5. Agricultural Drought Risk Assessment in Vojvodina

Selecting the Right SPEI Index for Monitoring Agricultural Drought in Vojvodina

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The occurrence of drought in Vojvodina can have serious consequences in agricultural production. There is drought to a certain extent almost every year, and it manifests as a factor that prevents high crop yields (Bezdan, 2014). Since in the geological and climate conditions of Vojvodina's agricultural production is limited by the quantity and distribution of precipitation, drought can have a very negative influence on the efficiency of production (Rajić and Bezdan, 2011).

In the last few years, agricultural production in Vojvodina suffered serious damages. In 2012 financial loss caused by crop damage amounted to 1 billion euros in 45 towns and villages in Vojvodina, in a period when the yield of certain crop types dropped by more than 50%.

At a global level drought is the type of natural disaster that affects the largest number of people directly. Basiscally drought is an ordinary natural phenomenon that occurs in any climate condition from time to time (Kogan 1997; Wilhelmi and Wilhte, 2002; Wilhite, 2005). Drought forms in those areas where there is considerable precipitation and also in those where there is little rainfall. Drought is a temporary deviation from the average, as opposed to aridity, that is a permanent or long-term characteristic of the climate, and occurs in regions where the precipitation level is low. As a result of the complex system of relationships between climate, hydrological, geological, geomorphologic, ecological and socio-economic factors, it is very difficult to give a universal and full definition of the drought phenomenon (Pereira and Paulo, 2003).

In practice drought is a natural phenomenon that must be studied regionally, from several perspectives, with the involvement of various branches of science. Drought can be defined from meteorological, hydrological, agricultural and socio-economic perspectives (Wilhite and Glantz, 1985; Prohaska, 2006). When we talk about meteorological drought, we mean a long period when the precipitation level is much lower than the longterm average, and when the amount of rainfall is at the lower limits. Hydrological drought refers to those periods when the water flow of rivers is very low, and the water level of reservoirs and lakes is low for a long period of time. In agriculture they talk about drought when the soil moisture level is way below the average, and the water in the soil isn't enough for the development of the crops grown. Socio-economic drought connects the demand for and supply of a given (economic) property with the elements of meteorological, agricultural and hydrological drought.

Drought has differing significance and impact in different fields such as agriculture, water management, hydropower, ecology, etc. For instance the decrease in crop yield resulting from drought formation isn't of the same magnitude with every industrial crop type, because it depends on the water needs and drought resistance of the given crop, the quality of soil cultivation and the water content of the soil. Compared with other natural disasters, drought is different in the sense that it stats slowly, it is difficult to notice and its effects accumulate slowly, during a longer period of time.

In order to simplify the complex phenomenon of drought a little, we detect its occurrence by utilising the drought index. To make the droughts of regions in various parts of the world comparable – which occurred in different historical periods too – it was necessary to come up with a numerical drought indicator (a drought index). Since drought itself can be defined in many ways, it is very difficult to develop some kind of universal index. At the same time due to the complexity of drought, no single index can describe the phenomenon in full (Prohaska, 2006).

There are various drought indexes used all over the world, and one of the most frequently applied indexes is the SPEI – Standardised Precipitation-Evapotransporation Index (Vicente-Serrano et al., 2010; Beguería et al., 2014). SPEI is based on the accumulated difference of precipitation and potential evapotransporation. When preparing this study, we decided work with this index because the best kind drought index for studying agricultural drought is the one that is based on rainfall and evapotransporation at the same time – these are the two fundamental components of the water balance (Moorhead et al., 2015).

In the first stage of the study we examined in Vojvodina how strong the relationship is between the average corn yields – corn is the most widely grown and the most important crop in the region – and the SPEI value calculated for the individual months, so that we can select the right SPEI index for studying the agricultural drought in Vojvodina. In the next phase, based on the cost analysis of corn growing, we estimated the corn yield that makes profitable corn farming possible; then based on the equations set up earlier for the regression, we defined those SPEI index values that indicate possible crop damage. These SPEI values are limit values, which should be taken into consideration when analysing agricultural drought in Vojvodina.

The study focuses on nine towns (Bečej, Kikinda, Subotica, Novi Sad, Sremska Mitrovica, Sombor, Vršac, Zrenjanin and Belgrade) in the 1971-2017 period. We used those towns where the main weather stations of the Republic Hydrometeorological Institute of Serbia can be found. Data on the average corn yield comes from the statistical yearbooks of the Republic of Serbia (Statistical Office of the Republic of Serbia, 2019). When calculating the costs and cost structure of corn growing, we used the method of analytic price calculation (Marko et al., 1998). By applying the regression methodology, we prepared the estimated SPEI index value that indicates possible crop damage. As for the cost calculations for corn farming, we performed them relying on the reports of the Chamber of Commerce of Vojvodina.

Corn is a high yield crop, the most important cereal in the region, which is grown in large areas both for seed and animal feed purposes; it is grown both as the main crop and as undersown crop. In Serbia corn is the most important cereal crop that is grown on 35-40% of cultivable agricultural land, mostly in the flat areas of the

Vojvodina region (Spasojević et al., 1994). Corn can give high yield (more than 20 t/ha). If grown in a large area without irrigation, in the years with medium weather conditions the yield can be 7-8 t/ha; with irrigation farming the yield can be around 10 t/ha.

The development of agricultural production, for instance the growth in agent utilisation, growing new crop varieties, increased herbicide use and more advanced soil cultivation result in improved agricultural output, which means that crop yields are rising (Potopová et al., 2015). In order to be able to analyse the impact of climate conditions exclusively on crop yields, it is necessary to eliminate trends from the times series of yields (Potopová et al., 2015). In the present study we used the method of least squares regression to eliminate trends from the time series of yields. The random errors of the 'trend-free' data series of corn yields were later used to calculate the standardised yield residual series (SYRS) (Fig 5.1).

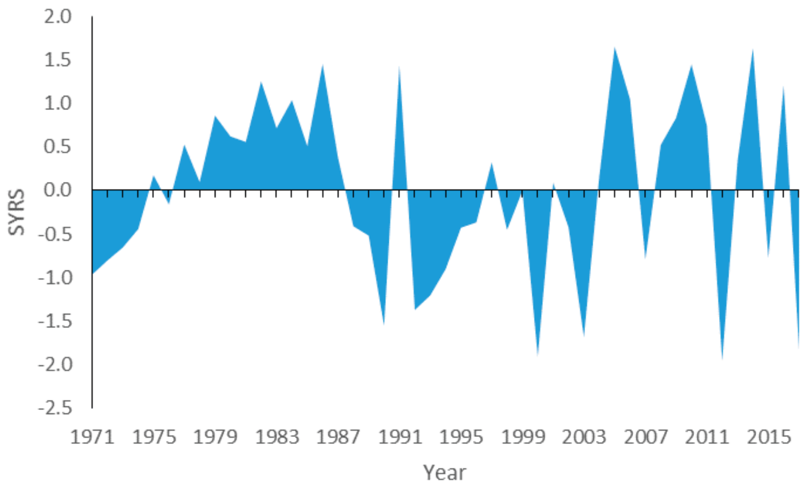

Figure 5.1 *Corn's SYRS values in Vojvodina, 1971-2017*

Next you can see the results of calculating the correlation coefficients to examine the strength of relationships between the average corn yields in Vojvodina and the average values of the SPEI index (Table 5.1).

Table 5.1 *Pearson correlation coefficient for corn's SYRS and SPEI indexes*

$SPEI1_{May}$	$SPEI1_{Jun}$	$SPEI1_{Jul}$	$SPEI1_{av}$	$SPEI1_{May}$	$SPEI2_{Jun}$	$SPEI2_{Jul}$	$SPEI2_{av}$	$SPEI3_{May}$	$SPEI3_{Jun}$	$SPEI3_{Jul}$	$SPEI3_{av}$
0.398	0.452	0.517	0.545	0.430	0.547	0.636	0.617	0.543	0.541	0.678	0.659

All values of the Pearson correlation coefficient indicate that there is a strong statistical relationship between corn yields in Vojvodina and the SPEI index, based on the α = 5% significance threshold. Statistically the yields' relationships are the strongest with the July SPEI3 index and the July SPEI2 index. This is the reason why these indexes are suitable for agricultural drought monitoring in the Vojvodina region. Fig

5.2 and 5.3 show the scatter diagrams and the least squares regression lines of the SPEI3July and SPEI2July indexes of the average corn yields.

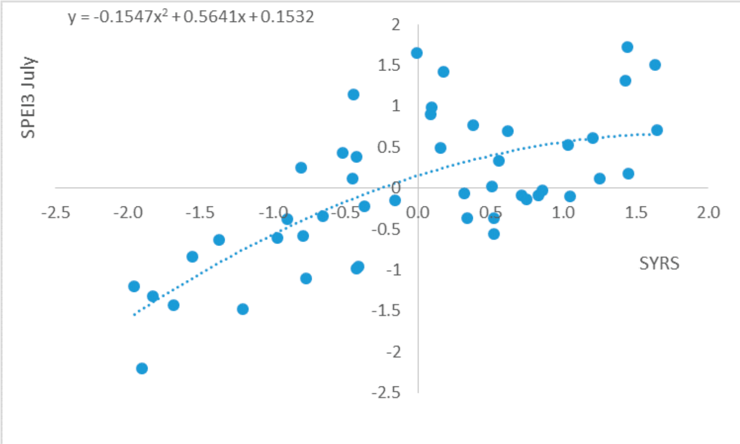

Figure 5.2 *Scatter diagram and the least squares regression line for SPEI3 July*

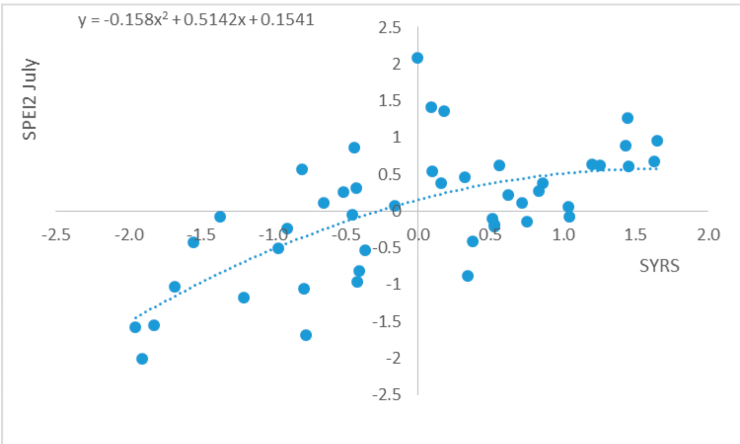

Figure 5.3 *Scatter diagram and the least squares regression line for SPEI2 July*

Table 5.2 was prepared based on a report by the Chamber of Commerce of Vojvodina on the conditions for crop farming (PKV, 2016), which includes the average corn yields of Vojvodina, the average prices, the value of production, direct costs and the gross profit margin. The data represent an average for the whole of Vojvodina's territory and refer to the following years: 2007, 2008, 2009, 2010, 2011 and 2014. Data wasn't available for other years. Direct production costs include the price of seeds, artificial fertilisers (NPK, UREA, KAN), herbicides and pesticides, and motor fuels. In the years examined, the estimated profitable average yield of corn was 3,880 kg.

Table 5.2 *Calculating corn's growing costs, gross profit margin and profit-generating yield*

	2007	2008	2009	2010	2011	2014
Average Yield (kg/ha)	4050	5235	5900	6710	5990	10000
Price (RSD/kg)	14	10	9,4	18,3	15,7	13
Value of production (RSD /ha)	56700	52350	55460	122811	93908	130000
Direct costs (RSD /ha)	31399	42440	52593	43789	52702	70800
Gross margin (RSD /ha)	25301	9910	2867	79022	41206	59200
Profitable Yield (kg)	2243	4244	5595	2393	3357	5446

According to the preliminary calculations, the critical value of the SPEI3 index for July was 0.52, while the critical value of the SPEI3 index for June was -0.6. Below these index values there is a chance for crop damage and financial loss in the corn farming of Vojvodina.

Drought Risk Assessment

Several authors have studied the concepts of risk, hazard and sensitivity, Blaikie et al. (1994), Knutson et al. (1998), Wilhite (2005), Greiving et al. (2006), Kumpulainen (2006), Petronijević et al. (2010), Bezdan (2014) and many others. One of the simplest risk definitions underlines that risk is the damage caused by some kind of phenomenon multiplied by the possibility of a loss. The likeliness of the event occurring depends on the how strong the natural hazard is. The bigger the natural hazard is, the less likely it is going to occur. A risk's scale is the magnitude of the hazard occurring in a situation. According to Thywissen (2006), the risk of dangerous events occurring is the combination of the likeliness of the hazardous situation's occurrence and its consequences, and usually it can be determined as the series of complex parameters such as hazard, vulnerability, exposedness and resistance. Therefore risk depends on the likeliness of an event's occurrence and on the intensity of the consequences of the event that has occurred. The chances for the risk's occurrence can be very frequent, frequent, rare or zero, while the consequences of the risk can be disastrous, critical, small or negligible.

Numerous types of risk assessment methods exist, and one of the most frequently used methods is based on the formula recommended by Blaikie et al. (1994), in which risk equals hazard multiplied by vulnerability:

$$\text{Risk} = \text{Hazard} \times \text{Vulnerability}$$

They define risk as a potentially harmful physical event, phenomenon or human activity, which results in the loss of lives, injury, property damage, social or economic changes, and environmental damages (UNISDR, 2004).

There can be several sources of the danger: natural or originating from human activity, which is mostly the result of human irresponsibility. Natural hazards are caused by natural phenomena and can be classified as follows (UN/ISDR, 2004):

- geological hazards (earthquake, landslide, tsunami, etc.);
- hydrometeorological hazards (floods, droughts, storms, cyclones, hurricanes, etc.) and
- biological hazards (environmental pollution, pandemics, pest invasion, etc.).

Sensitivity is a very important factor in risk assessment. There are various explanations and definitions for sensitivity, depending on the context. Sensitivity refers to the potential damage and it is a progressive variable, which makes sensitivity forecasting possible, telling what can happen to a population if certain risks and threats occur (Cannon et al., 2005). In a general sense we can define sensitivity as some kind of criteria for possible damages to the system, as a result of being exposed to some kind of threat, pressure or stressor of various origins (Turner, 2003). Sensitivity is a multidimensional (physical, social, economic, environmental, institutional and human) factor. Many of these are difficult to define quantity-wise.

We performed the vulnerability, hazard and risk assessment in a GIS environment. The method we used was the classification, reclassification and overlaying of layers, and we determined weighted factors by using the analytical hierarchy process (AHP). In order to be able to perform the overlaying of layers that (might) contain various data in GIS, the layers had to be standardised and we also had to classify them according to certain criteria. With layers classified based on determined criteria, each layer acquires the same type and the same dimension of data. In this case the input layers were given whole number values from 1 to 5 in the classification, where 1 meant the lowest level of sensitivity, threat or hazard, and 5 meant the highest level of these.

Drought vulnerability assessment

The factors that influence the area's drought vulnerability and the indexes that indicate how sensitive it is to drought were determined based on the natural characteristics of Vojvodina and on anthropogenic effects. We determined the factors that influence the development of drought and the factors that mitigate its effects relying on the data available and on the research work of many authors about drought vulnerability. We were working with the following elements of agricultural drought vulnerability: yield characteristics of the soil, irrigation needs of the crops grown and how the land is used.

Soil fertility and production potential

The productivity of agricultural land is basically its ability to ensure a certain level of yield (Živković et al., 1972). We could say that the productivity of the soil, if it is provided with nutrients, it isn't sodic, it isn't alkaline or boggy, can be determined based on the soil type, subtype (mechanical composition) and rock depth. These were the criteria used to classify the productivity of agricultural land. Four soil classes were specified:

- **1st class** – the most stable soil with highest yield value;
- **2nd class** – the yield value is a bit lower, but with the right cultivation, increased manure use and the necessary soil moisture high yields can be achieved;
- **3rd class** – soil with a low yield value, mostly used for orchards, vineyards, grazing and or wood;
- **4th class** – soil with very low yield value, case melioration steps don't matter from a crop growing perspective, these soils are used as grazing land or forest.

Reclassification (Figure 4) of the soils' fertility and production potential was done the following way: the areas with the best fertility and production potential were given 1st-class vulnerability, the soils with a moderate productivity were classified as 2nd-class vulnerability, soils with a low fertility and production potential became 4th-class vulnerability agricultural land, and those with a very low fertility and production potential ended up in the 5th-class vulnerability category (Fig 5.4). In Vojvodina 34 percent of soils have high fertility and production potential (1), 54 percent of soils are a little less fertility and production potential (2), 11 percent of them have low fertility and production potential (4) and 1 percent of the soils are characterised by very low fertility and production potential and were classified as 5th-class.

Irrigation requirements of the crops grown

We determined the irrigation needs of the crops grown by using the WinISAREG simulation model (Pereira et al., 2003; Parades and Pereira, 2010), which is based on the FAO-56 method of calculating evapotransporation, water level and irrigation need (Allen et al., 1998). The calculations were done for nine different crops grown (corn, soy, sugar beet, sunflower, potatoes, peas, cabbage, grapes and apple) for nine weather stations in Vojvodina (Bečej, Kikinda, Palić, Rimski Šančevi, Sremska Mitrovica, Sombor, Vršac, Zrenjanin and Belgrade), for the 1971-2017 period. We calculated the evapotransporation of crops using the coefficients referring to the individual development levels. In order to be able to estimate vulnerability to agricultural drought, the average irrigation needs were put into five equidistant classes, with values ranging from 1 to 5 in the case of every crop. Then we added them up and categorised them into yet another five equidistant classes. As a result of this, we got a map that unites the irrigation needs of all nine crops analysed, and basically works as an agricultural drought vulnerability map according to the criteria (Fig 5.5).

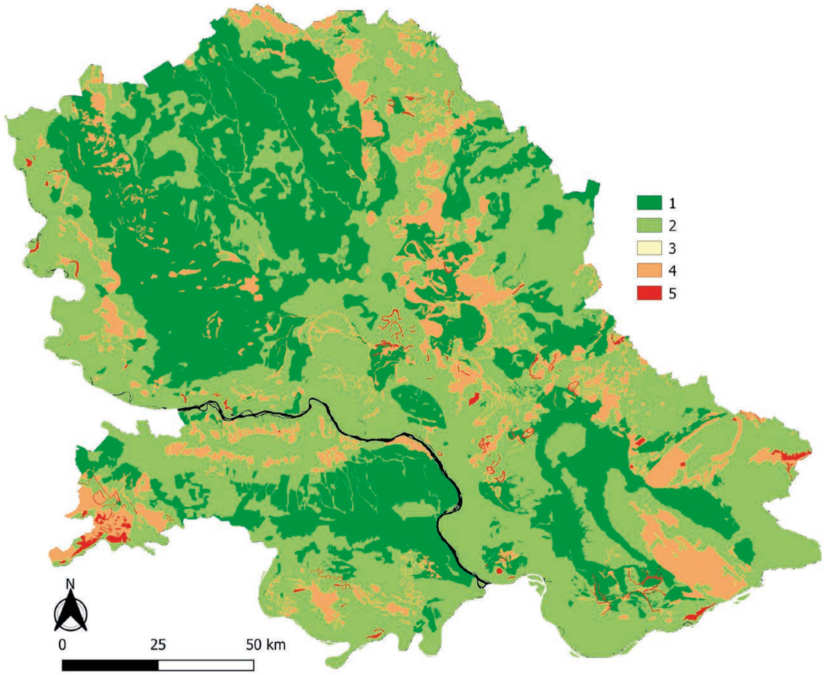

Figure 5.4 *Reclassification map of agricultural land in Vojvodina*

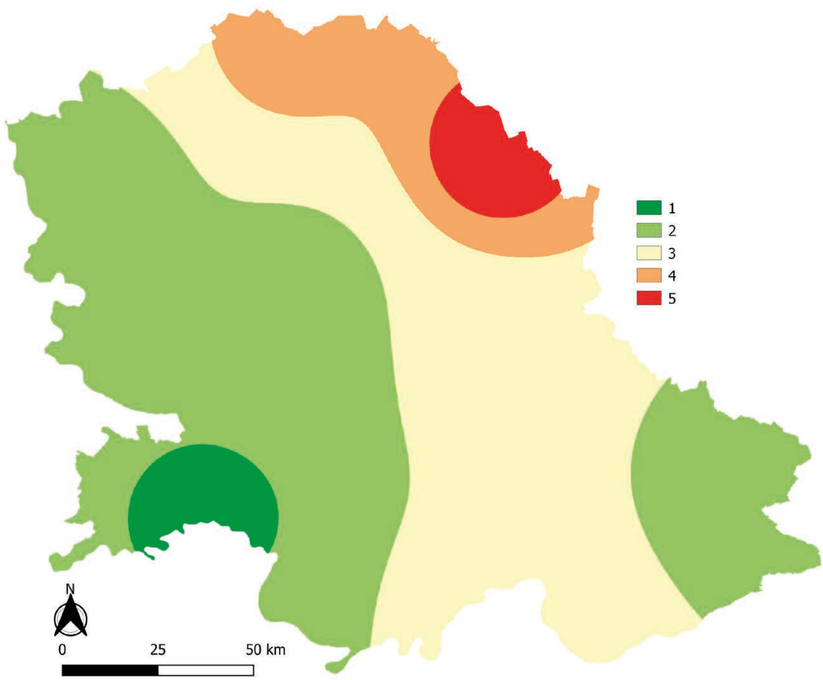

Figure 5.5 *Reclassified map of the average irrigation needs of the crops grown*

Land cover and land use

We developed the layer that describes how the land is used with the help of the CORINE Land Cover 2012 (CLC2012) land cover database. The reclassification of the CLC2012 land database was done as follows: we set the value of 1 to land categorised as 'Grazing land' and 'Mainly agricultural land with relatively large natural vegetation' – this meant the lowest drought sensitivity level. 'Non-irrigated cultivable land', 'Vineyards', 'Orchard and berry farming' and 'Complex of plots cultivated' were given the value of 2, which expresses a little higher level of vulnerability to drought. We didn't include the remaining land categories in the drought vulnerability assessment (Fig 5.6). What belong here are built-up and artificial areas, woods and water surfaces. Grazing land and agricultural land in large parts covered with natural vegetation got a lower drought vulnerability index than other agricultural land, because in these the vegetation adapts better to the weather conditions (Wilhelmi and Wilhte, 2002).

Determining the values of weighted factors

Certain factors of sensitivity and threat can have either small or great influence on the results of risk assessment, therefore they must be paired with the right weighted values. In the present study we applied the analytical hierarchy process (AHP) for determining the weighted factors.

The analytical hierarchy process – AHP (Saaty, 1980) is one of the most frequently used multifactor analysis methods in supporting decision-making in the agriculture sector (Matić-Kekić and Draginčić, 2013). AHP is a process that ranks decision related problems according to their importance – at the top there is the goal, below that we find the criteria and alternatives are at the bottom. Criteria are evaluated in pairs, compared with the goal, and then the same thing is done with the alternatives – comparing them with each criterion. This means that the evaluation is performed as a pairwise comparison of each factor, the basis of the comparison being the factor located higher at the same level of the hierarchy. The result of each comparison is a numeric value from Saaty's scale of relative importance (Draginčić et al., 2011). Detailed description of associating weighted values by using the AHP method can be found in professional literature (Blagojević et al., 2016a; Blagojević et al., 2016b; Blagojević et al., 2016c Srdjevic et al., 2015; Blagojević et al., 2014; Bezdan et al., 2019)

For the present study the alternatives – the comparison of vulnerability factors (the soil fertility and production potential, land uwse and land cover, the irrigation needs of the crops grown) was performed based on the data from professional literature and on the opinions of experts. Applying the AHP method resulted in the drought vulnerability factors being assigned the following weighted values: fertility and production potential of the soil (0.5), the irrigation needs of the crops grown (0.4) land use and land cover (0.1).

The results of the vulnerability factors' weighing with the help of the AHP method indicate that the fertility and production potential of the soil and the irrigation needs of the crops grown have the biggest impact on agricultural drought vulnerability, while the way the land is used has much smaller influence on it.

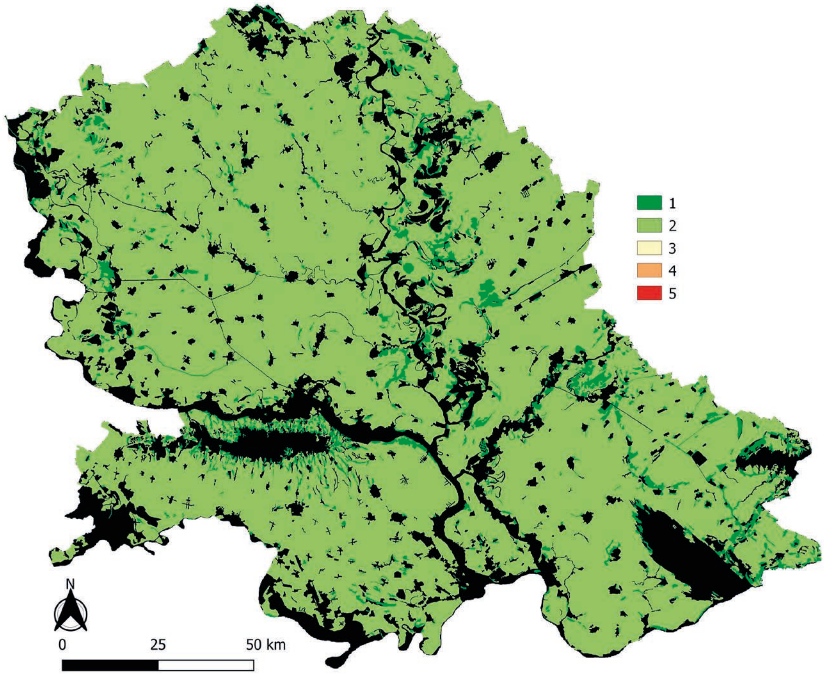

Figure 5.6 *Reclassified land use map*

Agricultural drought vulnerability map

The agricultural drought vulnerability map (Fig 5.7) was prepared by multiplying the raster layers (soil characteristics, topographic features, how the land is used, irrigation needs of the crops grown) of the drought vulnerability factors with the relevant weighted values, and in the next stage by adding up these layers in the GIS and classifying them into the five equidistant categories.

The majority of the territory of Vojvodina, approximately 54%of the area is characterised by low drought vulnerability values (1st- and 2nd-class vulnerability). It is in the Srem and the central and western parts of the Bačka region where the land belongs to the lowest- vulnerability class, where conditions are very good, as the irrigation needs of the crops grown are low and the soil characteristics are very good. From a drought vulnerability perspective, the worst areas are situated in the North East of the Banat region in comparison with other areas of Vojvodina, mainly because of the unfavourable climate and pedology characteristics.

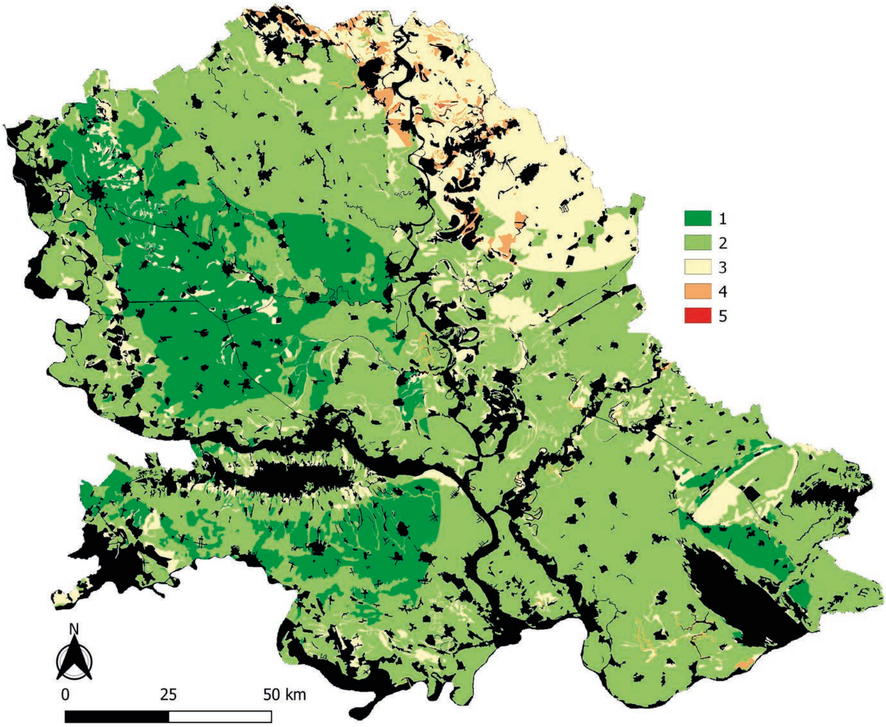

Figure 5.7 *Agricultural drought vulnerability map*

Drought hazard assessment

In order to be able to forecast drought hazard, we need to select the right drought indexes and the methods for analysing them. The present study analyses the SPEI3 index for July, because earlier analyses showed that this is one of the most suitable indexes for analysing agricultural drought. Generally speaking we can say that the hazard assigns a numeric value to the occurrence of a potentially damaging event. Risk assessment can be performed focusing on intensity or on the probability of a damaging event occurring. This is the principle on which the Drought Hazard Index – DHI is based (Dabanli, 2018; Kim et. al., 2015; Shahid and Behrrawan, 2008). We determined the probability of drought's occurrence based on the occurrence frequency of individual drought categories (Sonmez et al., 2005). As we have already noted it above, we analysed drought utilising the SPEI3 index for the month of July. In accordance with the method of DHI calculation, the drought categories were assigned weighted values, and then each drought category was classified based on occurrence frequency (Table 5.3). The principle was that we associated more intense drought periods with greater weighted values. Likewise, if drought more frequently occurs in a given area, we were calculating with higher values.

Table 5.3 *Weighted value and classification of individual drought categories*

SPEI3 Jul	Drought category	Weight (W)	Frequency of occurrence	Rating (R)
0 do -0.99	Near normal / mild drought (ND)	1	Low	1
			Moderate	2
			High	3
			Very high	4
-1.00 do -1.49	Moderate drought (MD)	2	Low	1
			Moderate	2
			High	3
			Very high	4
-1.50 do – 1.99	Severe drought (SD)	3	Low	1
			Moderate	2
			High	3
			Very high	4
< -2.00	Extreme drought (ED)	4	Low	1
			Moderate	2
			High	3
			Very high	4

The DHI was determined based on the weighted value and the classification as follows:

$$DHI = (ND_W \text{ X } ND_R) + (MD_W \text{ X } MD_R) + (SD_W \text{ X } SD_R) + (ED_W \text{ X } ED_R),$$

where ND, MD, SD and ED indicate drought categories, W indicates the relevant weighted value and R stands for the given classification.

The DHI was calculated for each weather station for the 1971-2017 period. We reclassified the DHI values in a way that their values correspond with the 1-5 range, where 1 indicates the lowest hazard rate and 5 stands for the highest rate of hazard. The map in Fig 5.8 contains the results. It shows that the areas in the central part of Vojvodina are exposed to the biggest hazard, while the drought hazard is the smallest in the southern parts.

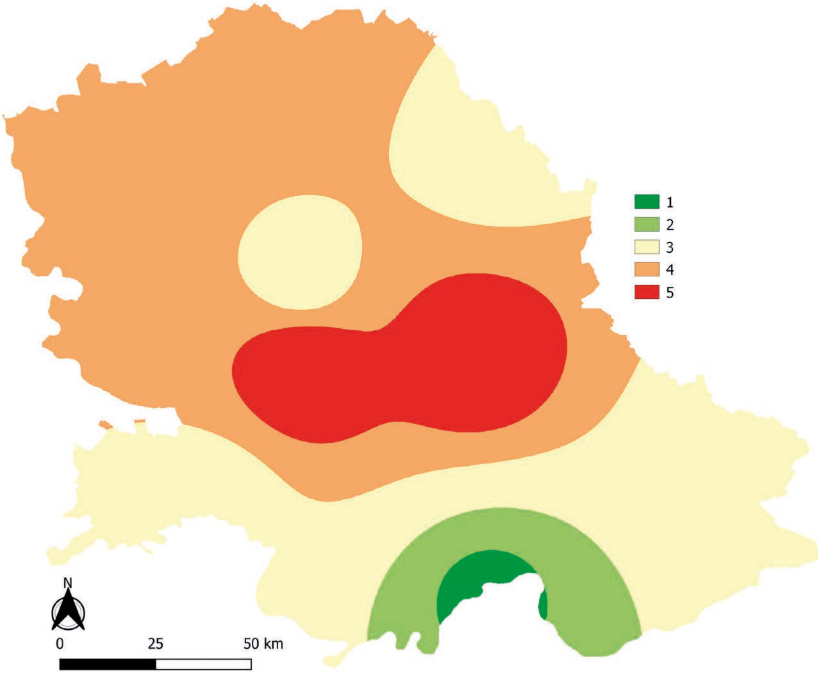

Figure 5.8 *Drought risk map based on DHI indexes*

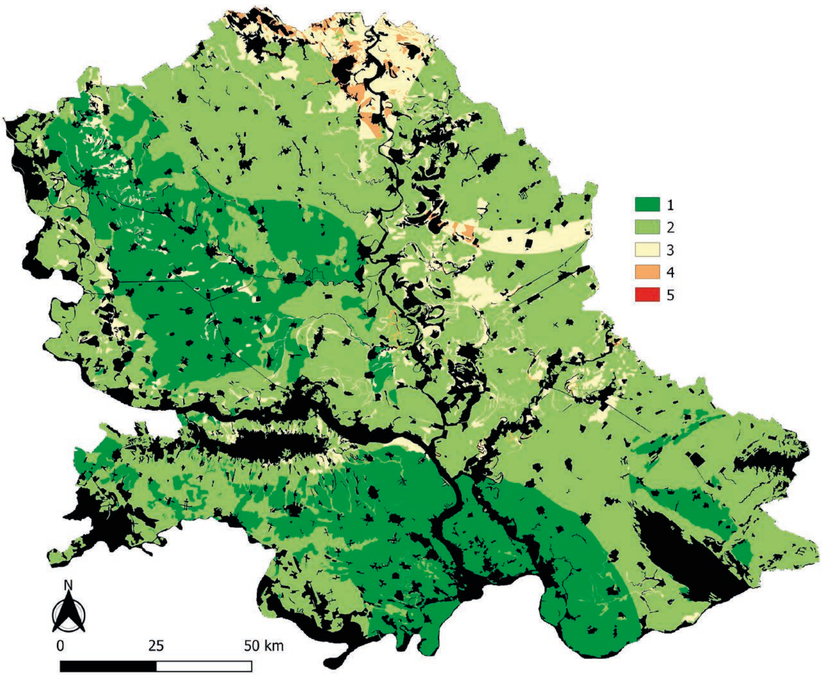

Figure 5.9 *Drought risk assessment map of Vojvodina*

Agricultural drought risk assessment

Agricultural drought risk assessment is based on the method that risk equals hazard multiplied by vulnerability. In the previous stages we did the agricultural drought vulnerability and hazard assessment. By overlaying these layers in GIS and by multiplying and classifying them, we created the map for five equidistant classes, with the help of which we prepared the drought risk assessment for the territory of Vojvodina (Fig 5.9).

Analysis revealed that the risk for 4th-class agricultural drought is the biggest in the North and North East of Vojvodina. In these regions, in comparison with other areas, the assessed hazard value is the highest and the level of vulnerability is also high, due to the relatively bad soil characteristics and the increased irrigation needs of the crops grown. From the territory of Vojvodina – which doesn't include urban and artificial areas, woods and water surfaces – 2% belongs to the 4th risk class; 8% of Vojvodina qualifies as 3rd-class risk territory, 64% is 2nd class area and 26% falls into the 1st class, where the risk for agricultural drought is the smallest. Thanks to the favourable combination of climate conditions and soil characteristics, the estimated risk is the smallest in the North West part of Vojvodina, around Sombor, and in the South, from Sremska Mitrovica through Belgrade to Vršac.