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Climate vulnerability of agriculture in statistical regions of Slovenia

Vulnerabilità climatica dell'agricoltura nelle regioni statistiche della Slovenia

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Abstract. Climate variability and extreme weather events, especially droughts, floods, hailstorms, low temperatures with frost and heat waves have significant negative effects on agriculture in Slovenia and increase its vulnerability. This study took into account the concept of vulnerability of the International Panel on Climate Change. The index of climate vulnerability of agriculture was developed on the basis of three indicators: exposure (climate variability and extreme weather events), sensitivity (threats due to natural conditions, changes in agriculture, vitality of the population) and adaptive capacity (income, sustainable management and natural resources). Climate vulnerability of agriculture was quantitatively analyzed with vulnerability indicators through the statistical regions of the Republic of Slovenia, and thus contributed to the regionally oriented approaches that seek to answer the challenges of climate vulnerability of agriculture in Slovenia. The results show higher climate vulnerability of agriculture in the western and central Slovenia and lower vulnerability in the eastern and northeastern part of the country.

Keywords. Climate change, vulnerability index, exposure, sensitivity, adaptive capacity.

Abstract. La variabilità climatica e gli eventi meteorologici estremi, specialmente la siccità, le alluvioni, le tempeste, l'abbassamento di temperature per le gelate e le ondate di calore, hanno effetti signifcativamente negativi per l'agricoltura in Slovenia ed aumentano la sua vulnerabilità. Questo studio ha preso in considerazione il concetto di vulnerabilità proposto dal IPCC. L'indice di vulnerabilità climatica dell'agricoltura è stato sviluppato sulla base di 3 indicatori: esposizione (variabilità climatica ed eventi meteo estemi), sensibilità (minaccia dovuta a condizioni naturali, cambiamenti in agricoltura, vitalità della popolazione) e capacità di adattamento (reddito, conduzione sostenibile e risorse naturali). La vulnerabilità climatica dell'agricoltura è stata analizzata quantitativamente con indicatori nelle regioni della Slovenia, e così ha contribuito agli approcci orientati regionalmente che cercano di rispondere alle sfide della vulnerabilità climatica dell'agricoltura in Slovenia. I risultati mostrano una più alta vulnerabilità climatica dell'agricoltura nell'ovest e centro della Slovenia e una minore nella parte est e nordest del paese.

Parole chiave. Cambiamento climatico, indice di vulnerabilità, esposizione, sensibilità, capacità di adattamento.

1. INTRODUCTION

Climate change has been scientifically confirmed and represents a challenge for the professional and general public to reflect on what can be expected in the future (Sušnik, 2014). Agricultural production is highly dependent on weather and consequently highly vulnerable in terms of climate change, mostly due to extreme weather, including droughts, floods, hailstorms and also low temperatures with frosts and heat waves (Antle, 1996). Slovenia is extremely diverse in terms of climate, it is located at the juncture of Alpine, continental and Mediterranean climate, and it is therefore necessary to interpret the trend of climate change with the complexity of the climate in each region (de Luis *et al.*, 2014). Climate change will affect agriculture in many ways; the physiology of cultivated crops and animals, and the phenology and adaptability of organisms will be changed. Climate change will affect livestock production directly and indirectly, mainly through changes in pastures and grazing and through health and nutrition of livestock (Kajfež Bogataj 2005). Among the rare, seemingly positive influences, the increase in air temperature will result in spatial changes in agricultural production: upward shift of vegetation belts, change in the extent of cultivated land - the improvement in thermal characteristics of previously cold areas, deterioration of characteristics of already flooded areas, movement of arable land to higher positions etc. (Olesen and Bindi, 2002).

The climate scenarios for the two upcoming 30-year periods: the near future (2011-2040) and mid-century (2041-2070) ones show that continued warming is expected in Slovenia in the future. In the next thirty years, the annual mean air temperature is expected to increase by 1 °C, and an additional degree in the following period. For precipitation, climate scenarios show greater uncertainty, but signals with a shift to the future are increasing. At the annual level, the changes are only visible in the second 30-year period (2041-2070) when the amount of precipitation should increase in the eastern half of Slovenia. At the seasonal level, the changes are already reflected in the first 30-year period. In winter period, the amount of precipitation is expected to increase, and it will decrease in the summer. In the second 30-year period, this signal is intensifying. Changes in potential evapotranspiration in the first 30-year period should not be significant. In the next thirty years, there is an increase in potential evapotranspiration, especially in the summer and autumn (EEA, 2017). Slovenia is already facing extreme weather events that are causing devastation in agriculture, and with further changes these events will be even more frequent and more pronounced, and the climate vulnerability in agriculture will increase. Climate changes are also represented by trends of meteorological variables (i.e. mean temperature), not only by extreme events. These will affect the population, especially at local and regional levels. Due to these events it is important to plan adaptations of potential scenarios of change at regional and local level (El Gafy and Grigg, 2016). The present study aims at supporting the planning of adaptation by developing indicators of climate vulnerability of Slovenian agriculture. The assessment of climate vulnerability of agriculture is presented through all 12 statistical regions of Slovenia (i.e. regions at NUTS 3 level) which are Mura, Drava, Carinthia, Savinja, Central Sava, Lower Sava, Southeast Slovenia, Littoral–Inner Carniola, Central Slovenia, Upper Carniola, Gorizia and Coastal–Karst region.

A wide spectrum of different scientific fields uses the term vulnerability (such as economics, anthropology, sociology and philosophy), it is also commonly used term in the field of climate change. The International Panel on Climate Change (hereinafter: IPCC) interprets vulnerability as a link, function of exposure, sensitivity, and adaptive capacity (McCarthy *et al.*, 2001). In a broader sense (Adger, 1999), the term vulnerability of a system, community or individual is related to the ability to cope with the problem. Sociologists and climatologists understand very different phenomena under the term vulnerability. Sociological vulnerability is a set of socioeconomic factors that determine the ability of people to cope with stress or change (Allen, 2003). Most often, vulnerability is interpreted as an integrated concept linking the social and biophysical dimensions of environmental change (Turner *et al.*, 2003). Fellmann (2012) defines vulnerability as a function of some variable, intensity, extent of climate change and the degree of system's (eg. region's) exposure, the sensitivity of the system and its adaptive capacity. Various definitions of climate vulnerability derive from various interpretations of climate change (O'Brian *et al.*, 2013) and various political responses to them (Demerritt, 2001; Forsyth, 2003). The vulnerability is not affected only by the change in the natural and social environment, but also by changes in social, economic, technological and other structures and processes so-called contextual state according to O'Brien *et al.* (2013). Vulnerability is interpreted as a negative state of a unit that is exposed to the consequences of climate change, and this situation can be quantified and improved. Vulnerability cannot be quantitatively measured as it is influenced by a wide range of factors and conditions. According to definitions of many authors dealing with the topic of vulnerability and climate change, the main parameters of vulnerability are: stress, which the system is exposed to, the sensitivity of the system and adaptive capacity of the system (e.g. regions, agriculture) to climate change (Adger, 2006).

The assessment of climate vulnerability represents an important basis for the development of guidelines for adaptation to climate factors in agriculture and for the development of appropriate policies for each statistical region and Slovenia as a whole. The assessment of vulnerability is complex and involves social, environmental and economic factors and is a prerequisite for the development of sustainable, low emission plans and strategies (Jun *et al.*, 2013). It also becomes an important assessment of vulnerability at local levels due to natural geographical and socio-economic differences between regions (Jun *et al.*, 2013). The adaptation of agriculture to extreme weather events is related not only with the decisions and measures of a particular farmer, but also with agricultural policy, market mechanisms and development and technological research (Kajfež Bogataj, 2005).

2. MATERIALS AND METHODS

2.1 Selection of conceptual framework of vulnerability

Individual vulnerability definitions describe individual vulnerability components, while the conceptual framework gives meaning to definitions so that they can be analysed according to the analytical context. Our approach is based on the definition of the IPCC (Parry *et al.*, 2007), according to which vulnerability to climate change is the degree to which geophysical, biological and socio-economic systems are susceptible to the negative impacts of climate change and can not cope with them. The system that is being dealt with is agriculture in the region. This means that the system is vulnerable if it is exposed and sensitive to the effects of climate change, but at the same time it has only limited adaptive capacity. Contrary to this, the system is less vulnerable when being less exposed, less sensitive, or has a strong adaptive capacity. Exposure refers to the nature and extent to which the system is exposed to significant climate change (McCarthy *et al.*, 2001). Exposure is represented by the climatic conditions and stimuli to which the system responds, and any changes in these conditions. Sensitivity means the degree of responsiveness of the system to climate change. The response to climate change can be as useful as it is also harmful to climate variability (O'Brian *et al.*, 2004). The effect may be direct (a change in crop in response to a change in average temperature, range or temperature variability) or indirect (damage caused by an increase in the frequency of floods) (Parry *et al.*, 2007). Sensitivity reflects the system's responsiveness to climate impacts and the extent to which climate change could be affected in its current form. Thus, the sensitive system is highly responsive to the climate and severely affected by moderate degree of climate change. Adaptive capacity is defined as the ability (or potential) of the system to successfully adapt to climate change (including climate and extreme variability), reducing potential damage, exploiting opportunities and/or managing the consequences (Füssel and Klein, 2006). Adaptive capacity involves the adaptation of both behavior and resources (Adger *et al.*, 2007) and can be thoroughly managed by human action's, which affects the biophysical and social elements of the system (Edenhofer *et al.*, 2014).

2.2 Research area

The index and indicators of climate vulnerability of agriculture are shown at the level of spatial units of Slovenia (regions). Statistical regions of Slovenia represent units of the research area for which climate vulnerability of agriculture and its indicators were presented (exposure, sensitivity and adaptive capacity), which were compared and evaluated. In addition to cohesion regions and municipalities, the statistical regions of Slovenia are one of the territorial levels for which the Statistical Office of the Republic of Slovenia collects and presents statistical data. In 2016, Eastern Slovenia consisted of 8 statistical regions (Mura, Drava, Carinthia, Savinja, Central Sava, Lower Sava, Southeastern Slovenia and Littoral–Inner Carniola). The Cohesion Region of Eastern Slovenia has an area of 12.212 km^2 and represents 60.2% of the territory of the Republic of Slovenia. In 2016, it had 1.091.570 inhabitants, representing 53% of the total population of Slovenia. Western Slovenia consists of 4 statistical regions (Central Slovenia, Upper Carniola, Gorizia and Coastal–Karst) with a total area of 8,061 km^2, representing 39.8% of the territory of the Republic of Slovenia. Population of western Slovenia represents 47% of Slovenia's total population (2016, 972.671 inhabitants). Western Slovenia covers the most economically developed areas in the country. Gross domestic product per capita amounted to 119.5% of the Slovenian average. The services contributed 75% of gross added value. In the cohesion region of Eastern Slovenia, the gross domestic product per capita was 82.7% of the Slovenian average. It is characterized by agricultural activity as it includes more than 70% of agricultural holdings and the majority of agricultural land (Regije v številkah ..., 2016).

2.3 Selection and design of variables and indicators that build Climate vulnerability index of agriculture

Later on, indicators and sub-indicators were developed and selected variables were chosen. In the selection of variables, derivation was made from the specific characteristics of agriculture in Slovenia, taking into account the availability of data by statistical regions of Slovenia from various data sources, which are also presented in Table 1. When selecting and designing variables and indicators, the following fundamental questions were followed: What is vulnerable (system)? Agriculture in the region. What is agriculture exposed to (exposure indicator)? To climate variability and extreme weather events. Why is agriculture sensitive (sensitivity indicator)? Because of the threats due to natural conditions, changes in agriculture, the vitality of the population. How can the vulnerability of agriculture (adaptive capacity indicator)be reduced? With income, sustainable management and natural resources.

The entire set of data was limited to those that can be displayed at the level of statistical regions. Since the statistical regions of Slovenia are not equally large, nor the agricultural activity is evenly distributed, the variables were dealt with in relation to agriculture - if the variable does not specifically refer to the agricultural activity, for example, air temperature, the temperature was treated only on agricultural surfaces or at meteorological stations below 1000 m of altitude. When defining the timing of the variables, the most uniform period and the latest available data were sought. Since this cannot always be achieved, some deviations also exist in the period 1961-2016 that was under consideration. For climatic variables, longer time period (30-50 years) was used. For variables that show greater fluctuations within individual years, the interest was also focused on a multiannual (e.g. 10-year) average or change. For variables that do not indicate significant fluctuations during years, particular interest was shown in the last situation, in our case this was 2016 and, exceptionally, also 2017. For each variable, it was necessary to find an appropriate method of calculation and display by statistical regions. The source of data and preliminary methodological treatment and, consequently, data quality were also important in this part. For example, in the case of climate variables, better quality data being those from meteorological stations of homogenized time series. Since these are limited to the last year of 2012, certain meteorological variables are not processed in the later period. A different treatment methodology was also encountered, for example, of agricultural land - once it was limited with an altitude of 1000 m, the next time they were treated in the graphic display of actual use of agricultural and forest land (RABA) and then as agricultural land in use from register of agricultural holdings (RKG).

When variables based on the available data were selected and developed, functional relationships between variables, indicators and vulnerability were determined, based on which the indicators and vulnerability across the statistical regions of Slovenia were evaluated (Table 1).

The selection and design of variables, the definition of mutual functional relationships between variables, indicators and vulnerability are important steps in the research, which are partially subjective. The choice itself also depends on the availability and quality of the data on which no influence was possible. Vintar Mally (2006) explains that, regardless of the scope of objective efforts, the choice of indicators (variables) is always at least partly subjective, since their choice is based on the subjective belief of an individual or group that they are important for measuring a certain amount of sustainability, in our case vulnerability. Therefore, it is necessary to realize that the ideal indicators do not exist and the indicators used are only better or worse substitutes for those who should completely capture certain phenomena, states and processes at all stages of the research.

2.4 Methods for combining variables for forming a composite index (aggregation)

In international literature, several different approaches are used to create a composite index based on different indicators and their variables. Many authors are concerned with comparing different methods of forming a composite vulnerability index that includes different approaches of standardization, weighting and aggregation in order to show similarities and differences between them (Monterroso, 2012; Tonmoy *et al.*, 2014; Yoon 2012; Žurovec *et al.*, 2017). All authors note that the final results of the vulnerability assessment depend on the choice of methods.

Tab. 1. Functional relationships of variables to vulnerability.
Tab. 1. Relazioni funzionali tra le variabili e la vulnerabilità.

Indicator	Sub-indicator	Variable	*Functional relationship	*Source
Exposure	Climate varaiability	Linear trend of average height of summer precipitation (%/decade), 1961–2011	-	ARSO
		Linear trend of average summer air temperature (°C/decade), 1961–2011	+	ARSO
		Linear trend of average summer potential evapotranspiration (%/decade), 1971–2012	+	ARSO
		Standard deviation of average summer precipitation on agricultural land (mm), 1981–2010	+	ARSO, MKGP
	Extreme weather events	75th percentile of summer meteorological water balance on agricultural land (mm), 1981–2010	-	ARSO, MKGP
		Average annual number of hot days, 1987–2016	+	ARSO
		Average annual amount of maximum daily precipitation (mm), 1987–2016	+	ARSO
		Average annual number of days with precipitation above 20 mm, 1987–2016	+	ARSO
		Average annual number of days with storms, 1987–2016	+	ARSO
		Weighted average of project wind speed on agricultural land (m/s), 1961–2006	+	ARSO, MKGP
		Average number of cold days in the spring, 1987–2016	+	ARSO
		Average number of frigid days in the spring, 1987–2016	+	ARSO
Sensitivity	Threats due to natural conditions	Share of flood threatened agricultural land (%), 2017	+	MKGP
		Weighted average of plants of accessible water for 50 cm deep soil on agricultural land (mm), 1999–2017	-	TIS/ICPVO, MKGP
		Share of utilised agricultural area in less-favored areas for agricultural activity (%), 2016	+	MKGP
		Share of average annual damage due to weather-related natural hazards in average gross domestic product (%), 2009–2016	+	SURS
	Changes in agriculture	Index of growth in the number of employees in agricultural activity, 2016/2007	-	SURS
		Growth index of utilized agricultural area, 2016/2007	-	SURS
	Vitality of population	Average age of the manager of the agricultural holding (in years), 2016	+	MKGP
		Average age of members of the agricultural holdings (in years), 2016	+	MKGP
Adaptive capacity	Income	Share of gross value added of agricultural activity in total gross value added (%), 2016	-	SURS
		Ratio between the standard income and the annual work unit of the agricultural (1000 EUR), 2016	-	SURS
		Share of agricultural holdings with supplementary farm activities (%), 2016	-	MKGP
		Ratio between average payments of agricultural policy measures and the average utilised agricultural area (1000 EUR/ha), 2007–2016	-	MKGP
	Sustainable management	Share of average annual investments for environmental protection in the average annual gross domestic product (%), 2007–2016	-	SURS
		Share of agricultural holdings with organic farming or in the state of conversion (%), 2016	-	MKGP
	Natural resources	Share of agricultural land with irrigation systems (%), 2017	-	MKGP, DRSV
		Ratio between the forest area and the number of inhabitants (ha/inh.), 2016	-	SURS

*Functional relationship:
In the functional relationship between vulnerability and variable higher and positive values of the variable in the + label mean higher vulnerability and in the – label lower vulnerability.
*Sources:
SEA – Slovenian Environmental Agency (ARSO – Agencija Republike Slovenije za okolje in proctor)
SIS/ICPEP – Soil Information System/Infrastructure Centre for Pedology and Environment Protection (Talni informacijski sistem/Infrastrukturni center za pedologijo in varstvo okolja)
MAFF – Ministry of Agriculture, Forestry and Food (MKGP – Ministrstvo za kmetijstvo, gozdarstvo in prehrano)
SWA – Slovenian water agency (DRSV – Direkcija Republike Slovenije za vode)
SORS – Statistical Office of Republic of Slovenia (SURS – Statistični urad Republike Slovenije)

2.4.1 Standardization of variables

The variables that build a common index and indicators in our research derive from different areas (social, economic and environmental), and therefore have different units and scales. Data normalization is a very important step when it comes to the variables of different units and scales. To ensure data comparability, the same measuring scale had to be used, in the interval between 0 and 1. Among the higher number of standardization methods, standardization proposed by UNDP for the calculation of the Human Development Index was selected. This methodology was also applied in the Balanced Development Index (Vintar Mally, 2011). In this respect, the methodology used to calculate the HDI before 2010 was followed. In 2010, unlike this method, it was calculated with an arithmetic mean, a geometric mean for the calculation of HDI, which is still used today (UNDP, 2018).

The variables were standardized according to the following equation:

$$Index = \frac{x - xmin}{xmax - xmin}$$

and for inverse ratios:

$$Index = 1 - \left(\frac{x - xmin}{xmax - xmin}\right)$$

Meaning: x - the value of the variable in the region, xmin - the minimum value of the variable (state or development in the country), xmax - the maximum value of the variable (state or development in the country).

In the next step, maximum and minimum values were set. According to Seljak (2001b), several solutions are possible for determining the lower and the upper limits of variables or limit referential values. When comparing the regions at a given time (state), the lowest value that appears in the observed row at the lower limit, and the highest value for the upper one can be observed, but this causes a problem in the interim comparison. When comparing changes in time (development), it is best to set the lower and upper limits as permanent. In our contribution, values of each variable were always calculated for all statistical regions of Slovenia, meaning that for each variable, the maximum value is always the highest value of the variable among all the values of the considered variable, and the same applies to the minimum value.

2.4.2 Assigning weights to variables and indicators

In the design of composed index, problems arise with selection of appropriate weights to determine the comparative power of individual variables. The simplest approach is where all variables have the same weight (Seljak, 2001a). Thus, in this research, the same weight was assigned to each indicator and also to the variables that build the individual indicator. A simple unweighted average (arithmetic mean) of normalized variables was used for creating indicators and a simple average (arithmetic mean) of indicators that form a composed vulnerability index. The most common method of assigning equal weights to variables was chosen according to international comparisons in the area of the composite index of vulnerability (Aubrecht and Özceylan, 2013; Chow *et al.*, 2012; Hahn *et al.*, 2009; Heltberg and Bonch-Osmolovskiy, 2010; Khajuria and Ravindranath, 2012; Krishnamurthy *et al.*, 2014; Tomlinson *et al.*, 2011; Yusuf and Francisco, 2009).

$$Average\ indicator = \frac{\left(Variable\ 1 + \ldots + Variable\ y\right)}{y}$$

Y is the number of variables in an indicator.

$$CVA = \frac{1}{3}\left(EAC + SAC + AACi\right)$$

The Climate vulnerability index of agriculture (CVA) is therefore 1/3 the exposure indicator of agriculture to the climate (EAC) + the sensitivity indicator of agriculture to the climate (SAC) + the adaptive capacity indicator of agriculture to the climate inverse (AACi).

The average indicator represents the arithmetic mean of all variables that build the indicator. Vulnerability is the arithmetic mean of all three indicators - exposure, sensitivity and adaptive capacity. Finally, in the same way that variables and indicators were normalized on a scale of 0 - 1, the same was done for final vulnerability index based on the average indices of individual indicators (exposure, sensitivity and adaptive capacity). Several international studies use the same normalizing method and display the final vulnerability index on a scale of 0-1 or 0-100 (Ahsan and Warner, 2014; Khajuria and Ravindranath, 2012; Krishnamurthy *et al.*, 2014; Sugiarto *et al.*, 2017; Yusuf and Francisco, 2009). In our survey, the lowest degree of vulnerability is represented by the value 0 and the highest with 1.

2.5 Methods for calculating the variables for presentation by statistical regions

Data for the calculations of variables were obtained from various databases and sources in various forms. The types of data vary greatly, and they also receive different treatment. For example, SORS data require fewer calculations since they are basically tabulated and already processed and sorted by region. On the other hand, raw data from the archives of the meteorological data of the SEA require much more caution and processing to reach final results - a presentation by statistical regions of Slovenia. Likewise, more processing requires data and graphic layers that have to be addressed with the ESRI ArcGIS software (hereinafter: ArcGIS). In addition to the ArcGIS software, MS Excel 2016 (hereinafter: MS Excel) was used for calculations.

In most cases, an arithmetic mean is used for the average value. The variables are also shown in proportions, ratios, indices, and the summer meteorological water balance as 75th percentile. In two cases, for plant-accessible water and project wind speed, a weighted average was used when the individual values have a different significance. The standard deviation is calculated for average precipitation using ArcGIS. The linear trend for each measuring station over a 10-year time period for precipitation variables, air temperature and potential evapotranspiration was calculated using the LINEST function within the MS Excel program with the least squares method.

3. RESULTS

3.1 Climate vulnerability of agriculture by statistical regions of Slovenia

The results of climate vulnerability of agriculture are at the level of statistical regions of Slovenia. Figure 1 shows the sum of all three indicators that build the vulnerability of each statistical region. The higher the sum of indices, the higher the climate vulnerability of agriculture. In this case, adaptive capacity is inverse, since the individual indices of the indicators are added and adaptive capacity has an inverse (positive) value at the index value of 1.00. Figure 1 shows the impact of each indicator on vulnerability. Mura region, for example, has a higher sensitivity than the Upper Carniola and the Central Slovenia regions, but the total vulnerability of the Mura region is still lower, as it has the lowest exposure. Each indicator contributes significantly to the overall vulnerability.

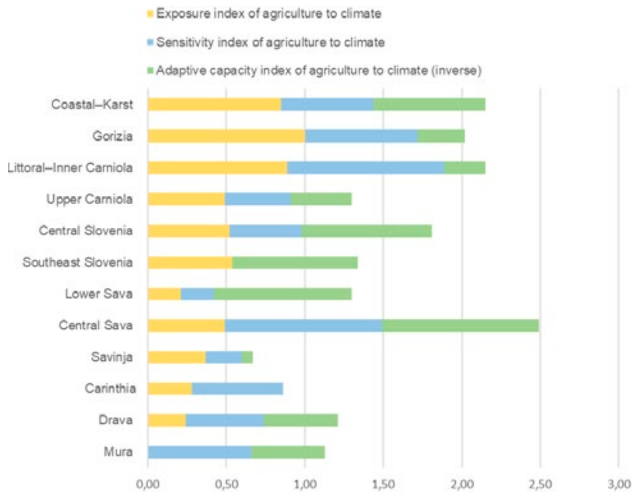

Fig. 1. Climate vulnerability of agriculture as a function of all three indicators: exposure, sensitivity and adaptive capacity (inverse).
Fig. 1. Vulnerabilità climatica dell'agricoltura in funzione di 3 indicatori: esposizione, sensibilità e capacità di adattamento (opposto).

Table 2 shows the final values of indices of individual indicators and vulnerability of the statistical regions in Slovenia. It was found that high exposure does not necessarily mean high sensitivity (Coastal–Karst region) or low adaptive capacity (Littoral–Inner Carniola region). The indicators are therefore independent of each other. The exposure of agriculture to the climate can be the highest and, at the same, time adaptive capacity can also be high (Gorizia region). Exposure may also be the lowest and there is still high sensitivity (Mura region). However, increasing vulnerability is exacerbated by increasing exposure and sensitivity and reducing adaptive capacity. The Central Sava region has the highest sensitivity (I = 1.00) and the lowest adaptive capacity (I = 0.00; I inverse = 1.00); therefore, the vulnerability is the highest (I = 1.00). The Savinja region does not have any extreme values. Since both exposure and sensitivity are low and adaptive capacity is very high which resulting in the lowest vulnerability (I = 0.00).

Figures 2-5 show the values of the indices of exposure, sensitivity, adaptive capacity and vulnerability according to the statistical regions of Slovenia. Index value 1.00 (green) means less exposure, less sensitivity, higher adaptive capacity and less vulnerability. Index value 0.00 (red) means the opposite.

Exposure index of agriculture to climate is concerned with climate variability and extreme weather events and declines in west-east direction. From the Mura region, where it attains the lowest value (I = 0.00) to Gorizia region with the highest value (I = 1.00) (Figure 2). The exposure of agriculture to climate is low in

Tab. 2. Values of indices of exposure, sensitivity, adaptive capacity and vulnerability by statistical regions of Slovenia.
Tab. 2. Valori degli indici di esposizione, sensibilità, capacità di adattamento e vulnerabilità nelle regioni della Slovenia.

Statistical region	Exposure index of agriculture to climate	Sensitivity index of agriculture to climate	Adaptive capacity index of agriculture to climate	Adaptive capacity index of agriculture to climate (inverse)	Climate vulnerability index of agriculture
Mura	0.00	0.66	0.53	0.47	0.25
Drava	0.24	0.50	0.53	0.47	0.30
Carinthia	0.28	0.58	1.00	0.00	0.10
Savinja	0.37	0.23	0.93	0.07	0.00
Central Sava	0.49	1.00	0.00	1.00	1.00
Lower Sava	0.21	0.21	0.12	0.88	0.35
Southeast Slovenia	0.54	0.00	0.20	0.80	0.37
Central Slovenia	0.52	0.46	0.17	0.83	0.63
Upper Carniola	0.49	0.42	0.61	0.39	0.35
Littoral–Inner Carniola	0.89	1.00	0.74	0.26	0.81
Gorizia	1.00	0.72	0.70	0.30	0.74
Coastal–Karst	0.85	0.59	0.29	0.71	0.81

the eastern part of Slovenia, which covers the Drava, Savinja, Carinthia in Lower Sava regions. In the central part of Slovenia (Upper Carniola, Central Sava, Central Slovenia in Southeast Slovenia), the exposure of agriculture to the climate is medium. The western part of Slovenia has the highest exposure of agriculture to climate in the Coastal–Karst, Littoral–Inner Carniola and Gorizia regions. The latter has the highest value (I = 1.00).

The climate variability was determined by the following variables: linear trend of average height of summer precipitation (%/decade) in the period 1961-2011, linear trend of average summer air temperature (°C/decade) in the period 1961-2011, linear trend of average summer potential evapotranspiration (%/decade) in the period 1971-2012 and the standard deviation of the average spring and summer precipitation on agricultural land (mm) in the period 1981-2010. It was found that the linear trend of average height of summer precipitation is negative at the vast majority of the measuring stations, which means that the summer precipitation will decrease. This leads to a lack of water in the growing season and a greater climatic vulnerability of agriculture. The decline in the precipitation rate in west-east direction is noticeable. Average values by statistical regions of Slovenia in the period 1961-2011 range from -0.1 %/10 years in the Carinthian region up to -4.9 %/10 years in the Coastal–Karst region. On the other hand, the linear trend of average summer air temperature increases at all measuring stations, which also affects the increased dryness. The eastern and south-eastern part of Slovenia is particularly exposed to the warming of the atmosphere. The average values by statistical regions in the period 1961-2011 ranged from 0.4 °C/10 years in the Upper Carniola, Gorizia to 0.5 °C/10 years Coastal–Karst regions. Linear trend of average summer potential evapotranspiration is also positive. So, evaporation is increasing which additionally affects the deficit of water. The southwestern part of Slovenia has the highest evaporation rate. The average values by regions in the period 1971-2012 ranged from 3.7 % in the Upper Carniola region to 5.1 % in the Gorizia region. The highest variability of precipitation, which is shown with the standard deviation of average spring and summer precipitation on agricultural land, is represented in the northwestern part of Slovenia, that is, in the area with the highest average precipitation values. The deviation values range from 3.8 mm in the Central Sava region to 37.1 mm in the Gorizia region.

Extreme weather events have been identified with various variables that are related to a particular event. Drought is shown with two variables; these are the 75th percentile of the summer meteorological water balance on agricultural land (mm) in the period 1981-2016, and the average annual number of hot days in the period 1987-2016. The average number of hot days varies from 5.3 in the Upper Carniola region to 36.8 days in the Gorizia region. Hot days when the temperature reaches or exceeds 30 °C has negative effects on the growth and development of crop plants. The 75th percentile of summer meteorological water balance on agricultural land has a positive value in only three regions; in the Upper Carniola region, where the highest value reaches 60.3 mm, and Carinthia and Gorizia, mainly because of higher precipitation. In all other regions, 75th percentile of summer meteorological water balance is negative. The highest negative value is in the Coastal–Karst region with -166.9 mm, which means high exposure to drought and thus higher vulnerability of agriculture. The flood as the second extreme weather event is defined by the average annual amount of the maximum daily precipitation (mm) in the period 1987-2016 and the average annual number of days with precipitation above 20 mm during the same period 1987-2016. Like a drought with water scarcity, it has a negative impact on agriculture as well, surplus water that causes damage to both crops and agricultural equipment. Both variables reach the highest values in the northwestern, the mountainous part of Slovenia. The average annual height of maximum daily precipitation varies from 49.6 mm in Mura to 123.0 mm in the Gorizia region. The average annual number of days with precipitation above 20 mm has the same pattern and range in the Mura region for at least 10.0 days, while in Gorizia it is a maximum of 34.1 days. Storms also have negative consequences in agriculture and increase climate vulnerability. It is shown with the average annual number of days with a storm in the period 1987-2016 and the weighted average of annual project wind speed on agricultural land (m/s) in the period 1961-2006. Storm occurrence can also be transferred to the hail. In the area where storms are more frequent, it is assumed that there is a greater likelihood of the occurrence of a hail, often accompanied by storms in Slovenia and destroying agricultural crops. Storms are typical for the whole area of Slovenia, with the most frequent occurrences in the Carinthian region an average of 28.2 storm days per year, and the least frequent in the Posavje region with 18.3 days per year. Project wind speed is an extreme value, and that is why most of Slovenia achieves the same weighted average annual project wind speed on agricultural land, 20 m/s with a return period of 50 years at a height of 10 m. The southwestern part of Slovenia is the most exposed to strong winds, where the Coastal–Karst region attains the highest average speed of 29.2 m/s. Spring frost is particularly problematic in fruit cultivation and wine growing when temperatures drop below -2°C. This was associated with the average number of cold days and average number of frigid days with frost in spring in the period 1987-2016. The average number of frigid days in the spring, when the air temperature reaches or drops below -10°C, is the lowest in the Gorizia region, where frigid days are rarely recorded, and the highest in the Littoral–Inner Carniola region with 0.6 days. The average number of cold days in the spring, when the air temperature drops below 0°C, varies from 2.1 days in the Coastal–Karst region to 9.1 days in the Upper Carniola region.

Sensitivity index of agriculture to climate concerned with threat due to natural conditions, changes in agriculture and the vitality of the population. Compared to exposure, the sensitivity pattern is somewhat different, and different index categories are distributed throughout Slovenia (Figure 3). The sensitivity index of agriculture to climate is the highest in the two regions, Central Sava and Littoral–Inner Carniola (I = 1.00), where agriculture is the most sensitive to the climate. Among the more sensitive (high sensitivity) are the Gorizia and Mura regions. The majority of statistical regions has medium sensitivity: the Coastal–Karst, Central Slovenia, Upper Carniola, Carinthia and Drava. The low sensitivity of agriculture to climate is in the Savinja and Lower Sava regions. The lowest sensitivity has Southeast Slovenia (I = 0.00).

The adaptive capacity index of agriculture to climate is concerned with income, sustainable management and natural resources. A certain pattern of allocation of categories of the index of adaptive capacity across Slovenia was detected (Figure 4). In the central and south-eastern part of Slovenia, agriculture has the least adaptive capacity to the climate. The Central Sava (I = 0.00), Lower Sava, Central Slovenia and Southeast Slovenia, have very low adaptive capacity, and only Coastal–Karst region has low adaptive capacity. The Mura and Drava regions in the north-eastern part of the country have medium adaptive capacity, while the western part of Slovenia with the Upper Carniola, Gorizia and Littoral–Inner Carniola regions has a high adaptive capacity. Agriculture is most capable of adapting to climate in the Savinja and Carinthia regions. The latter has the highest adaptive capacity (I = 1.00).

Climate vulnerability index of agriculture by statistical regions of Slovenia (Figure 5) reflects the indicators of exposure, sensitivity and adaptive capacity of agriculture to the climate. The demarcation between the more vulnerable western and central part of Slovenia and the less vulnerable eastern and northeastern part is evident. Each indicator has its own influence on the final vulnerability of the region (Figure 1). In the most vulnerable western and central part of Slovenia, Central Sava region (I = 1.00) has the highest vulnerability with the highest sensitivity (I = 1.00) and the lowest adaptive capacity (I = 0.00). The Coastal–Karst and Littoral–Inner Carniola regions, both with the same index value (I = 0.81), are also highly vulnerable (Table 2). The result in the Littoral–Inner Carniola region is mainly due to the highest sensitivity (I = 1.00) and very high exposure, while in the Coastal–Karst region there are very high exposure and low adaptive capacity. Highly vulnerable regions are the Gorizia and Central Slovenia regions; Gorizia achieves the highest exposure (I = 1,00) and high sensitivity, while the Central Slovenia has a very low adaptive

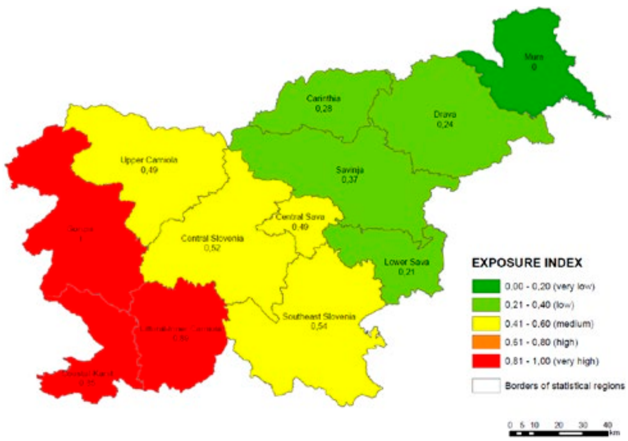

Fig. 2. Exposure index of agriculture to climate by statistical regions of Slovenia.
Fig. 2. Indice di esposizione dell'agricoltura al clima nelle regioni della Slovenia.

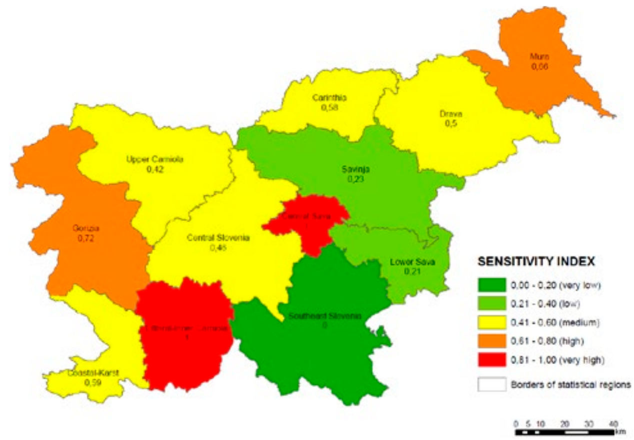

Fig. 3. Sensitivity index of agriculture to climate by statistical regions of Slovenia.
Fig. 3. Indice di sensibilità dell'agricoltura al clima nelle regioni della Slovenia.

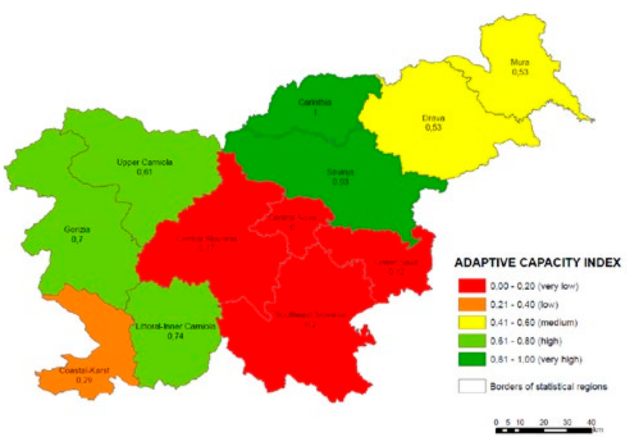

Fig. 4. Adaptive capacity index of agriculture to climate by statistical regions of Slovenia.
Fig. 4. Indice di capacità di adattabilità dell'agricoltura al clima nelle regioni della Slovenia.

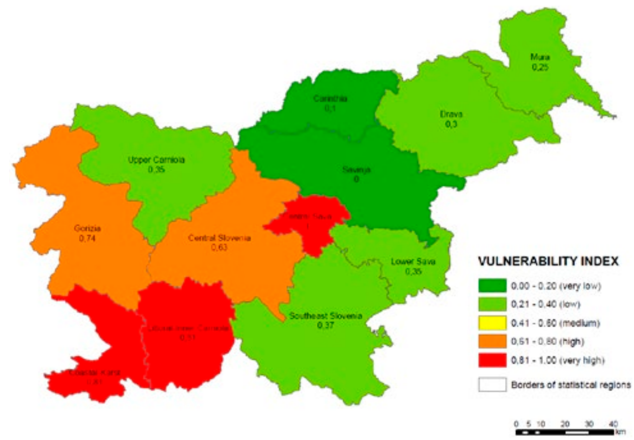

Fig. 5. Climate vulnerability index of agriculture by statistical regions of Slovenia.
Fig. 5. Indice di vulnerabilità climatica dell'agricoltura regioni della Slovenia.

capacity. Medium vulnerability was not detected. The western part of Slovenia with the Upper Carniola region is less vulnerable. The lowest vulnerability is recorded in the Savinja and Carinthia regions. The Savinja region has the lowest index value (I = 0.00) mainly due to the very high adaptive capacity and low exposure and sensitivity. Carinthia has very low vulnerability due to the highest adaptive capacity (I = 1.00) and low exposure. Most - five regions - are in the low vulnerability category: Mura, Drava, Lower Sava, Southeast Slovenia and the Upper Carniola. The Mura region has the lowest (I = 0.00), while the Drava and Lower Sava regions have very low exposure of agriculture to the climate. South-eastern Slovenia has the lowest sensitivity (I = 0.00), while the Upper Carniola region has the medium values in all three indicators (Figure 5).

4. DISCUSSION

Agriculture in Slovenia has an important role in economy and urgently needs a proper policy, since more than half of the population lives in rural areas, and agricultural land occupies one third of all areas. For agricultural policy, the greatest challenge is to find the right balance between adjustment of agricultural production and ensuring sufficient quantities of food and energy resources while reducing greenhouse gas emissions. Agriculture is heavily affected by climate change. Natural disasters are becoming more frequent and thus increase the production and income risks of agriculture. The agro-meteorological profession can help in dealing with problems and challenges in agriculture through its monitoring. It is necessary to improve knowledge on climate and weather, to draw up plans to identify and manage risk in agriculture. However, proper adaptation is a long-term process. In future, production processes in agriculture will need to be explicitly linked to weather and climate informations (Kajfež Bogataj *et al.*, 2003). Climate vulnerability assessments are carried out with the aim of helping policy makers to identify "hot spots" for allocating resources for adjustments, improving public awareness of climate risks, monitoring the effects of adaptation measures and improving understanding of weaknesses in the socio-ecological system, leading to vulnerability (Tonmoy *et al.*, 2014).

The Climate vulnerability index of agriculture in Slovenia was developed and was used to quantitatively evaluate the climate vulnerability of agriculture in all 12 statistical regions of Slovenia. It is a composite index from three indicators: exposure, sensitivity and adaptive capapcity, 11 sub-indicators and 28 variables, taking into account the social, economic and environmental factors that interact with the climate vulnerability of agriculture in Slovenia. The results show that the climate vulnerability of agriculture is the highest in the western and central part of Slovenia. The most vulnerable are the Central Sava region (I = 1.00) and the southwestern part of the country with the Littoral–Inner Carniola and Coastal–Karst region. Gorizia and Central Slovenia region are also highly vulnerable. In the northwestern part of Slovenia, with the Upper Carniola region, agriculture is less vulnerable to climate. Savinja (I = 0.00) and Carinthia regions are the least vulnerable. The low climate vulnerability of agriculture is present in most regions: Southeastern Slovenia, Upper Carniola, Posavina, Drava and Mura regions. It can be assumed that vulnerability, with the increasing frequency of extreme weather events and climate variability, will continue to increase, and most likely to impact the most vulnerable regions.

The work included dealing with issues of selecting the concept of vulnerability, methods of work, selection of the area and variables that build indicators and vulnerability. The literature on vulnerability assessments of socio-ecological systems is very diverse due to numerous quantitative and qualitative approaches. The vulnerability assessment based on indicators, which was used in this research, is one of the most common methods of assessment (Tonmoy *et al.*, 2014). The study follows a deductive approach using theories, models and frameworks on climate vulnerability. Regardless of the approach, standardization, aggregation and weighting of indicators are an inevitable subjective process (Vincent, 2004). In the development of the composite vulnerability index, one of the fundamental problems is the choice of the aggregation method (Adger *et al.*, 2004). Should the average value be used for the variables, or should the weights be assigned to the variables? If weights are used, how to determine them - by quantitative methods or by expert judgment? If weights are used, how can be taken into account the fact that the relative importance of vulnerability indicators varies by space and time? Experts' opinions are different, Eakin and Bojorquez-Tapia (2008) point out that the use of the same weights implies an implicit assessment of each variable and suggests the equal weighting of variables as the simplest but at the same time acceptable process that is available to us. However, determining weights based on expert judgment, in which this was subjectively decided on the basis of our knowledge of the problem, this may cause disagreements within the profession. Quantitative methods for determining weights are based on data variability which can represent an indicator with factor analysis and analysis of the main components. However, such approaches may be inadequate because they do not disclose the impact of each indicator on vulnerability (Hinkel, 2011). In this study, simple, unweighted averages of normalized variables were used, from which three main indicators were formulated (exposure, sensitivity and adaptive capacity) and the vulnerability index from these indicators. As Tonmoy *et al.* (2014) found, the equal weights is the method most commonly used in similar research. Planners, researchers and other actors must take into account that the degree of uncertainty is incorporated into the methods of work that were used. The results can vary significantly with the use of different methods.

5. CONCLUSION

The development of Climate vulnerability index of agriculture attempts to fill an important research gap, since for Slovenia such index has not been constructed yet. The main goal of the present research was the assessment of the climate vulnerability of agriculture to inform policy makers, farmers and researchers that it is necessary to reduce the risks associated with climate change. The assessment of the climate vulnerability of Slovenian agriculture was made in order to increase understanding of climate-vulnerable systems such as agriculture, as the purpose is to encourage policy and research institutions to prioritize the regions where climate vulnerability is highest, and to develop strategies that reduce vulnerability. It is important to raise awareness and encourage the agricultural holdings to implement agricultural practices that reduce vulnerability, but further research and analyzes of the climate vulnerability of Slovenian agriculture is needed: monitoring climate and impacts on agriculture and planning measures at regional and national levels.

The results which show the assessment of the climate vulnerability of Slovenian agriculture are primarily intended for farmers and agricultural policy. Since this is a global problem, public awareness and participation of both national and international policies, better results in reducing climate vulnerability of agriculture can not be expected without further investment in climate change research.

In order to better understand why agriculture is vulnerable to climate, further research, planning and engagement in practice is needed. Comparative research on the climate vulnerability of agriculture in Slovenia should be prepared and the new ways of assessing the climate vulnerability of agriculture should be sought. It is important to upgrade existing indicators in line with new developments in science. Further research and analysis of the agriculture climate vulnerability are encouraged: climate monitoring and impacts on agriculture and planning measures at regional and national level. Development of climate and socio-economic models, data for forecasting the future should also be included in the assessment of vulnerability. It is necessary to establish a comprehensive and effective publicly accessible geographic information system for monitoring the impact of climate change and the present/future climate vulnerability of agriculture. In order to achieve these goals, better availability and quality of publicly available environmental, social and economic data at the level of municipalities, regions and the state is essential. Geographic visualization can also be used for more transparent evaluation meaning more relevant information for understanding where and how vulnerability occurs.

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