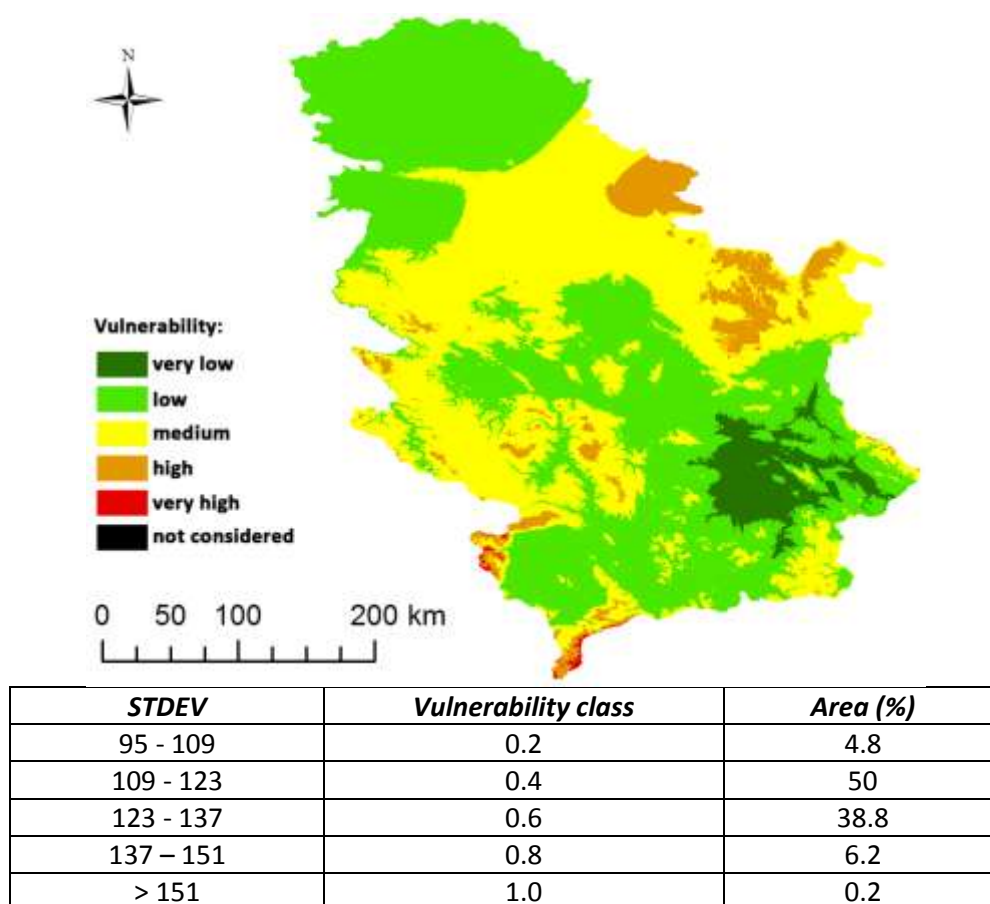


Figure 8. – Vulnerability map of standard deviation of annual precipitation

6.4.3 Coefficient of variation

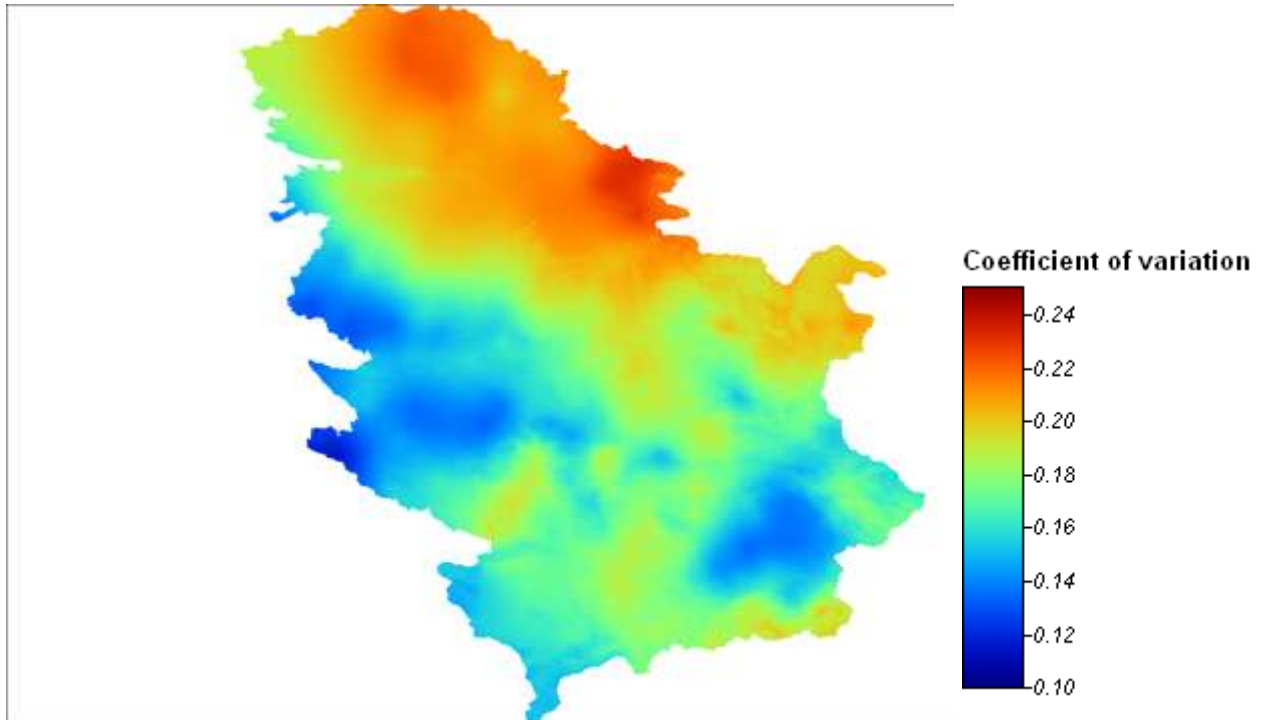


Figure 9. – Map of the coefficient of variation

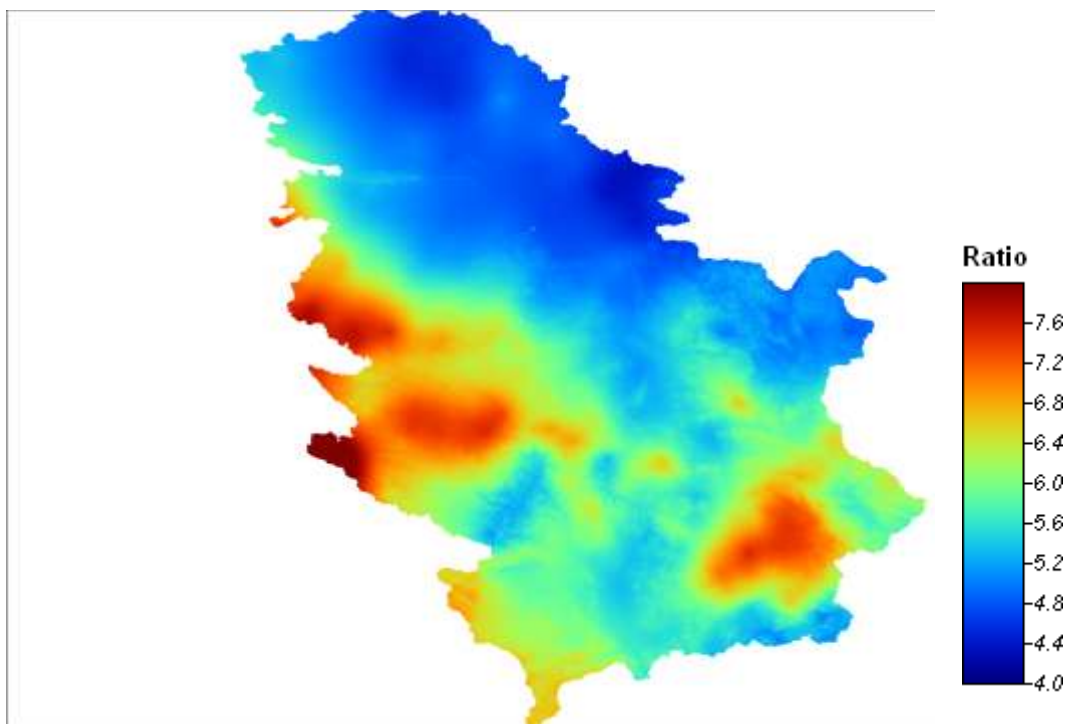


Figure 10. – Map of the ratio of annual precipitation and its' standard deviation

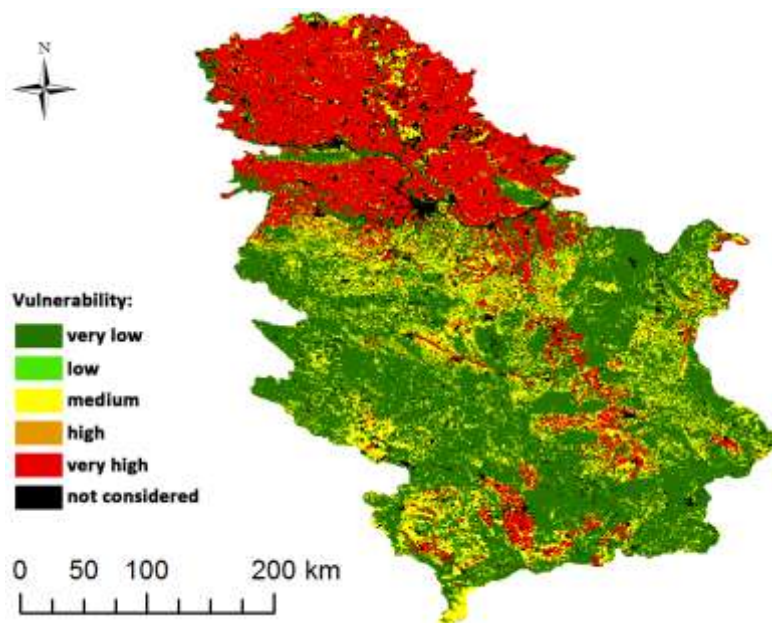
The coefficient of variations was adopted as a measure of precipitation variability in order to remove the dependency of the standard deviation on the mean precipitation. Coefficient is defined as the ratio of standard deviation to the mean and represents vulnerability to drought.

Coefficient values are between 0.1 and 0.25. It can be seen, that most of the Serbian territory is very sensitive to drought. Areas with the highest sensitivity are in North and East Serbia.

As proposed in Output standards for WP4, Activity 4.2.1, map of the ratio of annual precipitation and its' standard deviation is also done.

6.5. LAND COVER

Land use is one of the significant factors of agricultural drought vulnerability. Land use map is derived from CORINE Land Cover 2006 database. The input data was reclassified into six classes, regarding drought vulnerability. First class includes land principally occupied by agriculture and forests (~50% of Serbian territory). Those areas were considered as areas of very low vulnerability to drought. Areas considered as highly vulnerable to drought are areas that include fruit trees and berry plantations. Fifth class includes non-irrigated arable lands and those are areas of very high vulnerability to drought and occupy 24% of Serbia. Artificial surfaces, wetlands and water bodies are not taken into consideration of vulnerability assessment and because of that, vulnerability class of 100 was assigned to them for masking purposes.



<i>Description</i>	<i>Code</i>	<i>Vulnerability class</i>	<i>Area (%)</i>
Land principally occupied by agriculture, Broad-leaved forest, Coniferous forest, Mixed forest	243,311,312,313	0.2	49.5
Vineyards	221	0.4	0.2
Heterogeneous agricultural areas, Natural grasslands, Moors and heathland, Sclerophyllous vegetation, Sparsely vegetated areas	242,321,322,323,333	0.6	19.5
Fruit trees and berry plantations	222	0.8	0.1
Non-irrigated arable land	211	1.0	24.1
Artificial surfaces, Wetlands, Water bodies	111, 112, 121, 122,123, 124, 131, 132, 133, 141, 142, 334, 411, 511, 512	100	6.6

Figure 11. – Map of the land cover

6.6. SOIL TYPE

The soil map of Serbia was provided by the Department of Water Management, Faculty of Agriculture, University of Novi Sad. The most dominant soil types (52%) are arenosols, leptosols, solonchaks, vertisols. Those types of soil belong to class of the highest vulnerability and can be found mainly south of the Sava and the Danube river. Cambisols, chernozems, fluvisols are also well represented in 31% of the area.

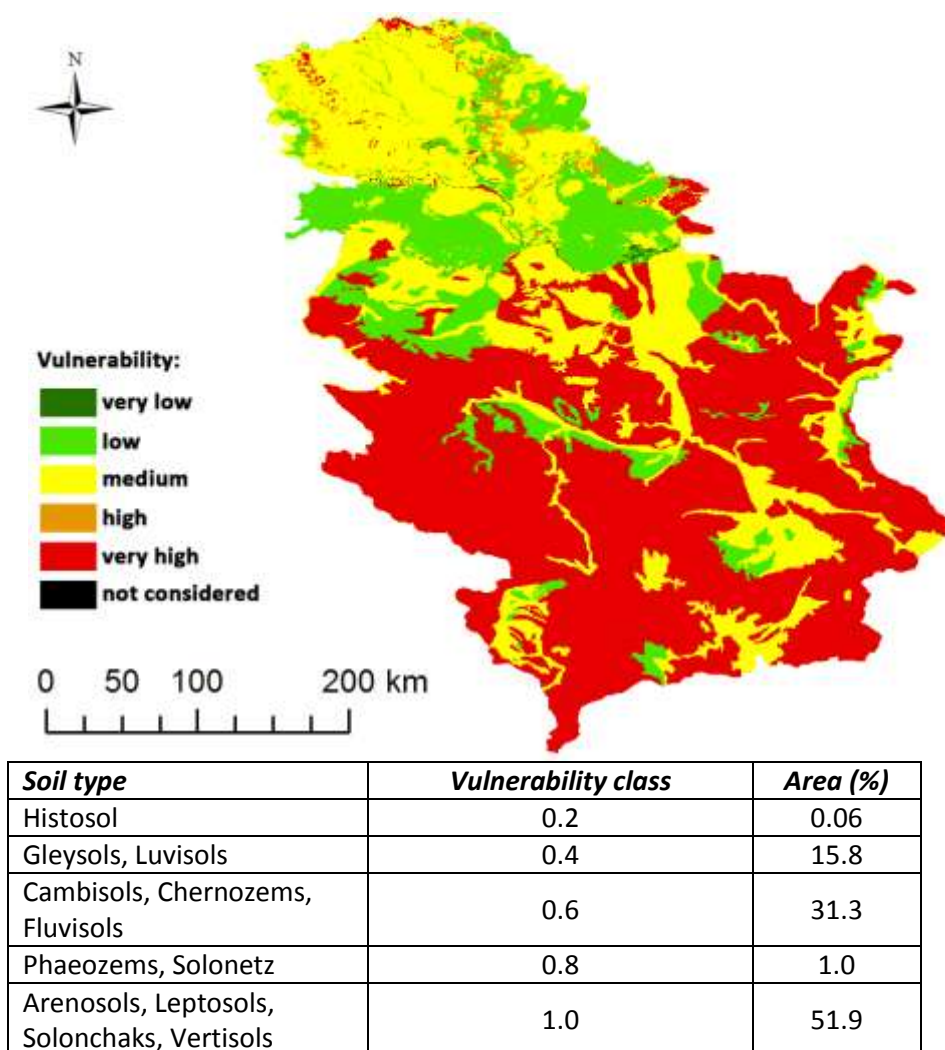


Figure 12. – Map of the soil type

6.7. VULNERABILITY MAP AND CONCLUSIONS

The category maps were created reclassifying the parameter maps using SAGA GIS software and provided classification tables.

According to the proposed methodology, the resulting drought vulnerability map was calculated as a sum of six previously created category maps. Resulting map was reclassified into five equidistant vulnerability classes and one additional class for masking out the areas that were not included in the vulnerability assessment.

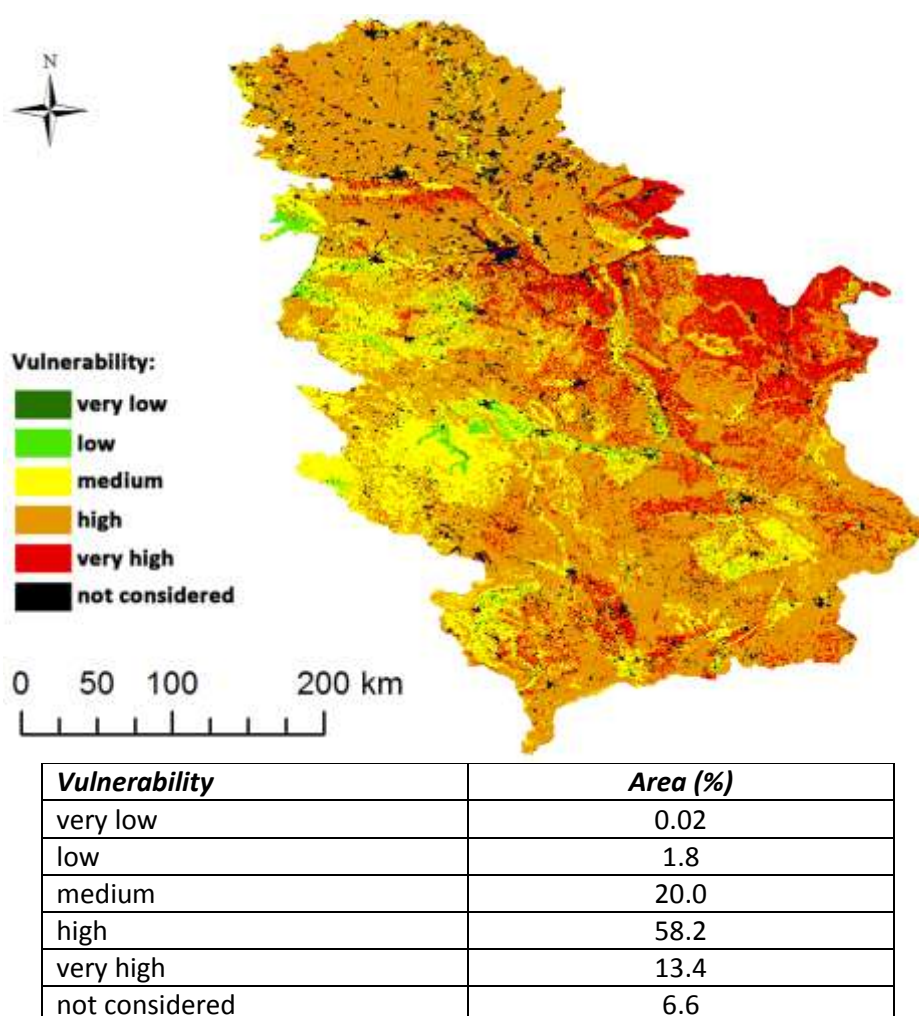
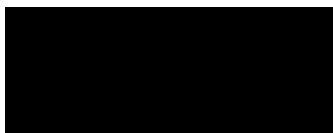


Figure 13. – Vulnerability map for Serbia

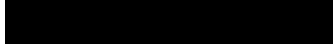
It can be seen, that major part of Serbian territory is 'high' (58%) to 'very high' (13.4%) vulnerable to drought. The highest vulnerability can be observed in Eastern Serbia and around river valleys. Medium vulnerability covers 20% of area.

7. SLOVENIA

Authors:



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Organization: Environmental Agency of Slovenia
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7.1. INTRODUCTION

Different definition of vulnerability exist, in general we could say that vulnerability is the degree to which people, property, resources, systems, and cultural, economic, environmental, and social activity is susceptible to harm, degradation, or destruction on being exposed to a hostile agent or factor.

When we speak about crops vulnerability to drought, we can define the vulnerability of crops to drought as the degree to which crops are likely to experience harm (= reduction in growth or yield) due to a drought (or drought stress).

Plant growth and productivity is adversely affected by nature's wrath in the form of various biotic and abiotic stress factors. Water deficit is one of the major abiotic stresses, which adversely affects crop growth and yield. Drought is commonly defined as a period without significant rainfall. Generally drought stress occurs when the available water in the soil is reduced and atmospheric conditions cause continuous loss of water by transpiration or evaporation. Drought stress tolerance is seen in almost all plants but its extent varies from species to species and even within species (Jaleel et al., 2009).

So, how big the damage to crops will be depends on the vulnerability and exposure of crops and on the duration and severity of drought.

We find out, that the vulnerability of crops to drought depends on several parameters, the most important one being the adaptivity of the particular type of crops to drought stress and the microlocation of its growth (soil characteristics, amount of solar radiation, terrain configuration, etc.). Irrigation can, except in extreme situations, reduce or altogether eliminate the effects of drought stress.

Because the vulnerability of crops depends on several parameters, a multi-criteria decision analysis (MCDA) based on geographical information system (GIS) was used. Idrisi Taiga (Clark Labs) was chosen as appropriate GIS tool.

The purpose of assessing crop vulnerability to drought was to identify which factors most influence the vulnerability of crops. Then appropriate actions could be taken to reduce vulnerability before the potential for damage is realized. Also the crops vulnerability map could be used to assess the damage after a period of drought.

7.2. THE LIST OF APPLIED PARAMETERS

The first step in this process is digital GIS database development. Different types of parameters were taken into account. Based on literature review, analytical studies, reports on past drought impacts and expert opinions, the following parameters were chosen: amounts of plant available water in the soil (EFC), slope, solar radiation, land use and irrigation infrastructure.

To produce a reliable vulnerability map for crops vulnerability to drought, input data (in raster or vector/shape format) with as high spatial resolution as possible are need. The final spatial resolutions of input data layers were 100 x 100 meters; the resolution of the vulnerability map is determined by the layer with lowest spatial resolution.

7.2.1. Amounts of plant available water in the soil - EFC

According to the available remaining water in the soil, it depends on how long plants can thrive even in dry periods or how long the drought will not affect them. This information is presented by an input layer which presents the amounts of plant available water (EFC), which is a portion of the total amount of water in the soil. The value of EFC differs for different soil types. Data for the EFC layer was obtained from University of Ljubljana, Biotechnical Faculty, Centre for Soil and Environmental Science (CPVO). They prepared a data layer with resolution of 100 x 100 m. The EFC was calculated on the basis of input data on soil depth, density, volume, texture, organic matter, skeletal and consistency (Finnern model) in the corresponding profiles of individual soil types (PSE) (Zupan et al., 2007).

Parameters	Unite	Vulnerability classification			Factor weight	Source of input data
Amounts of plant available water in the soil (EFC)	[mm]	From [mm]	To less then [mm]	Vulnerability class	0.1915	University of Ljubljana, Biotechnical Faculty, Centre for Soil and Environmental Science (CPVO).
		230	271	1 (very low)		
		150	230	2		
		80	150	3		
		30	80	4		
		0	30	5 (very high)		



7.2.2. Slope

Parameters	Unit	Vulnerability classification	Factor weight	Source of input data																		
Slope	[°]	<table border="1"> <thead> <tr> <th>From [°]</th><th>To less then [°]</th><th>Vulnerability class</th></tr> </thead> <tbody> <tr> <td>0</td><td>5</td><td>1 (very low)</td></tr> <tr> <td>5</td><td>12</td><td>2</td></tr> <tr> <td>12</td><td>20</td><td>3</td></tr> <tr> <td>20</td><td>25</td><td>4</td></tr> <tr> <td>35</td><td>90</td><td>5 (very high)</td></tr> </tbody> </table> <p>The inclinations were calculated from the digital terrain model for Slovenia.</p>	From [°]	To less then [°]	Vulnerability class	0	5	1 (very low)	5	12	2	12	20	3	20	25	4	35	90	5 (very high)	0.0307	Scientific Research Centre of the Slovenian Academy of Sciences and Arts.
From [°]	To less then [°]	Vulnerability class																				
0	5	1 (very low)																				
5	12	2																				
12	20	3																				
20	25	4																				
35	90	5 (very high)																				

Parameters	Unite	Vulnerability classification			Factor weight	Source of input data
Slope	[°]				0.0307	Scientific Research Centre of the Slovenian Academy of Sciences and Arts.
		From [°]	To less then [°]	Vulnerability class		
		0	5	1 (very low)		
		5	12	2		
		12	20	3		
		20	25	4		
		35	90	5 (very high)		
		The inclinations were calculated from the digital terrain model for Slovenia.				

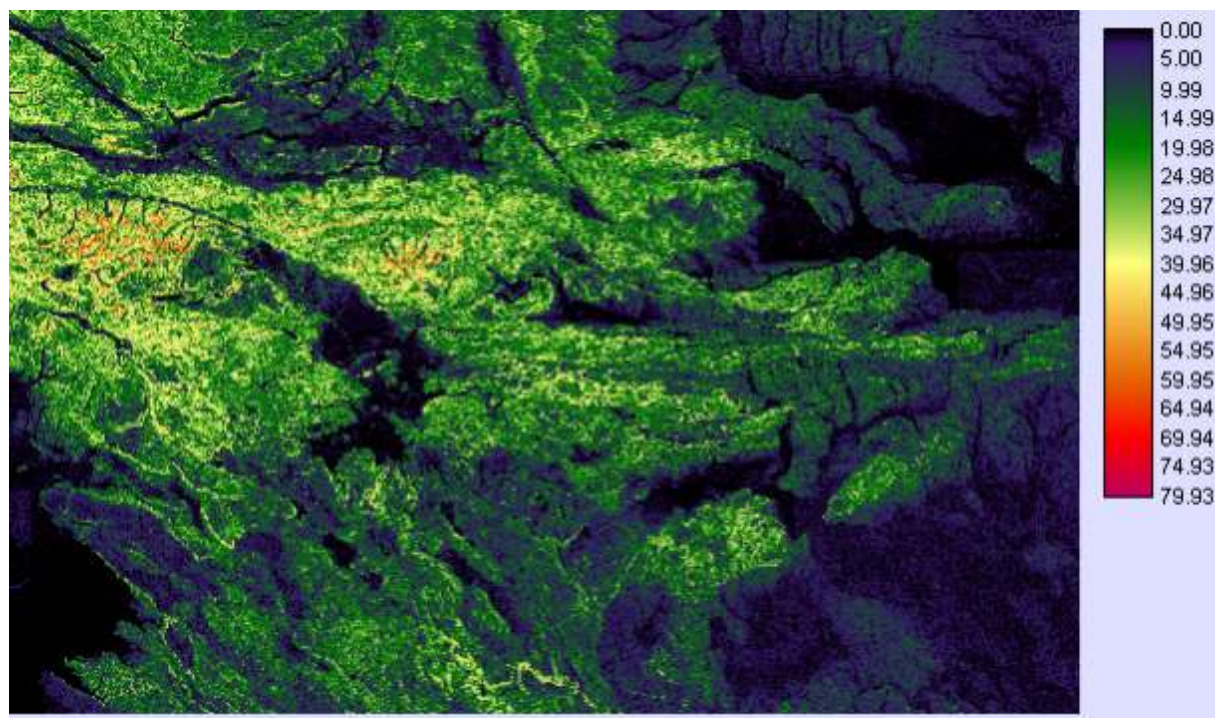


Figure 2: Map of slope [°] for Slovenia.

7.2.3. Solar radiation

Solar energy absorbed by the surface depends on the incidence angle of the sunlight to the ground, albedo of the surface, and on meteorological conditions (clouds, etc.). The input layer presents the amount of absorbed solar radiation in Slovenia for the vegetation period of the year (April - September). Data for Slovenia were obtained from the Scientific Research Centre of the Slovenian Academy of Sciences and Arts. The quasi-global radiation model was used to determine the solar illumination radiation of Slovenia. The solar energy depends mostly on the incidence angle defined by astronomical and surface parameters, and on meteorological conditions, especially duration of solar radiation. The surface parameters were calculated from the InSAR DMV 25 interferometric radar digital elevation model. The virtual Sun motion was simulated with equations derived from the astronomical almanac. Shade determination was considered as an important part of the model. If a part of the surface is in the shadow, it receives far less energy than sunny surfaces. Corresponding meteorological parameters were also integrated in the model. All calculations were done for hours and decades (ten-day periods). The annual quasi-global radiation energy was calculated as the sum of all energies over all decades (Zakšek et al., 2003).

Subsequently the quasi-global radiation energy was calculated only for the vegetation period (April-September) of the year.

Parameters	Unite	Vulnerability classification			Factor weight	Source of input data
Solar radiation	[MJm ⁻² /v.p.]	From [MJm ⁻² /v.p.]	To less then [MJm ⁻² /v.p.]	Vulnerability class	0.0316	Scientific Research Centre of the Slovenian Academy of Sciences and Arts.
		0	748	1 (very low)		
		748	1496	2		
		1496	2244	3		
		2244	2992	4		
		2992	3740	5 (very high)		
		Vegetation period of the year: April – September.				

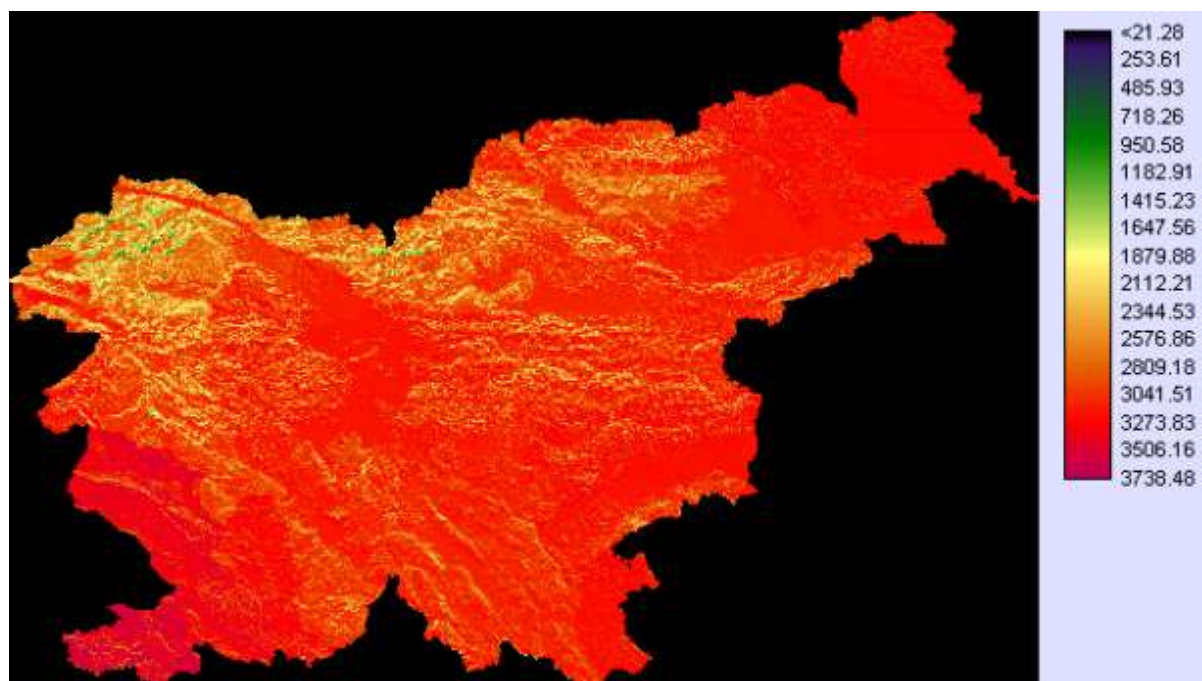


Figure 3: Map of solar illumination $[MJm^{-2}/v.p.]$ for Slovenia.

7.2.4. Land use

We are taking into consideration agricultural land only. The term “land use” refers to the types of crops that are growing in a location. This input layer presents the land use (vectorised polygon in national coordinate system), which is defined with Graphical Units of Agricultural Land (GERK) database – Slovenian Land Parcel Information System (LPIS). GERKs are defined as unified areas of agricultural land with a single land use and cultivated by the same owner on the base of aerial orto-photo images. Data for Slovenia is available from Ministry of Agriculture, Forestry and Food of the Republic of Slovenia (MKGP, 2011).

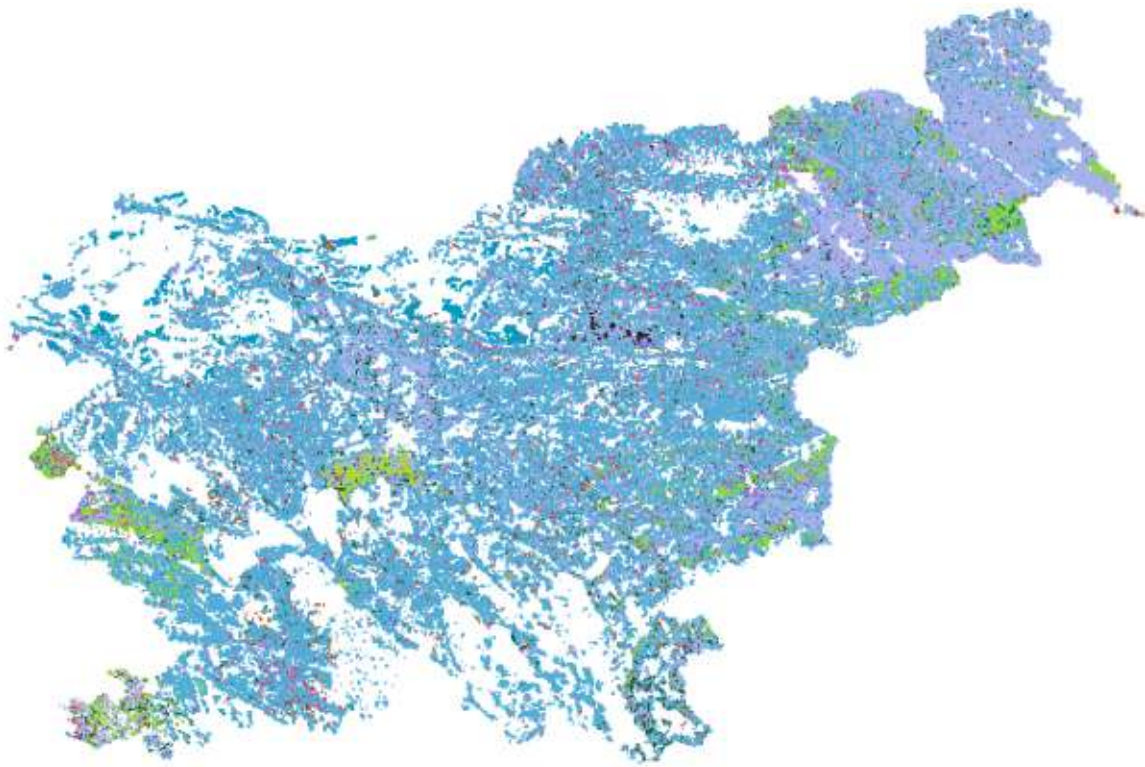


Figure 4: Map of agricultural land use for Slovenia (GERK, 2011).

Land Use ID	Land use	Land Use ID	Land use
1100	arable land	1240	other permanent crops
1130	temporary meadow (*2005)	1300	meadows and pastures
1160	hop fields	1321	swampy meadows
1180	other permanent crops on arable land	1330	mountain pastures (*2005)
1190	green houses	1800	forest trees on agricultural land
1211	vineyards	1410	over grown areas
1212	nursery	1420	forest plantations
1221	intensive orchards	1500	riparian overgrowth and forest hedges
1222	extensive orchards	1600	uncultivated agriculture land
1230	olive groves		

Tabel1: Type of land use in GERK

Parameters	Unite	Vulnerability classification		Factor weight	Source of input data
Land use (GERK)	[ID GERK] → [ha]	Type of actual agricultural use [ID GERK]	Vulnerability class	0.0989	Ministry of agriculture, Forestry and Food of the Republic of Slovenia.
		1190, 1230, 1800, 1410, 1500, 1600	1 (very low)		
		1211	2		
		1130, 1212, 1222, 1240, 1321, 1330, 1420	3		
		1160, 1221	4		
		1100, 1180, 1300	5 (very high)		
		Vulnerability assessment based on IRRFIB model.			

The vulnerability of agricultural land use was assessed based on literature review, reports on past drought impacts and expert opinions. To improve estimation of the objective assessment of the vulnerability according to the land use, e.g. individual plants, which are representatives of the vulnerability classes, we used Irrigation scheduling model IRRFIB (developed at AgMet Department of Meteorological sector of Hydrometeorological Institute of Slovenia).

7.2.5. Irrigation infrastructure

Irrigation is certainly not the only possible solution to alleviate droughts, but is despite the lengthy planning and construction of the irrigation system nevertheless the quickest response to drought. It is a very reasonable solution when water is in abundance not too far away from the areas experiencing draughts and under conditions, when crops (almost) every year lack water for optimal development. This input layer presents the irrigated area of agricultural land, which is defined with Graphical Units of Agricultural Land (GERK) database. GERKs are defined as unified areas of agricultural land with a single land use and cultivated by the same owner on the base of aerial orto-photo images. Data for Slovenia is available from Ministry of Agriculture, Forestry and Food of the Republic of Slovenia.



Figure 5: Map of irrigated agricultural land for Slovenia.

Parameters	Unite	Vulnerability classification		Factor weight	Source of input data						
Irrigation (GERK)	[ID GERK] → [ha]	<table><tr><td>Irrigation [ID GERK]</td><td>Vulnerability class</td></tr><tr><td>YES</td><td>1 (very low)</td></tr><tr><td>NO</td><td>0</td></tr></table>		Irrigation [ID GERK]	Vulnerability class	YES	1 (very low)	NO	0	0.6472	Ministry of agriculture, Forestry and Food of the Republic of Slovenia.
		Irrigation [ID GERK]	Vulnerability class								
		YES	1 (very low)								
		NO	0								
		Irrigated areas of agricultural land from small and big irrigation systems.									

7.3. THE METHOD USED

GIS-based multi-criteria decision analysis (MCDA) can be thought of as a process that combines and transforms spatial data into a resultant decision. There are many ways in which decision criteria can be combined in MCDA. We used a Weighted Linear Combination (WLC) within the Idrisi Taiga GIS software application. With the WLC, factors are combined by applying a weight to each followed by a summation of the results and multiplied by the product of the constraints, to yield a final vulnerability map. GIS based method with multi-criteria evaluation (WLC) can produce spatial information on the vulnerability of agricultural areas where crops grow, in the form of maps.

This method consist of the following steps: firstly data have to be evaluated in the light of how they influence vulnerability of crops to drought. We restricted our analysis only on agricultural land. Other land use was considered as constraints. So the processed data gets values in 5 categories (five grade scale), between 1 (low vulnerability) and 5 (very high vulnerability). Before putting them into software they have to be standardized to the measurement scale from 0 to 255 so that Idrisi Taiga is able to start analysis. In the analysis prepared data layers with proper weights are combined into a single layer- final vulnerability map with spatial resolution of 100m in both longitude and latitude.

When combining data layers this formula is used:

$$V = \sum w_i x_i \cdot \Pi c_j,$$

(V – vulnerability, w_i – factor weight, x_i – factor value, Πc_j – product of constraints). Factor weights were set with the help of literature and expert opinion. We choose a pairwise comparison methods technique for the development of weights, which involve pairwise comparison to create a ratio matrix. The technique of pairwise comparisons has been developed by Saaty (Saaty, 1977) in the context of a decision making process known as the Analytical Hierarchy Process (AHP).

In the case of n criteria, a set of weights is defined as follows:

$$w = (w_1, w_2, \dots, w_j, \dots, w_n) \rightarrow \sum w_j = 1$$

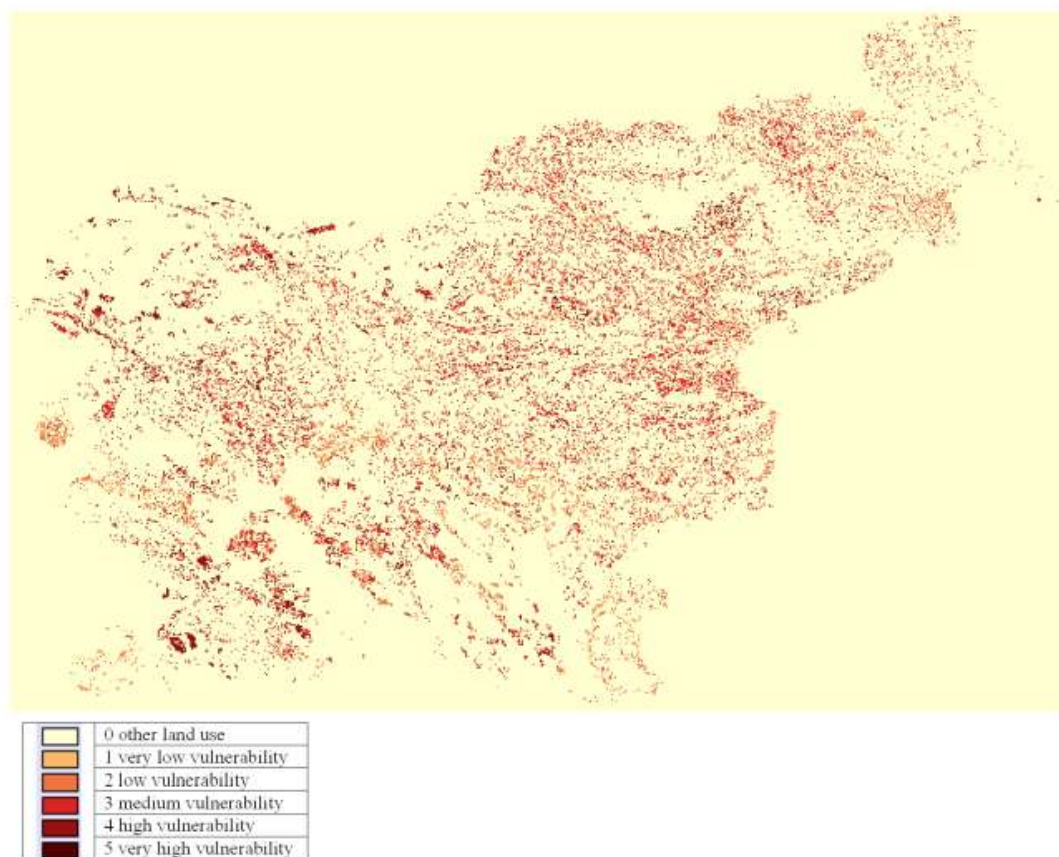
Consistency ratio (CR) – indicates the probability that the matrix ratings were randomly generated. Matrices with $CR > 0.10$ should be re-evaluated.

Implementation: After obtaining an output map, sensitivity analysis should be performed to determine robustness - how stable is the final conclusion.

7.4. CONCLUSION

The model output was crop vulnerability to drought map with a colour-coding categorization of drought vulnerability of the GERK spatial units (raster with spatial resolution 100x100m) (Figur 6). Results indicate the areas with different range of value of crop vulnerability to drought in Slovenia.

In the present study, the evaluation grades were assigned subjectively, however, we introduced objective tools and models to improve the evaluation. In the case of the assessment of the vulnerability of land use for certain types of crops in a specific GERK, an irrigation scheduling model IRRFIB was used, which estimates water consumption by crops during their growing and ripening season.



Picture 6: Final crops vulnerability map for Slovenia and legend (draft).

7.5. SOURCES

Clark Labs, 2009. Idrisi Taiga. Clark University, 950 Main Street, Worcester MA 01610-1477, USA.

Jaleel, C.A., P. Manivannan, A. Wahid, M. Farooq, R. Somasundaram and R. Panneerselvam, 2009.

Drought stress in plants: a review on morphological characteristics and pigments composition. *Int. J. Agric. Biol.*, 11: 100–105.

MKGP – Ministrstvo za kmetijstvo, gozdrastvo in prehrano, 2011. GERK viewer, available on-line: <http://rkg.gov.si/GERK/viewer.jsp>

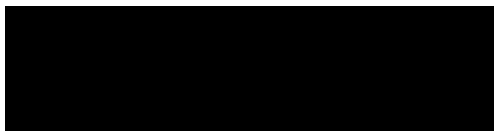
Saaty T. L. (1977). A Scaling Method for Priorities in Hierarchical Structures. *J. Math. Psychology*, 15, pp. 234–281.

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Zupan, M., Ruprecht, J., Tic, I., Persolja, J., Lobnik, F., Lisec, A., 2007. Pedološka karta. S: *Kmetijska tla in suša, Sodobno kmetijstvo (Priloga)*, 13-14.

8. HUNGARY

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Contact person:

Organization: Hungarian Meteorological Service

8.1. INTRODUCTION

In the region of Hungary drought is a natural aspect of climate. Developing of drought is most influenced by precipitation, which is one of the most varying meteorological parameters in Hungary both temporary and spatially. Due to the current researches the trend of changing in precipitation is not predictable clearly, but the frequency and duration of extreme weather events (like drought) are likely to rise in the future. Through precipitation the most endangered sector by drought is the agriculture. Although we cannot avoid or prevent drought, we can prepare for it to prevent agricultural damages. Drought vulnerability estimations serve this necessary preparation.

8.2. THE LIST OF APPLIED PARAMETERS

8.2.1. Slope angle

Firstly it was taken account that the larger is slope angle, the greater amount of precipitation runs off. The other important aspect is that by increasing of the slope angle the specific surface decreases consequently it can receive less precipitation (*Table 1., Figure 1.*).

The values were derived from SRTM digital elevation model.

Slope	Angle [°]	Vulnerability class
	(0-5)	0,2
	(5-12)	0,4
	(12-20)	0,6
	(20-35)	0,8
	(35-90)	1

Table 1. Classification of slope angle.

8.2.2. Relative groundwater level

As there is no available groundwater measurements in Hungary, we proceeded on the base of geographical practice. According to that groundwater is ignorable higher than 200 m above sea level, because at this height groundwater is located so deep, that it is cannot be available for plants (*Table 2., Figure 2.*)

Available groundwater	Height above Sea level [m]	Vulnerability class
	(0-200)	0,2
	(200-)	1

Table 2. Classification of available groundwater.

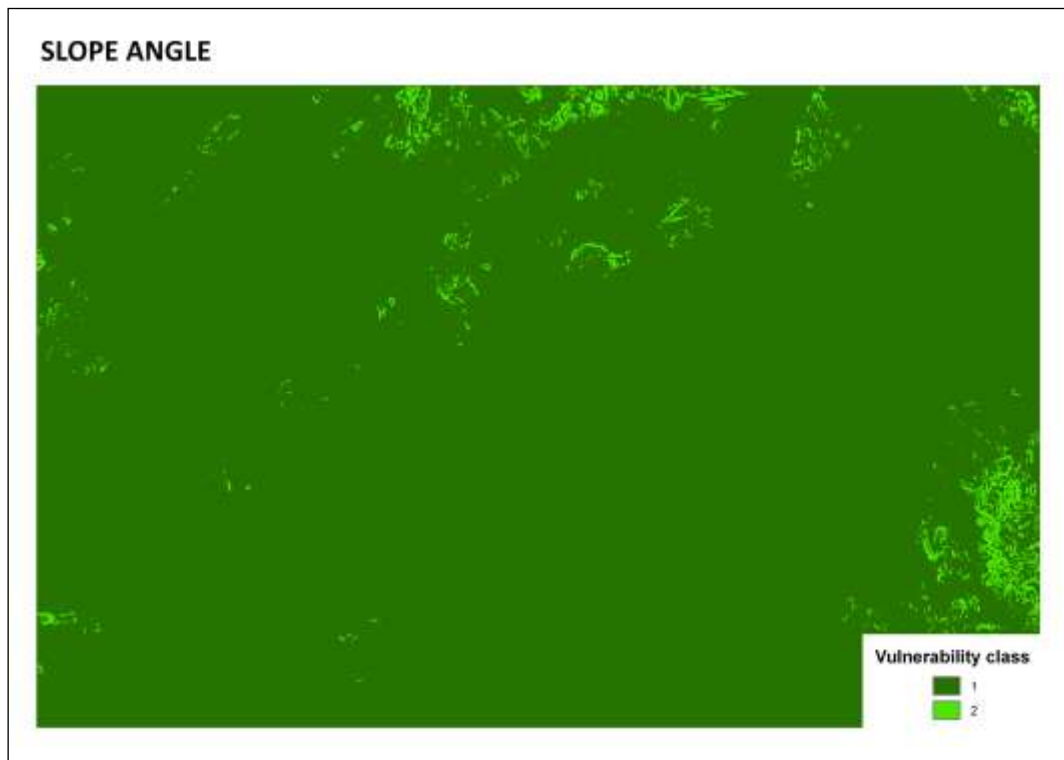


Figure 1. Category map of slope angle.

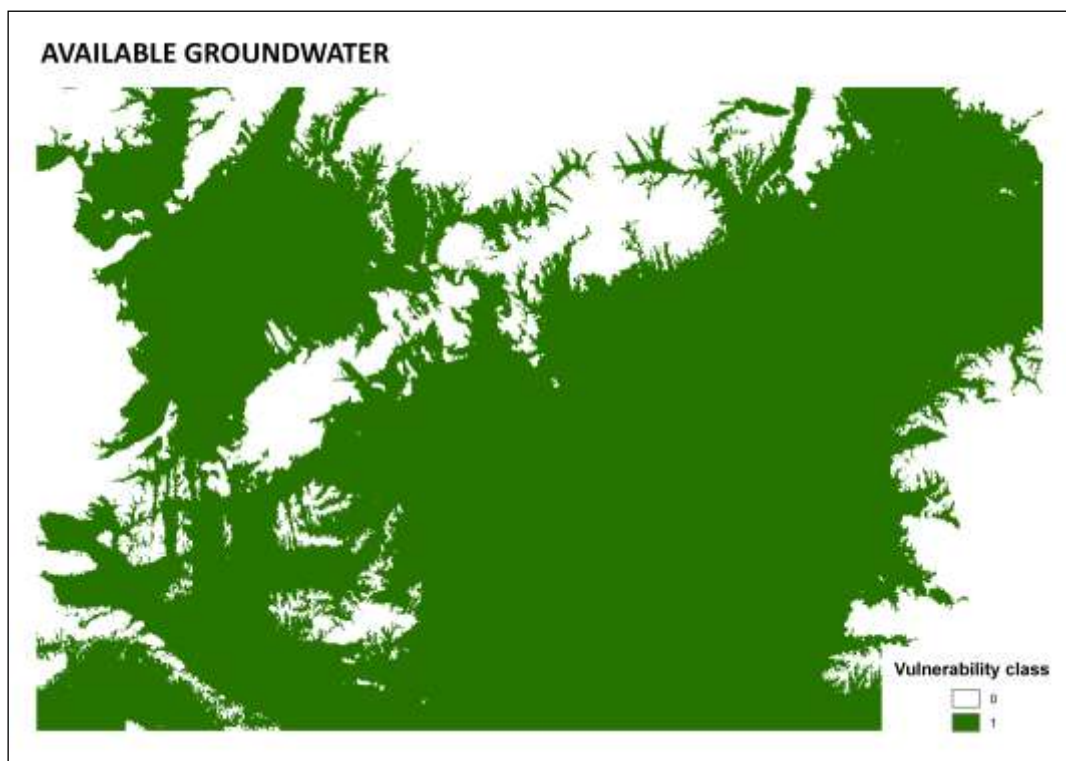


Figure 2. Category map of available groundwater.

8.2.3. Sunshine duration

The sunshine absorbed by surface and plants has an effect on evaporation. To represent this effect sunshine duration was used. The values, which were measured in the observing network during the vegetation period (April-September), were interpolated by MISH taking into account among others the influence of elevation (*Table 3., Figure 3.*).

Sunshine duration	Radiation [h]	Vulnerability class
	991,8-1109,9	0,2
	1109,9-1228,1	0,4
	1228,1-1346,2	0,6
	1346,2-1464,4	0,8
	1464,4-1582,5	1

Table 3. Classification of sunshine duration.

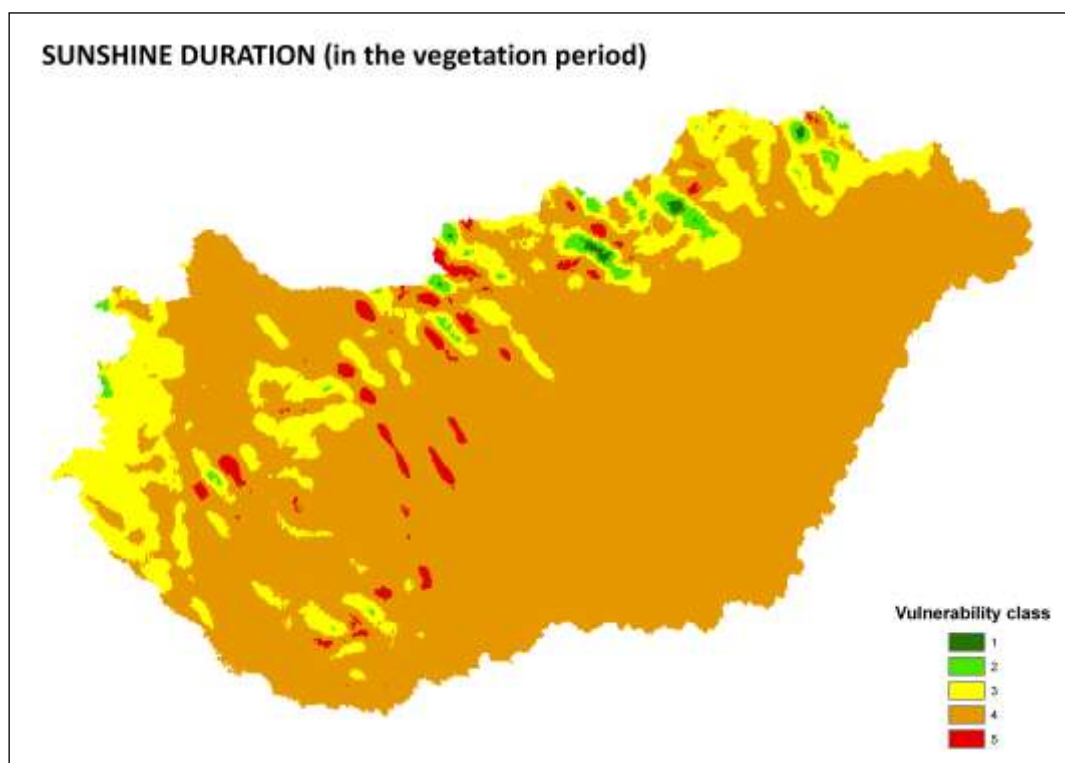


Figure 3. Category map of sunshine duration.

8.2.4. Precipitation

Our purpose was to quantify the extremity of the precipitation. As the precipitation follows Gamma-distribution, its expected value (E) and standard deviation (D) can be expressed as follows:

$$E = \frac{p}{\lambda}, \quad D = \frac{\sqrt{p}}{\lambda}$$

Where p and λ are the parameters of Gamma-distribution. If we take the ratio of these two values, we get a value, which depends just on one variable, p:

$$\frac{D}{E} = \frac{1}{\sqrt{p}}$$

This ratio can characterize the extremity. If D is great, it means that extreme sum can occur, while E is small, it means that low precipitation sum is expected in the given point. In this case the risk of drought is great and consequently the vulnerability is high (*Table 4. Figure 4.*).

Both the mean and the standard deviation were interpolated by MISH using homogenized data of 177 stations from period 1951-2010.

Precipitation	$\frac{D}{E}$	Vulnerability class
	0,148-0,172	0,2
	0,172-0,195	0,4
	0,195-0,219	0,6
	0,219-0,242	0,8
	0,242-0,266	1

Table 4. Classification of precipitation.

8.2.5. Land use

During the estimation only the agricultural land was taken into account. The map was derived from the Corine100 LandCover database (*Table 5., Figure 5.*).

Land use	Type of land use (CLC100)	Vulnerability class
	223, 243, 244, 311, 312, 313,324	0,2
	221	0,4
	241, 242, 321, 322, 323, 333	0,6
	222	0,8
	211, 212, 213	1

Table 5. Classification of land use.

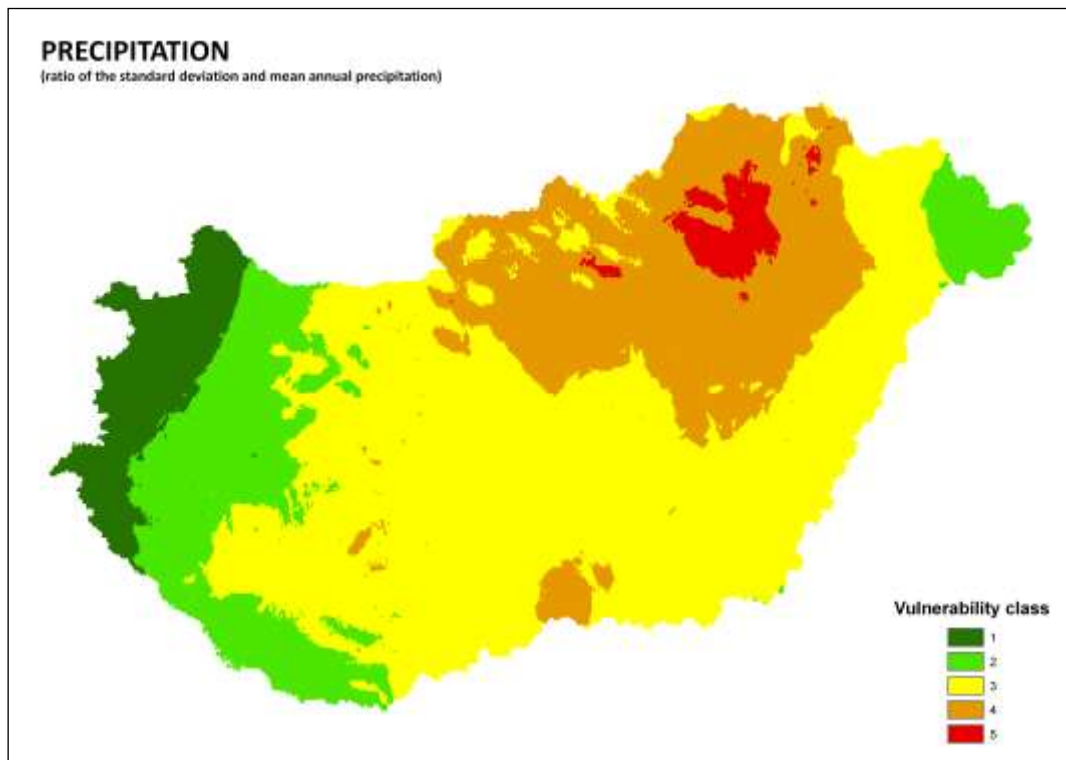


Figure 4. Category map of precipitation.

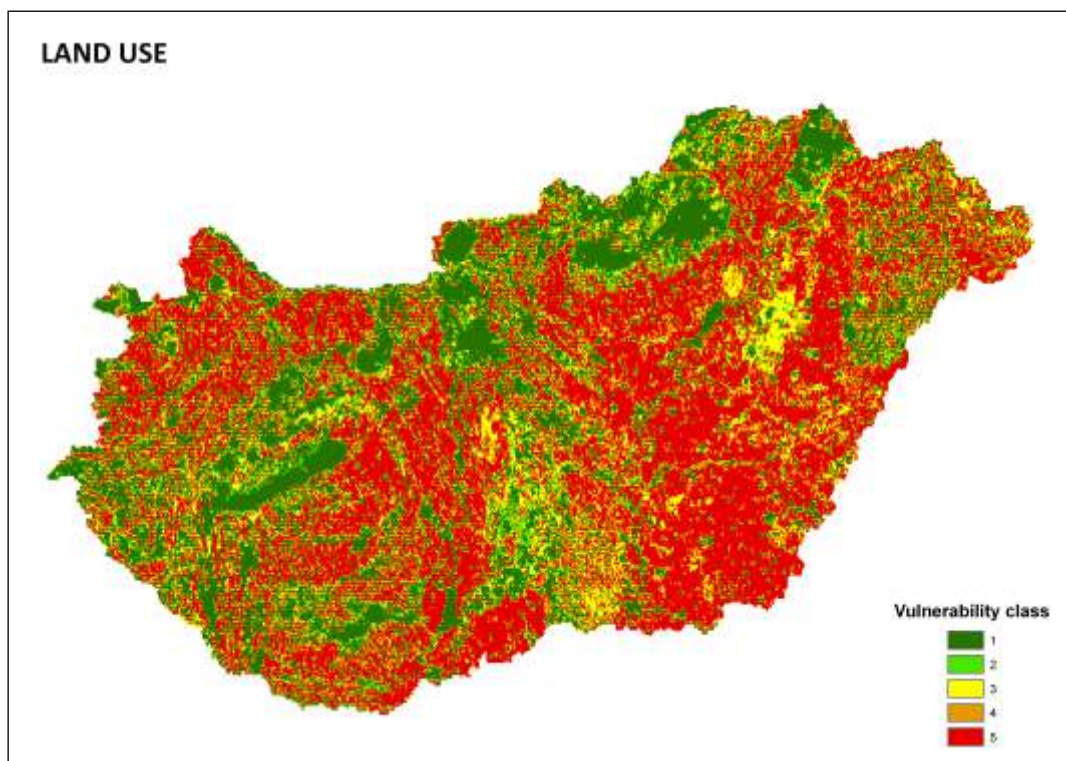


Figure 5. Category map of land use.

8.2.6. Soil type

In the case of drought it is a very important aspect as well that how much water can be stored in the soil, namely how good the soil's water capacity is. After the examination of the soil types of WRB, they were ranged into five vulnerability classes (*Table 6.*). In the final step the Hungarian soil types were reconciled with the types of WRB (*Figure 5.*).

Soil type	Soil type	Vulnerability class
	Histosols (HS)	0,2
	Gleysols (GL), Luvisols (LV)	0,4
	Cambisols (CM), Chernozems (CH), Fluvisols (FL)	0,6
	Phaeozems (PH), Solonetz (SN)	0,8
	Arenosols (AR), Leptosols (LP), Solonchaks (SC), Vertisols (VR)	1

Table 6. Classification of soil type.

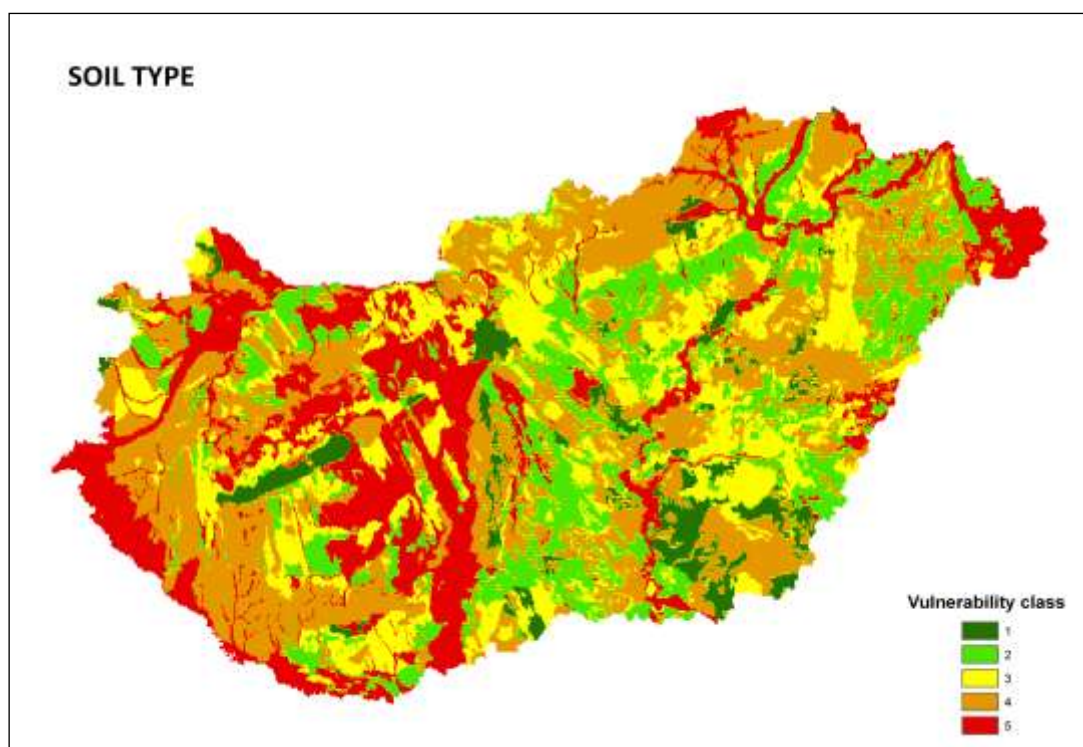


Figure 6. Category map of soil type.

8.2.7. Irrigation

In our opinion, it is rather useful taking into account the role of the irrigation, as it allows us to calculate with the human factor. According to our theory, if drought strikes an irrigated area, people can handle it by enhancing the irrigation, while in a non-irrigated area there is no chance for the human intervention. Consequently the irrigated areas are less vulnerable to drought than the non-irrigated ones (*Table 7., Figure 7.*).

Irrigation	Irrigation	Vulnerability class
	YES	0
	NO	1

Table 7. Classification of irrigation.

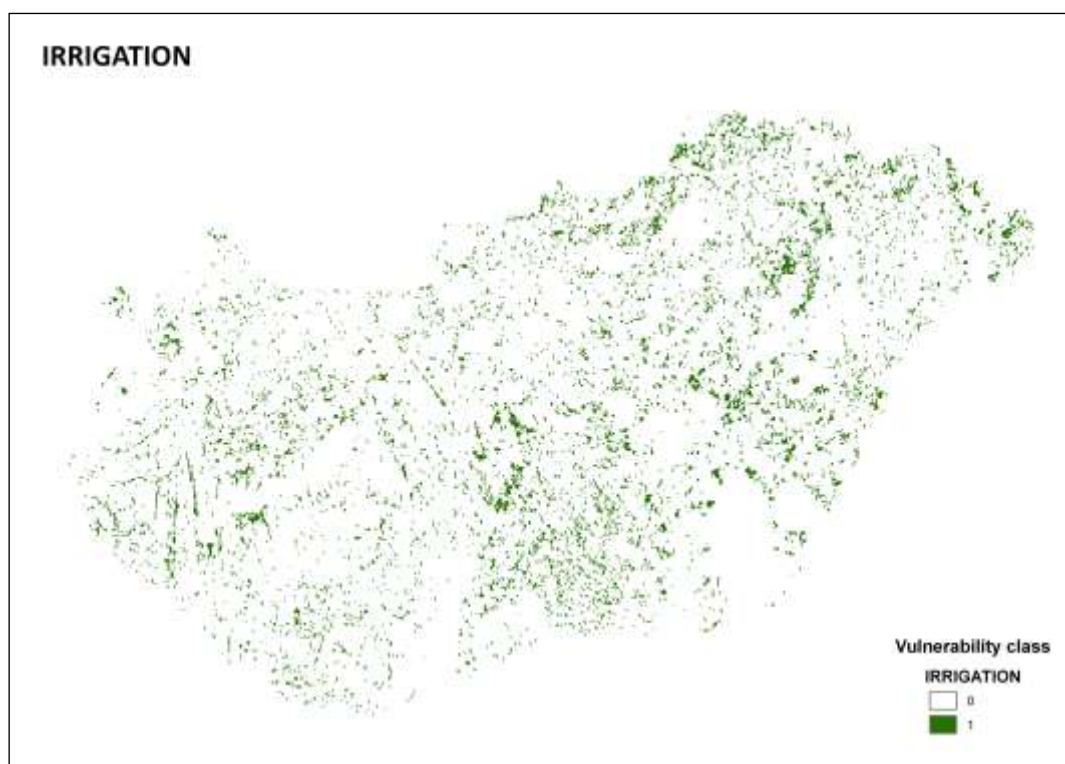


Figure 7. Category map of irrigation.

8.3. CONCLUSION

By using the category maps generated above the vulnerability map of Hungary was compiled (Figure 8.). According to the map the area of the country is mostly **moderate vulnerable**, but extended region is vulnerable as well – especially the region of East-Transdanubia, and the middle part of the Great Hungarian Plain. Strongly vulnerable are the slopes receiving the highest amount of sunshine, where even the type of land use and the soil type strengthen vulnerability much more. Less vulnerable are the higher points of the country (Mátra, Bükk) because of the less sunshine duration, the artificially covered city of Budapest, and the northwestern region of the country, where the low value of standard deviation of precipitation and high average of it simultaneously resulted in low vulnerability.

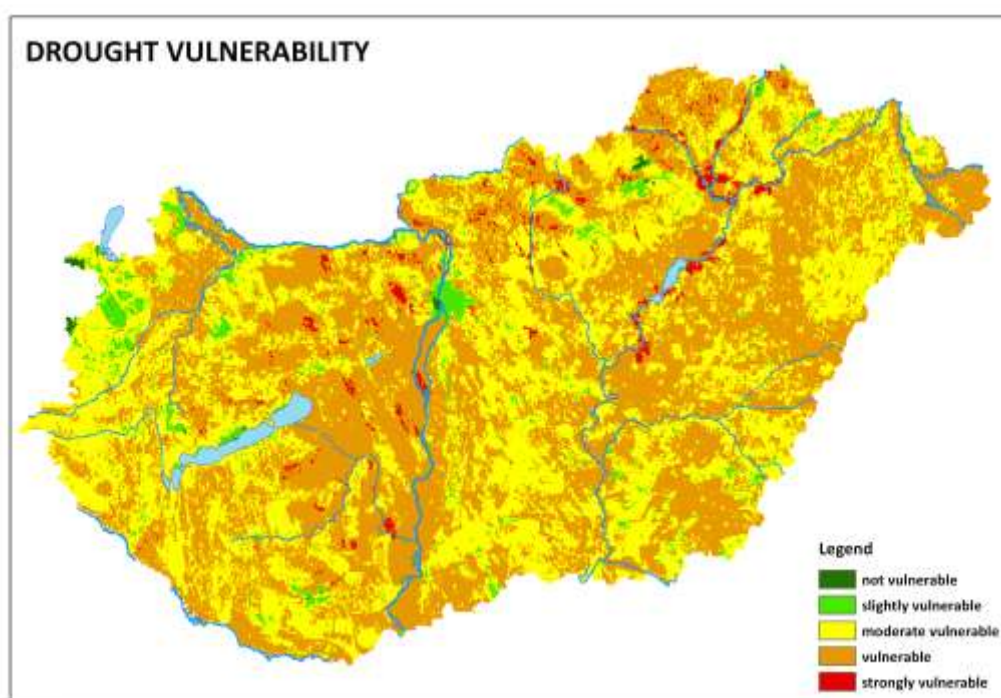


Figure 8. Drought vulnerability map of Hungary.

8.4. THE INTERPOLATION METHOD

Both the mean and the standard deviation, which calculated from the annual precipitation data, were interpolated using the updated version of MISH ((Meteorological Interpolation based on Surface Homogenized Data Basis; Szentimrey, Bihari, 2007).

8.5. CALCULATION METHOD OF THE MEAN

To calculate the values of the vulnerability map weighted mean of the category maps was used. The weights were generated by the software INDRISI Taiga. With consistency ratio of 0.1 the applied weights are presented in Table 8.

Parameter	Weight
Slope	0.1623
Available Groundwater	0.0518
Sunshine duration	0.3071
Precipitation	0.1180
Land use	0.0858
Soil type	0.2232
Irrigation	0.0518

Table 8. Weights of parameters used at calculation of mean.

9. BULGARIA

Author:

Contact person:

Organization: NATIONAL INSTITUTE OF METEOROLOGY AND HYDROLOGY

9.1. INTRODUCTION

The Bulgarian climate Bulgaria is situated on the Balkan Peninsula in southeast Europe. The country has an area of about 111,000 km² and consists of very diverse relief. Lowlands (0 to 200 m) cover 31.45% of the country, hills (200 to 600 m) 40.90%, highlands (600 to 1600 m) 25.13%, and mountains over 1600m 2.52% (FIG.1) . The local and regional climate is highly influenced by latitude, altitude, topography, proximity to the Black Sea and the dominant atmospheric circulation. Bulgaria is located on the transition between two climatic zones – moderate continental and Mediterranean.

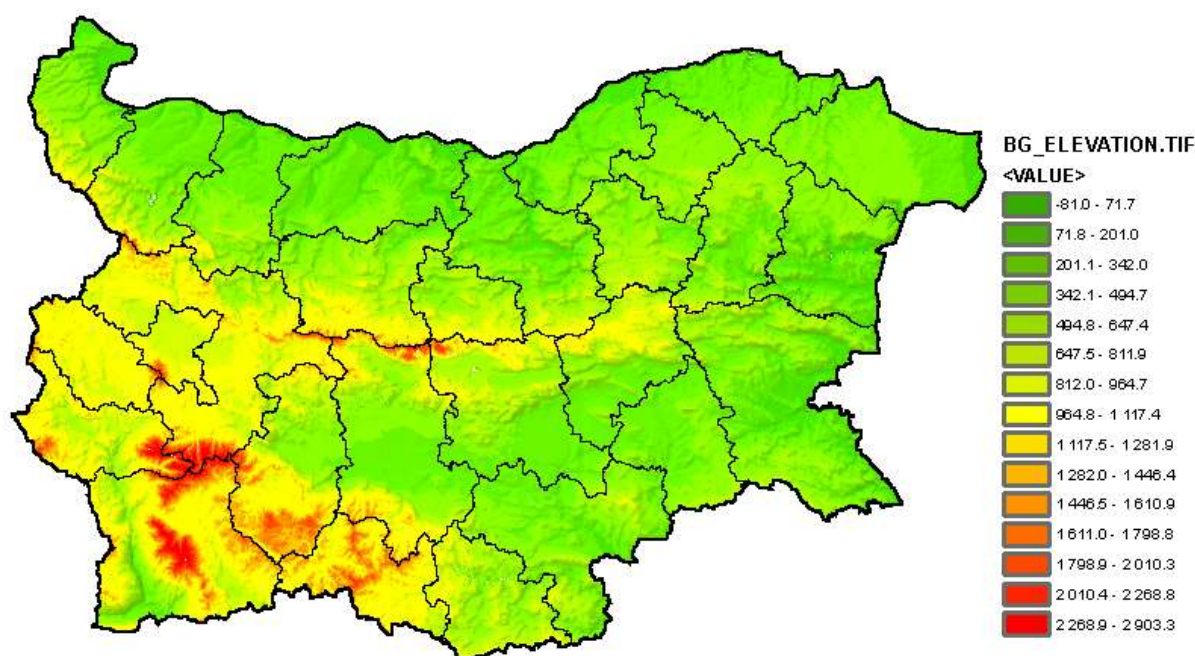


Figure 1. Elevation in Bulgaria (by applying DEM)

9.2. PRECIPITATION

The annual course of precipitation is different in these two zones. There are significant differences in the radiation balance in winter and summer, caused by latitudinal insolation. As a result, the thermal conditions are characterised by well-pronounced seasonality. The summer is warmer and the winter is relatively cold. The autumn is slightly warmer and drier than the spring. This seasonality is modified, to some extent, by the circulation conditions and by orographic influences. The zonal extension of the Balkan Mountains and Rila-Rhodope Mountain Massif is a natural barrier to invasions of cold air masses towards the southern part of the country. These mountains are also obstacles to warm air masses which overflow the mountains, and the foehn effect is observed over their northern slopes. Bulgaria is split into north and south regions by the Balkan Mountains, which have a strong effect on the temperature regime. Annual precipitation in Bulgaria ranges from 550–600mm in the lowest elevations of the country to 1000–1100mm in the highest elevations.

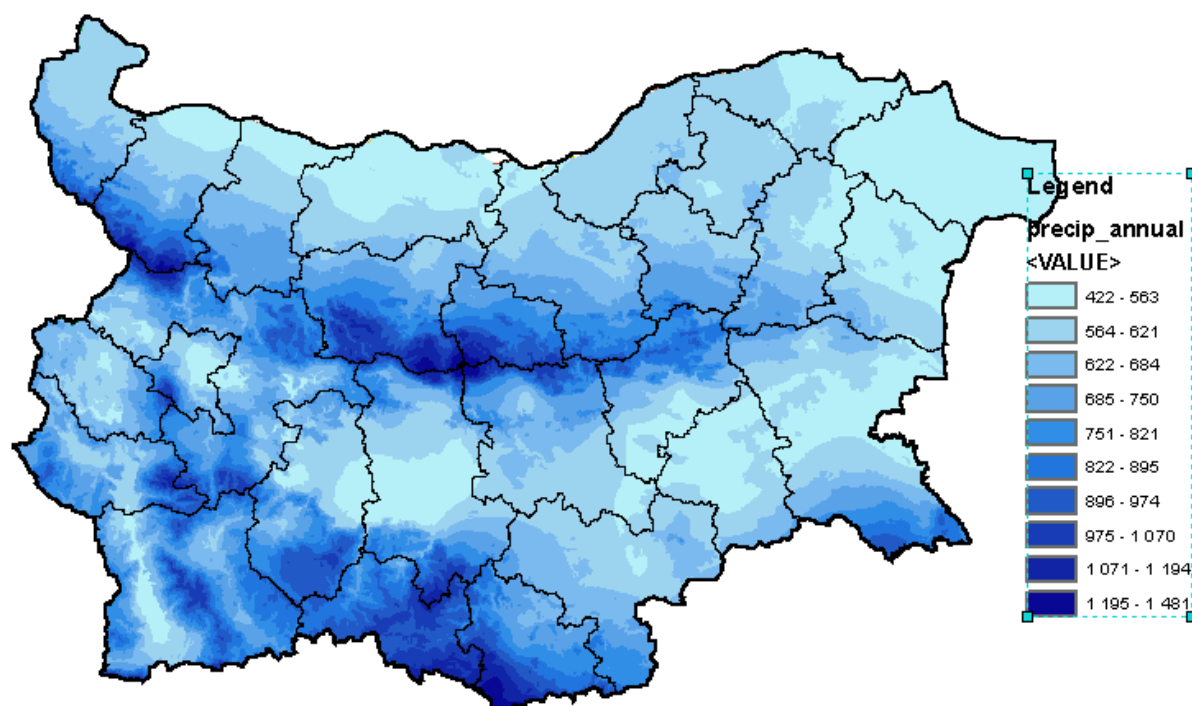


Figure.2 Annual precipitation in Bulgaria (in mm) for the current climate

The precipitation distribution across Bulgaria is mainly caused by synoptic atmospheric conditions, which are influenced considerably by topography. Insufficient precipitation is climatically common in some parts of Bulgaria, leading some scientists to speculate that the country has a tendency toward drought. According to the Budyko drought coefficient, the country is characterised by insufficient moisture. This coefficient is calculated using data from the annual radiation balance and total annual precipitation (*e.g. Budyko, 1974*). The Budyko drought coefficient is between 1.5 and 1.8 for Bulgaria. Drought in Bulgaria is usually a result of long periods with low precipitation under anticyclonic weather conditions. It can occur in any month of the year. The weather conditions during drought are characterised by decreased precipitation, high air temperatures, low humidity, and warm, strong winds. Long-term drought can negatively impact the water balance of plants, causing unstable crop physiological conditions and low crop yields, as well as threaten natural ecosystems and water supplies (*e.g. Slavov et al., 2004*).

The spatial distribution of annual precipitation defined as drought (insufficient climatic aspect in annual rainfall amounts) the following areas in the country: Danube municipalities in Montana, Vratsa and Pleven, some municipalities in the districts of Sofia and Sofia-city municipalities along the Struma (Blagoevgrad and Kyustendil District), Pazardzhik municipality and the municipalities located in the central part of Plovdiv, the majority of Yambol, as well as several municipalities in eastern Bulgaria - in Shoumen, Silistra, Dobrich,

Varna and Burgas. It should be noted that Dobrich is entirely at risk of drought. Low annual precipitation amounts are a prerequisite for a major vulnerability to drought municipalities General Toshevo, Shabla, Kavarna and Balchik. In areas of Varna and Burgas also included municipalities with high risk of drought - Aksakovo, Varna, Nessebar and Pomorie.

Except for the whole year precipitation in Bulgaria is unevenly distributed in different seasons of the year. The municipalities located closely at the BlackSea during the warm half of the year are at high risk of drought, also municipalities Petrich, Sandanski and Blagoevgrad in Strumyani. It should be noted that all of Southeast Bulgaria (excluding municipality of Malko Tarnovo) is potentially vulnerable to atmospheric drought during the period from April to September reas of fields Sofia and Sofia are limited amounts of rainfall in winter. The risk of winter drought is higher in northern Bulgaria, against the risk in southern Bulgaria, where the rainfall, especially in mountainous areas is significant.

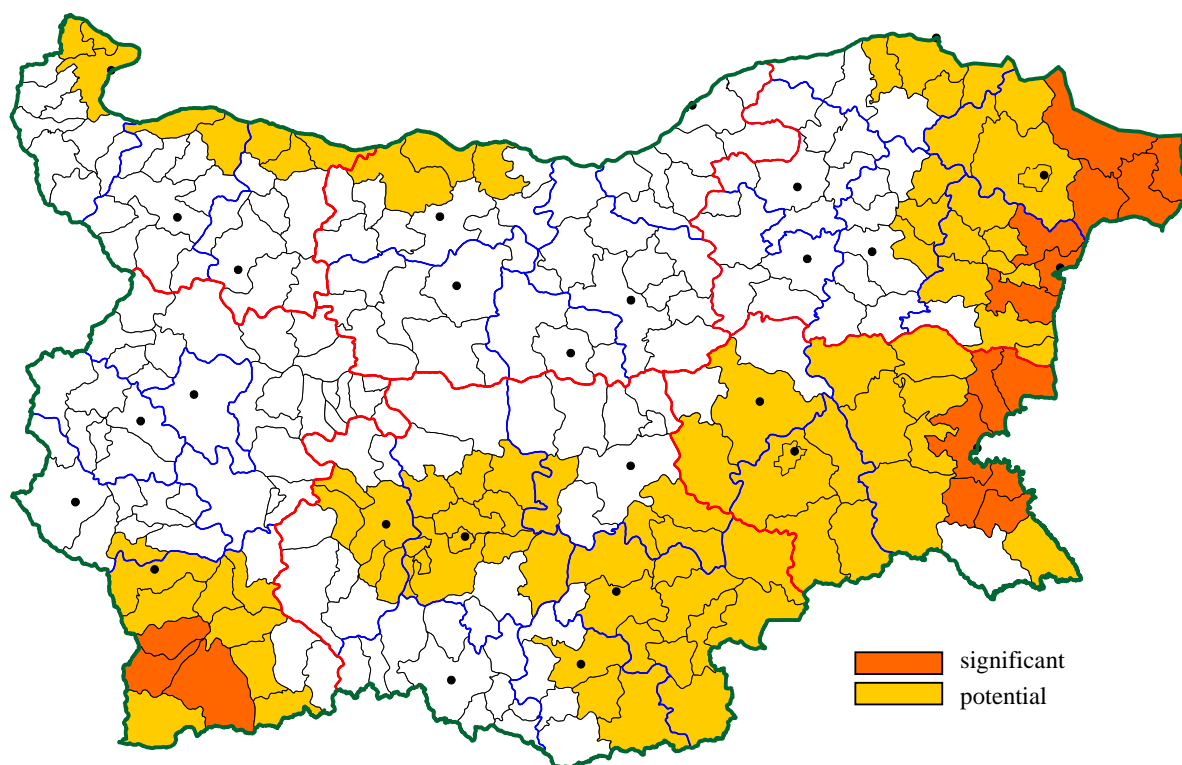


Figure. 3. Municipalities in Bulgaria, with atmospheric drought conditions during the warm half due to the spatial distribution of rainfall during this period

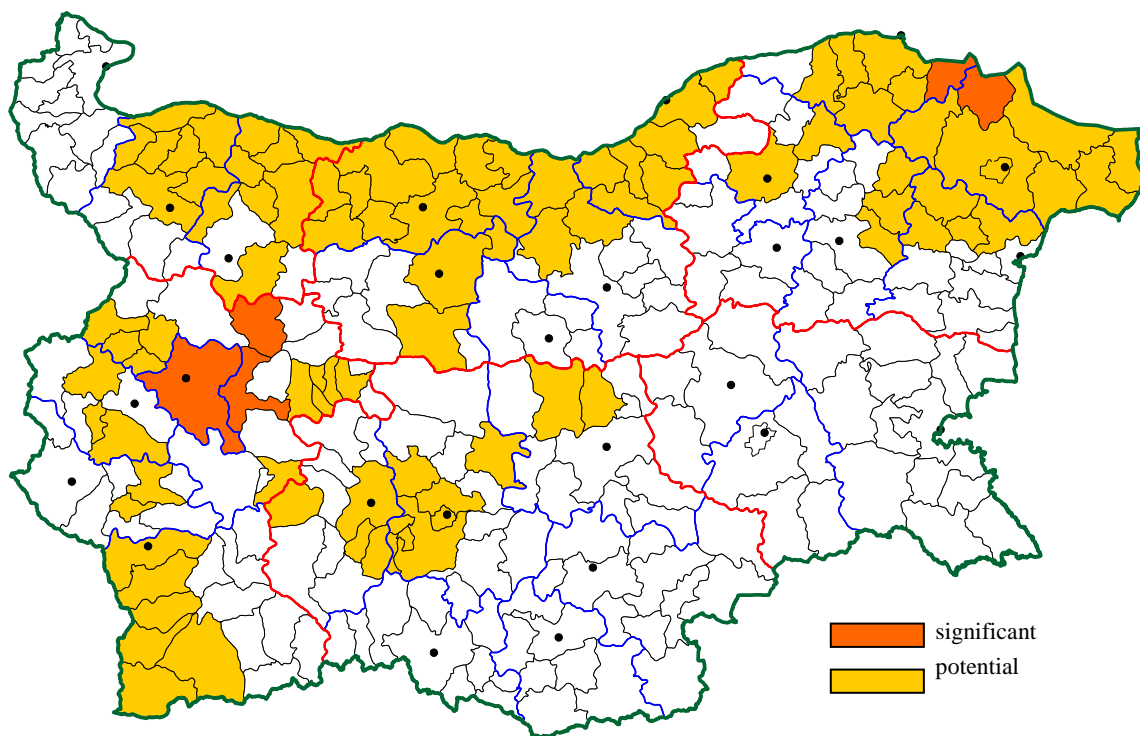


Figure. 4. Municipalities in Bulgaria, with atmospheric drought conditions during the winter due to the spatial distribution of winter precipitation

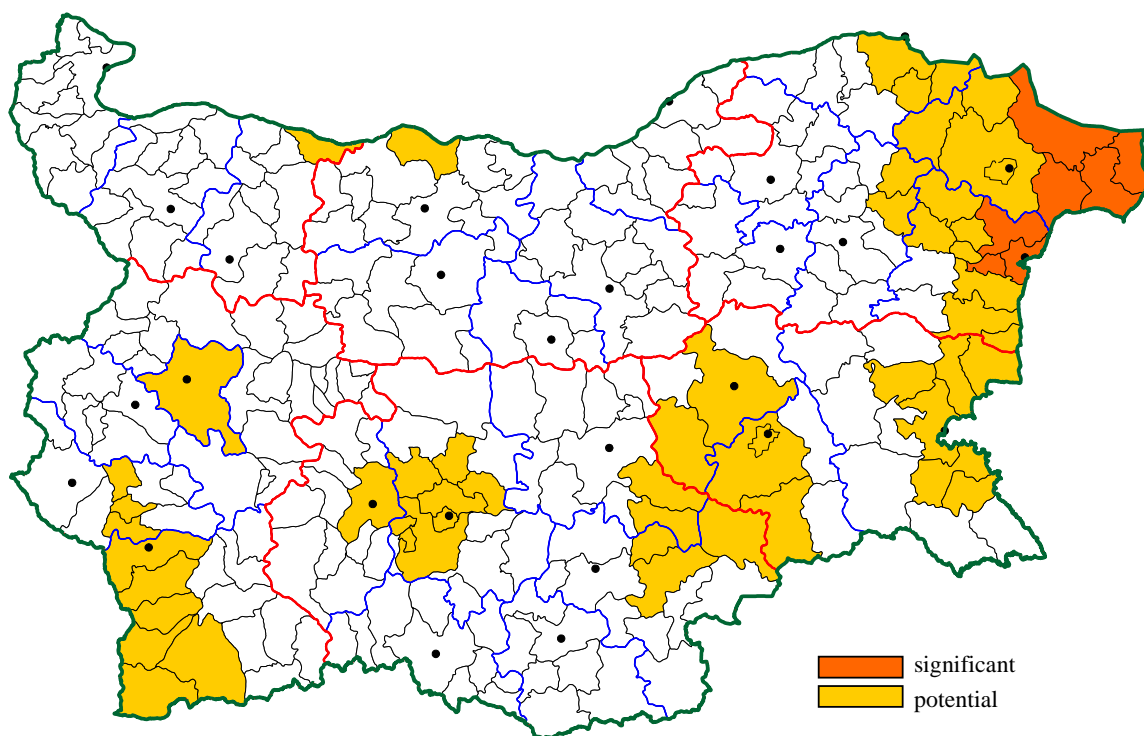


Figure. 5. Municipalities in Bulgaria, the atmospheric conditions of drought in the spring due to the spatial distribution of spring rainfall

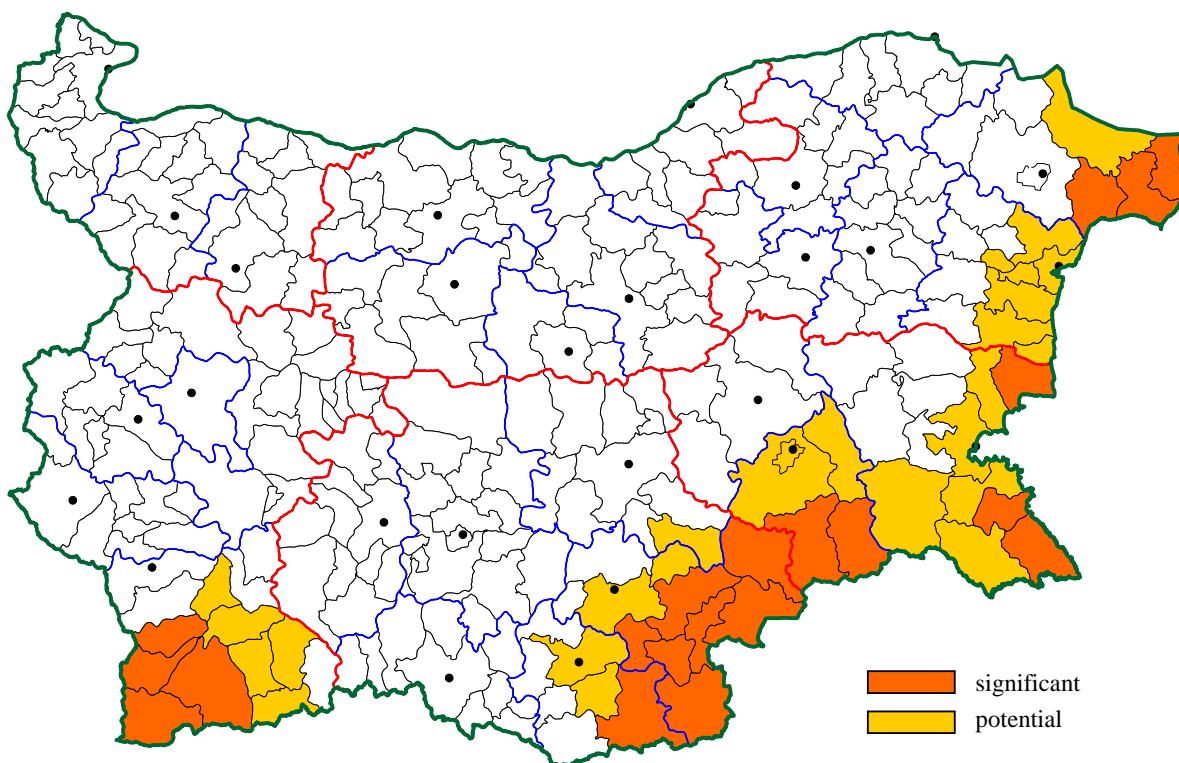


Figure.6. Municipalities in Bulgaria, the atmospheric conditions of drought in summer, due to the spatial distribution of summer rainfall

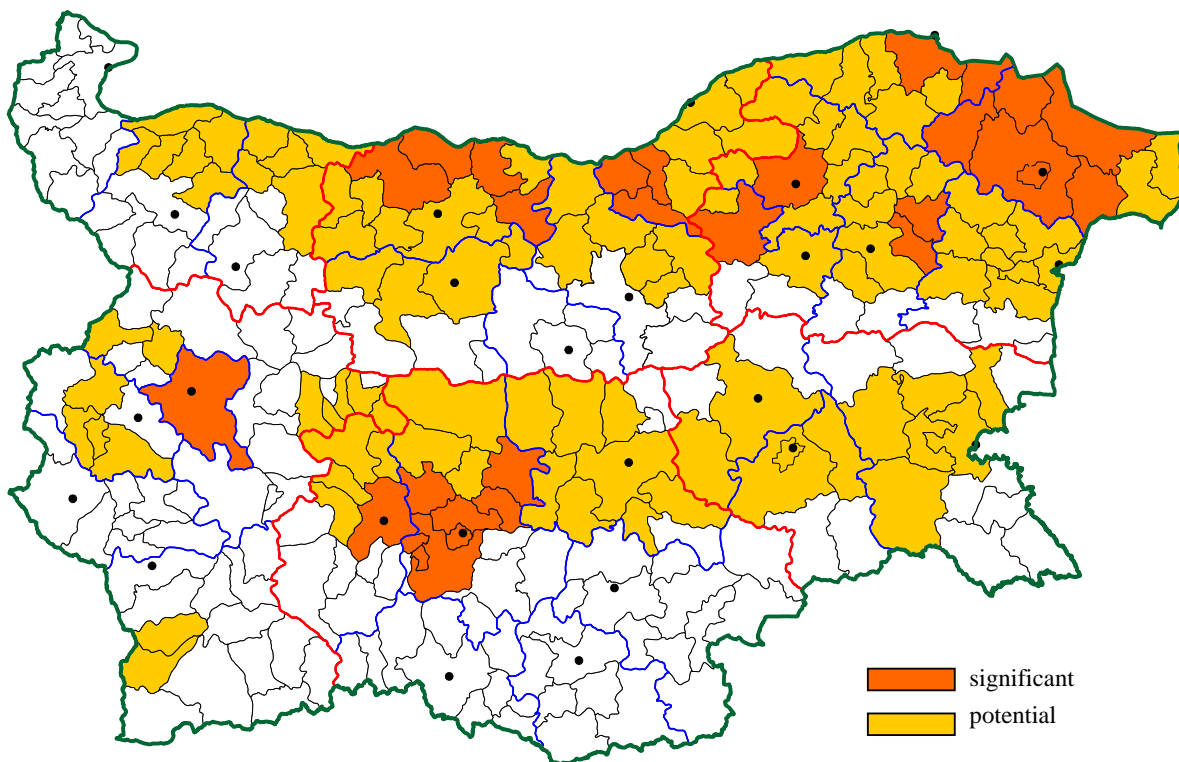


Figure. 7. Municipalities in Bulgaria, the atmospheric conditions of drought in the autumn due to the spatial distribution of autumn rains

The spring, potentially vulnerable to drought: Municipalities of Eastern Bulgaria, much of Yambol and areas of the lower valley of the Struma, Sliven, Plovdiv, and in Northern Bulgaria - Municipality Gulyantsi (Pleven District) – *Figure 5*. Municipalities in the southern districts of Haskovo, Yambol and Burgas are most vulnerable to the reduction in rainfall amounts during the summer. As the three municipalities in Dobrich - Balchik, Kavarna and Shabla, and the southwestern areas of the country. In summer the Danube valley receives more rainfall than the Thracian Valley. But in autumn, the Danube Plain is potentially vulnerable to smaller amounts of precipitation (*Fig. 7.*).

9.3. SLOPE

For the development of the parameter slope the acquired DEM was used. The DEM was used as an input in the GIS algorithm creating slope output in degrees. a slope map was produced (*Figure 8*).

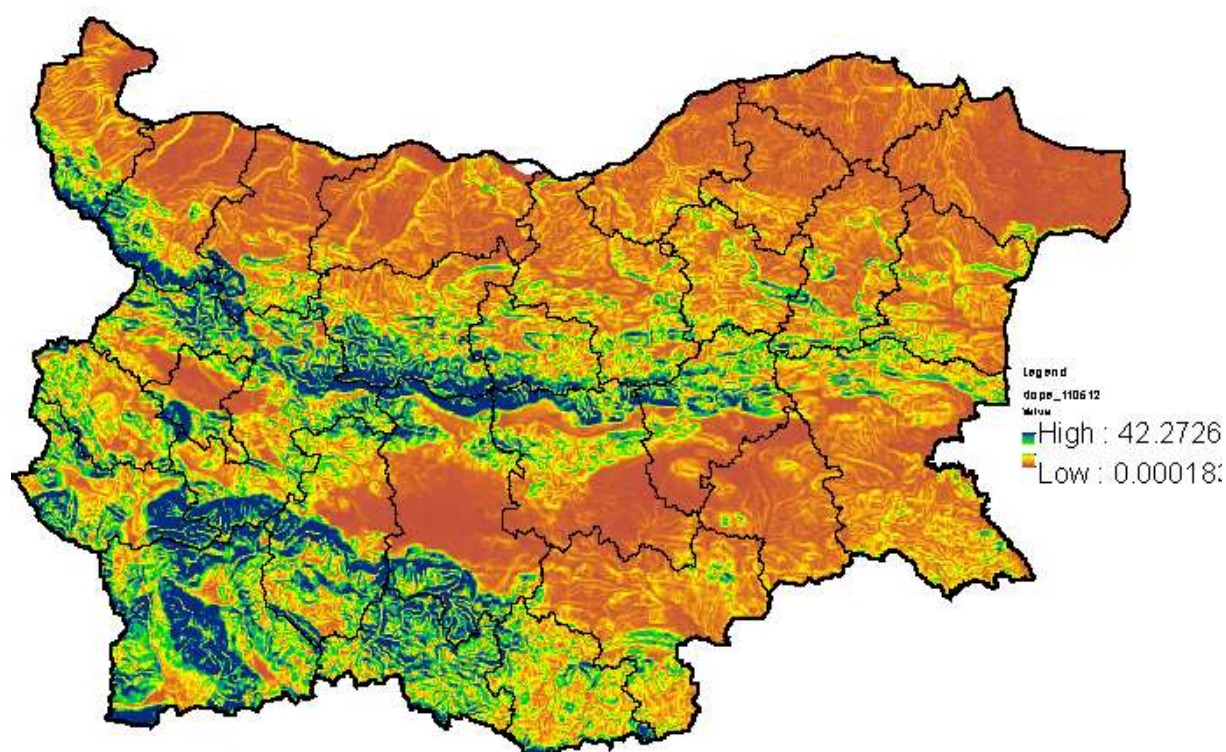


Figure. 8. Slope in Bulgaria (in degrees), based on the DEM applied

9.4. SOILS

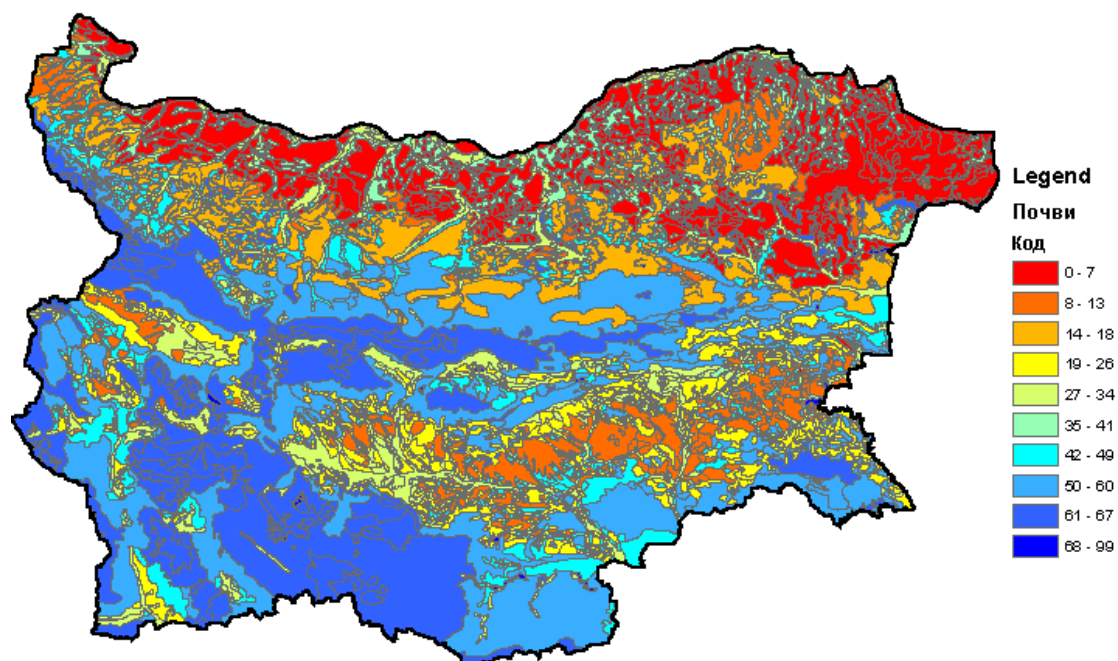


Figure 9. Soils in Bulgaria

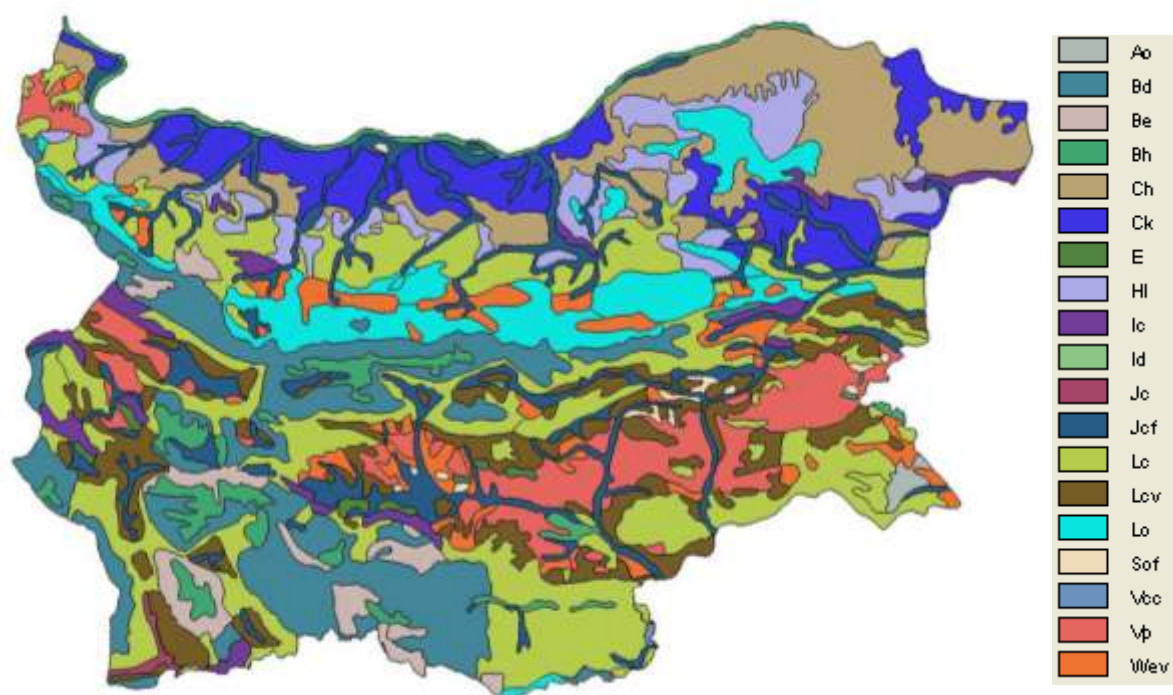


Figure 10. FAO classification of soils in Bulgaria

Code	Classification	Code	Classification
Ao	<i>Orthic Acrisol</i>	Jc	<i>Calcaric Fluvisol</i>
Bd	<i>Dystric Cambisol</i>	Jcf	<i>Fluvi-Calcaric Fluvisol</i>
Be	<i>Eutric Cambisol</i>	Lc	<i>Chromic Luvisol</i>
Bh	<i>Humic Cambisol</i>	Lcv	<i>Verti-Chromic Luvisol</i>
Ch	<i>Haplic Chernozem</i>	Lo	<i>Orthic Luvisol</i>
Ck	<i>Calcic Chernozem</i>	Sof	<i>Fluvi-Orthic Solonetz</i>
E	<i>Rendzina</i>	Vcc	<i>Calcaro-Chromic Vertisol</i>
Hl	<i>Luvic Phaeozem</i>	Vp	<i>Pellic Vertisol</i>
Ic	<i>Calcaric Lithosol</i>	Wev	<i>Verti-Eutric Planosol</i>
Id	<i>Dystric Lithosol</i>		

Table 2. FAO soil

As potentially vulnerable to drought soils may be mentioned:

- Acrisols: could be affected by drought (based are materials such as gravel and sand)
- Cambisols: young soils may be sensitive to drought, but are found in mountainous areas where rainfall generally more
- Rendzina: vlagomnost very low, shallow soils, with the risk of drought
- Lithosols: usually with rocks of shallow depth, resulting in low vlagomnost. Therefore - are vulnerable to drought.
- Fluvisols: sensitive to drought only in cases where there is high content of sand and gravel
- Luvisols: the risk of drought depends on the content of sand
- Solonetz: high salt content - vulnerable to drought, require more water for irrigation
- Vertisols: clay soils, which may also be sensitive to drought in the content of clay

Based on the above information is drawn map diagram presented in *Figure 11*.

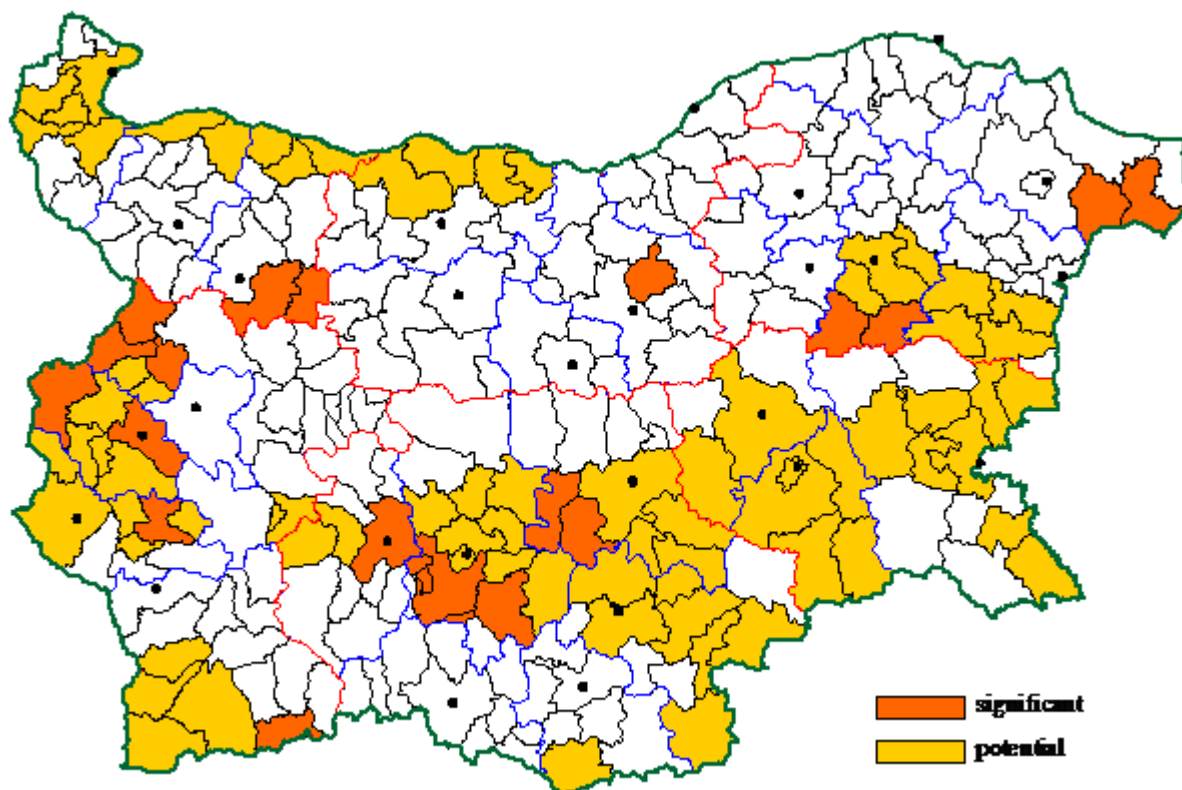


Figure 11. Municipalities in Bulgaria, with conditions (under water deficit) for soil drought, based on FAO soil classification

Figure 12. presents texture classes according to soil geographical data for Bulgaria developed in JRC in Ispra, Italy. These classes are formed based on the ratio of sand and clay in a soil profile. The upper base figure 5 textural class: 1 - <18% clay and> 65% sand, 2-18% <clay <35% and sand> 15%, or clay <18% and 15% <sand <65%, 3 - <35% clay and <15% sand, 4-35% <clay <60% 5 -> 60% clay. It is well known that sand evaporation is faster, sandy soils dry faster and are therefore more vulnerable to drought, compared with soils that contain large amounts of clay. Texture class 1 is almost absent in Bulgaria, but the texture class 2 except in mountainous areas is presented in the Danube area of northern Bulgaria and parts of northeastern Bulgaria.

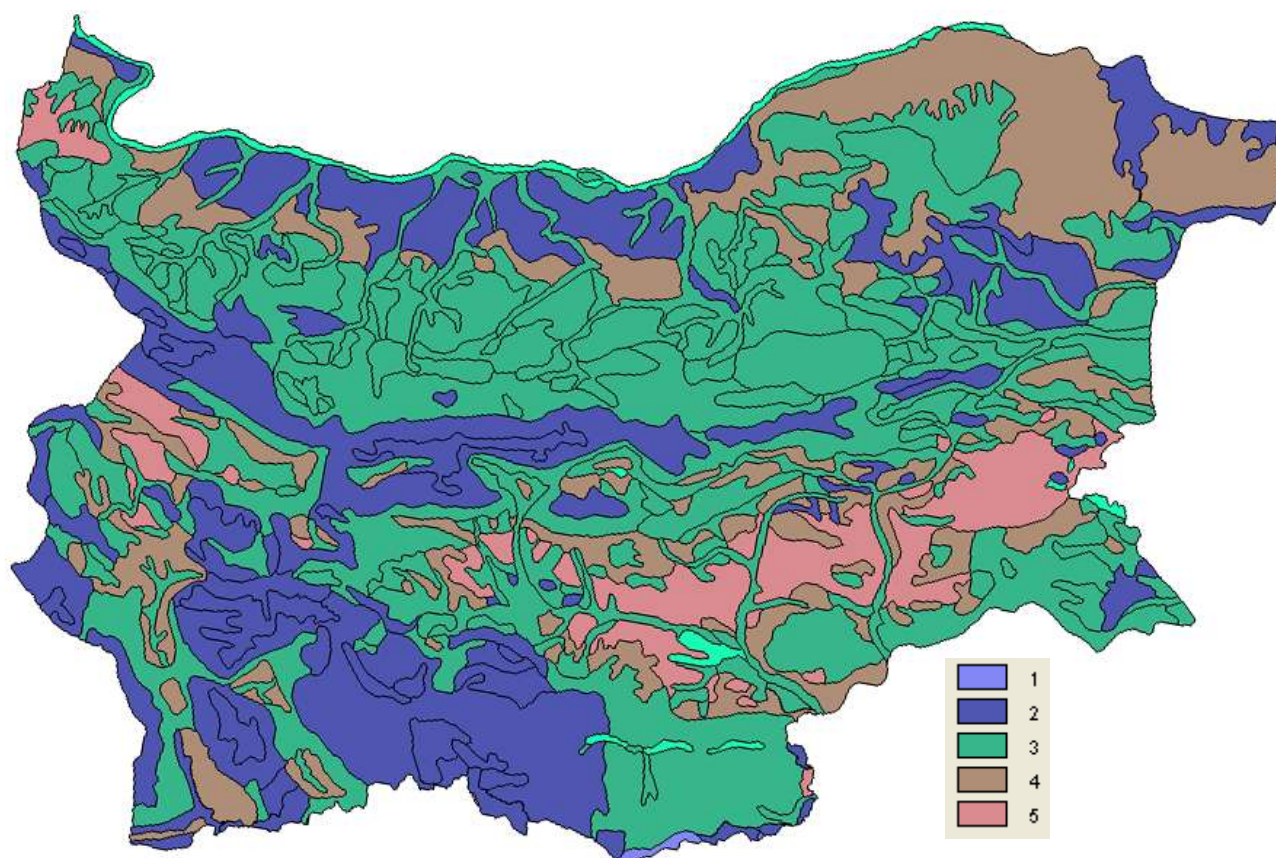


Figure 12. Textural classes of soils in Bulgaria.

9.5. SOLAR IRRADIATION

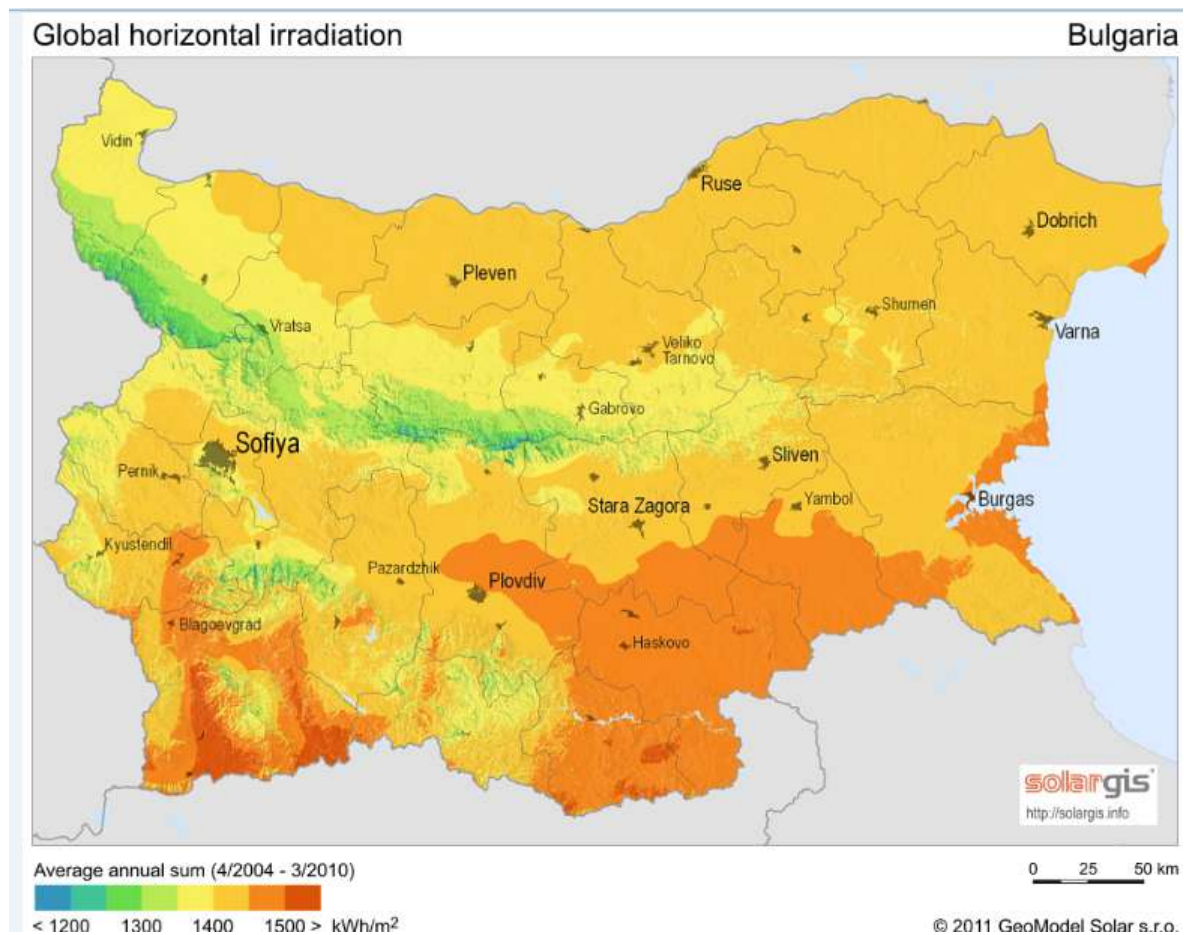


Figure 13. Solar radiation in Bulgaria

9.6. LAND USE

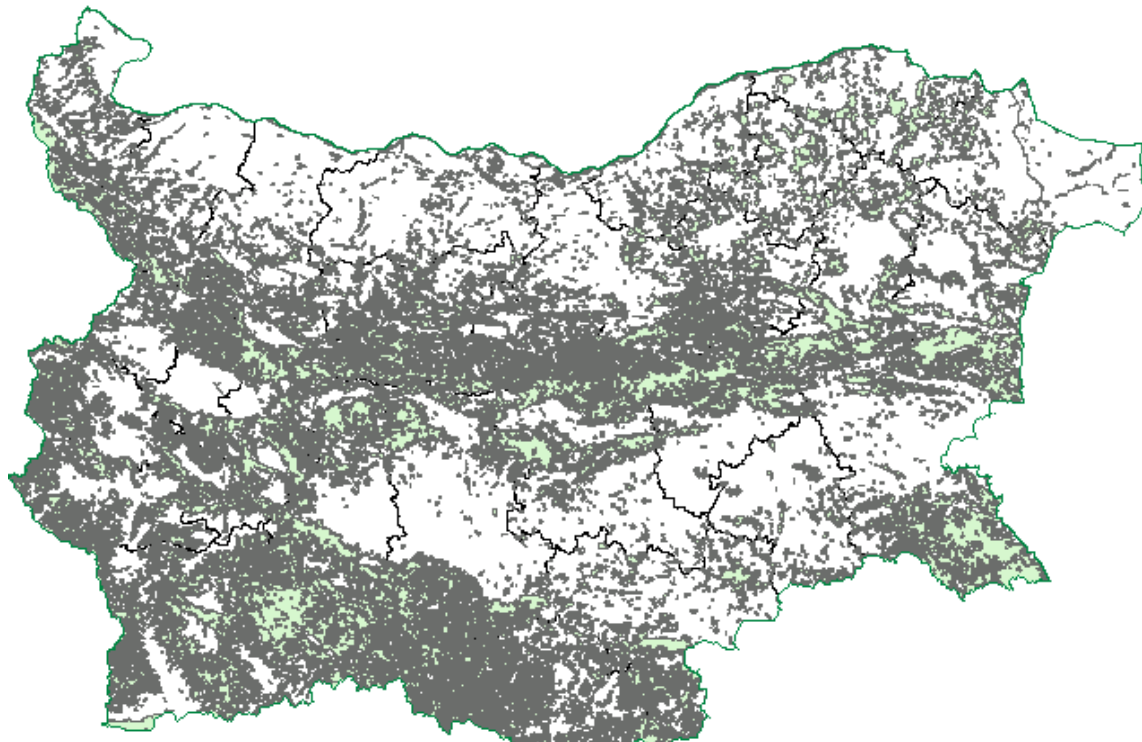


Figure 14. Land use/cover in Bulgaria (based on forestry data), source – COREINE (forest)

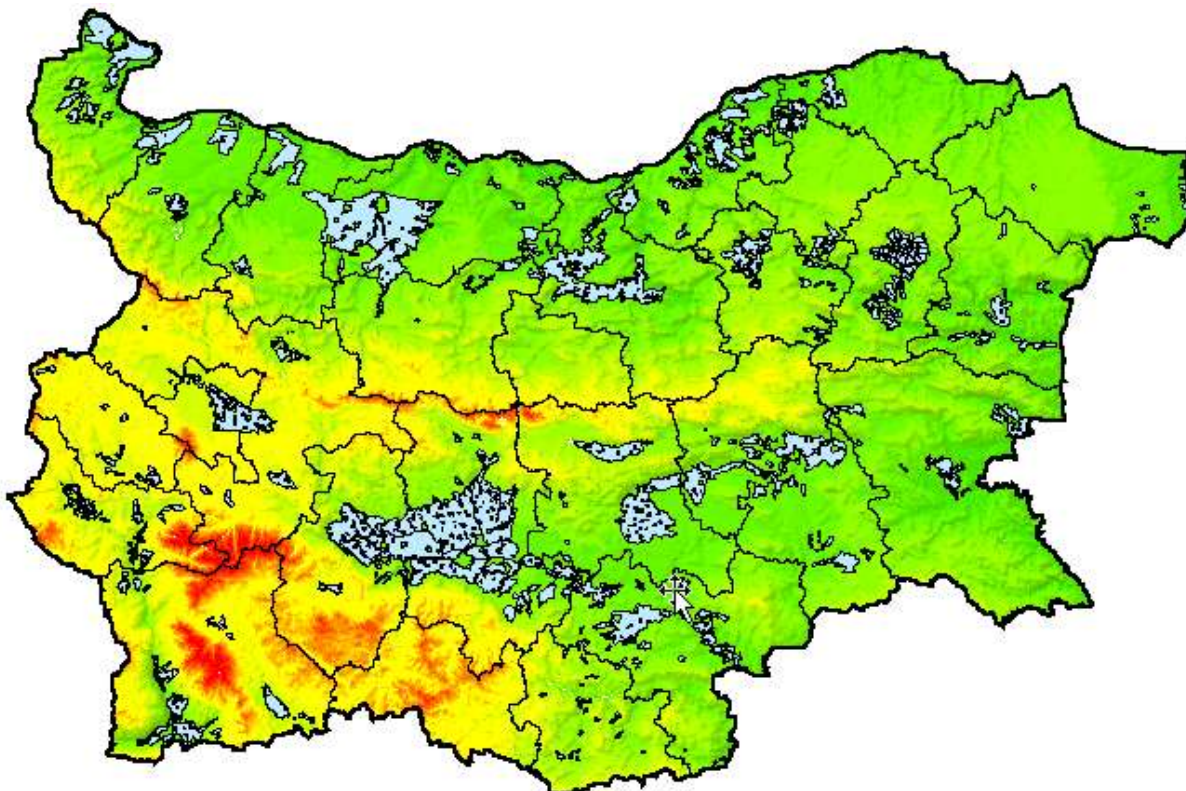


Figure 15. Irrigation in Bulgaria (irrigation systems across the country)

9.6.1. Spatial distribution of soil moisture and areas vulnerable to soil and atmospheric drought in Bulgaria

Water main soil properties are vlagoemnost and permeability. With a reduction in soil moisture in PPW (marginal field vlagoemnost) comes a time when the soil has more capillary water, but it is less mobile and harder for plants. Biggest infiltration have light sandy soils and least - heavy clay soils. From the agronomic point of view, large and small infiltration is undesirable - the first soil prone to waterlogging, while the latter - to drying up. In this respect, the best are sandy-clay soils, such as chernozem of Northern Bulgaria. In agro-climatic atlas of Bulgaria (1992) have mapped stocks productive moisture in the soil at different times of the year - mainly during the different phenological phases of winter wheat and maize. The relevant maps are excluded mountain areas are characterized by shallow soils, but with significant rainfall amounts. For those (shtrihirani in light brown) areas water balance is not calculation. Based on values of productive moisture reserves in alluvial, diluvial and meadow soils (mainly along the main rivers in Bulgaria), especially in deep soil moisture derived maps are municipalities with an increased risk to soil drought conditions). For example, stocks productive moisture in one-meter layer of soil during the regeneration of vegetation in spring wheat were lower in the northern part of the Danubian Plain, which is a prerequisite for increased risk of drought in this region.

Most of the municipalities along the Danube are potentially vulnerable to soil drought in the majority from the intervals: in sustainable transition over 10°C spring, during the ear formation in wheat, while corn izmetlyavane; during wax maturity of wheat. During these periods, and other municipalities - Eastern Bulgaria, Thracian lowland and the river valley. In the sowing of winter wheat this fall, the Danube plain is characterized by higher productive moisture reserves in the plow layer, unlike the Black Sea and the Thracian Plain).

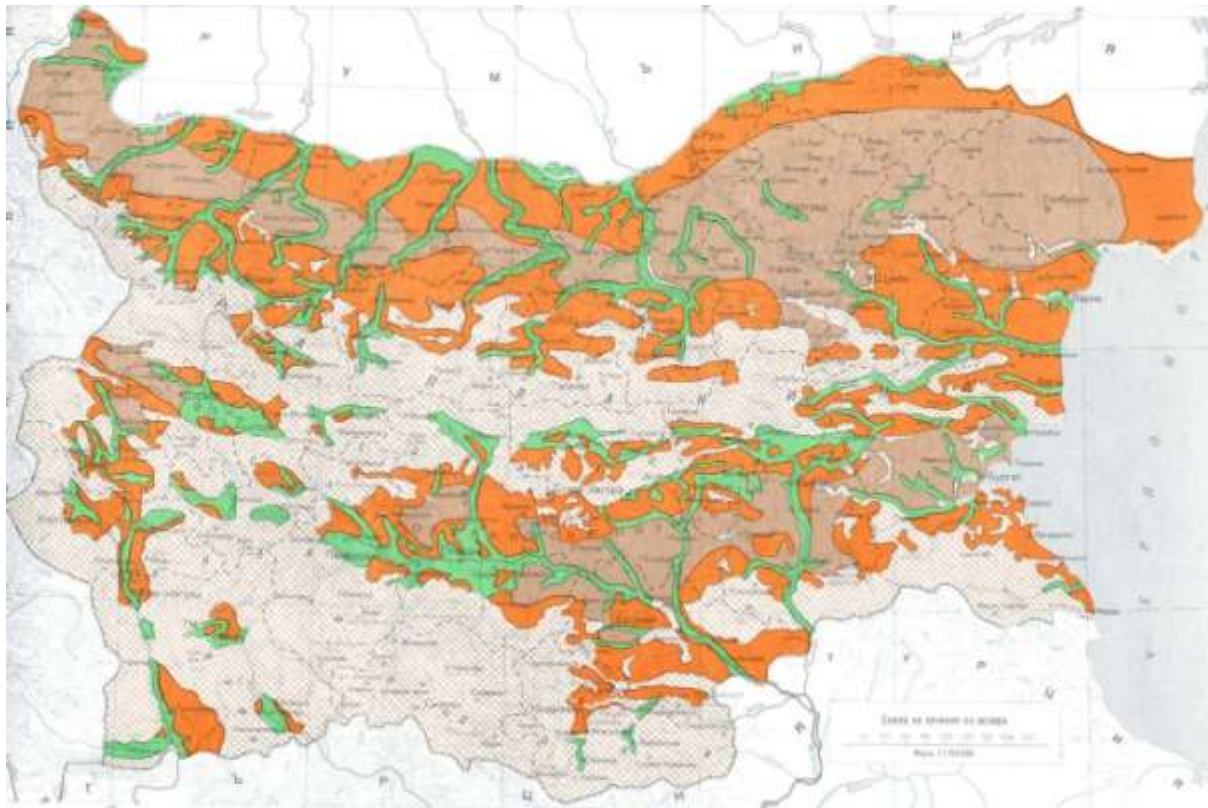


Figure 16. Stocks productive moisture in one-meter layer of soil during the regeneration of vegetation in spring wheat (source: agroclimatic atlas of Bulgaria, 1982); hatch - shallow soils, water supply is not fixed; green - alluvial, diluvial and meadow soils (moisture < 125 mm); orange - deep soils (125 mm < moisture < 150 mm); brown - deep soils (150 mm < moisture < 175 mm)

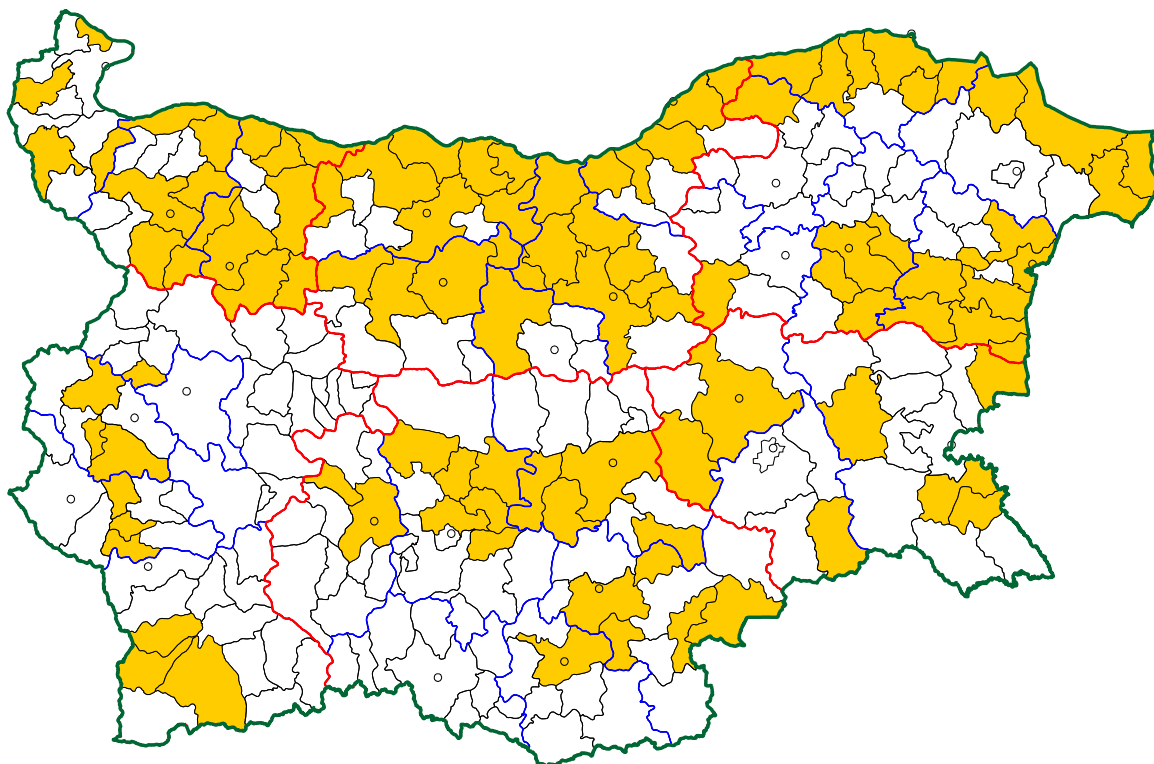


Figure 17. Municipalities in Bulgaria with potential conditions (in water deficit) for the drought in one-meter layer of soil in deep soils during the regeneration of vegetation in spring wheat

9.7. SUMMARY MAP OF DROUGHT IN BULGARIA

The national literature, there are several attempts for mapping drought in Bulgaria. For example, in agro-climatic atlas of Bulgaria (1984) has maps of rainfall amounts in potential vegetation period (in stable transition of air temperature over 10°C) nevegatitsionniya period; rainless periods in the warm half-year, etc. In this atlas has a map of the humidity ratio for the period with temperature above 10°C (Fig.18.). Humidity ratio is calculated based on the difference between precipitation and volatility. It outlines the areas in the country that are highly drought, moderate drought, with optimal humidity, with preovlazhnenie. It is believed that this card is a good example of spatial distribution of atmospheric drought in Bulgaria. Based on this map is created and the map with the municipalities in Bulgaria, classified according to the humidity ratio for the period with temperature above 10 ° C (Fig. 20). Most vulnerable are proving Danube municipalities of the coastal communities - around Varna and Burgas, most of the municipalities in the lower parts of southern Bulgaria, and some of the most southern communities along the Struma.

Was developed and other summary map of the spatial distribution of atmospheric drought (Fig. 20). This map is based on the rainfall maps for different time intervals and corresponding maps of municipalities potentially threatened by drought conditions (Figure 5-16). Eastern communities in Dobrich are the least rainfall in most of the year and therefore

are at higher risk to atmospheric drought. Then there are other municipalities in eastern Bulgaria, Pazardzhik municipality and municipalities of Plovdiv, Yambol and Blagoevgrad.

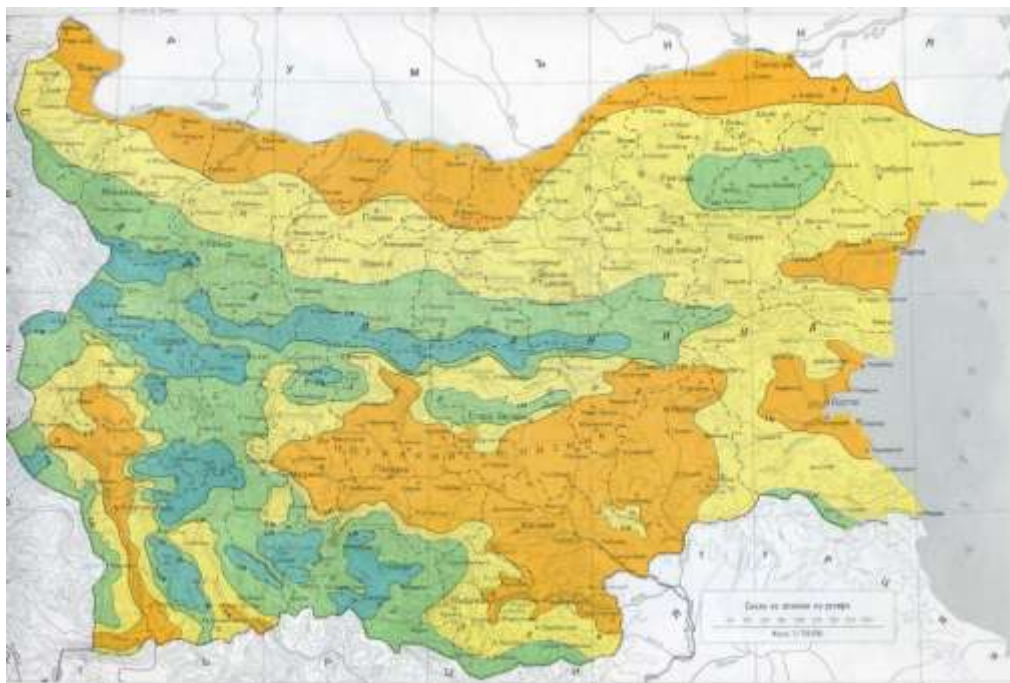


Figure 18. Coefficient of humidity for the period with temperature over 10°C (source: agroclimatic Atlas, 1984); orange area is very arid, yellow area is moderately arid, green area is an optimal humidity, blue zone: a preovlzhnenie

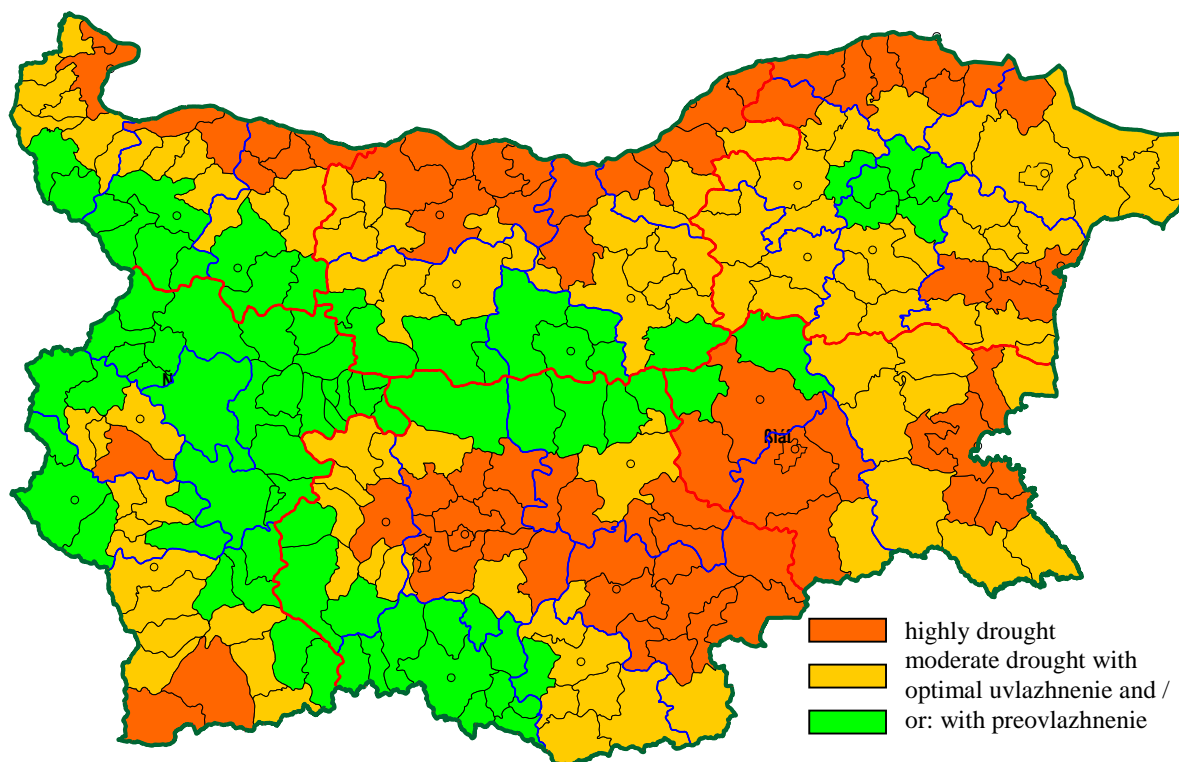


Figure 19. Municipalities in Bulgaria, classified according to the humidity ratio for the period with temperature over 10°C

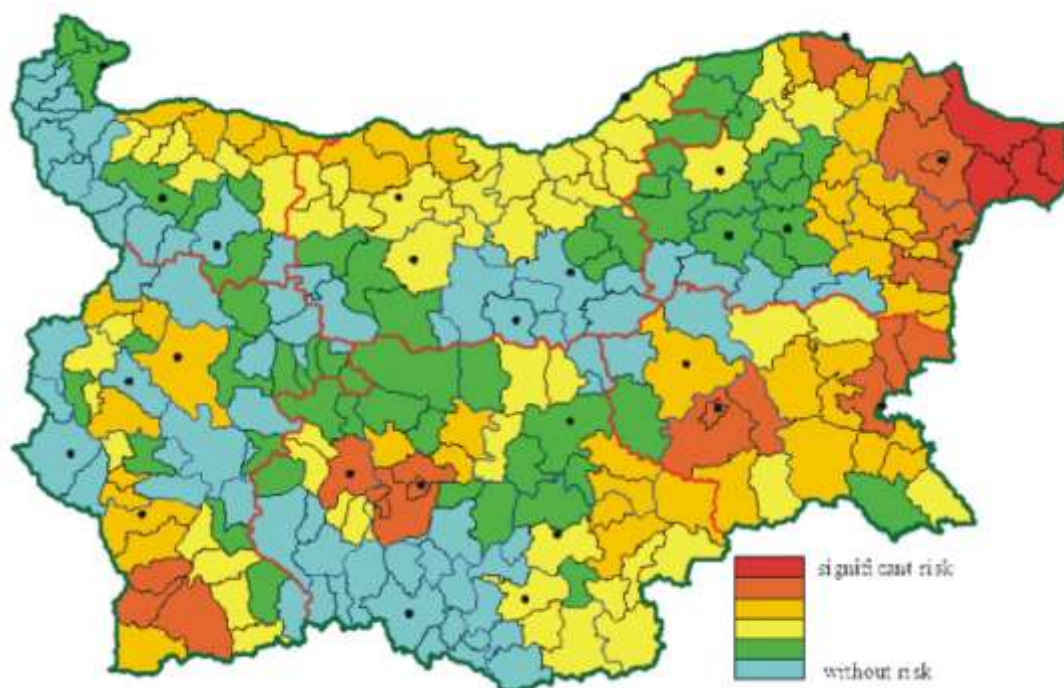


Figure. 20. Municipalities in Bulgaria, risking to atmospheric drought

Similarly, were created and aggregated maps of municipalities in Bulgaria, vulnerable to the occurrence of soil and soil-atmospheric drought. The first map - the soil drought - is based on data from FAO classification of soil types and texture classes in Bulgaria. Municipalities with an increased risk to soil drought in all planning regions. For example, in northwestern Bulgaria - of Lom Municipality Dolna to Metropolis, in eastern Bulgaria - Shumen region, in southern Bulgaria - municipalities in Pazardjik, Plovdiv and Stara Zagora, Bulgaria in the west - Municipality Dragoman, Tran and others. Municipalities in the country at risk to soil and atmospheric drought (based on a summary of soil moisture at different times of the year) are located in southern and eastern Bulgaria. Northern municipalities and the region of southeastern Bulgaria are also potentially vulnerable to the occurrence of soil atmospheric drought in the event of reduction of soil moisture. Presented in the report map material, presenting a summary or detailed information on areas and communities potentially vulnerable to droughts: atmospheric, soil and soil air. These materials would be useful in decision making, developing strategies and planning activities relating to monitoring, adaptation and mitigation of the effects of drought.

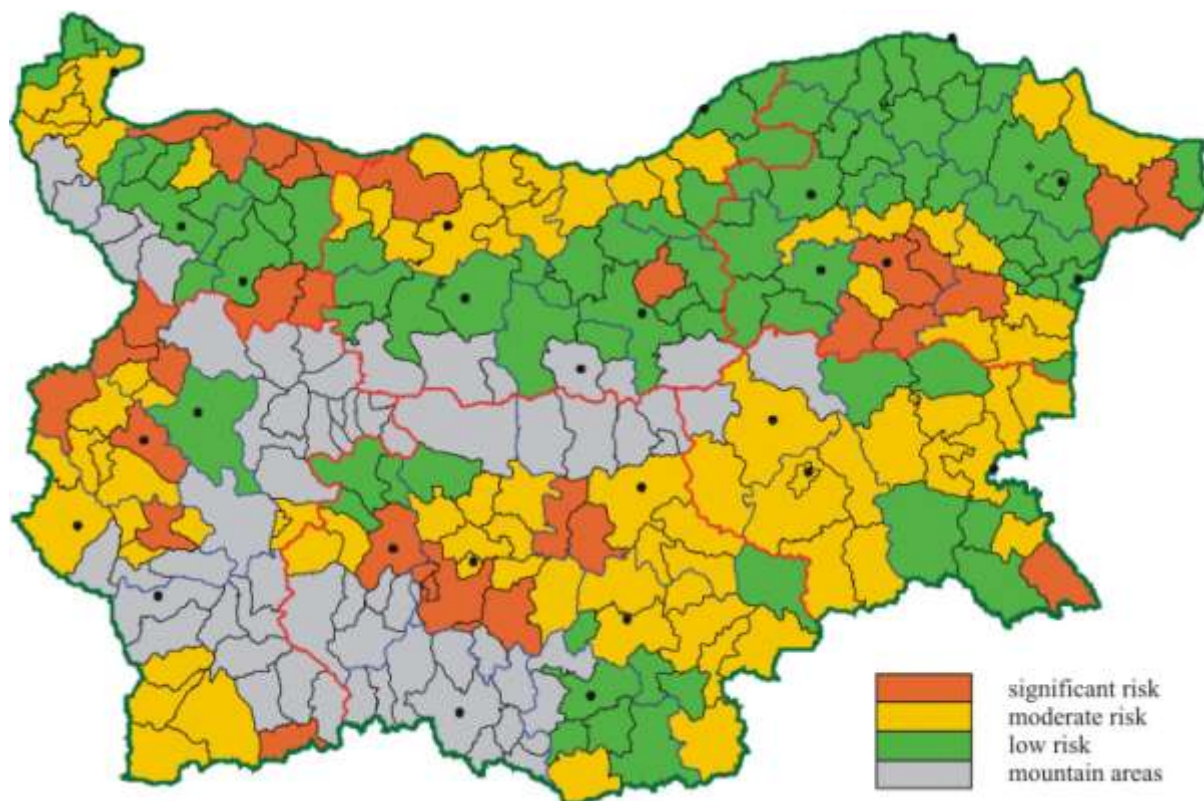


Figure 21. Municipalities in Bulgaria, with the risk to soil drought

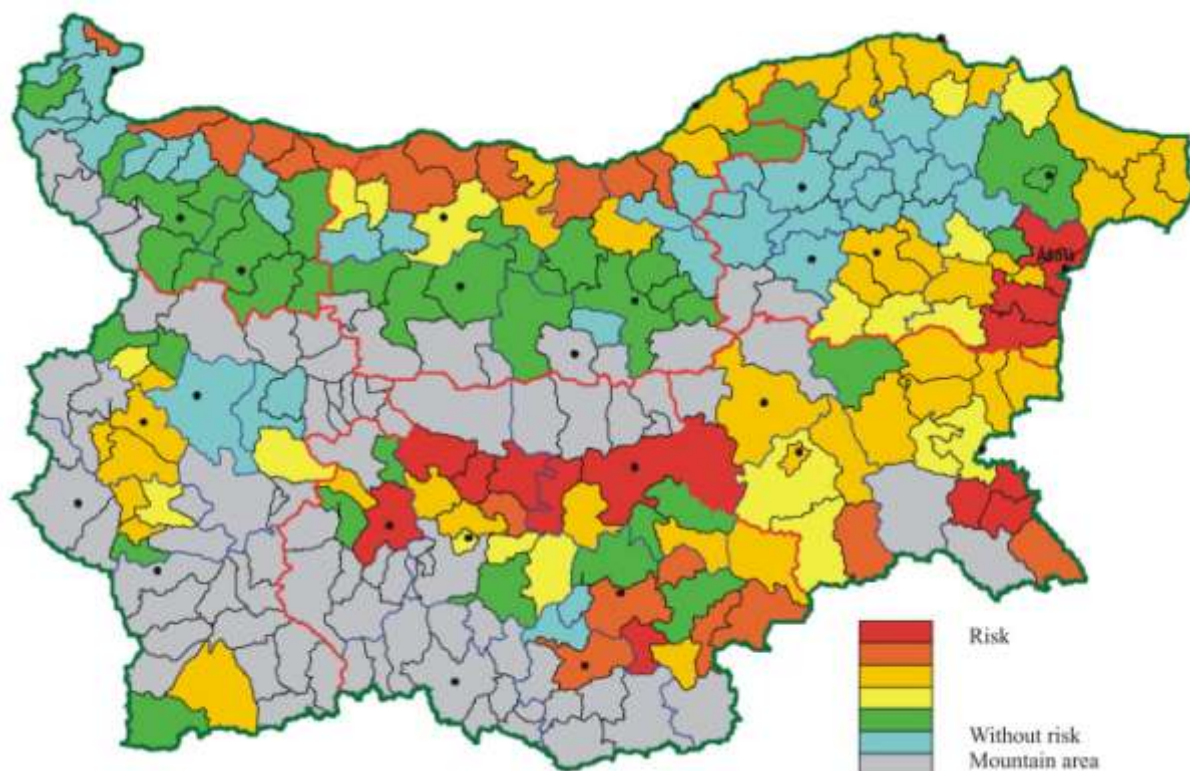


Figure 22. Municipalities in Bulgaria, with the risk to soil and atmospheric drought



10. HOMEPAGE

On the homepage of the DMCSEE organization (dmcsee.org/GISapp) the vulnerability maps of the project partners were uploaded.