

1. Drought vulnerability

- Drought causes the highest economic losses among all hydro-meteorological events in Croatia (Fig. 1).
- It is the most frequent hazard, which produces the highest damages in the agricultural sector.
- Following the recommended procedure within the project "Drought Management Centre for South

- East Europe" (DMCSEE-OMSZ, 2011), the map of vulnerability to drought for Croatia is prepared.
- This map is considered as one of the possibilities to summarize complex interactions of terrain, soil and climatological features in only one parameter that could describe the sensitivity to drought.

- A considerable water deficit through the year when the potential evapotranspiration (PET) is larger than precipitation (P) due to the atmospheric conditions is presented by aridity index (P/PET).

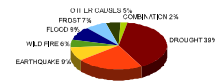


Figure 1 Damages in Croatia caused by natural hazards (1981-2010)

2. Maps of the parameters affecting the vulnerability to drought

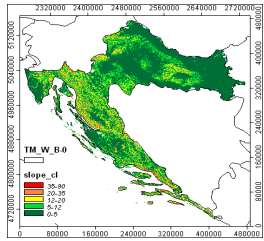


Figure 2 Slope map

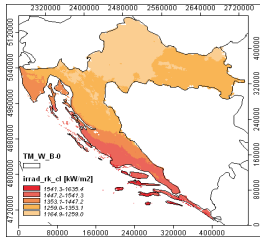


Figure 3 Solar irradiation map for the 1961-1980 period.

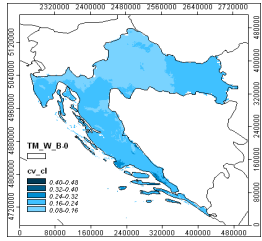


Figure 4 Coefficient of variation of precipitation for the 1971-2000 period

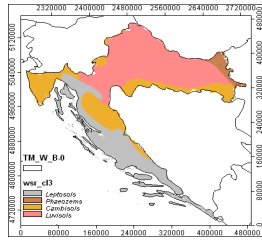


Figure 5 Soil classes (adopted from the Map of World Soil Resources (WSRC))

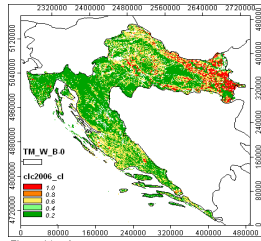


Figure 6 Land use map

- Slope angle is calculated from 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.
- Slopes principally range from 0-12° and predominant are slopes from 0-5°.
- Map of soil classes is adapted from the World Soil Resources Coverage (WSRC) that has 32 soil classes for the world.
- Luvisols dominate in the continental part of the Croatia, with some Cambisols and Phaeozems.
- Cambisols dominate in Istria peninsula and the mountainous

- Lika region.
- The rest of the coastal area is covered with Leptosols.
- Map of the coefficient of variation of precipitation, c_v is calculated as the ratio of standard deviation map and precipitation map for the 1971-2000 period.
- Precipitation and standard deviation maps are calculated from measurements and auxiliary maps within the regression kriging framework.
- Higher values of c_v (higher inter-annual variability) are connected with the higher vulnerability to drought.
- The most sensitive areas are on the southern coast.
- c_v is lower than 24% almost everywhere and mainly it is in

- the 16-24% range.
- Solar irradiation map is estimated from the available data for the 1961-1980 period (Zaninović et al. 2008).
- The irradiation rises from the north to the south and it is larger on the coast than inland.
- The values are lower on the mountain tops due to the increased cloudiness in summer.
- Irradiance is mainly from 1165-1353 kWhm⁻².
- 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) (Tab. 1).

Vuln. class	Description	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	56.4%
0.4	Vineyards	0.5%
0.6	Complex cultivation patterns, Natural grasslands, Moors and heathland, Sclerophyllous vegetation, Sparsely vegetated areas	26.2%
0.8	Fruit trees and berry plantations	0.2%
1.0	Non-irrigated arable land, Permanently irrigated land	6.7%
	Without vegetation, water area	10.1%

3. Category maps of the parameters affecting the vulnerability to drought

- Maps of the necessary (Fig. 2 to Fig. 4) and optional parameters (Fig. 5, Fig. 6) are classified according to limits (Tab. 2) to create a category maps of the parameters.
- On the category maps values are 0.2 if the low vulnerability to drought is assumed, 1.0 if the high vulnerability is supposed and 0.4, 0.6 and 0.8 for the intermediate classes.
- The tree necessary category maps have the predominant low vulnerability classes of 0.2 and 0.4.

- Soil map is dominated by Luvisols that are not so sensitive to drought. On the other hand, the Leptosols, the 2nd important soil class in Croatia, (and the world's most extensive soils) belong to a class 1.0.
- According to CBS (2011), forests occupy 39.5% of the territory which results in the largest area of the land cover map in the class 0.2. Significant is also the class 0.6.

Table 2 Proportion of the area in each class expressed in km² for all maps of the parameters. Soil classes: LV = Luvisol, CM = Cambisol, PH = Phaeozem, LP = Leptosol. Land cover code according to Tab. 1. The proportions for the predominant classes are highlighted.

Vuln. Class	Slope Limits	Slope Area	Irradiation Limits	Irradiation Area	C. of variation Limits	C. of variation Area	World soil Type	World soil Area	Land cover Code	Land cover Area
0.2	0-5	32226	1165-1259	18609	0.08-0.16	21583	-	-	223,243,311,312,313,324	31879
0.4	5-12	14482	1259-1353	22765	0.16-0.24	33803	LV	24924	221	289
0.6	12-20	6699	1353-1447	6527	0.24-0.32	1130	CM	13508	242,321,322,323,333	14804
0.8	20-35	2876	1447-1541	7486	0.32-0.40	38	PH	1825	222	96
1.0	35-90	172	1541-1635	1169	0.40-0.48	2	LP	16299	211,212	3797

4. Drought vulnerability map of Croatia

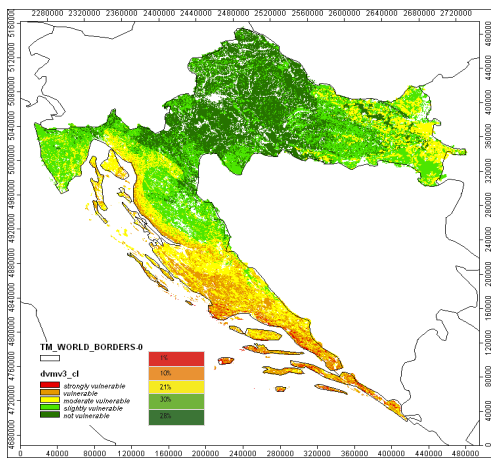


Figure 7 Categorical drought vulnerability map for the areas covered with vegetation. 10% of the land (without vegetation or water bodies) has not been classified. Percentage of the area in a certain category is in the legend.

- The categorical maps of the parameters are summed and classified. The result is a category map of the vulnerability to drought with five categories: *not vulnerable*, *slightly vulnerable*, *moderately vulnerable*, *vulnerable* and *strongly vulnerable* (Fig. 7).
- 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. Precipitation is lower than on the western continental part. 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* since the precipitation is also larger compared to the eastern lowland.
- *Slightly vulnerable* are also the Istria peninsula and the mountainous 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* to drought.

6. Conclusions

- The preliminary results for Croatia, according to the recommended procedure in the framework of DMCSEE project, show the most sensitive areas to drought in the middle and southern Adriatic coast and eastern continental lowland (Fig. 7).
- Spatial distribution of aridity index through the year indicate the susceptibility to desertification on monthly scale according to the atmospheric conditions (Fig. 8).
- The vulnerability classes should not be considered as absolute, but relative,

- defining the areas more or less sensitive to drought for the range of values of the parameters on the territory of Croatia.
- As such, they are not fully comparable with the maps for other areas.
- Further research should be oriented to the definition of the vulnerability classes 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.

5. Spatio-temporal distribution of aridity index

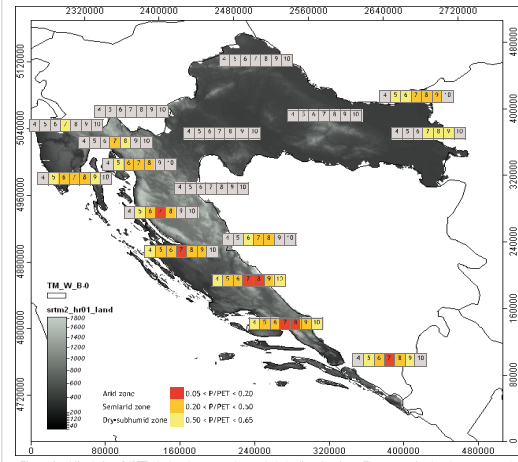


Figure 8 Aridity index (P/PET) during the vegetation period (April to October). The categorisation due to susceptibility to desertification is also in the legend (Arid, Semi-arid and Dry-sub-humid zones). 1961-1990.

- According to the United Nations Convention to Combat Desertification (UNCCD) definition and criteria accepted by UNEP/GEIS (1992) the next scheme shows the threat to desertification due to climate conditions:
 - (desertification) $0.05 \leq P/PET < 0.65$ (no desertification)
 where the ratio of precipitation (P) and potential evapotranspiration (PET) is the aridity index.
- In the warm half of the year the most pronounced susceptibility to desertification is at the Adriatic coast and islands and it increases towards the south.
- To the less extent susceptibility to desertification is also present in the eastern Croatia (Slavonia) in dry-sub-humid zone during the warmest months.

7. References

- CLC (2006) Corine Land Cover 2006 raster data - version 15
- CBS (2011) Croatia in Figures, 2011. Croatian Bureau of Statistics
- DMCSEE-OMSZ (2011) Output_standard_drought_vulnerability_v31.doc
- UNEP/GEIS, 1992. Global reassessment of desertification
- WSRC World Soil Resources Coverage
- Zaninović K, Gajić-Čapka M, Perčec Tadić M, Vučetić M, Milković J, Bajić A, Cindrić K, Cvitan L, Katušin Z, Kaučić D, Likso T, Lončar E, Lončar Ž, Mihačević D, Pandžić K, Patarić M, Smeč L, Vučetić V (2008) Klimatski atlas Hrvatske / Climate atlas of Croatia 1961-1990., 1971-2000. Zagreb, Državni hidrometeorološki zavod / Meteorological and Hydrological Service of Croatia. 200 pp