Integrated Drought Management Programme

Activity 5.4. Drought Risk Management Scheme: a decision support system

Milestone no. 2.2.

Framing methodology for vulnerability to drought assessment based on available GIS information including population map, type of economic

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Name of the milestone:	2.2. Framing methodology for vulnerability to drought assessment based on available GIS information including population map, type of economic activity map and protected area to showing the potential adverse consequences.
WP:	5.4.
Activity:	Drought Risk Management Scheme: a decision support system
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1. Introduction

Drought risk is a combined effect of drought hazard (likelihood) and drought consequence (vulnerability). Drought hazard is determined by frequency, duration and severity of droughts. Drought impact on various ecosystems and economy depends on the vulnerability of the affected system. Drought exposure is often defined geographically by assigning a spatially averaged value within administrative, landscape, and river basin boundaries. Consequently a methodology for drought vulnerability assessment has to be developed at the regional as well as at the country, municipality levels or for different river catchments. ***The vulnerability assessment is one of the most important aspects of drought risk map creation and development of drought management plans***.

The main task of current report is to provide insights for the development of the methodology for vulnerability assessment for the particular sector of economy (i.e. agriculture and water resources) including drought impact analysis.

The report includes presentation of the vulnerability assessment for the agricultural sector in Poland and Romania and for water resources sector in Lithuania. Joint conclusions summarized the methodology for the development of the vulnerability functions as the element of drought risk mapping.

2. Vulnerability assessment

2.1 Vulnerability assessment for agricultural sector in Poland

Vulnerability of agriculture to drought is generally referred to as the degree to which agricultural systems (crops) are likely to experience harm due to drought stress. When drought occurs, vulnerability of crops depends on several parameters, the most important ones being the ability of the particular type of crops to adapt to drought stress and the environment of its growth (soil, climate, available soil water). Literature sources suggests that climate, soils and cultivated crop types are the most significant factors of agricultural drought risk that should be taken into account.

Vulnerability assessment for agricultural sector in Poland was done in terms of the effect of meteorological drought expressed with the use of SPI indicator on crop yield reduction in different agro-climatic regions of Poland. The country was divided into eight regions on the basis of diversity of agro-climatic conditions (Fig. 1): A – north-eastern, B – north, C – central-western, D – central-north, E – central,F – central-eastern, G – south-western, H – south-eastern.

Fig. 1 Agro-climatic regions in Poland.

A linear crop-water production function was used to predict the reduction in crop yield *YR* (Doorenbos, Kassam 1979):

$$YR = \left(1 - \frac{Y_{re}}{Y_p}\right) = ky\left(1 - \frac{ET_{re}}{ET_p}\right) \quad (1)$$

where:

Y_{re} – actual crop yield reduced due to water stress,

Y_p – maximum (potential) yield that can be expected under the given growing conditions for non-limiting water conditions,
k_y - yield response factor,
ET_{re} – actual evapotranspiration under soil water deficit,
ET_p – potential evapotranspiration under non-limiting water conditions.

The term $\left(1-\frac{ET_{re}}{ET_p}\right)$, called Crop Drought Index (*CDI*), is used as an agricultural drought index. Eq. (1) can be written then as:

$$YR = k_y \cdot CDI \quad (2)$$

Eq. (2) combines agricultural drought measured by *CDI* and its effect as crop yield reduction.

Assessment of potential crop yield losses on the basis of *CDI* was made for the following field crops: late potato, sugar beet, winter wheat, winter rape and maize on two mineral soils: light soil with total available soil water (TASW) equal 120 mm and heavy soil with TASW = 200 mm in the soil profile 0-100 cm and for permanent grasslands (meadows) on two mineral-organic soils with TASW = 50 mm and TASW = 80 mm in the soil profile 0-30 cm.

The effect of meteorological drought on agricultural drought is quantified using the relationships between *CDI* and *SPI*. The relationships as linear regression equations were determined by Bąk (2006), Łabędzki and Bąk (2006) and Łabędzki *et al*. (2008) for 40 meteorological stations in Poland, using the meteorological data from 1970-2004 and the model CROPBALANCE (Łabędzki 2006; Łabędzki *et al*. 2008) based on the methodology given by Allen *et al*. (1998). The values of yield response factor k_y are taken after Doorenbos and Kassam (1979).

The prediction of reduction in crop yield was calculated using Eqs. (1) and (2) for the following ranges of SPI values corresponding to drought severity classes [Paulo and Pereira, 2006); Vermes, 1998]: (-1.0 ≥ SPI > -1.5), severe meteorological drought (-1.5 ≥ SPI > -2.0) and extreme meteorological drought (SPI ≤ -2.0).

Yield reduction is predicted for the whole growing period for a specified crop. Drought is assumed to be uniformly distributed throughout the growing period. The consequence of assumption is that the SPI values qualified the whole growing period and yield response factors k_y are seasonal yield response functions. Potential crop yield reduction caused by meteorological drought of different intensity were investigated for two soils types with different total available soil water, in each of the eight agro-climatic regions.

. The less reduction is observed on the soil with greater TASW values all analyzed crops. Late potato is the most vulnerable crop to be damaged by drought (Fig. 3). Its potential yield reduction can be more than 50% on light soils on most area of Poland during extreme meteorological drought. Least yield reduction is for winter wheat and winter rape (Fig. 4). The spatial distribution of yield reduction of all crops shows the central, central-east and central-west part of Poland, where agriculture droughts risk is the greatest.

Meteorological drought	TASW = 120 mm	TASW = 200 mm

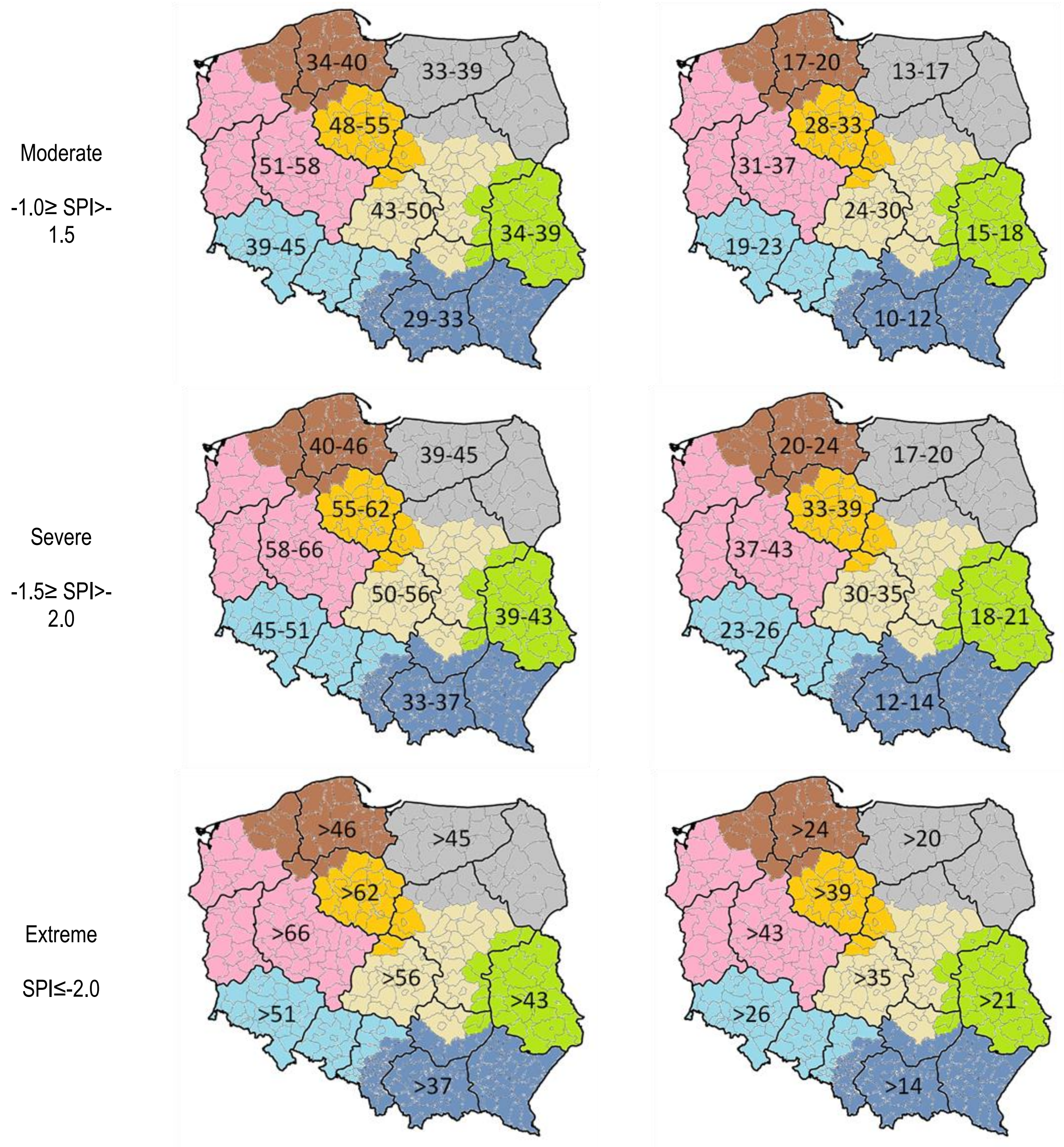


Fig. 2 Maps of reduction (%)in late potato yield for different meteorological drought intensity on two soils with total available soil water TASW

Meteorological drought	TASW = 120 mm	TASW = 200 mm

Moderate

-1.0≥ SPI>-1.5

Severe

-1.5≥ SPI>-2.0

Extreme

SPI≤-2.0

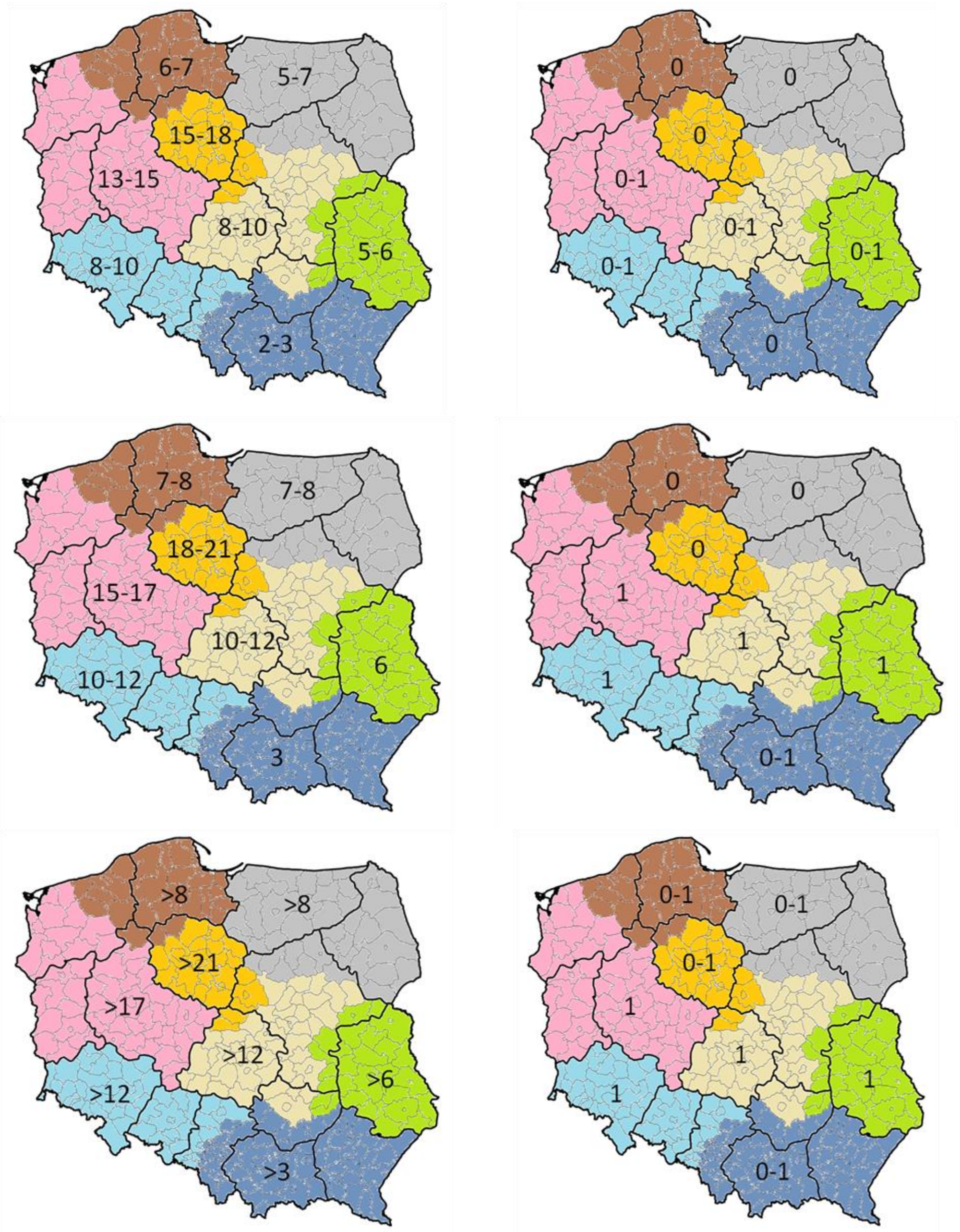


Fig. 3 Maps of reduction (%)in winter rape yield for different meteorological drought intensity on two soils with total available soil water TASW

2.2 Vulnerability assessment for agricultural sector in Romania

In Romania the sector most vulnerable to drought losses is agriculture (Mateescu and Alexandru, 2010; Mateescu et all. 2012). Risk analysis should include the assessment of the probability of occurence of an event (hazard) and the assesement of its impact on the elements at risk (vulerability). Impact assessment is made in terms of qualitative or quantatitative metrics (Table 1).

Table 1. Risk metrics for agriculture.

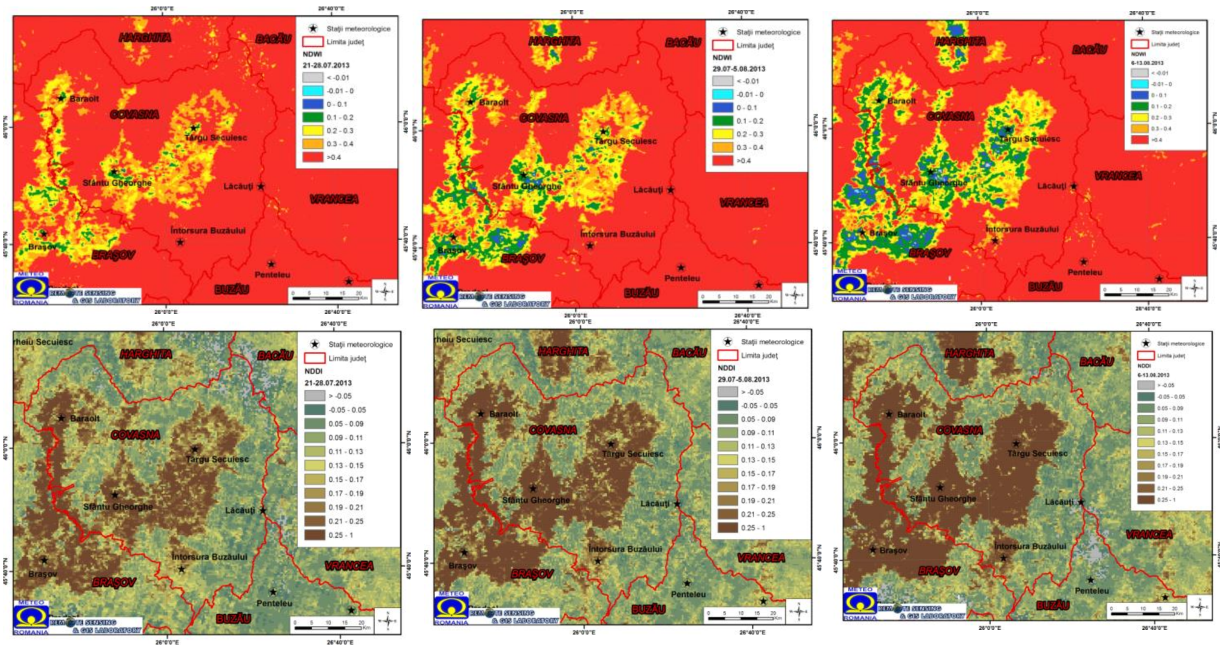
Risk Metric qualitative RA	Risk Metric quantitative RA
-High/medium/low based on type for crops and their	Absolute number of economic loss per hectar (raster) or per

vulnerability to the specific hazard - High/medium/low according to the profit of the harvest	field (vector) based on the type of crops and the expected profit

In agriculture the qualitative risk assessment is based on the types of crops together with the knowledge regarding the capacity of each type of crops to resist without water or information regarding its sensitivity to lack or insufficient of precipitation. The most vulnerable crops to drought appear to be the maize and the sunflower particularly during the summer time in Romania.

The following satellite-derived indicators for crops vegetation were used to monitor and assess state of the crop vegetation: Normalized Difference Vegetation Index (NDVI), Normalized Difference Drought Index (NDDI), Normalized Difference Water Index (NDWI) was applied.

Figures 4 provide visualization of changes in the state of crop vegetation as NDWI and NDDI values for the Covasna agricultural areas in the period of 10 July to 20 August 2013. The lower values correspond with moderate and strong pedological drought over large agriculture surface in this period (Table 2).



21.07 – 28.07.2013 **29.07 – 5.08.2013** **6.08 – 13.08.2013**

Fig. 4 MODIS – NDWI and NDDI products over Covasna county on 21 July to 20 August 2013

Table 2. Characteristics of drought in the period of investigation

Date	Soil moisture (mc/ha)	% CAu (Soil water supply capacity)	Classes
10.07.2013	1216	76 %CAu	Close to the optimal supply
20.07.2013	883	55 %CAu	Satisfactory supply
31.07.2013	695	43 %CAu	Moderate pedological drought
10.08.2013	548	34 %CAu	Strong pedological drought
20.08.2013	667	42 %CAu	Moderate pedological drought

Elaboration of the drought hazard maps are based upon using a geospatial information infrastructure, stored in georeferentiated GIS databases (thematic layers regarding the land cover/use, roads, hydrographical basins, borders of the administrative-territorial units, numerical models for the land, satellite images taken by radar sensors, aerial images, data collected in-situ from the weather or hydrological stations etc.).

In literature (Yohe and Tol, 2002, 2006; Iglesias et al, 2007a; Moneo, 2007, Kumar, 2009), quantitative assessment of vulnerability is usually done by constructing a ”vulnerability index” wchich may be based on several set of indicators that result in vulnerability of a region. It produces a single number, which can be used to compare different zones. Drought vulnerability index (DVI) can be therefore calculated using the following formula:

$$DVI = \frac{\sum W_i}{kN}, \text{ where:}$$

DVI = Drought Vulnerability Index,
N = Number of indicators under consideration,
W_I = Weights of drought vulnerability indicators, where *I = 1, 2….N*,
k = Upper limit of vulnerability weights (e.g. scale = 0-*k,* where k is highest value of W_I.

In order to establish the drought vulnerability scales (Table 3), three indicators were evaluated: values of the heat stress (HS), Standardized Precipitation Evapotranspiration Index (SPEI) and available water content of the soil (%AWC) during the critical period for water needs crops (summer season) (Table 4).

Table 3. Drought vulnerability scales

DVI	Vulnerability Scales	Color scale
0.00 – 0.49	No or less vulnerability	
0.50 – 0.99	Low vulnerability	
1.00 – 1.49	Medium vulnerability	
1.50 – 1.99	High vulnerability	
2.00 – 2.49	Very high vulnerability	
2.50 – 3.00	Extreme vulnerability	

Table 4. Drought vulnerability scale

Vulnerability level	Scales								
	Heat stress (HS)			SPEI			Soil Moisture (SM)		
No vulnerability	0	No stress	<10	0	No deficit	<-0.99	0	No deficit	100%AWC
Low Vulnerability	1	Low stress	11-30	1	Low deficit	-1.99 to -1	1	Low deficit	65-100%AWC
High vulnerability	2	Moderate stress	31 - 50	2	Moderate dry	-2.99 to -2	2	Moderate deficit	35-65%AWC
Extreme vulnerability	3	Strong stress	>51	3	Very Dry	<-3	3	Strong deficit	0-35%AWC

Considering the three indicators of heat and hydric stress analyzed there were drawn the drought vulnerability maps based on their intensity. Figure 5 present areas vulnerable to drought for maize in Romania, the most critical areas recorded in the south, south-east and west regions for August.

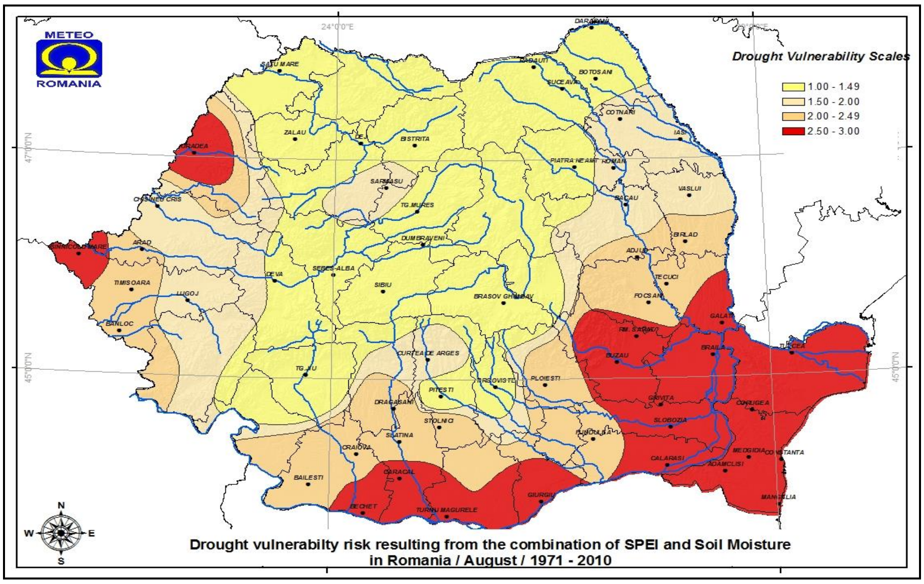


Fig. 5. Vulnerable drought areas for maize crop during the critical period for water plant needs (August) in Romania

2.3 Vulnerability assessment for water resources sector in Lithuania

The quantitative-qualitative approach allows using more general and more available data for vulnerability studies. For example, the economic activity data presented as water consumption for different sectors (Fig. 6) is widely available and is well related to the magnitude of drought impacts.

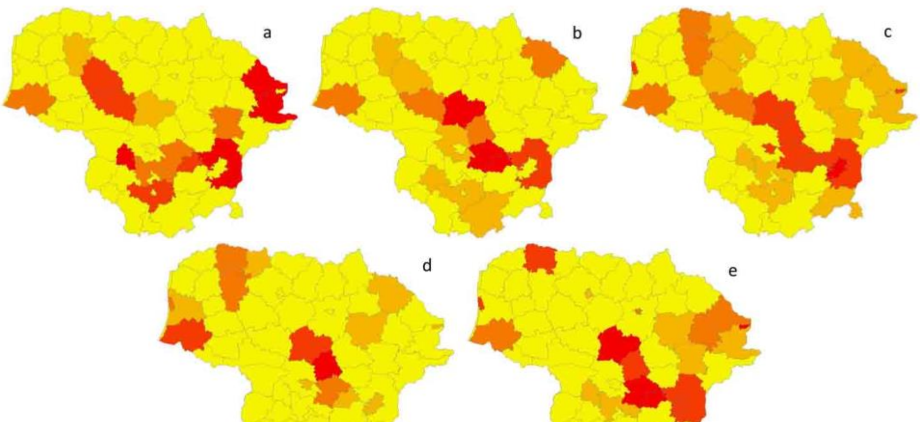


Fig. 6. Water consumption in Lithuanian municipalities in fishery (a), agriculture (b), domestic (c), industry (d) and energy (e) sectors. The yellow color represents the least water consumption while intense red color - the highest consumption.

The river basins and sub-basins are the most suitable spatial units for vulnerability estimation for water resources sector. The vulnerability of 3 watersheds located in Lithuania was studied (Fig 7). The annual runoff ranges between 500000 thousand m^3/s and 1000000 thousand m^3/s in these basins (Fig. 8). The consumption in municipalities was multiplied by the ratio of municipality area in the basin to total municipality area. If the water consumption in the municipality is distributed unevenly, for example, there is one major water user outside the overlapping area; the water consumptions was adjusted. The largest total surface water consumption was identified in Žeimena basin (Fig. 8).

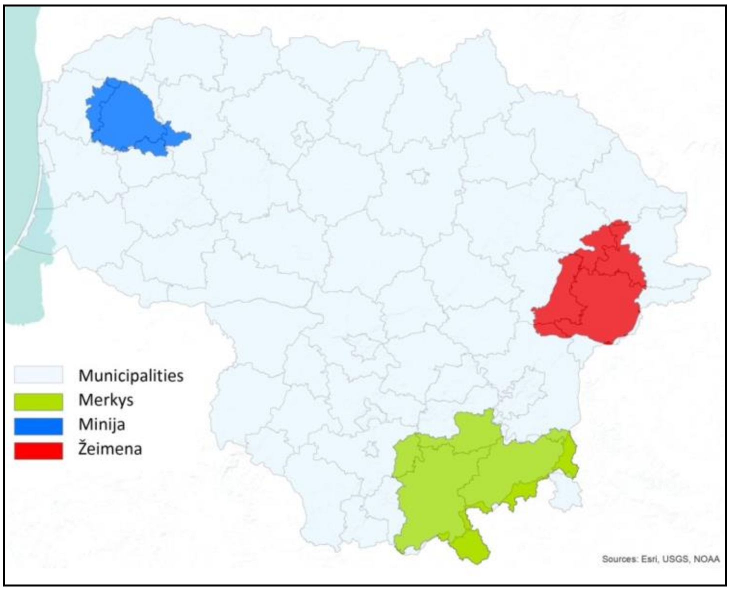


Fig. 7. Areas of analyzed watersheds (colours) and municipality boundaries (thin grey contours).

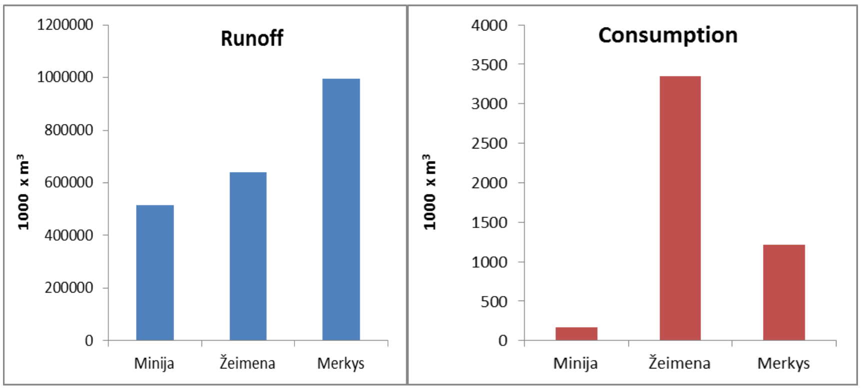


Fig. 8. The mean annual runoff (left) and the surface water consumption (right) in the analyzed river basins.

River basin vulnerability to droughts in water resources sector was assessed as a ratio of surface water resources to surface water consumption for different hydrological conditions. SRI and FI indicators were used to represent these conditions. This assessment was done for different moisture conditions represented with the use of SRI indicator develop for different time scales (SRI1, SRI3, SRI12) – Fig. 9.

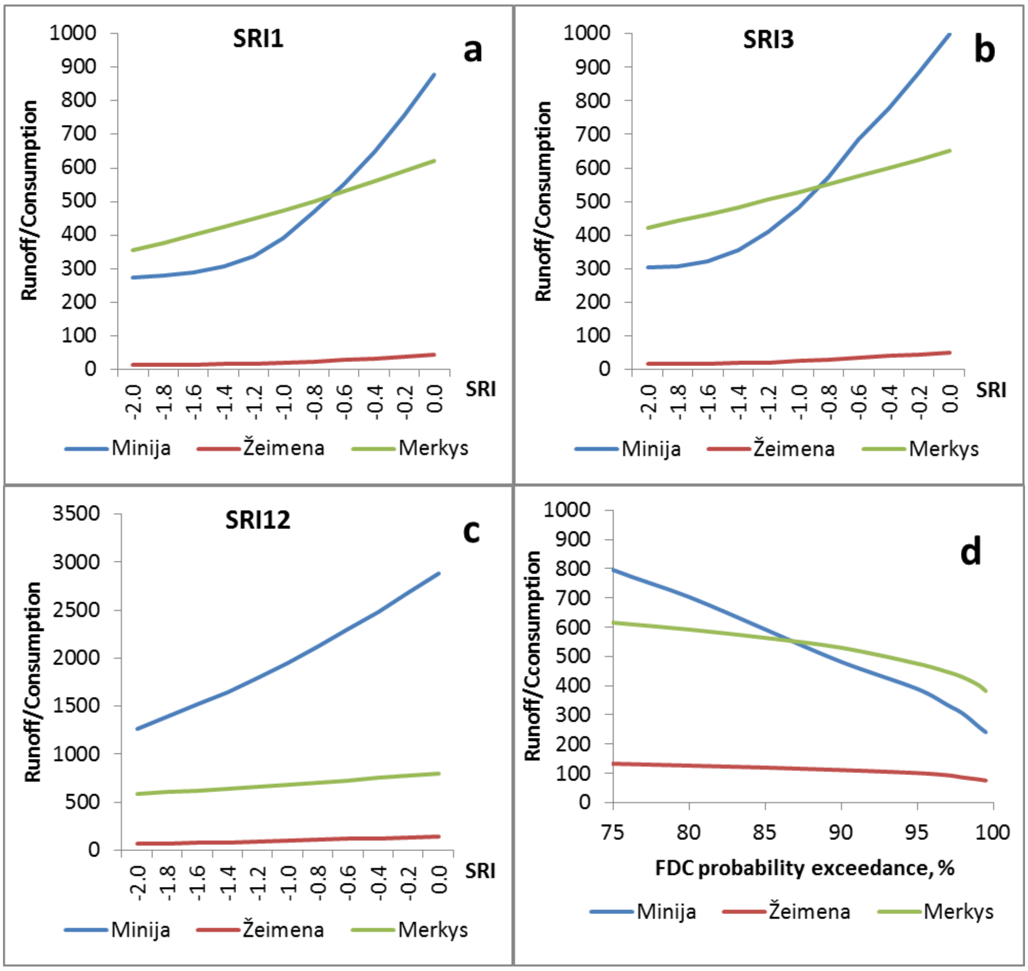


Fig. 9 Vulnerability functions for different hydrological conditions based on 1, 3, 12 month SRI (a, b and c respectively) and FDC (d).

The largest vulnerability has been identified in Minija river basin (Fig. 3.4) with the steepest slope. In this basin the ratio of water consumption to runoff is the most affected by the changes of hydrological conditions.

Žeimena river originates in a large lakeland where many lakes are interconnected by various rivers and streams. Therefore the seasonal variation of the runoff is relatively small and so the vulnerability function's slope is very small.

The vulnerability functions based on SRI1 and SRI3 are very similar. Only one instead of two those functions may be used. The SRI12 is calculated using 12 month runoff data and therefore the seasonal variation is suppressed. SRI12 poorly describes the hydrological conditions during summer and winter low runoff periods when the systems are mostly vulnerable.

Strengths and weaknesses of vulnerability function method are summarized below:

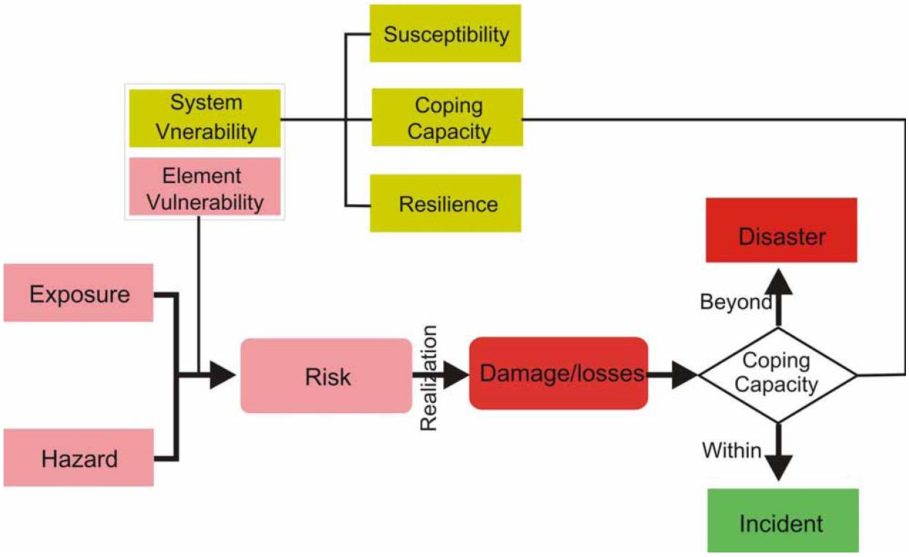
+	The vulnerability is estimated using available data: river runoff and water consumption in administrative units
+	Vulnerability functions represent the water demand coverage in different hydrological conditions
+	The usage of SRI and FDC allows to the estimate the probabilities of different water demand coverage
+	Different river basin vulnerability functions may be compared
-	The method covers only the vulnerability of surface water users. It covers only one part of total system vulnerability estimation

- The water resources and water consumption are assumed to be evenly distributed in administrative regions, across river basin and in time. The inventory of major water users may increase the accuracy of the method

3. Conclusions

Risk mapping requires georaphically related information on exposure and vulnerability to drought. Vulnerability is defined as the potential impact of a drought event on people, environment and economic activities. Vulnerability refers therefore to the complicated system of interconected characteristics and circumstances of a community, phisical and biological factors or asset that make it susceptible to the damaging effects of a hazard.

Within the framework of the project the partnership countries have provided information on the regional context and indicated sectors of economy and elements of the system of the biggest drought risk. The identified elements were investigated in terms of applied methodologies for the vulnerability assessment. Element vulnerability refers to the degree of potential physical damage to the target elements at risk, such as particular crop spice, water users, forest biota etc. in response to a hazard event of a given intensity [Fig. 10 Jianping Yan, 2010].



[source: Jianping Yan, 2010]

Fig. 10 Elements of drought risk assessment scheme.

Performed vulnerability analysis aimed at building ***vulnerability functions*** that represents the relationship between potential damage or loss to a given element at risk against a specified event intensity. For Poland and Romania, the vulnerability functions were built for agricultural sector while in Lithuania for water resources. In the regional study performed for Poland, the vulnerability function was describing the relation between drought intensity expressed in terms of SPI indicator and the specific crop yield: late potato, sugar beet, winter wheat, winter rape and maize with the distinction of two classes of total available soil water. In Romania the vulnerability functions were built for maize and the sunflower. State of the crop vegetation was assessed with the use of satellite-derived indicators: NDVI, NDDI and NDWI. Drought hazard was expressed with the use of the following indicators: heat stress (HS), Standardized Precipitation Evapotranspiration Index (SPEI) and available water content of the soil (%AWC) during the critical period for water needs crops (summer season). In Lithuania the vulnerability function were developed for the losses described as the ratio of surface water resources to surface water consumption. Drought intensity was expressed in terms of value of Standardized Runoff Index (SRI) and Flow Index estimated from Frequency Duration Curve (FDC).

The obtain results will use for building drought risk mapping strategy that can be applied in the countries participating in the Activity 5.4.

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