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Tools for agricultural drought detection in the frame of Drought Management Centre for Southeastern Europe – DMCSEE

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ABSTRACT

Numerous specialized indices have been proposed to assess drought severity, but the precise quantification of drought is a difficult challenge. The purpose of this paper is to evaluate two indices: the well known Standardized Precipitation Index (SPI) and the Net Irrigation Requirements (NIR) derived by WinISAREG model. WinISAREG water balance model is tested in the frame of working activities of Drought Management Centre for Southeastern Europe (DMCSEE). The drought assessment for areas with different climatic characteristics in Slovenia is achieved using both indices for maize crop in the period from 1961 to 2010. A simple water balance was used for the comparison with the both indices.
Results of the indices were compared with information about drought available in the agrometeorological reports of the Environmental Agency of the Republic of Slovenia for analysed time period. For the comparison among indices qualitative analysis for the vegetation season (April-September) was performed. For this reason 1-month and 6-month Standardized Precipitation Index were used. Soil type with low soil water holding capacity was chosen for the study.
Seasonal NIR generally responds in a similar fashion to the 6-month Standardized Precipitation Index. With both indices extremely dry periods were validated by agrometeorological reports. There are some years with drought which are only confirmed by NIR and not confirmed by SPI6. SPI6 performs relatively well as indicator of long-term meteorological droughts caused by the lack of precipitation while NIR identifies also long-term agricultural droughts provoked by high evapotranspiration triggered by temperature stress. Study showed that at all locations NIR in the last ten years (2001-2010) increased on soils with low water holding capacity. NIR could be proposed as indicator for agricultural drought detection in the frame of DMCSEE.

Key words: drought, crop water balance, WinISAREG model, Standardized Precipitation Index, Net Irrigation Requirements, climate variability

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IZVLEČEK

ORODJA ZA UGOTAVLJANJE KMETIJSKE SUŠE V OKVIRU CENTRA ZA UPRAVLJANJE S SUŠO V JV EVROPI – DMCSEE

Intenzivnost suše je, kljub številnim specifičnim kazalcem, zelo težko natančno vrednotiti. Namen članka je ovrednotenje dveh indeksov: že dobro poznanega Standardiziranega padavinskega indeksa (SPI) in Neto namakalne potrebe (NIR), izračunane s programom WinISAREG. Vodno bilančni model WinISAREG je preizkušen v okviru delovnih aktivnosti Centra za upravljanje s sušo v jugovzhodni Evropi - DMCSEE. V študijo so bile vključene lokacije po Sloveniji, z različnimi podnebnimi značilnostmi, za primer koruze, v obdobju 1961-2010. Za primerjavo obeh indeksov je bila uporabljena enostavna vodna bilanca.
Vrednosti indeksov za analizirano obdobje so bile primerjane z arhivskimi podatki o sušah, dostopnih v agrometeoroloških zapisih na Agenciji Republike Slovenije za okolje. Analizirana so bila vegetacijska obdobja, ki trajajo od aprila do septembra, zato sta bila uporabljena 1-mesečni in 6-mesečni SPI. V študiji so bila uporabljena tla s slabo zadrževalno kapaciteto za vodo. Sezonski NIR (obdobje rasti rastline) v splošnem odgovarja 6-mesečnem Standardiziranem padavinskem indeksu (SPI6).

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Agrometeorološki zapisi so potrdili ekstremno sušna leta glede na oba indeksa. Pojavili pa so tudi primeri, ko so bila nekatera sušna leta potrjena z NIR-om, z SPI6 pa ne in obratno. Oba indeksa dobro zaznata dolgotrajne suše, SPI6 meteorološke suše na račun pomanjkanja padavin, NIR pa upošteva tudi visoko izhlapevanje povzročeno s temperaturnim stresom. Študija je pokazala, da se trend vrednosti NIR-a na vseh izbranih lokacijah v zadnjem desetletju (2001-2010) povečuje na tleh s slabo zadrževalno kapaciteto za vodo. V okviru DMCSEE NIR lahko predlagamo kot kazalec določanja kmetijske suše.

Ključne besede: suša, vodna bilanca rastlin, WinISAREG model, Standardizirani padavinski indeks, Neto namakalne potrebe, podnebna spremenljivost

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1 INTRODUCTION

Drought is at least occasionally a normal part of climate in virtually all regions of the world. Southeastern Europe is no exception; in past decades the drought-related damages have had large impact on the economy and welfare.

The climate of a region or a country is determined by long-term average, frequency and extremes of several weather parameters, notably precipitation and temperature. Drought, in particular, is considered by many to be the most complex but least understood of all natural hazards. The American Meteorological Society (1997) groups drought definitions and types into four categories: meteorological or climatological, agricultural, hydrological, and socioeconomic. A prolonged (e.g., of several months or years duration) *meteorological drought* – the atmospheric conditions resulting in the absence or reduction of precipitation – can develop quickly and end abruptly (in some cases, the transition can occur almost literally overnight). Short-term (i.e., a few weeks duration) dryness in the surface layers (root zone), which occurs at a critical time during the growing season, can result in an *agricultural drought* that severely reduces crop yields, even though deeper soil levels may be saturated. Hot temperatures, low relative humidity, and desiccating winds often add to the impact of the lack of rainfall. The onset of an agricultural drought may lag that of a meteorological drought, depending on the prior moisture status of the surface soil layers. Precipitation deficits over a prolonged period that affect surface or subsurface water supply, thus reducing streamflow, groundwater, reservoir, and lake levels, will result in a *hydrological drought*, which will persist long after a meteorological drought has ended. *Socioeconomic drought* associates the supply and demand of some economic good with elements of meteorological, agricultural, and hydrological drought. (Heim, Jr., 2002)

In the last century, many drought indices were formulated by integrating weather variables such as rainfall, evapotranspiration and temperature into a single number. Drought indices, in general, enable the detection of the onset of drought events and the measurement of their severity, thereby allowing an examination of the spatial and temporal characteristics of drought, and comparison between different regions. An important feature of drought is timescale, which can vary substantially. A single month of deficient rainfall can adversely affect rainfed crops while having small or no impact on large reservoirs.

Drought indices are important elements of drought monitoring while they interrelate among many climate and climate – related parameters. Attempts to coordinate and facilitate the development, assessment, and application of drought monitoring tools is also important task of Drought Management Centre for Southeastern Europe (DMCSEE) which was established in Slovenia in 2006.

At present, the most commonly used drought index in the frame of DMCSEE is the Standardized Precipitation Index (SPI) (McKee et al., 1993; 1995) which takes into account the role of antecedent conditions in quantifying drought severity. It is based on the consideration that each component of a water resources system reacts to a deficit in precipitation over different time scales. Beside SPI, simple water balance (WB) and Net Irrigation Requirement (NIR) derived by WinISAREG model were analysed for Slovenia. Given the high potential of the SPI to detect drought periods in southeastern Europe, the present study was focused on investigating the applicability of three indicators of agricultural drought in four agricultural regions in Slovenia in the period 1961-2010.

2 MATERIALS AND METHODS

2.1 Site descriptions

In Slovenia three climatic belts are met: continental climate in the northeast, southeast and partly in central Slovenia, alpine climate in the mountainous region in the north and sub – Mediterranean climate in the southwest.

Figure 1: Site locations
Slika 1: Lege postaj

This study was conducted in main agricultural areas in Slovenia: Ljubljana, Murska Sobota and Novo mesto are situated in central, northeast and southeast Slovenia (respectively) and Bilje is situated in southwest (Figure 1).

The average annual (vegetation season) air temperature in the period 1971–2000 ranges from 12 °C (17.6 °C) at Bilje to around 10 °C (16 °C) at the other three stations. The lowest monthly average air temperature is in January and the highest in July. Annual (vegetation season) precipitation amounts are the lowest at the east and increasing towards the west. The average precipitation ranges from 805 mm (Murska Sobota) to 1446 mm (Bilje) for annual and from 502 mm (Murska Sobota) to 754 mm (Bilje) for vegetative season. The calculated evapotranspiration (ETP) sums in the seasons are less variable: from 600 mm (Murska Sobota) to 640 mm (Bilje), with increasing trend in recent years.

Table 1: Climatic characteristics of selected sites (SEA/ARSO, 2010)
Tabela 1: Podnebne karakteristike izbranih postaj (SEA/ARSO, 2010)

	1971–2000	Average air temperature (°C)	Precipitation (mm)	ETP (mm)	Sunshine duration (h)	Number of days with ETP > 5mm
Ljubljana	annual	10.2	1368	762	1798	22.3
46°4' N	vegetation season	16.5	752	620	1291	
14°31' E	maximum monthly	23.9	147	154	267	
299 m. a. s. l.	minimum monthly	–2.7	71	6	45	
Murska Sobota	annual	9.6	805	741	1913	14.6
46°39' N	vegetation season	16.1	502	599	1343	
16°12' E	maximum monthly	19.7	104	148	265	
188 m. a. s. l.	minimum monthly	–1.2	31	4	57	
Novo mesto	annual	9.9	1147	764	1890	20.0
45°48' N	vegetation season	16.1	663	612	1316	
15°11' E	maximum monthly	19.9	123	152	272	
220 m. a. s. l.	minimum monthly	–0.2	49	5	66	
Bilje	annual	12.0	1446	842	2102	24.3
45°54' N	vegetation season	17.6	754	642	1348	
13°38' E	maximum monthly	21.7	164	174	279	
55 m. a. s. l.	minimum monthly	3.0	74	2	96	

2.2 Input data

2.2.1. Meteorological data

Daily meteorological data (precipitation, wind velocity, minimum relative humidity and potential ETP calculated by Penman-Monteith equation) for the period 1961-2010 for four climatological stations were retrieved from the archives of the Slovenian National Meteorological Service at Slovenian Environment Agency (SEA/ARSO).

2.2.2. Soil data

Soil type with low water holding capacity (LWHC) was chosen for the study. The water holding capacity of each layer is represented by field capacity (FC) and wilting point (WP). Detailed description of soil characteristics is available in Table 2. This soil type is typical for agricultural areas on alluvial plains of north-east Slovenia where frequent damage due to agricultural drought is reported.

Table 2: Soil characteristics (SEA/ARSO/AWS, 2010)
Tabela 2: Lastnosti tal (SEA/ARSO/AWS, 2010)

Soil layers	Top depth (m)	Bottom depth (m)	Layer thickness (m)	FC (%)	WP (%)
1	0.00	0.10	0.10	0.30	0.16
2	0.10	0.37	0.27	0.22	0.12
3	0.37	0.60	0.23	0.31	0.16

Soil texture of superficial layer	
Depth (m)	0.10
Sand (%)	35
Clay (%)	25

2.2.3 Crop data

In general vegetation season in Slovenia begins on the first of April and lasts till the end of September. In the study maize crop was analysed. Phenological data for maize (*Zea mays*) hybrid 'Cisco', data of rooting zone layers were derived by experimental data (SEA/ARSO/AWS, 2010). Crop coefficient (K_c) is dimensionless coefficient used to calculate ETP requirement for a particular crop from the potential ETP for a reference crop (ET0). Crop coefficients are determined experimentally and take into account leaf area development of the crop and the crop canopy physiology (Australian… 2001). Due to lack of experimental data, data from literature were used (Doorenbos and Kassam, 1986). The phenological development for maize is described by 6 phenological stages. All used data are described in Table 3. Soil depletion fraction for no stress (p) was set to 0.4.

Table 3: Maize phenological development rooting depths and crop coefficients (SEA/ARSO/AWS, 2010; Doorenbos and Kassam, 1986)
Tabela 3: Fenološki razvoj globin korenin in koeficienti rastlin za koruzo (SEA/ARSO/AWS, 2010; Doorenbos and Kassam, 1986)

Stages	Date	Root depth (m)	p
A – sowing	20.4.	0.01	0.4
B – third leaf	7.5.	0.20	0.4
C – tasseling	9.7.	0.50	0.4
D – milky ripe	16.8.	0.50	0.4
E – fully ripe	8.10.	0.50	0.4
F – harvest	14.10.	0.50	0.4

Date	K_c
30.4.	0.20
7.5.	0.50
11.5.	0.90
28.6.	1.10
9.7.	1.20
16.8.	0.60
20.9.	0.50

2.3 Methods

2.3.1 Water balance

Simple surface water balance accumulation (denoted as WB and calculated as difference between precipitation and ETP accumulation) is used as one of drought indicators in this paper. 50 vegetation seasons are available in the database records. In the first part of investigation the 30-day WB was used in comparison to SPI1, following by analysis of 10-day WB and NIR in the second part.

2.3.2 Standardized precipitation index

The Standardized Precipitation Index makes it possible to quantify the precipitation anomaly with respect to long time average condition (1971-2000) for a specific month and time scale. The long term precipitation record is fit to a probability distribution, which is then normalised so that the mean (average) SPI for any place and time period is zero. Positive SPI values indicate greater than median precipitation and negative values mean less than median precipitation. Drought is defined when SPI reaches value of –1 or less, while value of 1 or more defines wet spell. Value also classifies severity of drought or wetness (Table 4).

SPI is typical meteorological index, the short time scale (1-month; SPI1) and medium-term time scale (6-month; SPI6) have been chosen for the analysis. SPI1, which includes 30 days antecedent precipitation, was calculated for each decade in the vegetation seasons. SPI1 is suitable for detecting the presence, in drought event dynamics, of changes that could be particularly important from agricultural viewpoint. SPI6 was chosen as indicator of cumulative property of vegetation season since SPI6 – if evaluated in September – covers whole period from early spring to harvest of typical summer crops.

Table 4: Classification of SPI values (McKee et al., 1993)
Tabela 3: Razvrstitev vrednosti SPI (McKee in sod.,1993)

SPI value:	Drought category
2.00 and above	extremely wet
1.50 to 1.99	very wet
1.00 to 1.49	moderately wet
−0.99 to 0.99	near normal
−1.00 to −1.49	moderately dry
−1.50 to −1.99	severely dry
−2.00 and less	extremely dry

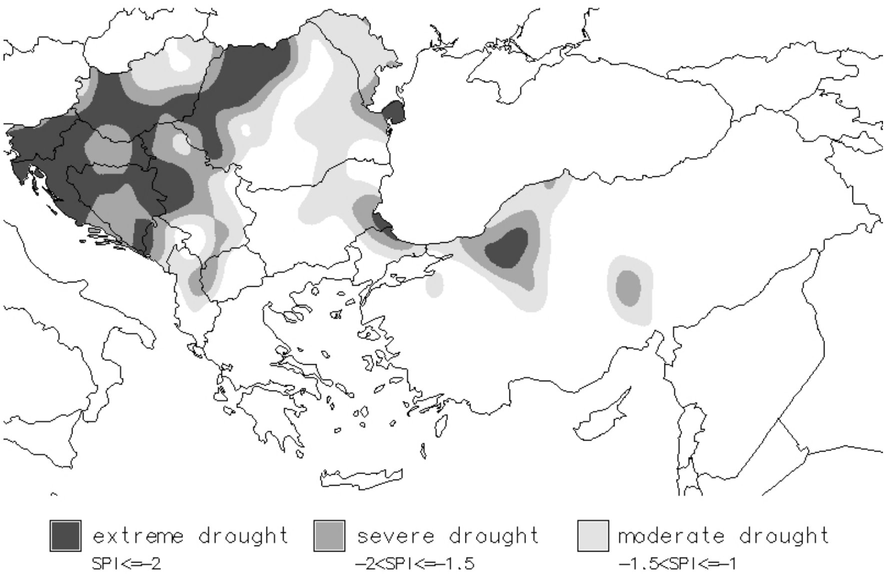

Figure 2: Spatial distribution of SPI6 for September 2003 (available at: http://www.dmcsee.org/en/drought_monitor/)
Slika 2: Prostorska porazdelitev SPI6 za september 2003 (dostopno na: http://www.dmcsee.org/en/drought_monitor/)

2.3.3. WinISAREG model

With the aim of obtaining an actual description of the changes expected in the agricultural WB of the locations, the time series of simulated maize consumption were computed by model WinISAREG. Model WinISAREG (Pereira et. al, 2003; Paredes and Pereira, 2010) is a conceptual WB model for simulating crop irrigation schedules at field level and provides calculation of irrigation requirements under optimal and/or water stressed conditions. Besides input meteorological data (precipitation, ETP, wind velocity and minimum relative humidity) for WB calculation model demands crop data, soil data and irrigation option data. Also it is optional to define ground water contribution, water supply restrictions and salinity. In this study, these three parameters were not included. Model includes modul EVAP56 (Pereira et al., 2003) for computation of reference ETP using FAO Penman Monteith method but since ETP calculation is calculated routinely in SEA/ARSO this module was not used. Water balance is performed for a multilayered soil, crop coefficients and root depths at time scale of defined development periods of certain crop. For estimation of crop WB or irrigation, model setting named field, horticultural and tree crops was used. Fixed dates of maize phenological development for year 2010 were set for all the years. According to the experience of Popova and Pereira (2008) it is optional to use the yield response factor K_y that is derived from field data on yields relative to various irrigation and rainfed regimes. The parameter K_y introduces in the WinISAREG model, the relation between ETP deficit caused by water stress and the corresponding yield decrease (Paredes and Pereira, 2010). Unfortunately, data for Slovenia are not available therefore crop coefficients from FAO (Doorenbos and Kassam, 1986) were used in the study and adjusted to the local root depth measurements (SEA/ARSO/AWS, 2010). In our analysis we used value 1.25 for K_y (Doorenbos and Kassam, 1986). The model initializes soil water simulations with initial soil water content provided by user. Initial total available water (TAW) was set on 100 %. Various time steps of model calculation are adopted depending on weather data availability and required output variable. Model simulation was performed in a way to recognize drought periods according to irrigation requirements. Therefore in WinISAREG model Irrigation Simulation Options mode NIR was used. After simulation model provides information on soil WB or irrigation requirements. In our study daily data were used for ten days and seasonal calculations of NIR, which were input for further investigations.

2.3.4. Statistical methods

Results of the crop water simulations were compared with the information available in the agrometeorological reports of SEA/ARSO (1960-2010). Dry seasons detected by study were compared to descriptions in the reports. Beside that, yield decrease and damage due to drought described by the reports of statistical office (Statistical... 2010) were included into discussion and results.

In order to evaluate trends of WB and evapotranspiration at local scale, linear regression was performed.

3 RESULTS

3.1 Analysis of Standardized Precipitation Index for vegetation seasons 1961–2010

The analysis of the vegetation season time series of SPI6 in the period 1961-2010 shows that from 6 (Novo mesto) to 11 (Bilje) seasons were dry and from 6 (Novo mesto) to 10 (Murska Sobota) seasons were wet. At all locations, except for Bilje, drought in years 2003 and 1992 were detected by SPI6 (Figure 4) as extremely severe. Drought in year 2000 (Ljubljana, Novo mesto, Murska Sobota) and in year 2006 (Bilje) were extreme but more regionalised. The main reason for extreme drought detected by SPI6 in the vegetation period in Bilje region was lack of precipitation. In the period from April to July only 190 mm of rain fall, in comparison to other analysed regions were amount of precipitation was more than 400 mm. Above mentioned years were analysed more in details with all the indicators. According to the fact that SPI6 was not appropriate indicator to detect drought dynamics due to its large internal time scale, SPI1 was calculated in ten day updating intervals during the vegetation seasons.

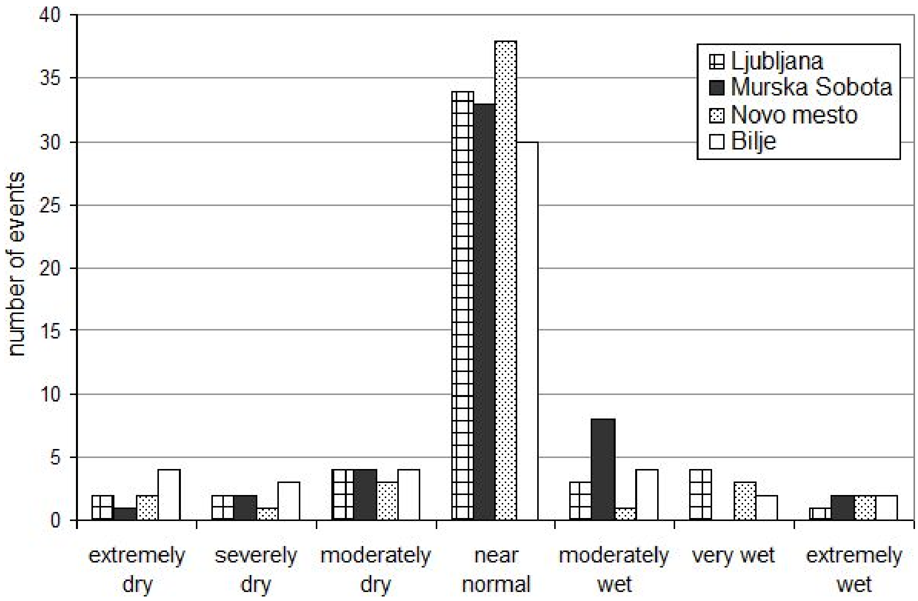

Figure 3: Number of vegetation seasons distributed in SPI6 classes
Slika 3: Število vegetacijskih sezon porazdeljenih v SPI6 razrede

In the Figure 3 for all the locations number of years in specific SPI class is presented.

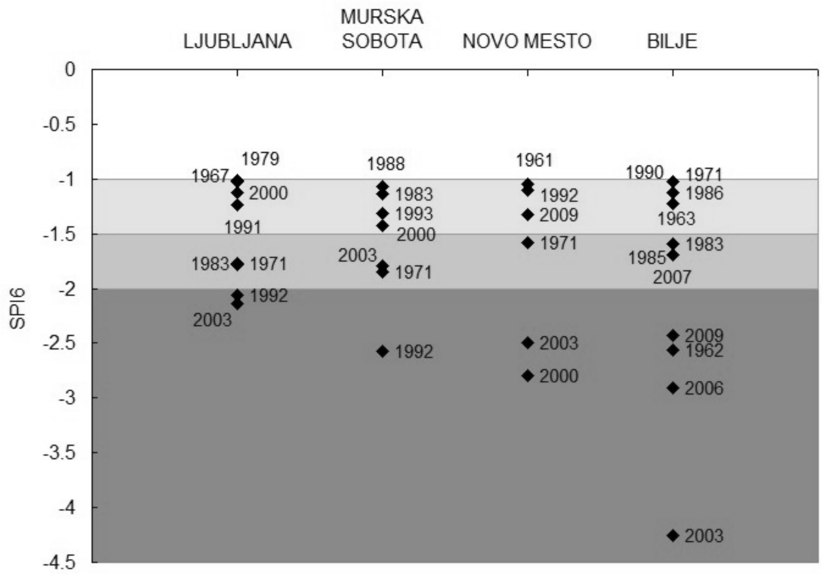

Figure 4: Vegetation seasons classified according to SPI6 in the range of dry years
Slika 4: Sušne vegetacijske sezone razvrščene po SPI6

3.2 Analysis of water balance

Average 40-year vegetation water balance shows that ETP during vegetation season is mainly covered by precipitation amount, unfavourable only at Murska Sobota (long term water deficit is 104 mm). In the last ten years the circumstances are getting drier which reflects in slightly lower WB in the eastern Slovenia and significant decrease in western Slovenia (Figure 5). Only in Ljubljana region there is a slight increase of WB during vegetation season. In the dormancy small change of WB is in Ljubljana, Novo mesto and Bilje are observed. The largest decrease of WB is in Murska Sobota, 47 mm.

The reason for changing water balance is higher ETP rate (more than 5 mm) in the period 2001-2010 increased from 5 to 16 days in comparison to the period 1971-2000 (Figure 6).

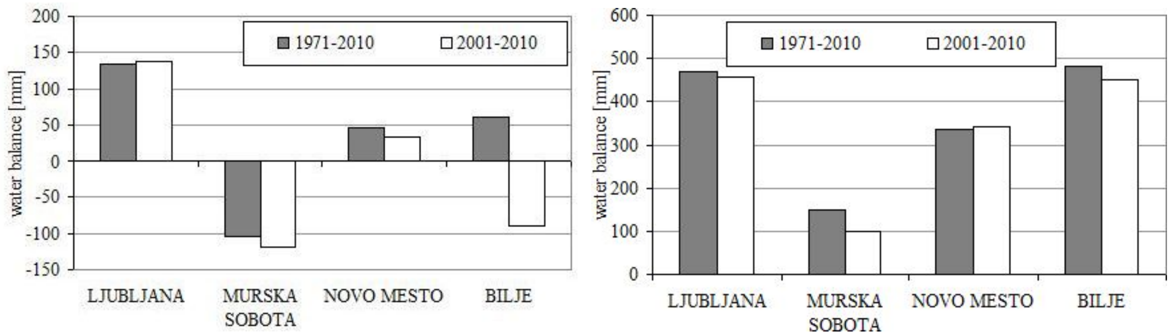

Figure 5: Average water balance in vegetation season (left) and in dormancy (right) in periods 1971-2010 and 2001-2010

Slika 5: Dolgoletna povprečja vodne bilance vegetacijski sezoni (levo) in v dormanci (desno) v obdobjih 1971-2010 in 2001-2010

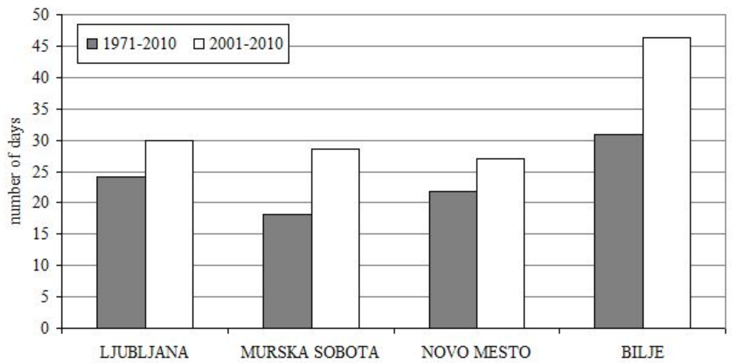

Figure 6: Number of days with ETP > 5 mm in the period 1971-2010 and 2001-2010 in vegetation seasons

Slika 6: Število dni z visokim izhlapevanjem, ETP > 5 mm v vegetacijskih sezonah v obdobju 1971-2010 in 2001-2010

3.3 Drought analysis using Net Irrigation Requirements

NIRs show similar pattern at specific locations as SPI6. According to the cumulative frequency of NIR, years in the range between 80 % in 100 % were determined as dry. In Ljubljana years 2003, 2001, 2006, 2000 were detected as dry by NIR but only 2000 and 2003 were detected by SPI6 (Figure 7).

Distribution of dry years by NIR does not fit always with the order using SPI6. The best fit is only with extremely dry years. This result was somehow expected; while during extreme droughts in the vegetation season both severe lack of precipitation and increased ETP appear simultaneously, this is not the case in years that are near to normal conditions. Very important impact on the severity of drought is distribution of precipitation (drought in year 2006). Shorter heat waves can be interchanged by wet periods so SPI6 (presenting total precipitation anomaly) and NIR (presenting total irrigation requirements) can show different trends.

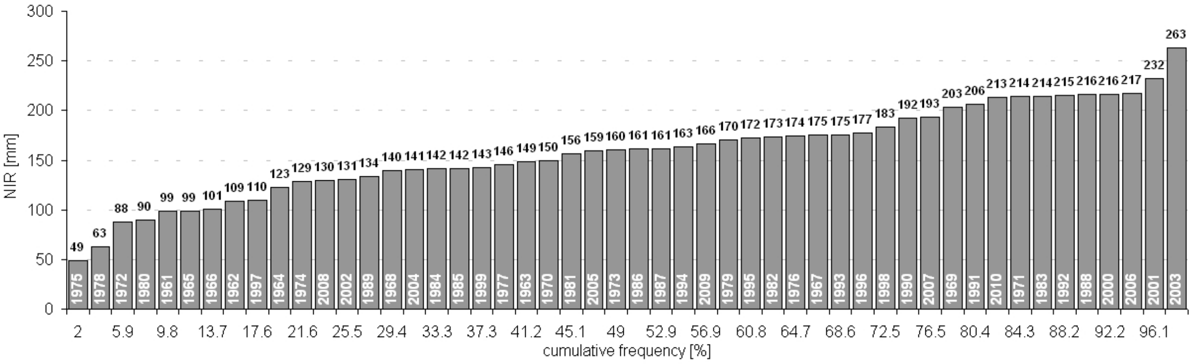

Figure 7: Classification of NIR according to cumulative frequency in Ljubljana in the period 1961-2010
Slika 7: Razvrstitev NIR-a glede na kumulativno frekvenco za Ljubljano v obdobju 1961-2010

3.4 Comparison of SPI1 to 30-day water balance and NIR to 10-day water balance

WB, NIR and SPI1 calculations were performed for 10-day periods. Years with extreme droughts are described more in details in sections 3.4.1. Detailed simulations of all indicators are presented in two graphs in Figure 8, 9, 10 and 11. For specific dry vegetation season upper graph represents SPI1 and WB30 describing 30-day weather conditions. In the graph below NIR and WB10 are simulating 10-day circumstances

3.4.1 Case studies – years with extreme droughts

SPI1, NIR and WB for 1992, 2000, 2003 and 2006 vegetation seasons are presented in the Figure 8, 9, 10 and 11.

3.4.1.1. Year 1992

The drought in Murska Sobota has started already in spring. It continued in May and affected besides Murska Sobota region also other areas. The agriculture drought damaged maize crops. At the end of May, instable weather with precipitation interrupted the dry spell. Precipitation in the first decade of June moistened the soil.

At the end of June second drought appeared. At the end of second decade of June curled leaves of crops have already been noticed in some parts of Slovenia. Drought lasted in Murska Sobota region until the end of August. According to the reports agricultural drought was present also at the other parts in Slovenia, but the most extreme was in region around Murska Sobota. Maize crops on sandy soils were affected the most, from 70 to 90 % of maize crops were damaged due to drought. Most of rainfed agricultural crops ripened forcedly.

In Figure 8 SP1, NIR and WB for vegetation season 1992 is presented. According to SPI1 there were two major dry spells, first at the end of May and second lasting through the whole August, while according to WB and NIR there were three periods of drought appearing in May, June and August. Magnitude of drought in August was classified as the most severe. SPI results imply the lack of precipitation was the highest in Murska Sobota. Comparison of SPI for all sites shows the lowest drought severity in Bilje. The highest magnitude and the longest duration of drought are identified in Murska Sobota also by WB and NIR indices.

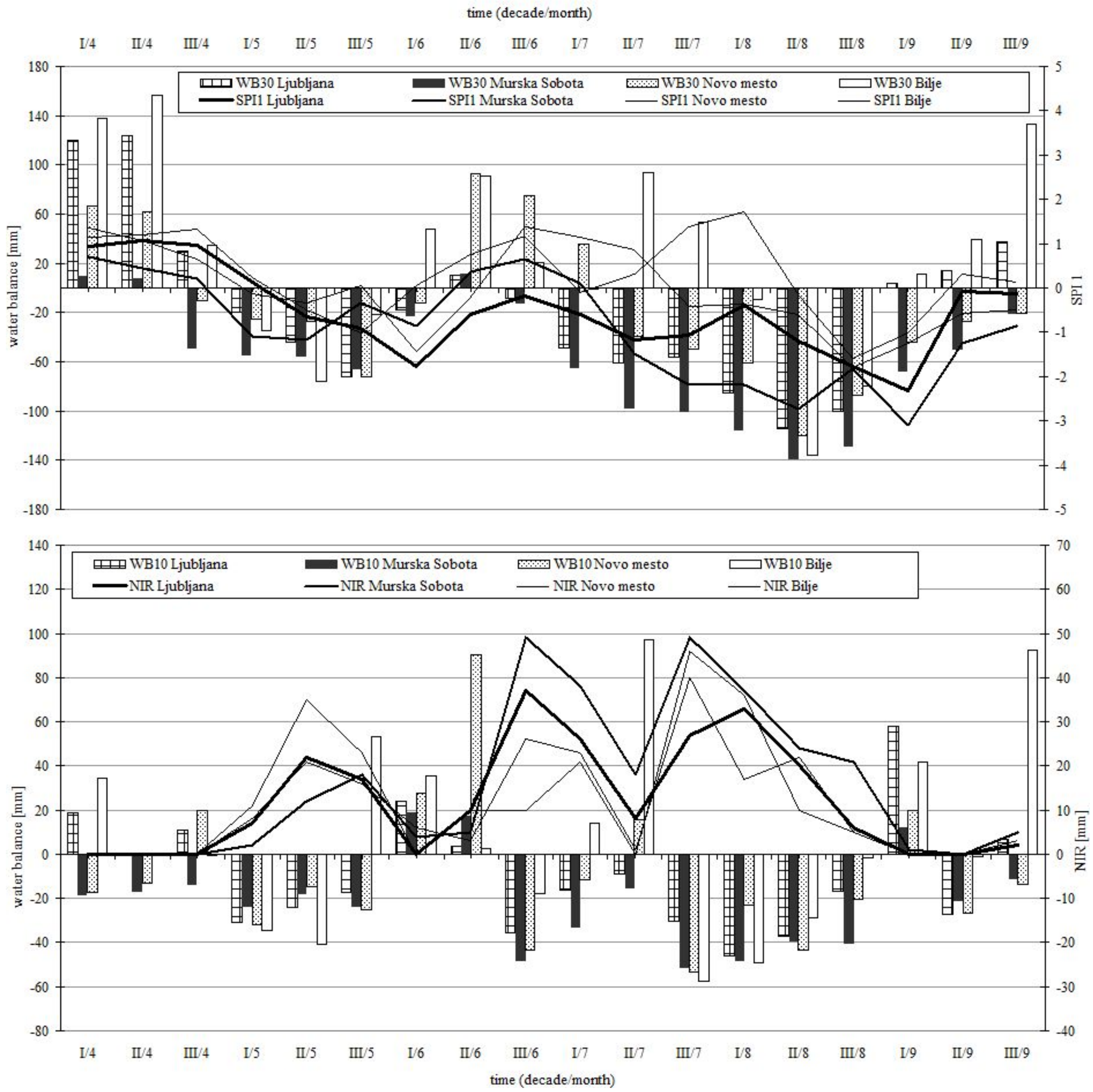

Figure 8: Ten day SPI1, WB30, NIR and WB10 values for vegetation season 1992
Slika 8: Vrednosti SPI1, WB30, NIR in WB10, računane na vsako dekado za vegetacijsko sezono 1992

3.4.1.2. Year 2000

Due to the lack of precipitation during the winter and early spring, the first interval of agricultural drought was detected in the middle of April. Consequently the winter crops were delayed in the tillering stage.

Results of drought indices calculation for the year 2000 are shown in Figure 9 and confirmed by agrometeorological report survey. The second dry interval appeared in the summer in the major agricultural areas in Slovenia. SPI1 shows period of drought from the beginning of May till the middle of July for Novo mesto. Regarding to SPI1 two short periods with lower drought severity in summer appeared also at other sites. WB for vegetation season is mostly negative with few exceptions at particular individual site. NIR is resulting in a way complementary to WB, as negative soil WB demands irrigation. The short wet interval with positive WB was in the second decade of July. This was the most severe agricultural drought in the 10-year period from 1990 to 2000.

Drought affected most agricultural plants in the most sensitive phenological stages: maize crops in the tasseling and pollinating stages, setting of cobs and ripening. By the end of June the agricultural drought had halved the normally expected yield, while at the end of the first third of July the consequences attained the extent of a natural disaster. The most distressed regions were the agricultural areas around Novo mesto and Murska Sobota. The maximum damage was recorded in maize crops, which represents the major crop in the agricultural areas of Murska Sobota. Crop yield in the areas of Murska Sobota, Novo mesto and Bilje was reduced by 20 – 30 %. The drought was terminated by abundant precipitation at all sites in the beginning of September.

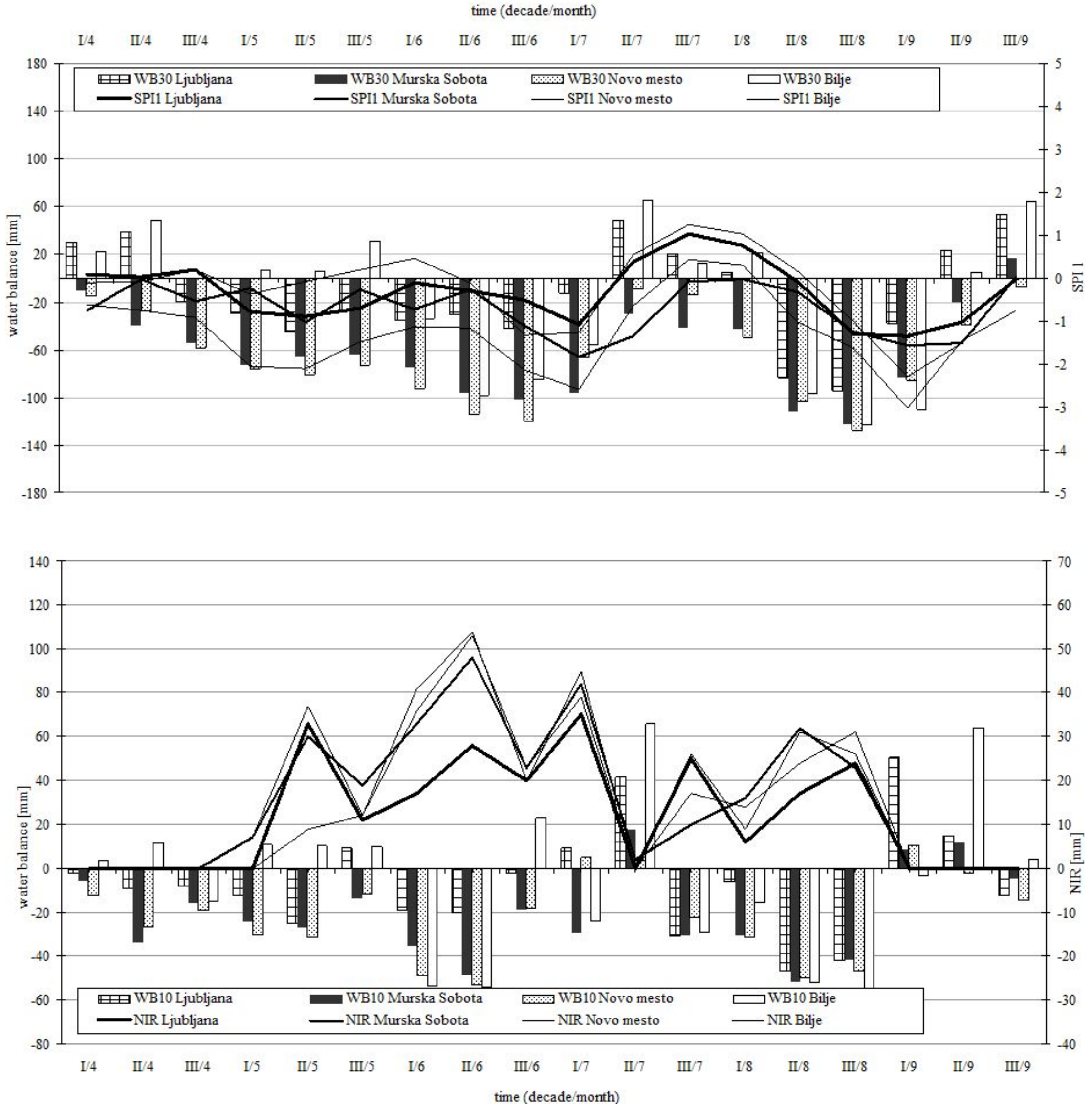

Figure 9: Ten day SPI1, WB30, NIR and WB10 values for vegetation season 2000
Slika 9: Vrednosti SPI1, WB30, NIR in WB10, računane na vsako dekado za vegetacijsko sezono 2000

3.4.1.3 Year 2003

Drought in 2003 lasted from end of April up to second decade of July. It affected the whole country. The damage due to drought attained the extent of a natural disaster which ranked amongst the worst in the previous 50 years. Vegetation season of the year 2003 using SPI1, WB and NIR indices are presented in Figure 10. SPI1 corresponds to precipitation conditions for all sites, continuously below zero SPI value in the major part of the vegetation season.

SPI1 indicates severe drought at all sites at the beginning of April. Another drought period for all sites except for Murska Sobota started in the second decade of May. According to SPI1 in Bilje drought lasted till the second decade in August, in Novo mesto till the first decade of July, in Ljubljana dry spell also lasted till the first decade of July but was interrupted at the beginning of June. In Murska Sobota drought lasted from the second decade of June till the end of July.

The soil water reservoir was not refilled until abundant precipitation in September. However, the WB equilibrium was not restored due to enormous summer water deficit until the end of the year.

The consequences of summer drought were detected also in earlier timing of autumn phenological phases. Long standing water stress heavily influenced the development of maize. Maize grown on shallow and sandy soils visibly lagged behind the normal growth. The damage was assessed to more than 128 million €. It attained the extent of a heavy natural disaster. About 83 % of Slovenian agricultural area was distressed (Statistical..., 2010).

The drought characteristics were detected also by WB. NIR corresponds to negative WB. With respect to WB values and NIR drought severity was the highest in Bilje following by Murska Sobota and Novo mesto.

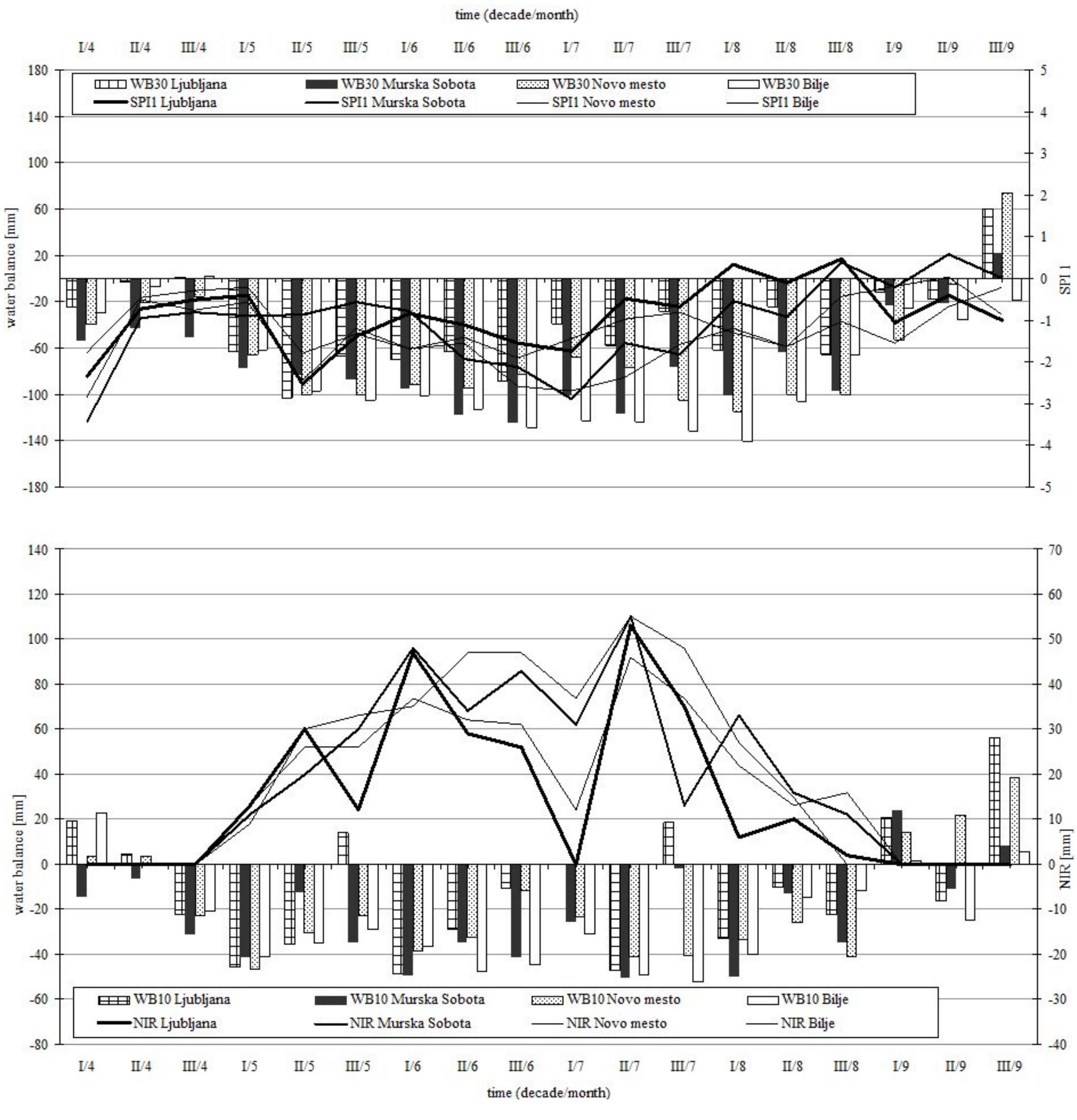

Figure 10: Ten day SPI1, WB30, NIR and WB10 values for vegetation season 2003
Slika 10: Vrednosti SPI1, WB30, NIR in WB10, računane na vsako dekado za vegetacijsko sezono 2003

3.4.1.4 Year 2006

In the last decade of June 2006 the distinctive water shortage by agriculture crops was detected due to the lack of precipitation. Drought was intensified till the end of July at whole Slovenia but the most seriously in the area of Bilje and Novo mesto. At the beginning of August the abundant precipitation ceased two months lasting summer drought. At Bilje region maximum damage due to drought was recorded. Maize yield was reduced by 40 to 90 %. According to SPI1 drought has not appeared in Murska Sobota in July which neglected the real situation. On the contrary, WB and NIR confirmed dry signal in June and July. SPI1 and NIR indicate the maximum SPI1 and the highest values of irrigation requirements among all analysed years in Bilje.

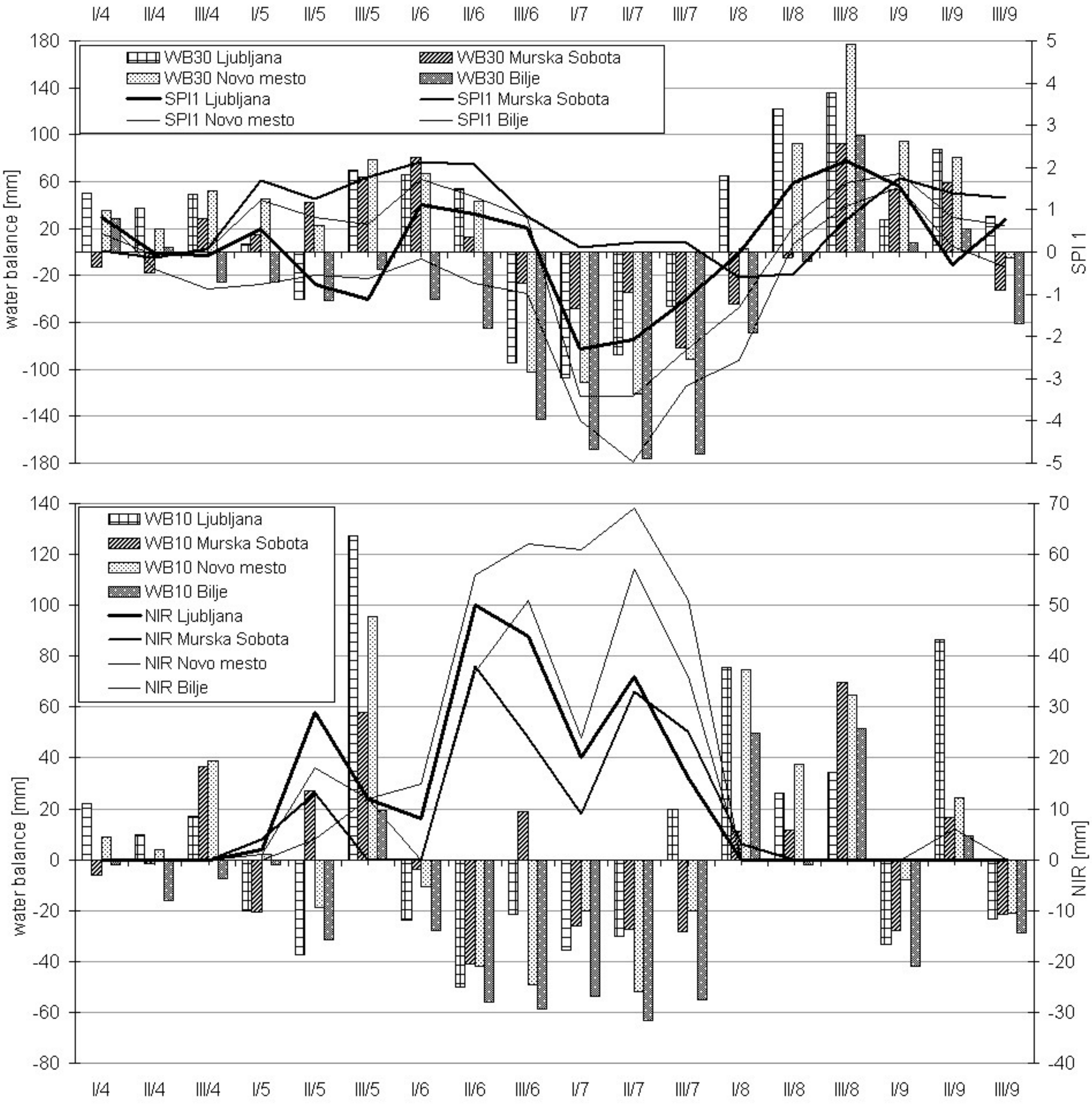

Figure 11: Ten day SPI1, WB30, NIR and WB10 values for vegetation season 2006
Slika 11: Vrednosti SPI1, WB30, NIR in WB10, računane na vsako dekado za vegetacijsko sezono 2006

3.5. Data verification

Data verification was strictly limited to maize in the vegetation season. Dryness (defined by NIR and SPI6) in the vegetation season was checked by reports about drought agricultural impacts reported in the bulletins of the SEA/ARSO.

Only years detected as dry by SPI6 and NIR were included in the evaluation process. In Table comparison with reports for dry years is presented. Only year 2003 was confirmed with both indicators and reports.

Table 5: Classification of dry years with drought within vegetation season detected by SPI6, NIR and comparison with reports of SEA/ARSO (+ drought, - no drought) for Ljubljana (LJ), Murska Sobota (MS), Novo mesto (NM) and Bilje (BI)

Tabela 4: Razvrstitev suhih let, s sušo v vegetacijski sezoni, ugotovljeno z indeksi SPI6 in NIR ter primerjano z arhivom ARSO (+ suša, - ni suše) za Ljubljano (LJ), Mursko Soboto (MS), Novo mesto (NM) in Bilje (BI)

	SPI6				NIR				ARSO				
	LJ	MS	NM	BI	LJ	MS	NM	BI	LJ	MS	NM	BI	REMARKS
1961	-	-	+	-	-	-	-	-	-	-	-	-	NM - precipitation below the average (SPI6), but not low enough for drought
1962	-	-	-	+	-	-	-	-	-	-	-	+	BI - NIR value slightly below chosen threshold, short - term drought
1963	-	-	-	+	-	-	-	-	-	-	-	-	BI - precipitation below the average (SPI6), but not low enough for drought
1967	+	-	-	-	-	-	-	-	-	-	-	-	LJ - precipitation below the average, but not low enough for drought
1971	+	+	+	+	+	+	-	-	+	+	+	+	NM - NIR value slightly below chosen threshold, short - term drought; BI - wet first three months of vegetative season
1973	-	-	-	-	-	-	+	-	-	-	+	-	NM - precipitation (SPI6) near threshold for drought
1976	-	-	-	-	-	-	+	-	-	-	+	-	NM - precipitation on the dry side of normall range (SPI6)
1979	+	-	-	-	-	-	+	-	+	-	+	-	LJ - short - term drought (according to SEA/ARSO); NM - SPI6 near threshold for drought
1981	-	-	-	-	-	+	-	-	-	+	-	-	BI - irregularly distributon of precipitation; large amount of rain in June (130 mm in 3 days) and september
1983	+	+	-	+	+	+	-	-	+	+	-	+	BI - hot and dry condition at the time of polination influenced on harvest
1985	-	-	-	+	-	-	-	+	-	-	-	+	
1986	-	-	-	+	-	-	-	+	-	-	-	+	
1988	-	+	-	-	+	-	-	-	+	+	-	+	LJ - precipitation near normal value, but not enough for maize; MS - NIR value slightly below chosen threshold; BI - hot and dry condition at the time of polination influenced on harvest
1990	-	-	-	+	-	-	-	-	-	-	-	+	BI - NIR value slightly below chosen threshold, short - term drought
1991	+	-	-	-	+	-	-	-	+	-	-	-	
1992	+	+	+	-	+	+	-	-	+	+	+	-	NM - NIR value slightly below chosen threshold, short - term drought
1993	-	+	-	-	-	+	+	-	-	+	+	-	NM - precipitation below the average (SPI6), but not low enough for drought
1994	-	-	-	-	-	-	-	+	-	-	-	+	BI - precipitation below the average (SPI6), but not low enough for drought
1996	-	-	-	-	-	-	+	-	-	-	+	-	NM - precipitation below the average (SPI6), but not low enough for drought
2000	+	+	+	-	+	+	+	+	+	+	+	+	BI - precipitation below the average (SPI6), but not low enough for drought
2001	-	-	-	-	+	+	+	+	+	+	+	+	a large amount of precipitation in September affect SPI6
2003	+	+	+	+	+	+	+	+	+	+	+	+	
2004	-	-	-	-	-	-	-	+	-	-	-	-	BI - NIR value equal to chosen threshold
2006	-	-	-	+	+	-	+	+	+	-	+	+	LJ and NM - a large amount of precipitation in August affect on SPI6
2007	-	-	-	+	-	+	-	+	-	+	-	+	MS - a large amount of precipitation in September affect on SPI6
2009	-	-	+	+	-	-	-	+	-	-	+	+	NM - NIR value slightly below chosen threshold
2010	-	-	-	-	+	+	+	-	-	-	-	-	LJ, MS, NM - NIR value near chosen threshold

3.6. Trend analysis

Additionally time trends of water components were performed for the period 1961–2010. The hypothesis that cumulative ETP and number of days with high ETP rate (more than 5 mm/day) in the vegetation season are increasing was confirmed. The trend is statistically significant at all locations. The largest increase was recorded in Bilje, absolute change around 7 %/10 years and the minor increase in Novo mesto with almost 2 %/10 years. At all locations the noticeable increase of crop water consumption in last ten years is observed, from 20 to 40 %.

The slight trend of precipitation decrease during vegetation season was detected. The trend analysis of vegetation season precipitation amount showed that the average trend is around 1 %/10 years at all locations. The WB during the vegetation season showed trend to more intense water deficit in last ten years, only in Ljubljana WB slightly increases.

Table 6: Absolute and relative change of ETP and NIR in the period 1961-2010
Tabela 5: Absolutna in relativna sprememba ETP in NIR v obdobju 1961-2010

		Ljubljana	Murska Sobota	Novo mesto	Bilje*
ETP in vegetation season	absolute change (mm/10 years)	14.6	20.4	10.1	42.5
	relative change (%/10 years)	+2.4 **	+3.4 **	+1.7	+6.6 **
ETP > 5 mm in vegetation season	absolute change (NOD/10 years)	4.1	4.6	3.6	10.0
	relative change (%/10 years)	+18.6 **	+31.7 **	+18.1 **	+41.1 **
NIR in vegetation season	absolute change (mm/10 years)	13.9	14.4	11.8	26.7
	relative change (%/10 years)	+8.8	+8.7	+7.2 %	+14.0

NOD … Number of days
* … Period 1962-2010
** … Statistically significant

SPI6 is showing increase of dry vegetation season in the period 2001-2010 in comparison to the period 1971-1990 in Novo mesto and Bilje. In Ljubljana and Murska Sobota SPI6 shows even decrease.

NIR trends for maize during the vegetation season vary a lot, but it is common that all the locations are characterised by the increase of the deficit for 8 – 14 %/10 years (Table 6). In last ten years (2001-2010) in comparison to the reference period (1971-2010) on average increased for 23% in the range from 17 to 38 % (Table 7).

Table 7: Average NIR in the period 1971-2000 and relative change of NIR in the period 2001-2010 in comparison to the period 1971-2000
Tabela 6: Povprečni NIR v obdobju 1971-2000 in relativna sprememba NIR-a v obdobju 2001-2010 v primerjavi z obdobjem 1971-2000

	LJUBLJANA		**MURSKA SOBOTA**		**NOVO MESTO**		**BILJE**	
	1971-2000	2001-2010	1971-2000	2001-2010	1971-2000	2001-2010	1971-2000	2001-2010
NIR (mm)	158	+17 %	166	+20 %	163	+17 %	191	+38 %

4 DISCUSSION

In general, concern about rising frequency and impacts of drought is justified. Economical costs are increasing. In year 2000 almost 79 million € damage due to drought was recorded, in 2001 almost 42 million €, in 2003 more than 128 million € and in 2006 almost 50 million €. A drought monitoring and early warning systems should be established to provide information on the formation, development and end of drought. In our study SPI as indicator was less suitable for detecting agricultural drought than crop WB and NIR. In order to monitor the occurrence and development of agricultural drought efficiently and provide information on the strength and range of drought more indicators should be included in the monitoring. For agricultural drought monitoring only integrated tools as plant – soil – climate models will dynamically monitor occurrence and evolution of drought over specific region.

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