SOUTH EAST EUROPE
Jointly for our common future

DMCSEE
Drought Management Centre for Southeastern Europe

Programme co-funded by the EUROPEAN UNION

EXTERNAL EXPERTS' REPORTS

DHMZ

ZAGREB, 2012

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CONTENT

1. Report on preparation climate data

PROJECT INFORMATION	
Project acronym:	DMCSEE
Project title:	Drought Management Centre for South East Europe
Contract number:	2008-0017-201002
Starting date:	17. 05. 2010
Ending date:	17. 05. 2012
Project WEB site address:	http://meteo.hr/DMCSEE/
Partner organisation:	Meteorological and Hydrological Service of Croatia
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DELIVERABLE INFORMATION	
Title of the deliverable:	**Report on preparation of climate data**
WP/activity related to the deliverable:	Act. 3.1 Preparation of climate data and maps
Type (internal or restricted or public):	Public
Location (if relevant):	Zagreb, Croatia
Author:	Mrs Marina Mileta, external expert
Deadline	17.04.2012. Draft report

Description of available meteorological (including climatological) data

1.1.1 Description of measurement network operated by DHMZ

<u>Density of the network::</u>

DHMZ is operating 41 main (M), 117 climatological (C), 336 precipitation (P) and 23 rain storage stations. Automated weather stations (AMS) are co-located at 32 main meteorological station sites, and 26 AMS are installed at other locations. Standard measurement time resolution for AMS is 10 minutes with the same potential of transmission. Terrestrial observations (such are: soil temperature, soil moisture, pan evaporation, and solar radiation measurements) are co-located at 19 Main Meteorological Stations. DHMZ is also operating 47 automatic hydrological stations plus 52 stations overseen by the Croatian Waters. DHMZ takes care of the two radio-sounding systems in Zagreb and Zadar, 2 Doppler S band + 6 small S band weather radars and one sodar. Average distance between main meteorological stations is about 50 km, between climatological stations about 20 km and precipitation stations about 10 km (Table 1.1). Area of Croatia: 56 540 square km (Figure 1 and Figure 2).

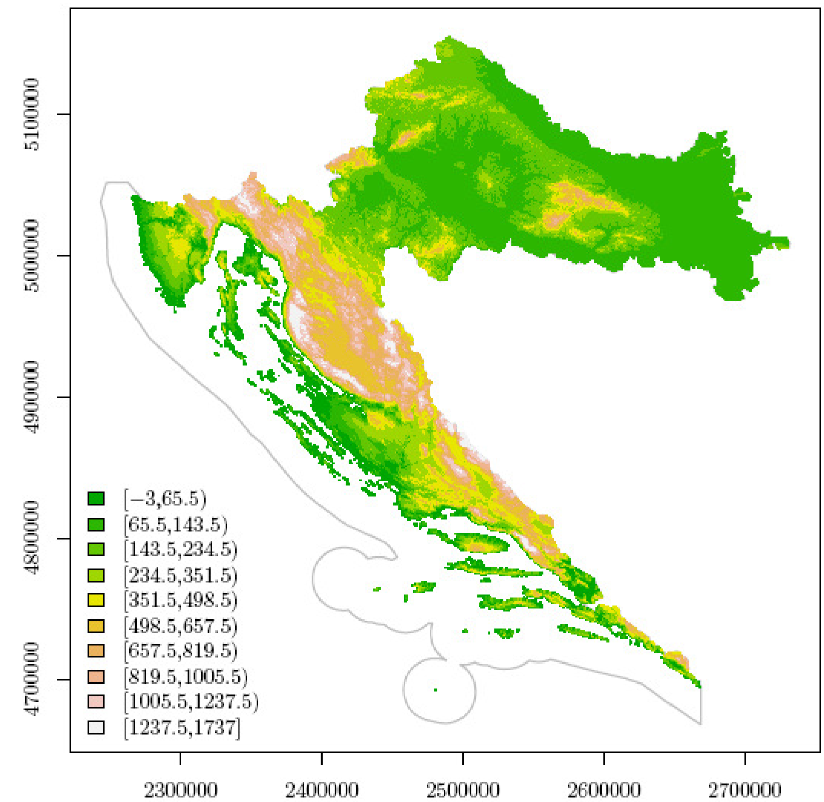

Figure1.1 Heights of terrain of Croatia with a resolution of 1 km.

Table 1.1 Categories of weather stations which suit to the distribution of the altitude in Croatia

Altitude	Area in	Number of all active	Representativity of the

categories*	percents (%) of Croatian area	meteorological stations (%)	category (very good, good, acceptable, poor)
0-200 m	53	78 (M), 69 (C), 60 (P)	very good
201-400 m	20	10 (M), 13 (C), 19 (P)	good
401-600 m	10	3 (M), 5 (C), 9 (P)	acceptable
601-800 m	7	0 (M), 5 (C), 6 (P)	poor
801-1000 m	6	0 (M), 1 (C), 1 (P)	poor
1001-1300 m	3	3 (M), 2 (C), 1 (P)	good
1301-1600 m	0.8	1 (M), 1 (C), 1 (P)	good
Higher of 1600 m	0.2	0 (M), 1 (C), 0 (P)	poor

1.1.2 Metadata and other information of the station network

Following metadata are stored: official name, geographical coordinates and altitude (Table 1.2).

There are metadata for each meteorological station from the beginning its establishment.

Gegraphical coordinates are in degrees and minutes of an angle while altitudes are in meters.

Table 1.2 Metadata of the highest meteorological station

Name	Longitude	Latitude	Altitude	Type	Beginning of measure-ments	Measured elements
Zavizan	44°49'N	14°59'E	1594 m	main	1962	air temperature, pressure, relative humidity, precipitation amount, sunshine duration, snow height

Calibration of instruments is each two years.

Control of stations: main weather stations each year, climatological once in two years and precipitation stations once in five years.

1.1.3 Manned meteorological stations

Total number of manned meteorological stations is 336 (both profesional and voluntary) what measure at least daily precipitation amounts.

There are 117 of manned meteorological stations that (apart from precipitation) measure at least also temperature (at least daily minimum and maximum temperature; Figure 3).

Figure 1.2 Distribution of main and climatological manned stations in Croatia.

Hours of observations:

On precipitation stations: *1 time at 7 o'clock Central European Time (CET)*

On other stations: *3 times at climatological (7, 14 and 21 o'clock of local time) and*

24 times at 1, 2, 3 etc. o'clock of UTC (Universal Time Coordinated) at limited number of main stations.

Some additional parameters are measured on manned ordinary climatological stations (Table 1. 3).

Table 1.3 Additional parameters measured on manned ordinary climatological stations.:

	the parameter is measured on

	(almost) all stations	majority of stations	less than half of the stations	few stations	none
sunshine duration	X				
wind speed and direction	X				
relative humidity	X				
cloud cover	X				
snow cover	X				
soil temperature			X		
leaf wetness				X	

Data availability in digital form of the majority of manned stations is more than one month (Table 1.4).

Table 1. 4 Data availability.

	precipitation	temperature
real time		
near real time (few days of delay)		
approximately one month		
more than one month	X	X

1.1.4 Automatic meteorological stations

Active automatic meteorological stations is 67 (Figure 1.4). That number is rising continuosly last 20 years. That increas has been very gradual and honogeneity of data has been meintained because of manned observation has been don ebeside electronic one. Exceptions are weather stations of some users where in centain number of cases there are not observers.

Time resolution of measurement is each 10 minutes at least.

Figure 1.3 Distribution of Automatic Weather Stations (AWS) in Croatia.

Conventional weather parameters are measured at automatic weather stations (Table 1.5).

Table 1.5 List of parameters measured at automatic weather stations and data availibilty.

Measured parameters:

	the parameter is measured on				
	(almost) all stations	majority of stations	less than half of the stations	few stations	none
sunshine duration				X	
wind speed and direction	X				
relative humidity	X				
cloud cover					X
snow cover					X
soil temperature				X	
leaf wetness					X

Data availability:

real time	X
near real time (few days of delay)	
approximately one month	
more than one month	

1.1.5 Description of length of digitized time series of stations

Almost all data since 1981 are in digitalized form (Table 1.6).

Table 1.6 Length of time series and number of stations with data in digitalized form.

Elements	Number of stations	Length of time series	Temporal resolution (daily/ monthly)	Rate of missing data
Air temperature	117	1981	daily	1%
Relative humidity	117	1981	daily	1%
Air pressure	117	1981	daily	1%
Wind speed and direction	117	1981	daily	1%
Precipitation amounts	117	1981	daily	1%
Sunshine duration	117	1981	daily	1%
Snow height	117	1981	daily	1%

1.1.6 Description of data base

Internal data base.

Row data are available.

Internal software is used for a treatment of long data records and metadata within database. I

1.1.7 Other questions about measurements and data

For air temperature a daily mean is calculated as average of summ of data for 7 and 14 o'clock plus two times for 21 o'clock divided by four. For the rest elemets simple average for three observation hours is calculated.

The morning precipitation amount measurements belong to the same day.

A day with dew is a day without precipitation.

Snow water equivalent is used for precipitation amount measurements.

Both, snow depth and new snow depth are measured.

For about 40 stations (including AWS) is transmit synoptic message over the Global Telecommunication System of the WMO.

1.1.8 Description of quality control procedures

A quality control procedures of meteorological data is regularly made..

Only corrected data are kept in electronic archive while both of them are kept in hard copy.

There are different types of data quality control: logical tests, physical/climatological limits, internal and spatial consistency of measured parameters, multi-source comparison, integrated (in-situ and remote sensing) Quality Control (QC) system, etc.

Procedures are regularly applied on all data.

Data are checked mostly off-line.

1.2 Data homogenization

1.2. 1 Purpose of homogenization

The time series of a climatological variable (air temperature, humidity or pressure, wind speed and direction, precipitation amounts and others) are considered homogeneous if their variability is related only to regional weather and climate variability. However, observation of these variables is most frequently exposed to artificial influences caused by changes in the weather stations: their relocation, the exchange of observers and/or instruments, change in the environment, even including changes in observation rules. For example, during the nineteenth century, the screens for measuring air temperature were installed near windows, on the northern side of observation buildings, while in the twentieth century these screens were moved to an elevation of 2 metres above ground, located on the observation sites (Begert et al., 2005). In addition, observation sites are continuously under the influence of environment change: the planting or uprooting of trees, the construction or redevelopment of houses, buildings, towers, roads, play-grounds and other infrastructural objects. This influence is stronger in big cites and the observation sites are frequently removed further to the periphery, thus "running away" from urbanization. Of course, the reasons for changing the position of observation sites can be quite different in their nature. Artificial gradual change in the observation site environment causes an artificial gradual trend in e.g. air temperature, while observation site relocation usually causes an abrupt significant change in the air temperature average in comparison with the average of rather long periods before relocation.

Different statistical tests can be used for the detection of artificial changes or inhomogeneities in the statistical properties of climatological variables like long-term averages, trends or standard deviations. They can be classified into two groups: *absolute* and *relative* homogeneity testing. Absolute homogeneity is considered within a particular time series, called the *candidate* time series i.e. the time series which is tested. Disadvantage of these tests is the impossibility to make a distinction between an inhomogeneity and a regional variation of weather and climate. On the other hand, when applying relative tests, the testing of the *candidate* time series is made in relation to the *reference* time series, which is assumed to exhibit the same natural variations of weather and climate and is assumed homogeneous. A reference series allows to separate the real climate signal and to highlight the artificial changes in the candidate series that do not occur in the reference series. A large number of both absolute and relative tests have been described by Marković (1975), Peterson et al. (1998) and Aguilar et al. (2003). Relative tests are more convenient for the non-stationary time series with the evidence of climatic changes. As there are an increasing number of non-stationary time series, relative tests are recently applied more frequently than absolute tests. The most popular test was developed by Alexandersson (1986) to detect inhomogeneities in temperature and precipitation series: Standard Normal Homogeneity Test which has root in Hawkins (1977). One version of this test indicates only abrupt breaks in homogeneity, while the second version indicates both abrupt and gradual changes of the mean value in the candidate series when compared with homogeneous reference series. All versions of SNHT give practical information: the date, the size and significance of break. This information is used in the homogeneity testing and adjusting of time series (Tuomenvirta and Alexandersson, 1996). Principally the Alexandersson's test can find only the most significant inhomogeneity in a time series. Therefore the test has to be used in an iterative procedure. When a statistically significant inhomogeneity is found, the time series is homogenised for this inhomogeneity using the size of the inhomogeneity given by the test. Then the time series is tested again and a second inhomogeneity may be found (Herzog and Müller-Westermeier, 1996). Elements for validation of the technique chosen can be also found in DeGaetano (1996), Vincent (1998), Vincent and Gullett (1999), Ducré-Robitaille et al. (2003), Li et al. (2004), Drogue et al. (2005), Brunetti et al. (2006), DeGaetano (2006) and Reeves et al. (2007).

The SNHT has been applied in Croatia by Likso (2003) for homogeneity testing of several annual[2] air temperature time series for Croatia. Recently, the necessity has appeared for a more systematic approach to this topic because of the work on the Croatian Climate Atlas for the standard period 1961-1990. For this purpose a more general version of the SNHT has been applied, which includes artificial linear trends in the temperature time series in addition to abrupt breaks in homogeneity (Section 2) and 22 time series of annual air temperature for the period 1961-2000 have been chosen (time series for conventional sensors are only considered because data for electronic sensors are available for short time in the considered period), well covering the different climate regions of Croatia (Section 3). The results of homogeneity testing and application of a homogenisation procedure are described in Section 4. In addition to the other, differences between total linear trends for homogenised and unhomogenised 22 average annual air temperature time series have been calculated and represented in Section 5. Consequently, it is possible to conclude that there is a gradual rise of linear trend in mean annual

[2] According to Marković (1975), average annual values can successfully be used in order to be established long-term modification, variables averaged in shorter time units have a greater mutual dependence among individual members and a larger variance which diminishes the test's discriminatory power.

temperature from south to the north of the Croatian territory in considered period what is very probably a consequence of global warming.

1.2.2 Relative homogeneity testing methods for meteorological time series and homogenisation

As it has been mentioned in Section 1, the Swedish meteorologist Alexandersson (1986) the first applied the Standard Normal Homogeneity Test for testing the homogeneity of meteorological variables. The test has been designed to remove the influence of the natural variation of weather and climate on a regional scale i.e. (mostly) for the detection of artificially-caused abrupt breaks in the homogeneity of meteorological time series.

Let Y_i indicate the *i*-th term (of total *n*) of the meteorological time series being tested (Y-series), while X_{ji} is the *i*-th term of the *j*-th (of total *k*, also with *n* terms each) reference time series for surrounding meteorological stations (X-series). The relative inhomogeneity to be detected as a series of q_i (q-series) is defined as

$$q_i = \left(\frac{Y_i - \overline{Y}}{s} \right) - \left[\sum_{j=1}^{k} \rho_j^{\,2} \left(\frac{X_{ji} - \overline{X}_j}{s_j} \right) / \sum_{j=1}^{k} \rho_j^{\,2} \right], \qquad (1.1)$$

where $\overline{Y}$ and $\overline{X}_j$ are the sample averages for candidate and reference time series, respectively, s is the standard deviation of the candidate and s_j is the standard deviation for the *j-th* reference series and ρ_j is the correlation coefficient between the candidate and the *j*-th reference series.

The SNHTs are applied to standardized time series

$$Z_i = \frac{q_i - \overline{q}}{s_q}, \qquad (1.2)$$

where $\overline{q}$ is the average value of the series of differences, s_q is the corresponding standard deviation calculated by (*n*-1) weight in case *n* is a number of the time series terms. It is assumed that Z_i is N(0,1) distributed. Alexandersson and Moberg (1997) discussed the problem of assumption that standardization produces series with a unit variance (equation 2) and showed that standard deviations within two parts of the series, before and after a possible break, can be lower than "exact" value for the whole series[3]. In addition to that, the same authors indicate that an use of SNHT with two standard deviations could give often artificial breaks near the end of the series.

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[3] Reeves et al. (2007) also discussed this problem with reference to Alexandersson (1986) only.

According to *likelihood ratio* theory (e.g. Mood et al., 1974; Lindgren, 1976; Wilks, 2006), a critical value of the test parameter can be found

$$T_0 = \max_{1<a<n}(T_a) = \max_{1<a<n}\left[a\,\overline{Z}_1^{\,2} + (n-a)\overline{Z}_2^{\,2}\right]^{1/2}, \qquad (1.3)$$

where

$$\overline{Z}_1 = \frac{1}{a}\sum_{i=1}^{a} Z_i \qquad \overline{Z}_2 = \frac{1}{n-a}\sum_{i=a+1}^{n} Z_i \qquad (4)$$

Thus, having an available standardized series of differences $Z_1, Z_2, ..., Z_n$ defined by (2) and by the calculation of sub-sample means $\overline{Z}_1$ and $\overline{Z}_2$, the values of T_a and T_0 are obtained (in short *T*-series). Several statements can be extracted:

1. If T_0 is greater, then the critical value candidate series should be considered to be inhomogeneous at a certain test level, e.g. with a probability of 95% (the probability of erroneous conclusion is 5% in this case).
2. a indicates the term of the series after which a most probable inhomogeneity appears.
3. $\overline{q}_1$ and $\overline{q}_2$ are the mean values of the differences between candidate and reference series before and after the possible break of homogeneity. Then, the difference $\overline{q}_2 - \overline{q}_1$ indicates the magnitude of the relative change in the candidate series compared to the reference series.

Now, a model can be introduced in which the "mean level" of the series $q_1, q_2, ... q_n$ is changed gradually within its arbitrary length segment from *a* to *b*. Then

$$\overline{Z}_1' = \frac{1}{a}\sum_{i=1}^{a} Z_i$$

and

$$\overline{Z}_2' = \frac{1}{n-b}\sum_{i=b+1}^{n} Z_i$$

indicate the arithmetic means in the series $Z_1, Z_2, ..., Z_n$, before and after the linear trend period, respectively. When $b = a+1$, then test parameter for gradual trends T'_0 is reduced to the test parameter for abrupt breaks of homogeneity T_0. In addition to this, according to Alexandersson and Moberg (1997), the critical values for the test parameters T_0 and T'_0, i.e. for abrupt breaks and gradual trends, respectively, are practically the same. It is usual practice to homogenise the time series so that their statistical parameters (e.g. mean values) for parts of the series before homogenisation are adjusted to the statistical parameters (average values) of the parts after homogenisation i.e. the new states. Simply, the terms of the series before the break are corrected for the difference between means after and before the break, respectively. If this difference is positive, the terms which are in chronological order before the break are increased for the difference and if it is negative, the same members are decreased for the same amount.

If a homogeneity break is in the form of linear trend, then correction as before is applied to the terms preceding the break while for the terms which are under the influence of the linear trend the correction applied depends on the ordinal number of the term (see Alexandersson and Moberg, 1997).

What is the procedure in case of more than one break in the series $Z_1, Z_2, ..., Z_n$? In principle, break by break has to be solved in chronological order. After the first break is detected, the described homogenisation procedure can be applied. Then, the next break is detected and homogenised and so on, until the time series is completely homogenised. Thus, a successive procedure should be applied to obtain the final homogenisation of a time series what has been applied in this paper.

1.2.3 Time series of annual mean air temperature

For the Climate Atlas of Croatia, the homogeneity of time series of mean annual temperature for 22 weather stations, indicated by numbers in Figure 1.4 and with the names in Table 2, almost uniformly distributed over Croatia has been considered for the period 1961-2000. It is clear that the whole territory of the country is rather well covered i.e. all climate zones are included: lowland, mountainous and coastal.

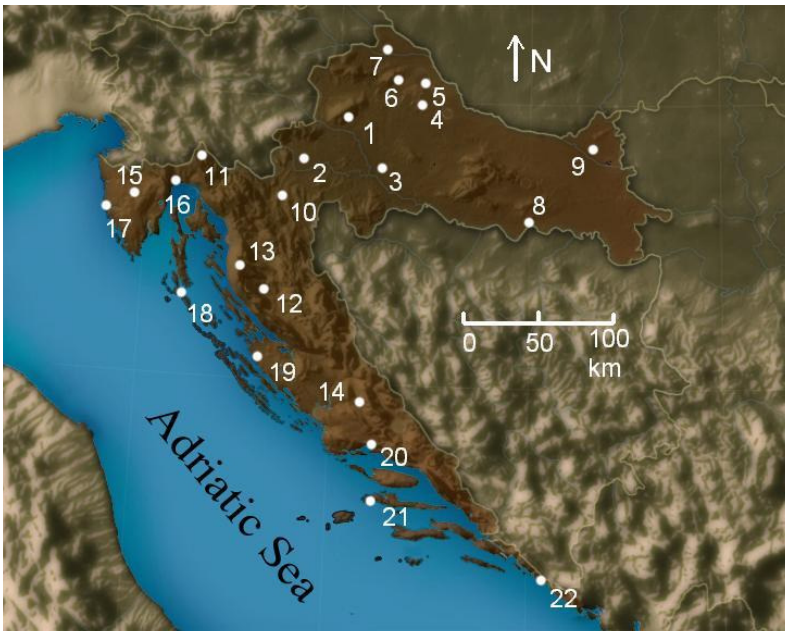


Figure 1.4 Geographical map of Croatia with weather station numbers.

1.2.4 The results of homogeneity testing and homogenisation

Using the theory described in Section 2, the authors have produced algorithms and computing programmes for the calculation of the T- and q-series, T'_0 test quantity, as well as the beginning and the end of the linear trends in the q-series. If the difference is only one year, i.e. *b*=*a*+1, then an abrupt break of homogeneity is in question. Thus, using a unique algorithm and graphical visualization of the T-series, detection of abrupt and gradual breaks of homogeneity is achieved in the q-series of mean annual air temperature in Croatia. An algorithm and the necessary computing programmes have been developed for the homogenisation of the time series. The programmes have been developed in MS-DOS FORTRAN 77 and can be run on personal computers. The results have been compared with those of internationally accepted *Standard Normal Homogeneity Test for Windows* software which was developed in Danish Meteorological Institute (DMI) for detection abrupt breaks and trends (Steffensen, 1996) and also used by Likso (2003).

As the density of weather stations is higher in the lowland than in the mountainous and coastal regions, reference series for the lowland part of Croatia have been constructed on the basis of five time series from the closest weather stations, while for the mountainous and coastal regions data from the three closest weather stations have been used. It turned out that the results with data from three weather stations are as stable as those from five weather stations. This preliminary conclusion is in agreement with the results by Moberg and Alexandersson (1997), which show that spatial average is "immune" from independent inhomogeneities of a particular time series, which eventually mutually annul each other. This statement will be also confirmed in this study.
The numerical results of the homogeneity testing of 22 time series of 40-year mean annual values of air temperature are presented in Figure 1.4. Those test quantities which exceed the critical value of $T'_0 = 8.10$, by a confidence level of 95%, in the case of *n*=40, are marked by an asterisk in Table 1.7. Lower values than 8.10, but still close to it, are sometimes considered as a signal of homogeneity break, while others, i.e. low enough, at corresponding locations in the time series, are not considered to be breaks in homogeneity.

Table 1.7. The results of homogeneity testing of mean annual air temperature time series from 22 weather stations of Croatia, for the period 1961-2000.

		Homogeneity break		Mean change for Y-series		Potential cause of inhomogeneity
Weather station	T'_0	*a*	*b*	°C	°C/year	
1. Zagreb-Maksimir	11.8* 20.4* 10.0* 9.9* 9.2*	1964 1979 1977 1991 1995	1966 1993 1993 1998	-0.20 0.24 0.11 0.11 -0.13	-0.10 0.02 0.01 -0.04	General urbanization, especially construction of the *Kraš* factory and tennis courts in the vicinity, in the 80's and 90's of last century, respectively
2. Karlovac	 9.4* 28.7* 7.8	1979 1992 1968	1991	0.26 -0.59 -0.15	0.02	Urbanization and relocation of the weather station on 9 November 1992
3. Sisak	 17.4* 9.2*	1968 1975	1970 1986	0.28 -0.13	0.14 -0.01	Urbanization and change of environment

4. Bjelovar	13.2* 13.9*	1983 1985 1988	0.33 0.17 -0.24	Change in environment
5. Đurđevac	12.3* 14.8* 11.2*	1966 1971 1977 1987	-0.24 -0.05 0.20 0.15	Change in environment
6. Križevci	12.8* 24.1*	1968 1970 1981 1983	-0.06 -0.03 -0.21 -0.11	Fruit tree planting in the 80's of last century
7. Varaždin	13.6* 6.9 11.6*	1971 1982 1994 1997	-0.25 0.11 -0.21 -0.07	Relocation of the weather station on 1 January 1972
8. Slavonski Brod	17.5* 18.7* 16.6* 6.3	1969 1986 1992 1996 1969	-0.45 0.39 0.07 -0.36 -0.12	From 1 January 1970, data are from the new location (parallel work of two station for one year); urbanization
9. Osijek	7.5 8.5*	1968 1990 1992	-0.18 -0.18 -0.09	Relocation of the weather station, on 17 October 1991
10. Ogulin	2.5	1968		Probably no break in homogeneity
11. Parg	13.8* 20.9*	1968 1974 1985	0.41 -0.48 -0.04	Probable influence of the reconstruction of the station site?
12. Gospić	4.4	1976 1979		Probably no break in homogeneity
13. Zavižan	3.2	1984		Probably no break in homogeneity
14. Knin	8.6* 9.7*	1964 1967 1995	0.28 0.09 -0.25	Station relocated twice: 16 May 1971 and 22 December 1988; war in 1995
15. Pazin	19.2* 18.6*	1969 1982 1987 1989	0.38 0.03 -0.30 -0.15	Change in environment
16. Rijeka	14.6*	1976	-0.18	Relocation of the weather station on 1 December 1977
17. Rovinj		1979 1981	-0.41 -0.21	Relocation of the weather

	17.3* 14.6* 9.1*	1986 1989 1987	0.37 0.12 0.16	station on 17 December 1979; change in environment
18. Mali Lošinj	4.3	1970 1972		Probably no break in homogeneity
19. Zadar	7.4 16.1*	1963 1965 1994	0.29 0.15 0.29	Station relocated twice: 1 Jan. 1965 and 27 June 1995
20. Split-Marjan	14.5* 16.4*	1963 1969 1979	-0.22 -0.04 0.14	Change in environment
21. Hvar	6.8	1964		Probably no break in homogeneity
22. Dubrovnik	10.3*	1970	-0.24	Relocation of the weather station on 12 May 1979

Further, in Table 1.7, *a* indicates the year preceding a homogeneity break and *b* is the last year within the linear trend period. In the case of an abrupt break of homogeneity, i.e. when b=a+1, then *b* is omitted.
The differences between the average values of the Y-series for the parts preceding the homogeneity breaks and those following the breaks, as well as the "linear trend" per year, for cases with such a trend, are represented in the fourth column of Table 1.7. Finally, in the last column, possible causes of homogeneity breaks are described: relocation of observation site, change in the site environment, e.g. urbanization in the case of big cities. Other possible causes of inhomogeneity like change of instrumentation or observer, including possible isolated natural local influences, are not considered here.
From Table 1.7, it is obvious that a certain number of homogeneity breaks coincide with the times of weather station relocation: Karlovac (1992), Varaždin (1971), Slavonski Brod (1969), Osijek, Rijeka and Zadar (1994). In some cases, i.e. in: Rovinj, Zadar (1965) and Dubrovnik, a relocation of weather stations took place, but significant homogeneity breaks are not indicated.
A diagnosis of the graphical representation of the T- and q-series additionally explains the results represented in Table 1.7. The simplest representations are for the mentioned five weather stations (of a total of 22) for which no inhomogeneity has been detected. A very illustrative example is Karlovac (Figures 6a and 7a), where both considered types of inhomogeneity have been detected and successfully explained. On the other hand, in some cases (Bjelovar, Đurđevac, Parg, Pazin, Rovinj and some others) the explanation is not very clear even after the homogenisation of the time series. It seems that the air temperature time series for, in data quality, lower-rank weather stations are more confuse when it comes to homogeneity than the air temperature time series for higher-rank stations although the latter are frequently under a stronger influence of urbanization because they are usually connected with big urban centres. For those which are not under the urbanization, no inhomogeneity has been established (examples are Ogulin, Gospić and Zavižan). Ilustration of *T*- and *q*-series for the last group of weather stations is represented in Figure 1.5b and 1.6b, respectively.

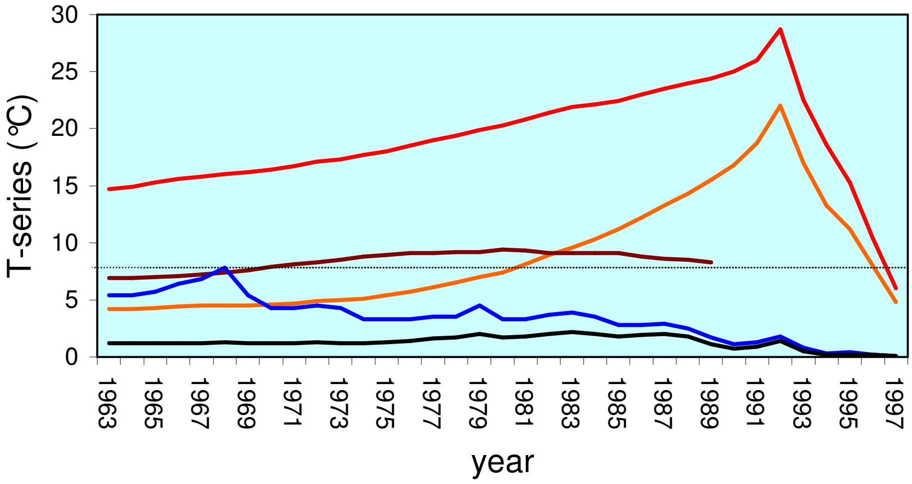


Figure 1.5a Representation of T-series for Karlovac

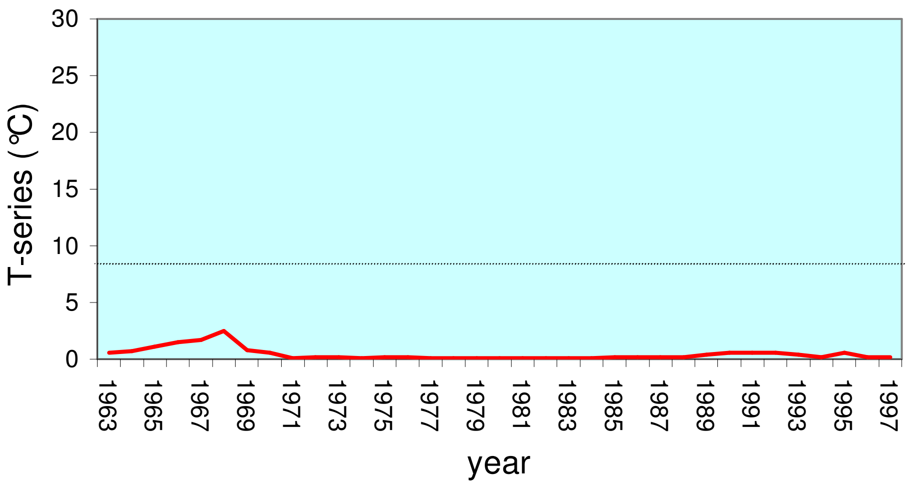


Figure 1.5b Representation of T-series for Ogulin.

On the other hand, at the Zagreb-Maksimir, Karlovac (1968), Bjelovar, Đurđevac, Varaždin (1982), Slavonski Brod (1969 and 1996), Parg, Knin, Rovinj, Split-Marjan and Dubrovnik weather stations, abrupt breaks of homogeneity have been discovered although a relocation of these weather stations has not been registered. Possible reasons could be the building of infrastructure objects like the tennis-court near the Zagreb-Maksimir weather station toward the end of last century. At some weather stations, the appearance of a linear trend could be justified as a consequence of general urbanization (e.g. Zagreb-Maksimir and Karlovac), while in some other cases it could have been caused by the planting or uprooting of trees in their vicinity (e.g. a phenological garden was planted in Križevci). No homogeneity

break has been discovered at three weather stations in the mountainous area (Ogulin, Gospić and Zavižan) and at two coastal stations (Mali Lošinj and Hvar).
Thus, even in rather complex environmental conditions, good quality observation and a solid metabase (i.e. data like relocation dates, exchange of instruments, change of environment etc.) for the time series of annual mean air temperature, solid information can be extracted after the application of homogenisation procedure. The influence of inhomogeneities on the diagnostic parameters of the air temperature time series for Croatia (natural trend indices, correlation functions etc.) will be considered in the next section.

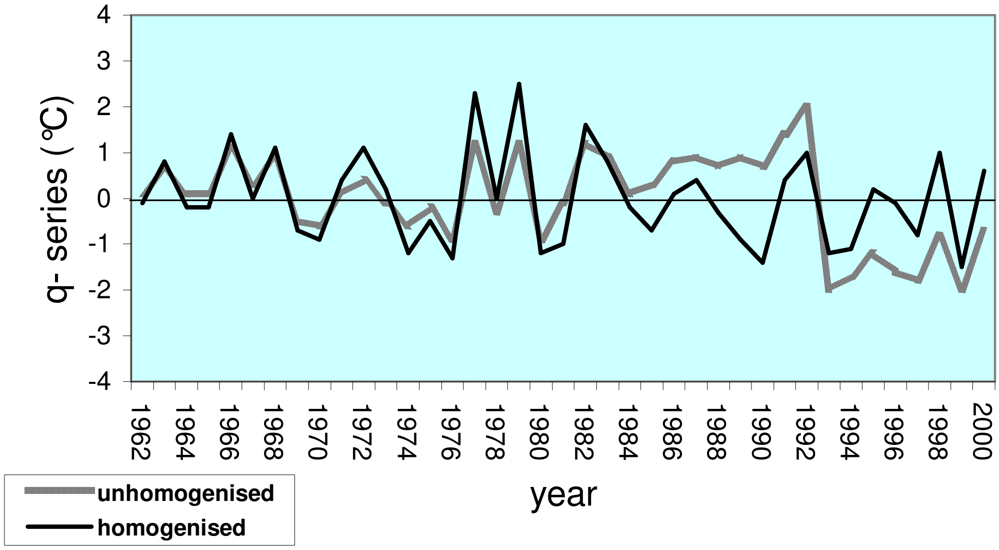


Figure 1.6a Representation of q-series for Karlovac before and after homogenisation.

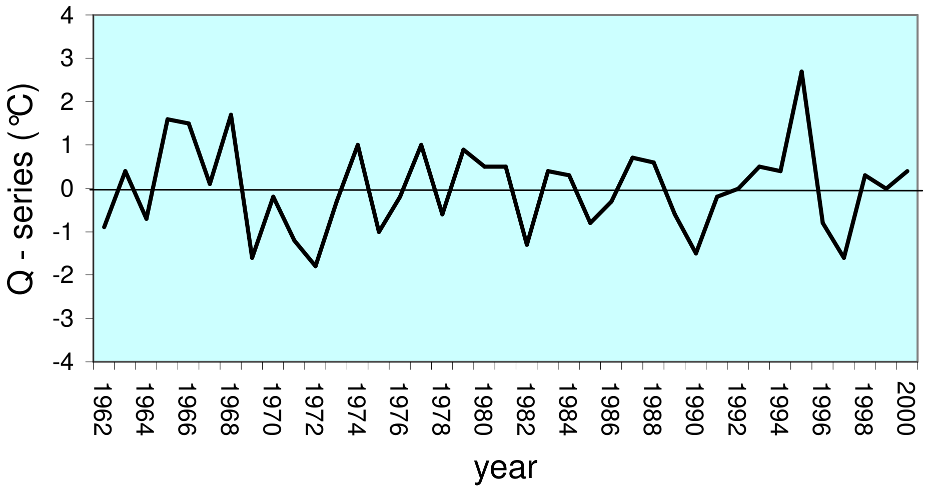


Figure 1.6b Representation of q-series for Ogulin.

1.2.5 Influence of data inhomogeneity on time-spatial diagnostic parameters

In the introduction, word was about the possible influence of data inhomogeneity on statistical parameters like means, variance, extremes, correlation, probability density functions etc. As it is obvious from the average change examples represented in Table 1.7 (the highest being up to 0.5℃), these changes are difficult to notice compared with the real air temperature time series before and after homogenisation because these changes are small when they are compared with the natural variations of mean annual air temperature (in the order of several degrees Celsius). Therefore, a more illustrative representation of these differences is necessary.

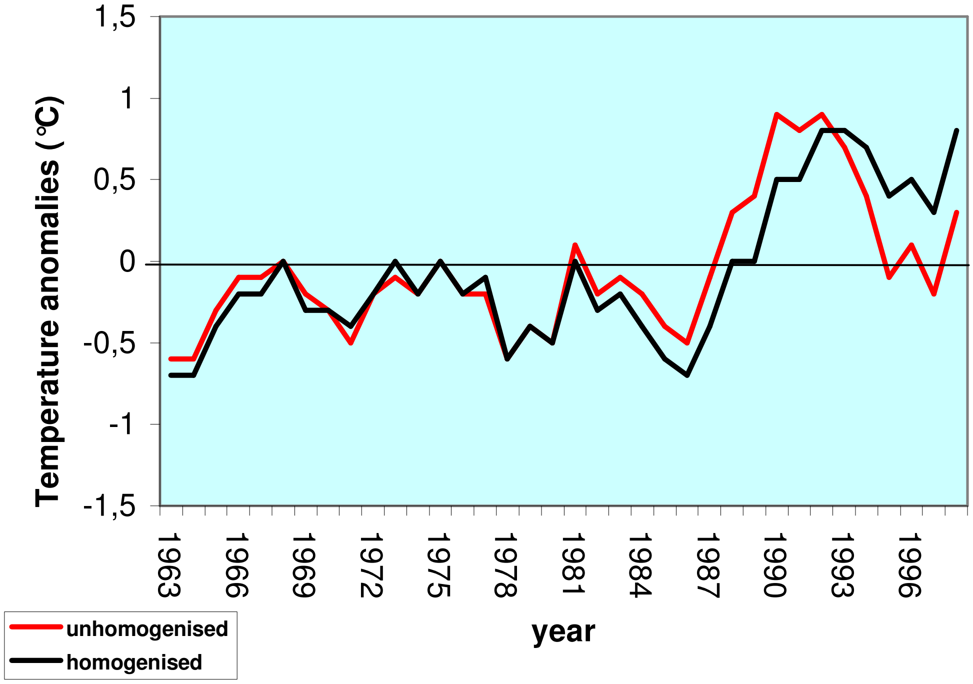


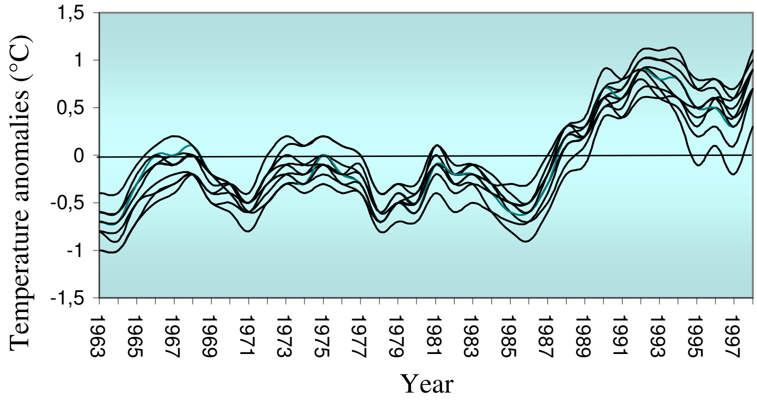
Figure 1.7 Comparison of 5-year moving averages of unhomogenised and homogenised anomalies of the mean annual air temperature defined for the reference period 1961-2000,

for the Karlovac weather station.

One possibility is to consider the 5-year moving average anomalies calculated for homogenised and unhomogenised time series in reference to multiannual averages before and after homogenisation, respectively. Indeed, after the application of this procedure, the difference in values before and after homogenisation is clear, as the example of the Karlovac weather station shows (Figure 1.7). Thus, it is obvious that 5-year moving average anomalies are lower during a trend period while they are higher in average about 0.5℃ after the station has been relocated out of town.
The representation of 5-year moving averages of unhomogenised (Figure 1.8A) and homogenised (Figure 1.8B) anomalies of the mean annual air temperature time series from 10 weather stations in Northern (lowland) Croatia is also illustrative. A wider range of anomalies is obvious for the unhomogenised series compared with the homogenised ones, which means that the correlation

coefficients go mostly up after homogenisation. This is confirmed by Figure 1.9, where the correlation coefficients (between Karlovac and other weather stations) are presented both before and after homogenisation. As it was expected, the correlation coefficients are mostly from 0.1 to 0.2 higher for the homogenised smoothed time series than for the unhomogenised.

A)



B)

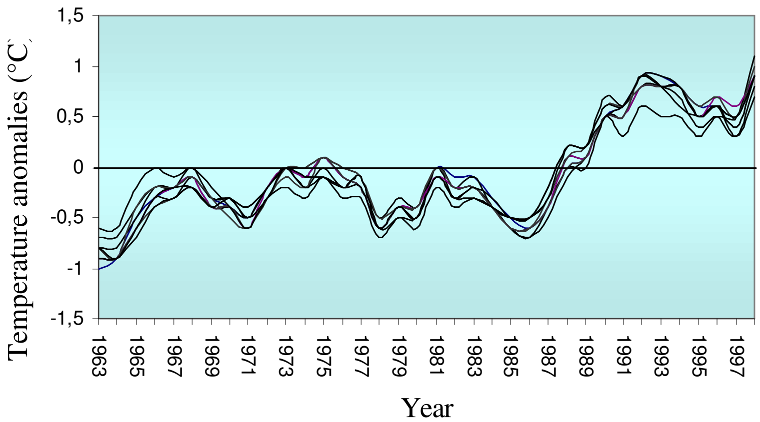


Figure 1.8 Comparison of the 5-year moving averages of unhomogenised (A) and homogenised (B) anomalies of the mean annual air temperature series defined for the reference period 1961-2000, from 10 weather stations in Northern Croatia.

Above discussed could be related to the liner trend changes as well. For calculation of linear trend a simple linear regression equation has been used where discrete time (time step of 1 year) has been taken as independent and average annual temperature as dependent stochastic variable (see e.g. Penzar and Penzar, 2000; Wilks, 2006). Differences between total linear trends for homogenised and unhomogenised 22 average annual air temperature time series have been calculated. The results are represented in Figure 1.10a. The values range from –0.34°C/40years for Zadar to 0.39°C/40years for Osijek. The "true" annual temperature linear trends are represented in Figure 1.10b. There is a gradual rise of linear trend from south to the north of the Croatian territory in considered period what is very probably a consequence of global warming. Without homogenisation a rather false picture would be obtained (see e.g. Vincent and Gullett, 1999).

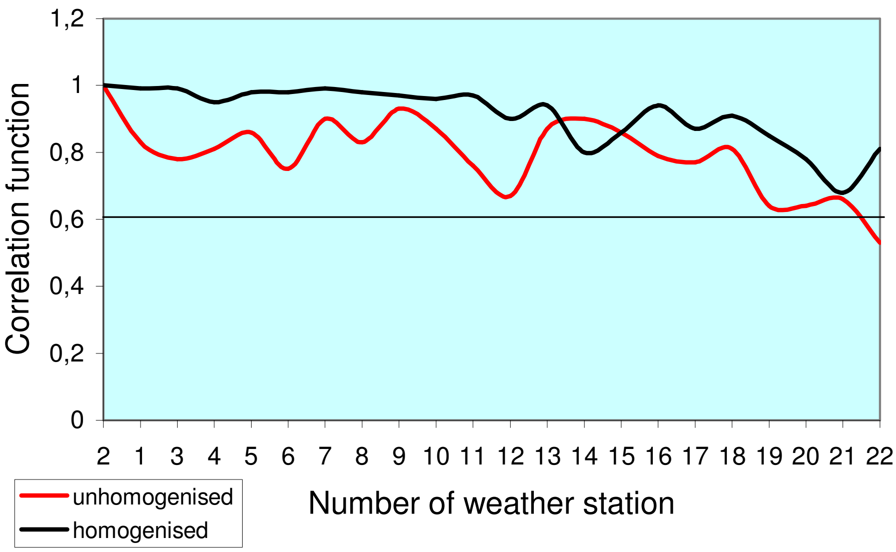


Figure 1.9 Comparison of correlation functions for the 5-year moving averages of unhomogenised and homogenised anomalies of the mean annual air temperature series, defined for the reference period 1961-2000 between the Karlovac weather station, designated as number 2 in Figure 1.4, and other stations, also designated by number in the same figure. Higher numbers roughly correspond to higher distance of other weather stations from Karlovac.

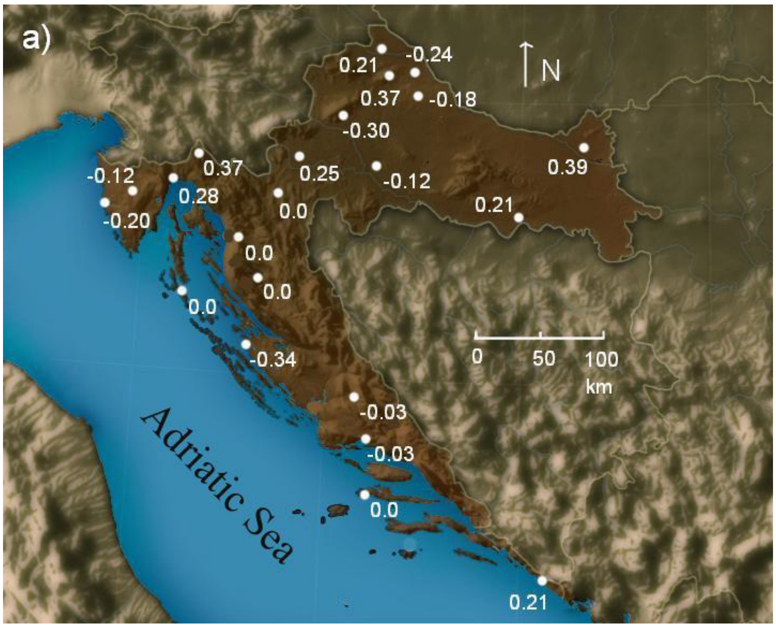


Figure 1.10a Differences between total linear trends for homogenised and unhomogenised 22 average annual air temperature time series for Croatia in degree Celsius per 40 years.

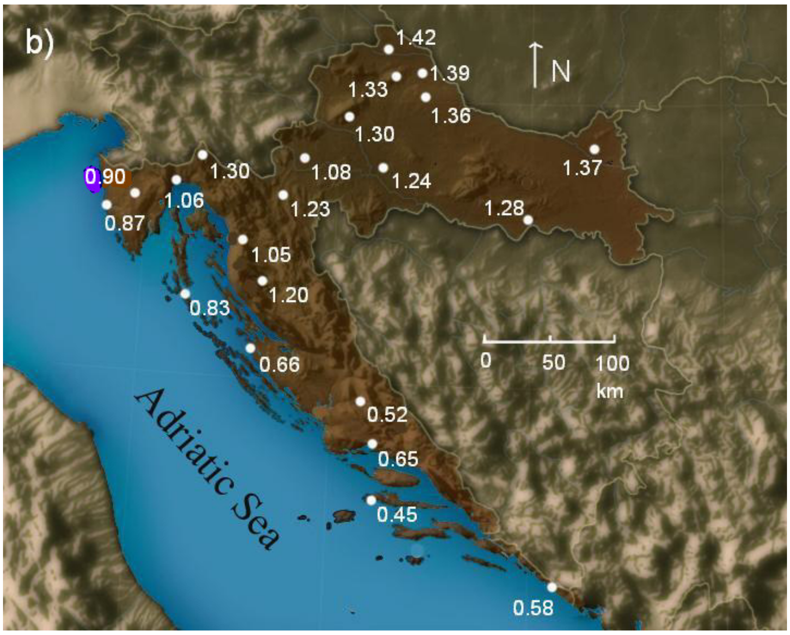


Figure 1.10b Linear trends for homogenised 22 average annual air temperature time series for Croatia in degree Celsius per 40 years.

Finally, the amplitude of the first principal component (PC) for the 5-year mean annual temperature moving averages before and after homogenisation are considered (see also Begert et al., 2005; Pandžić, 1986; Preisendorfer, 1986). As it is obvious form Table 1.8, the first PC describes 84% of the total field variance before homogenisation and 90% after homogenisation. Thus, the statistical structure is more compact (the correlation coefficients are higher) after homogenisation. On the other hand, there is no significant difference between the time variation of the amplitude of the PC before and after homogenisation, which is represented in Figure 1.11. This result is in accordance with that of Begert et al. (2005) as well as with those of Moberg and Alexandersson (1997). They have stated that the spatial average of mean annual air temperature is "immune" to the existing inhomogeneities which appear in the mean annual air temperature time series considered for Sweden and Switzerland.

Table 1.8 Eigen values (%) of the first four principal components (PCs) for the 5-year moving averages of air temperature in Croatia, before (a) and after (b) homogenisation.

	PC1	PC2	PC3	PC4
a	84	7	3	2
b	90	7	1	1

Thus, spatial averaging acts as a kind of filter for the rejection of inhomogeneities appearing in a particular time series. Conclusion like to this was obtained even for global scale (Easterling and Peterson, 1995a,b) what could be very important from the point of view of global mean air temperature

calculation. According to this, a global air temperature mean could be insensitive to at least a category of the possible unhomogeneities of a particular time series produced in operational meteorological practice. On the other hand, this immunity can be used to define the reference series as a weighted average of the weather station time series surrounding the candidate station (it seems that the use of time series for 3 to 5 surrounding weather stations is reasonable in Croatian conditions).
On the other hand, as it has been shown in the example of the 5-year moving average application, temporal smoothing of time series emphasizes their inhomogeneities. Therefore, when calculating correlation coefficients or performing a trend analysis, special attention has to be devoted to the homogeneity of the time series. As it is expected, although in most cases weak in this study, inhomogeneity of air temperature series has an influence to multiannual averages i.e. climate normals. Relatively small changes in multiannual averages are frequently also a consequence of the variability of the change sign within a particular time series (see Table 1.7). Exceptions can be homogeneity breaks which are a consequence of station relocation (e.g. Karlovac) or urbanisation (e.g. Zagreb-Maksimir).
The results described refer to mean annual air temperature time series. However, testing seasonal, monthly, daily or extreme values of air temperature can give, in some cases, results which can be different from those obtained for the annual time scale (see e.g. Zwiers and Storch, 1995; Wijngaard et al., 2003).

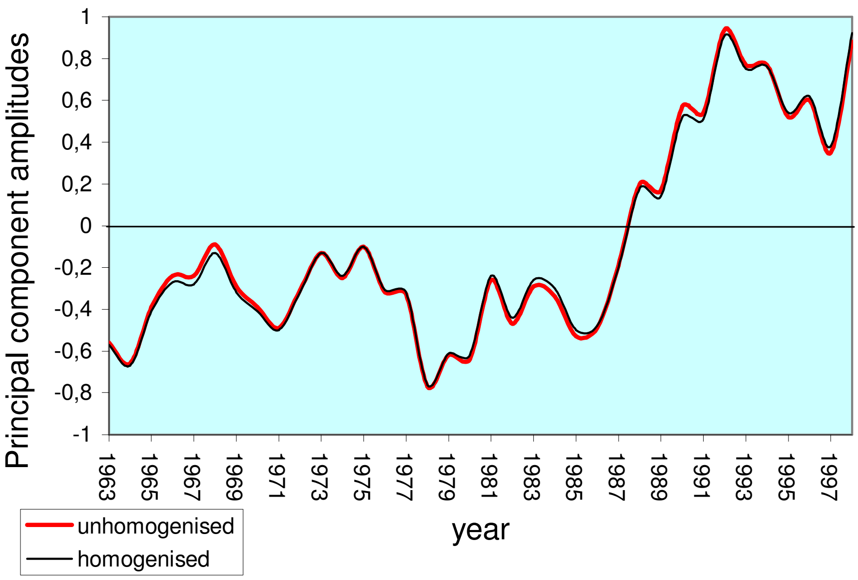


Figure 1.11 Comparison of the first principal component (PC) amplitudes for 5-year mean annual temperature moving average anomalies, defined for the period 1961-2000, before and after homogenisation. The anomalies refer to the 22 weather stations in Croatia which are shown in Figure 4.

1.2.6 Homogenized data series

Method described in Section 1.2.3 is also applied on precipitation amount time series and final availibility of time series is represented in Table 1.9.

Table 1.9 Results of homogenization for Croatia

Type of the element (temperature, precipitation, etc.)	Temporal resolution of data series (annual/ monthly/ daily)	Approximate rate of missing data in original series	Length of data series	Number of stations
Air temperature	annual	1%	50	20
Precipitation amount	annual	1%	50	30

Bibliography

Aguilar E, Auer I, Brunet M, Peterson TC, Wieringa J. 2003. *Guidelines on climate metadata and homogenization*. Report WMO-TD 1186, World meteorological Organization, Geneva, Switzerland. 50 pp.

Alexandersson H. 1986. A homogeneity test applied to precipitation data. *J. Climatol.* 6: 661-675.

Alexandersson H, Moberg A. 1997. Homogenization of Swedish temperature data. Part I: Homogeneity test for linear trends. *Int. J. Climatol.* 17: 25-34.

Begert M, Schlegel T, Kirchhofer W. 2005. Homogeneous temperature and precipitation series of Switzerland from 1864 to 2000. *Int. J. Climatol.* 25: 65-80.

Brunetti M, Maugeri M, Monti F, Nannia T. 2006. Temperature and precipitation variability in Italy in the last two centuries from homogenised instrumental time series. *Int. J. Climatol.* 26: 345-381.

DeGaetano AT. 1996. Recent trends in maximum and minimum temperature threshold exceedences in the NorthEastern United States. *J. Climate* 9: 1646-1660.

DeGaetano AT. 2006. Attributes of several methods for detecting discontinuities in mean temperature series. *J. Climate* 19: 838-853.

Drogue G, Mestre O, Hoffman L, Iffly JF, Pfister L. 2005. Recent warming in a small region with semi-oceanic climate, 1949-1998: what is the ground truth? *Theor. Appl. Climatol.* 81: 1-10.

Ducré-Robitaille JF, Boulet G, Vincent LA. 2003. Comparison of techniques for detection of discontinuities in temperature series. *Int. J. Climatol.* 23: 1087-2003.

Easterling DR, Peterson TC. 1995a. A new method for detecting and adjusting for undocumented discontinuities in climatological time series. *Int. J. Climatol.* 18: 1493-1517.

Easterling DR, Peterson TC. 1995b. The effect of artificial discontinuities on recent trends in minimum and maximum temperatures. *Atmos. Res.* 37:19-26.

Hawkins DM. 1977. Testing a sequence of observations for a shift in location. *J. Am. Statist. Assoc.* 73: 180-185.

Herzog J, Müller-Westermeier G. 1996. Homogenization of various climatological parameters in the German weather service. In *Proceedings of the First Seminar for Homogenization of Surface Climatological data*. Budapest, Hungary, 6-12 October, 1996.

Khaliq MN, Ouarda TBMJ. 2007. A note on the critical values of the Standard Normal Homogeneity Test (SNHT). *Int. J. Climatol.* 27: 681-687.

Li QX, Liu XN, Zhang HZ, Peterson TC, Easterling DR. 2004. Detecting and adjusting temporal inhomogeneity in Chinese mean surface air temperature data. *Adv. Atmos. Sci.* 21: 260-268.

Likso T. 2003: Inhomogeneities in temperature time series in Croatia. *Hrvatski meteorološki časopis* 38: 3-9.

Lindgren BW. 1976. *Statistical theory.* Third Edition., Macmillan, London. 614 pp.

Marković RD. 1975. *Mathematical-statistical methods of testing consistency and homogeneity of meteorological and hydrological elements of human environment.* Federal Hydrometeorological Institute, Belgrade. 48 pp.

Moberg A, Alexandersson H. 1997. Homogeneization of Swedish temperature data. Part II: Homogenized gridded air temperature compared with the subset of global gridded air temperature since 1861. *Int. J. Climatol.* 17: 35-54.

Mood AM, Graybill FA, Boes DC. 1974. *Introduction to the theory of statistics.* McGraw-Hill Kogakusha, Tokyo. 564 pp.

Pandžić K. 1986. Factor analysis of temperature field on a relatively small area. *Idojaras* 90: 321-331.

Pavlić I. 1970. *Statistical theory and application* (in Croatian). Tehnička knjiga, Zagreb. 343 pp.

Penzar I, Penzar B. 2000. *Agrometeorology* (in Croatian). Školska knjiga, Zagreb. 222 pp.

Peterson TC, Eastrling DR. 1994. Creation of homogeneous composite climatological reference series. *Int. J. Climatol.* 14: 671-679.

Peterson TC, Easterling DR, Karl TR, Groisman P, Nicholls N, Plummer N, Torok S, Auer I, Boehm R, Gullett D, Vincent L, Heino R, Tuomenvirta H, Mestre O, Szentimrey T, Salinger J, Forland EJ, Hanssen-Bauer I, Alexandersson H, Jones P, Parker D. 1998. Homogeneity adjustments of in situ atmospheric climate data: a review. *Int. J. Climatol.* 18: 1493-1517.

Preisendorfer RW. 1988. *Principal component analysis in meteorology and oceanography.* Elsevier, Amsterdam. 425 pp.

Reeves J, Chen J, Wang XL, Lund R, Lu Q. 2007: A review and comparison of changepoint detection techniques for climate data. *J. App. Meteor. Climatol.* 46, 900-915.

Steffensen P. 1996. *Standard Normal Homogeneity Test for Windows.* DMI Technical Report No. 9613, Copenhagenn. 35 pp.

Tuomenvirta H, Alexandersson H. 1996. Review on the methodology of the standard normal homogeneity test. In *Proceedings of the First Seminar for Homogenization of Surface Climatological data*. Budapest, Hungary, 6-12 October, 1996.

Vincent LA. 1998. A technique for the identification of inhomogeneities in Canadian temperature series. *J. Climate* 11: 1094-1104.

Vincent LA, Gullett DW. 1999. Canadian historical and homogeneous temperature datasets for climate change analyses. *Int. J. Climatol.* 19: 1375-1388.

Wilks DS. 2006. *Statistical methods in the atmospheric sciences.* Elsevier, Amsterdam. 627 pp.

Wijngaard JB, Klein Tank AMG, Konnen GP. 2003. Homogeneity of 20-th century European daily temperature and precipitation series. *Int. J. Climatol.* 23: 679-692.

Zwiers FW, von Storch H. 1995. Taking serial correlation into account in tests of the mean. *J. Climate* 8: 336-351.

2. Report on preparation climate maps

DHMZ

PROJECT INFORMATION	
Project acronym:	DMCSEE
Project title:	Drought Management Centre for South East Europe
Contract number:	2008-0017-201002
Starting date:	17. 05. 2010
Ending date:	17. 05. 2012
Project WEB site address:	http://meteo.hr/DMCSEE/
Partner organisation:	Meteorological and Hydrological Service of Croatia
Name of representative:	M. Sc. Ivan Čačić, director
Project manager:	dr. Krešo Pandžić
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Telephone number:	+386 (0)1 45 65 684
DELIVERABLE INFORMATION	
Title of the deliverable:	**Report on preparation of climate maps**
WP/activity related to the deliverable:	Act. 3.1 Preparation of climate data and maps
Type (internal or restricted or public):	Public
Location (if relevant):	Zagreb, Croatia
Author:	Mr Zvonimir Katušin, external expert
Deadline	17.04.2012. Draft report

2.1 Beginning remarks

Kriging is a commonly used method of interpolation (prediction) for spatial data. The data are a set of observations of some variable(s) of interest, with some spatial correlation present (sea also Percec Tadic, 2010).
Usually, the result of kriging is the expected value (\kriging mean") and variance (\kriging variance") computed for every point within a region. Practically, this is done on a fine enough grid.
Illustration: suppose we observe some variable Z along 1-dim space (X). There are 5 measurements made. We might ask ourselves, knowing the probabilistic behavior of the random field being observed, what are possible trajectories (realizations) of the random field, that agree with the data? This is answered by conditional simulation. In Fig. 2.1, you see two sets of 5 conditional simulations for the same data. The one on the left is for one value of σ^2 = variance

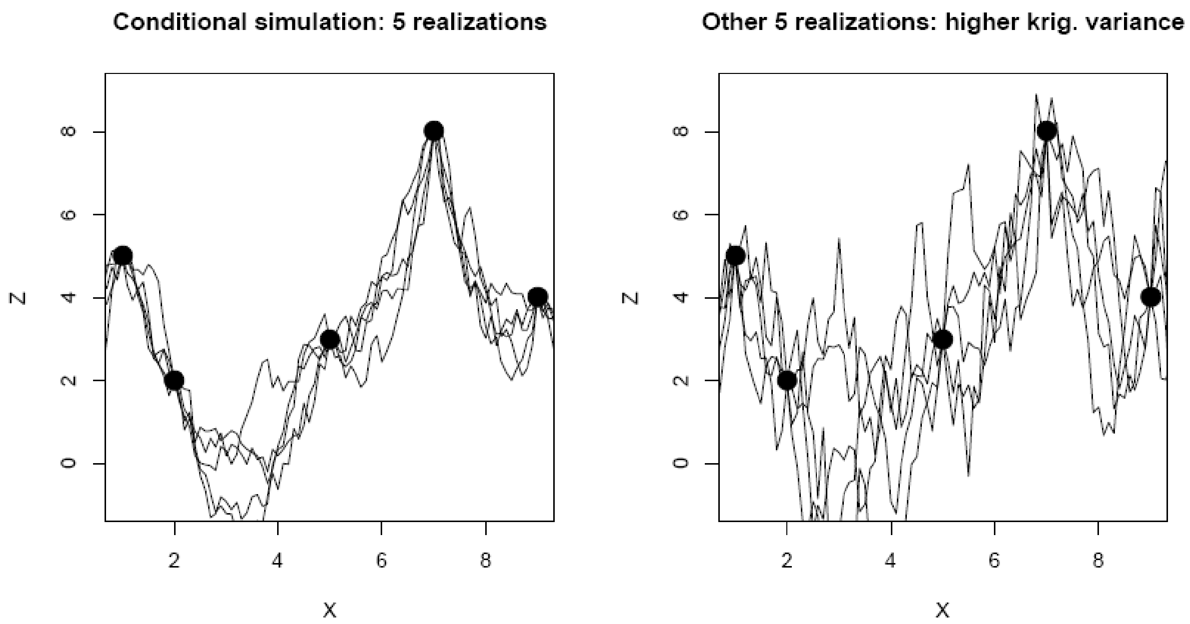

Figure 2.1 Conditional simulations, data given by dots

of the random field, the one on the right is for another, higher, value. All the realizations are faithful to the data, but also faithful to the statistical model for the random field (i.e. mean and variogram) that we selected.

Kriging mean for every location can be thought of as the average of the whole ensemble of possible realizations, conditioned on data. Kriging variance is the variance of that ensemble. (The ensemble is of course infinite, we only show 5 of its representatives.)

You may see that the trajectories tend to diverge away from the observed data, that is, the kriging variance increases. Also, for the random field with higher variance (the one on the right in Fig. 2.1)

We will observe similar qualitative behavior frequently in the future.

2.2 Simple kriging

Let us observe some stationary (WSS) random field $V(\mathbf{x})$ at some points $\mathbf{x}_j$, $j = 1, ..., n$. First, assume that the mean m and covariance function $C(\cdot)$ of this process are known. The case of prediction with the known mean is often called *simple kriging*.

In order to better understand what happens and to devise an extendable approach, let's attack the question by directly trying to minimize MSE.

We will seek an estimate $\hat{V}_0$ of the value of V at the point $\mathbf{x}_0$. For simplicity, denote $V_j := V(\mathbf{x}_j)$. Also, denote $C(i,j) = Cov(V_i, V_j)$.

We may assume that the mean $m = 0$. Otherwise, subtract m from all of the V_j values, estimate V_0, then add the mean back.

Search for the estimate of the form

$$\hat{V}_0 = \sum_{j=1}^{n} \lambda_j V_j,$$

under the assumption of 0 mean, it is automatically unbiased. (Why?)

We will find the *kriging weights* λ_j that minimize MSE:

$$\text{MSE} = \mathbb{E}\left[\left(V_0 - \sum \lambda_j V_j\right)^2\right] = Var\left(V_0 - \sum \lambda_j V_j\right) = \qquad \text{(Why?)}$$

$$= Var(V_0) - 2\sum \lambda_j Cov(V_0, V_j) + \sum\sum \lambda_j \lambda_i Cov(V_i, V_j)$$

That is,

$$\texttt{MSE} = C(0,0) - 2\sum \lambda_j C(0,j) + \sum\sum \lambda_j \lambda_i C(i,j)$$

(2.1).

where $C(i,j) = C_V(\mathbf{x}_i - \mathbf{x}_j)$ might be interpreted as the elements of covariance matrix $\mathbf{C}$. Note that the values $C(0,j)$ depend on the location $\mathbf{x}_0$.

To minimize MSE, we take the derivatives with respect to λ_k and equate to 0:

$$\frac{\partial\, \texttt{MSE}}{\partial \lambda_k} = -2C(0,k) + 2\lambda_k C(k,k) + 2\sum_{j \neq k} \lambda_j C(k,j) = 0, \qquad k = 1, ..., n$$

That is, solve the system of equations[1]

$$\sum_{j=1}^{n} \lambda_j C(k,j) = C(0,k), \qquad k = 1, ..., n$$

(2.2).

In matrix form, the above equations look like

$$\mathbf{C}\boldsymbol{\lambda} = \mathbf{b} \qquad \text{same as} \qquad \boldsymbol{\lambda} = \mathbf{C}^{-1}\mathbf{b}$$

(2.3).

If we denote the covariance matrix of the vector $(V_0, V_1, ..., V_n)'$ as $\boldsymbol{\Sigma}$, then

$$\boldsymbol{\Sigma} = \begin{bmatrix} \sigma_0^2 & \mathbf{b}' \\ \mathbf{b} & \mathbf{C} \end{bmatrix} \qquad \text{and} \qquad \texttt{MSE}=\ \sigma^2_{\texttt{SK}} = C(0,0) - 2\boldsymbol{\lambda}'\mathbf{b} + \boldsymbol{\lambda}'\mathbf{C}\boldsymbol{\lambda} = C(0,0) - \boldsymbol{\lambda}'\mathbf{b}$$

Now compare the equation (3) with the formula for conditional mean in Lecture 6, p. 4. It turns out that the above minimization argument is directly related to the BLUE theory for multivariate Normal!

To avoid ambiguity, we will sometimes denote the optimal kriging weights $\lambda^{\texttt{SK}}$. From the equations (1) and (2), the optimal kriging variance is

$$\sigma^2_{\texttt{SK}} = C(0,0) - \sum \lambda_j^{\texttt{SK}} C(0,j) \qquad (4)$$

Compare this to the conditional variance formula from Lecture 6.

What happens when you "predict" at one of the existing points $\mathbf{x}_j$? It is clear that the best choice is to just take V_j, in which case the kriging variance is 0! If we use the covariance function such that $C(\mathbf{h}) \to C(0)\sigma^2$ as $|\mathbf{h}| \to 0$, that is, dealing with a continuous random field (no nugget!), then we should obtain

$$\lim_{\mathbf{x}_0 \to \mathbf{x}_j} \hat{V}(\mathbf{x}_0) = V_j \qquad \text{and} \qquad \sigma^2_{\mathsf{SK}} \to 0$$

A simple case:

Suppose that $C(i,j) = 0,\ i \neq j$, only $C(0,j) \neq 0,\ j = 1, ..., n$. In this case, the kriging equations (2) are solved by

$$\lambda_j = \frac{C(0,j)}{C(j,j)} = \rho_{0,j}\frac{\sigma_0}{\sigma_j},$$

where $\rho_{0,j}$ is the correlation coefficient. We obtain the prediction

$$\frac{\hat{V}_0}{\sigma_0} = \sum \rho_{0,j}\frac{V_j}{\sigma_j}$$

That is, the weights reflect the strength of correlation. This reminds us of simple linear regression.

Also,

$$\sigma^2_{\mathsf{SK}} = \sigma^2_0(1 - \sum \rho^2_{0,j})$$

where we recognize the quantity $\sum \rho^2_{0,j}$ as coefficient of determination R^2! (Question: why $\sum \rho^2_{0,j} \leq 1$?)

2.3 Mapping air temperature and precipitation amount fields

Using kriging theory described in Section 2.2 digital maps for annual mean air temperature for the period 1961-2000 have been constructed with a resolution of the rasters of 100X100m. A digital terrain of the same nresolution has been used (Figure 1.1 and 2.1).

As expected, reference mean air temperature average range from 3℃ in the mountainous region to 16℃ southern Adriatic coastal region. Meanwhile, annual precipitation amounts range from 500 mm in Eastern Slavonia and open sea up to more than 3000 mm in the hinterland of the northern Adriatic. GIS graphical software is used for representation of the results.

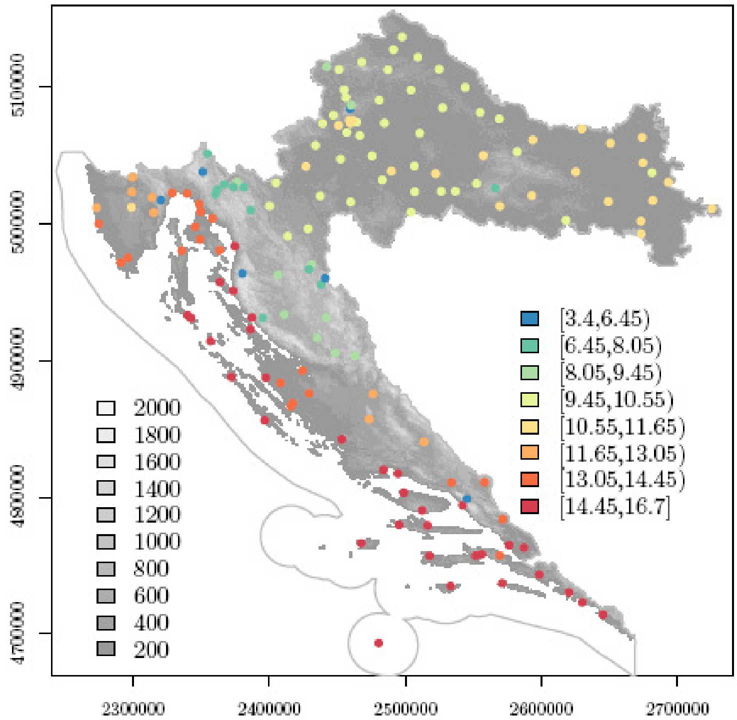

Figure 2.2 Average annual air temperature (℃) for the period 1961-2000 for Croatia, indicated by coloured circles with the terrain heights in background.

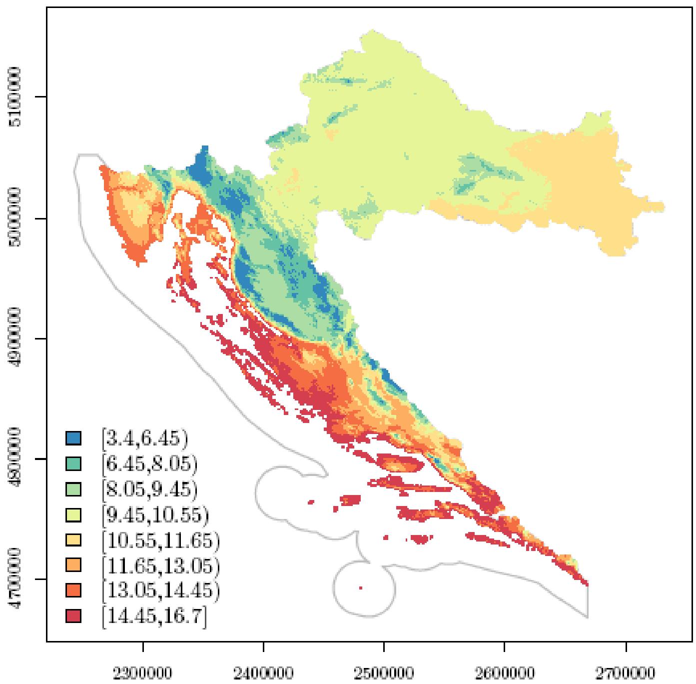

Figure 2.3 Distribution of mean annual air temperature for

The period 1961 - 2000

The mean annual amount of precipitation in Croatia ranges from 300 mm to slightly over 3500 mm. The smallest annual amounts fall on the outer islands of the southern Adriatic (Palagruža, 311 mm). About 800 mm to 900 mm of precipitation can be expected on the islands and the coast of central and northern Dalmatia as well as on the west coast of the Istrian Peninsula. The amount of precipitation increases towards the coast, especially near the mountainsides due to the forced elevation of air masses.

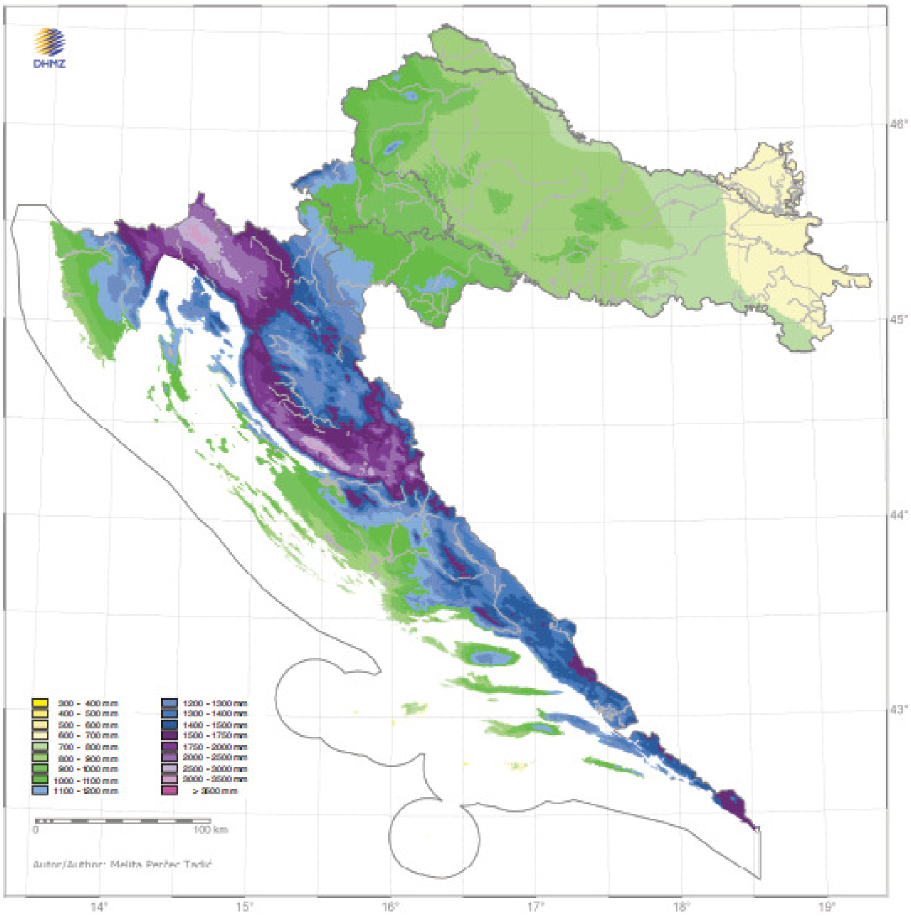

Figure 2.4 Distribution of mean annual precipitation amounts for the period 1961-2000

Biblography

Percec-Tadic, M., 2010: Gredid Croatian climatolog for the period 1961-1990. Theor. Appl. Climatol., 102, 87-103.

3. Report on standard precipitation index (SPI) and Palmer's drought severity index (PDSI)

PROJECT INFORMATION	
Project acronym:	DMCSEE
Project title:	Drought Management Centre for South East Europe
Contract number:	2008-0017-201002
Starting date:	17. 05. 2010
Ending date:	17. 05. 2012
Project WEB site address:	http://meteo.hr/DMCSEE/
Partner organisation:	Meteorological and Hydrological Service of Croatia
Name of representative:	M. Sc. Ivan Čačić, director
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DELIVERABLE INFORMATION	
Title of the deliverable:	**Report on standard precipitation index (SPI) and Palmer's drought severity index (PDSI)**
WP/activity related to the deliverable:	Act. 3.2 Implementation of drought monitoring system
Type (internal or restricted or public):	Public
Location (if relevant):	Zagreb, Croatia
Author:	Mrs Branka Penzar, external expert
Deadline	17.04.2012. Draft report

3.1 Introduction

Drought is a complex natural process influencing many different areas of human activities (agriculture , tourism, industry). Defining the start or the end of the drought is not possible before definition of the drought.

Meteorological drought is a prolonged period of precipitation deficit in relation to the climate normal of the specific location at the Earth surface. Many indexes were developed in order to capture the magnitude and duration of the meteorological droughts. Since 1990s the work of Mckee (1993; 1995) demonstrated the usefulness of analyzing meteorological drought using Standardized precipitation index. Researchers around the word accepted SPI as a measure of the precipitation anomalies. The same is valid for the Croatia.

In this study the analysis of precipitation anomalies during year 2003 has been done using SPI on four different time scales (one, three, six and twelve months).

3.2 Description of data

Meteorological network

The meteorological station network maintained by the Meteorological and Hydrological Service of Croatia(DHMZ) is part of the World Meteorological Organisation Global Observing System. According to their organisation, meteorological stations are divided into: main meteorological stations, with 2 to 5 professional observers, ordinary (climatological) meteorological stations, with amateur observers and observations at 7 am, 2 pm and 9 pm local time and with 24-hour observations of meteorological phenomena, precipitation stations, with amateur observers, measuring precipitation at 7 am and observing meteorological phenomena over 24 hours, storage rain-gauge stations, collecting annual amounts of precipitation, automatic stations, with automatic registration of meteorological elements and direct connection to the information system. The current meteorological station network consists of 41 main meteorological stations (M), 113 climatological stations (C), 333 precipitation stations (P), 23 storage rain-gauge stations, and 63 automatic stations (AMS).
DHMZ is also operating 47 automatic hydrological stations plus 52 stations invested by the Croatian Waters. DHMZ takes care of the two radio-sounding systems in Zagreb and Zadar, 2 Doppler S band + 6 small S band weather radars and one sodar. Average distance between main meteorological stations is about 50 km, between climatological stations abot 20 km and precipitation stations about 10 km. The network covers the area of Croatia of 56 540 square km (Table 3.1)..

Table 3.1 Categories of weather stations which suit to the distribution of the altitude in Croatia:

Altitude categories*	Area in percents (%) of Croatian area	Number of all active meteorological stations (%)	Representativity of the category (very good, good, acceptable, poor)
0-200 m	53	78 (M), 69 (C), 60 (P)	very good
201-400 m	20	10 (M), 13 (C), 19 (P)	good
401-600 m	10	3 (M), 5 (C), 9 (P)	acceptable
601-800 m	7	0 (M), 5 (C), 6 (P)	poor
801-1000 m	6	0 (M), 1 (C), 1 (P)	poor
1001-1300 m	3	3 (M), 2 (C), 1 (P)	good
1301-1600 m	0.8	1 (M), 1 (C), 1 (P)	good
Higher of 1600 m	0.2	0 (M), 1 (C), 0 (P)	poor

According to observation programmes, meteorological stations are divided into: synoptic stations, upper-air stations (radio-sonde and pilot-balloon) stations, climatological stations, aeronautical stations, agrometeorological stations, air quality measurement stations and special meteorological stations, which are further divided into: radar stations, solar radiation measurement stations, ozone quantity monitoring stations, air radioactivity measurement stations and stations for measuring atmospheric electricity and electric discharge.

Data records

Near–real–time data

Data obtained in near real time are available at 41 main meteorological stations. However, for SPI calculations it is necessary to have long time series. There are only 23 stations with precipitation data from the period 1961-2000. Furthermore, for the purpose of Climate atlas of Croatia (2008) data from additional 6 main stations are completed and missing data are interpolated. That means that for the future studies there are available 29 main stations in Croatia with long term series and with real time data for monitoring drought conditions using SPI.

Classical data

Data from climatological and precipitation stations arrives to the data base with around one month delay. There are 104 climatological and precipitation stations with data records for period 1961-2000. (Table 2 in **separate Excel file**)

3.3 Calculation of Standardized precipitation index

Calculation of the SPI has been done by using two parameter gamma distribution. Maximum likelihood method was used to calculate alpha and beta parameter of the gamma distribution. SPI has been calculated on four different time scales (one, three, six and twelve months). The detailed description of the method can be found in the work of Mckee (1993; 1995). Application used was written in the programming language Fortran90 using G95 compiler.

Table 1 gives the list of meteorological stations for which monthly precipitation data are employed for operational calculation of SPI in DHMZ. For all these stations daily records data are also available. Although the measurement records were accurately checked through standard data-quality control procedures (completeness, logic, spatial and graphic controls) provided by the DHMZ, the SPI calculation should be preceded by testing the data for homogeneity. Therefore, the standard normal homogeneity test (SNHT; Alexandersson 1986) was applied to yearly precipitation data (Cindrić et al, 2010).

Precipitation data from the period January 1971 – December 2000 are used as a calibration period.

Table 1. Geograhical data for 23 main meteorological stations which data are employed for. ϕ: latitude (°), λ: longitude (°), h: height above sea level (m)

Station name	ϕ	λ	h	***Missing data***
Bjelovar	45.93	16.81	141	
Daruvar	45.60	17.23	161	
Dubrovnik	42.67	18.12	52	Apr 1978
Gospić	44.55	15.38	564	
Hvar	43.16	16.45	20	
Karlovac	45.50	15.56	110	
Knin	44.03	16.20	255	Aug 1995
Križevci	46.03	16.55	155	
Mali Lošinj	44.53	14.48	53	
Ogulin	45.26	15.23	328	
Osijek	45.53	18.73	89	17th Oct–Dec 1991; Jan to 15th Feb 1992
Parg	45.60	14.63	863	
Pazin	45.23	13.93	291	
Rijeka	45.33	14.45	120	
Senj	45.00	14.90	26	
Sisak	45.50	16.36	98	Jan 1989; Apr to May 1992; Jan 1993
Slavonski Brod	45.16	18.00	88	

Split Marjan	43.51	16.43	122	
Šibenik	43.73	15.91	77	
Varaždin	46.30	16.38	167	
Zadar	44.13	15.21	5	
Zagreb Maksimir	45.98	16.03	123	
Zavižan	44.81	14.98	1594	

3.4 Calculation of Palmer drought severity index

The Palmer Index was developed by Wayne Palmer in the 1960s and uses temperature and rainfall information in a formula to determine dryness. It has become the semi-official drought index (see Penzar, 1976).

The Palmer Index is most effective in determining long term drought—a matter of several months—and is not as good with short-term forecasts (a matter of weeks). It uses a 0 as normal, and drought is shown in terms of minus numbers; for example, minus 2 is moderate drought, minus 3 is severe drought, and minus 4 is extreme drought. At present, northern Virginia is at a minus 4.0 point; north central Maryland is at a minus 4.2 level, and southern Maryland is at least a minus 4 level.

The Palmer Index can also reflect excess rain using a corresponding level reflected by plus figures; i.e., 0 is normal, plus 2 is moderate rainfall, etc. At present, north central Iowa is at a plus 5.2 level, and parts of South Dakota are even higher.

The advantage of the Palmer Index is that it is standardized to local climate, so it can be applied to any part of the country to demonstrate relative drought or rainfall conditions. The negative is that it is not as good for short term forecasts, and is not particularly useful in calculating supplies of water locked up in snow, so it works best east of the Continental Divide.

The Crop Moisture Index (CMI) is also a formula that was also developed by Wayne Palmer subsequent to his development of the Palmer Drought Index.

The CMI responds more rapidly than the Palmer Index and can change considerably from week to week, so it is more effective in calculating short-term abnormal dryness or wetness affecting agriculture.

CMI is designed to indicate normal conditions at the beginning and end of the growing season; it uses the same levels as the Palmer Drought Index.

It differs from the Palmer Index in that the formula places less weight on the data from previous weeks and more weight on the recent week.

A FORTRAN programe is available for calculation of PDSI is developed.

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DMCSEE
Drought Management Centre for Southeastern Europe

Programme co-funded by the EUROPEAN UNION

Bibliography

Alexandersson H (1986) A homogeneity test applied to precipitation data. J Clim 6:661–675

Cindrić K., Pasarić Z., Gajić-Čapka M., 2009: Spatial and temporal analysis of dry spells in Croatia. Theor. Appl. Climatol., 102 (2010) , 1-2; 171-184

McKee, T.B.; N.J. Doesken; and J. Kleist. 1995. Drought monitoring with multiple time scales. Preprints, 9th Conference on Applied Climatology, pp. 233–236. January 15–20, Dallas, Texas.

McKee, T.B.; N.J. Doesken; and J. Kleist. 1993. The relationship of drought frequency and duration to time scales. Preprints, 8th Conference on Applied Climatology, pp. 179–184. January 17–22, Anaheim, California.

Penzar, B., 1976: Drought severity indices for Zagreb and their statistical forecast (in Croatian). Rasprave i prikazi br. 13, 1-58.

Zaninović, K., Gajić-Čapka, M., Perčec Tadić, M. et al, 2008: Klimatski atlas Hrvatske / Climate atlas of Croatia 1961-1990., 1971-2000. Državni hidrometeorološki zavod, Zagreb, 200 str.

Programme co-funded by the EUROPEAN UNION

4. Report on standard precipitation index and irrigation

DHMZ

PROJECT INFORMATION	
Project acronym:	DMCSEE
Project title:	Drought Management Centre for South East Europe
Contract number:	2008-0017-201002
Starting date:	17. 05. 2010
Ending date:	17. 05. 2012
Project WEB site address:	http://meteo.hr/DMCSEE/
Partner organisation:	Meteorological and Hydrological Service of Croatia
Name of representative:	M. Sc. Ivan Čačić, director
Project manager:	dr. Krešo Pandžić
E-mail:	pandzic@cirus.dhz.hr
Telephone number:	+386 (0)1 45 65 684
DELIVERABLE INFORMATION	
Title of the deliverable:	**Standard precipitation index and irrigation**
WP/activity related to the deliverable:	Act. 3.2 Implementation of drought monitoring system
Type (internal or restricted or public):	Public
Location (if relevant):	Zagreb, Croatia
Author:	Mr Andrija Bratanić, external expert
Deadline	17.04.2012. Draft report

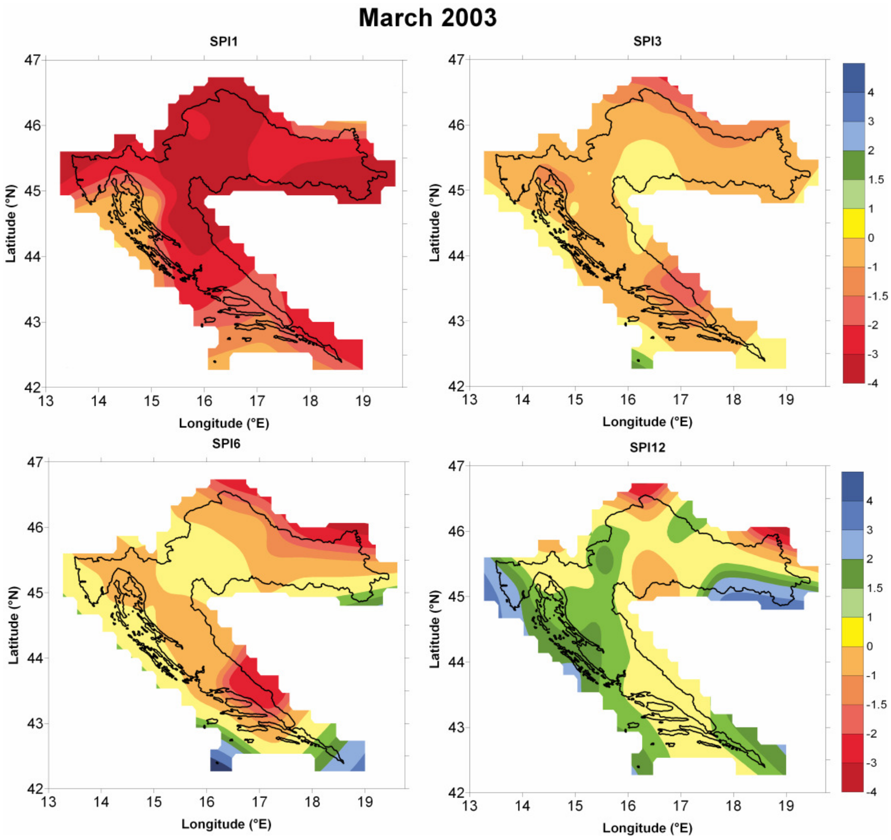
4.1 Case Study for drought period March-August 2003

Monthly precipitation data from the period March 2002 – August 2003 were used to calculate precipitation anomalies for the time interval February – August 2003. SPI value for the July 2003 at the station Dubrovnik could not be calculated because monthly precipitation amount in July 2003 was 0 mm. In the base period 1971-2000 there was no case with the precipitation amount of 0 mm at that station.

Spatial distribution maps of the SPI values at the four time scales (one, three, six and twelve months) has been made using application surface mapping application called “Surfer” (version 8.0) created by company “Golden software”. Interpolation method used was “Modified shepard’s method”. Grid spacing in x and y direction was 0.068° and 0.067°. Time series of the relative frequency for different categories are done by using application called “Grapher” (version 3.03) created by company “Golden software”.

The drought period in 2003 started with an extremely dry March, and the monthly sums were much less than the normal. The spatial distribution of the SPI values is presented on figures from 4.1(a) to 4.6(a). Relative frequency of the SPI values at different time scales are also summarised in graphs from 4.1(b) to 4.6(b).

a)



b)

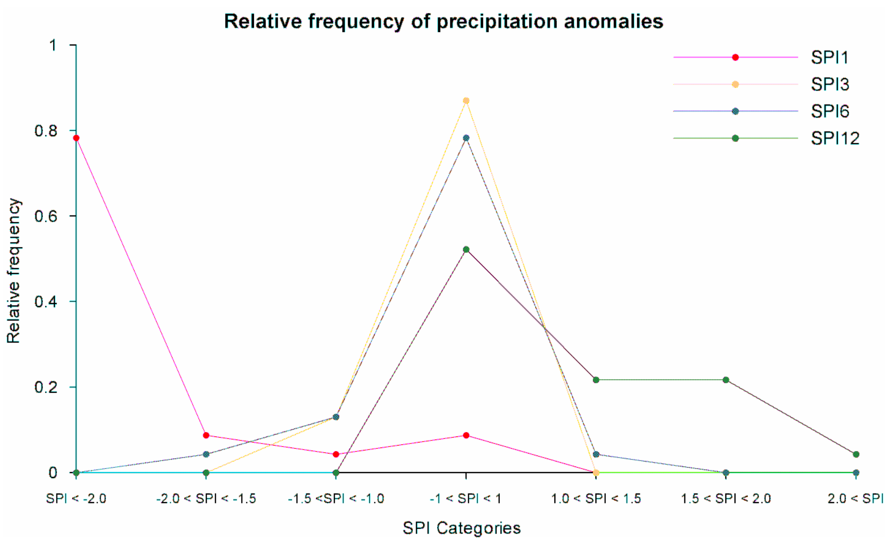
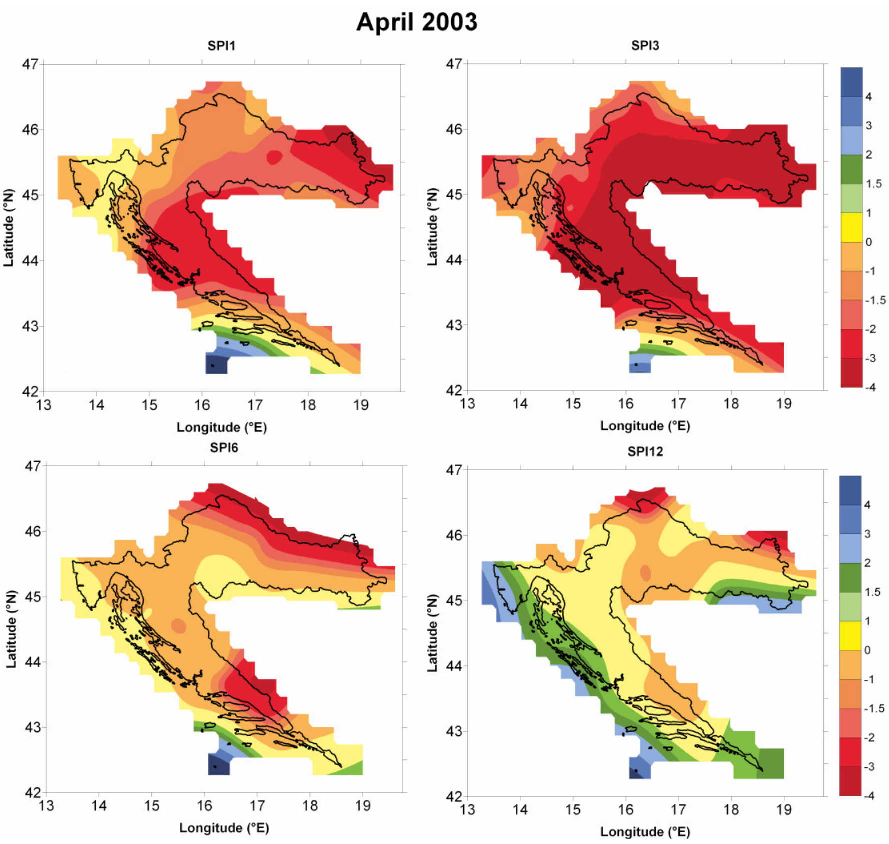


Figure 4.1. a) Spatial distribution map of the SPI and b) Relative frequency of the SPI values at the time scales of 1, 3, 6 and 12 months in March 2003

a)



b)

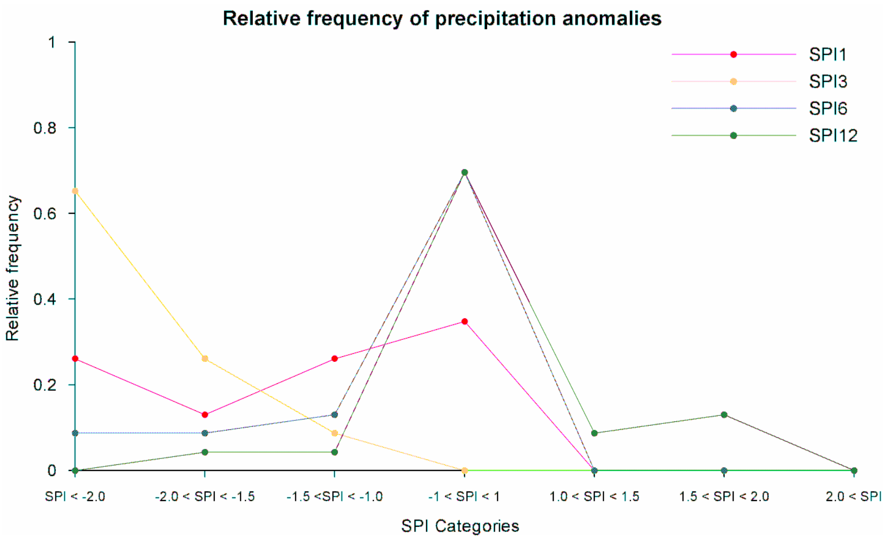
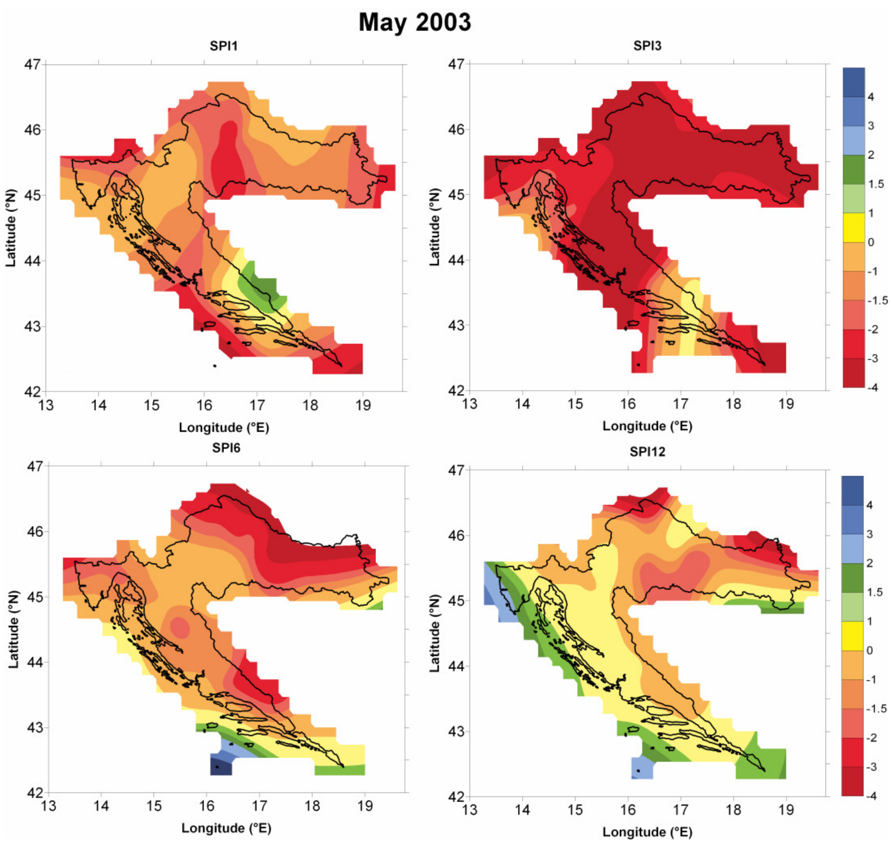


Figure 4.2. a) Spatial distribution map of the SPI and b) Relative frequency of the SPI values at the time scales of 1, 3, 6 and 12 months in April 2003

a)



b)

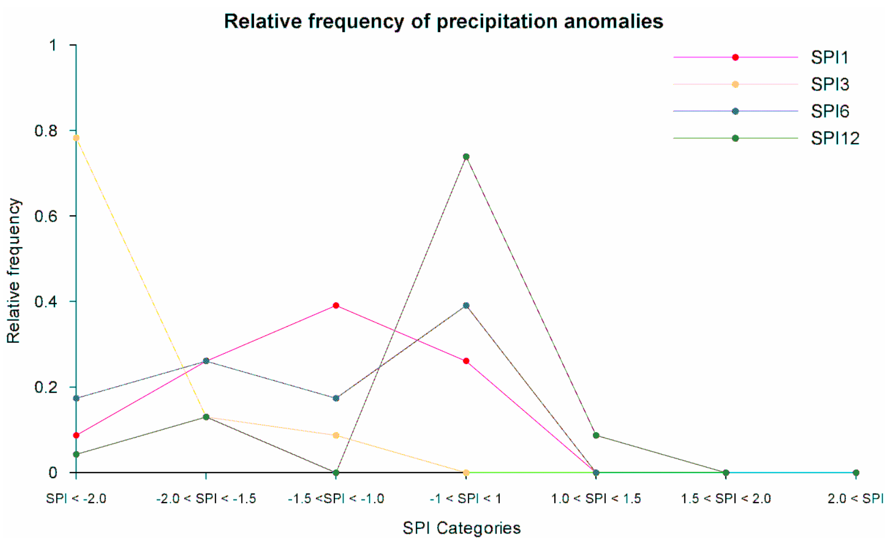
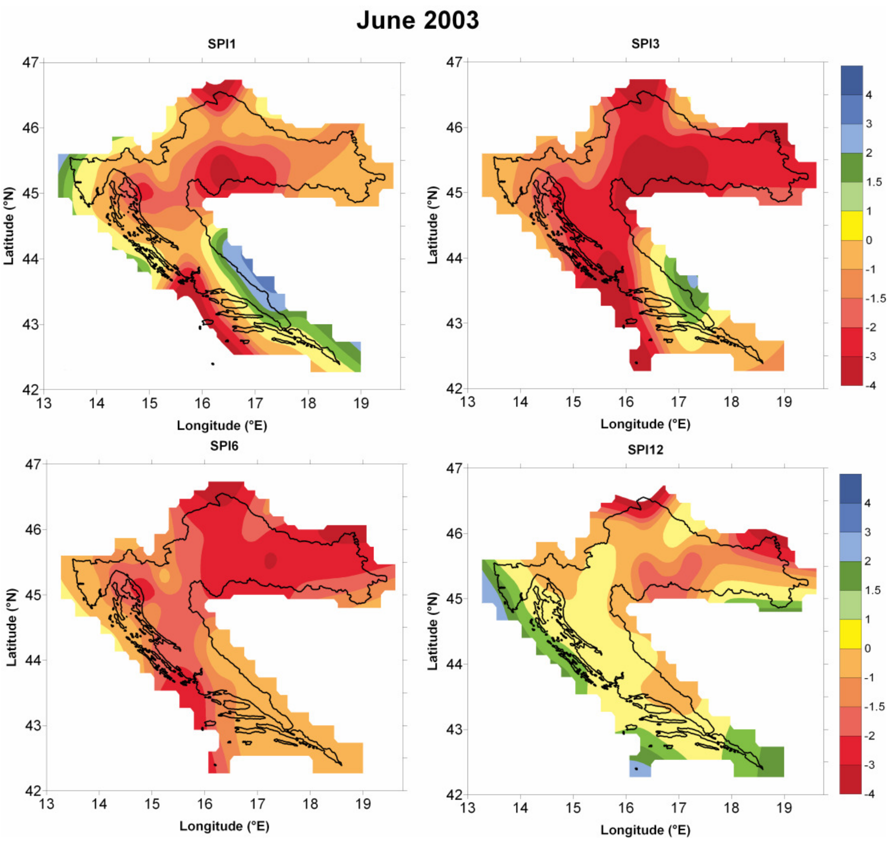


Figure 4.3. a) Spatial distribution map of the SPI and b) Relative frequency of the SPI values at the time scales of 1, 3, 6 and 12 months in May 2003

a)



b)

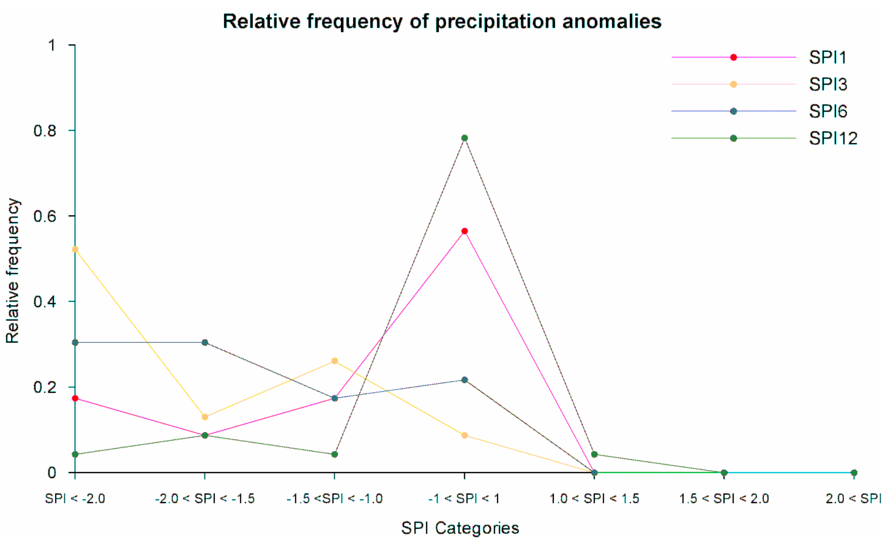
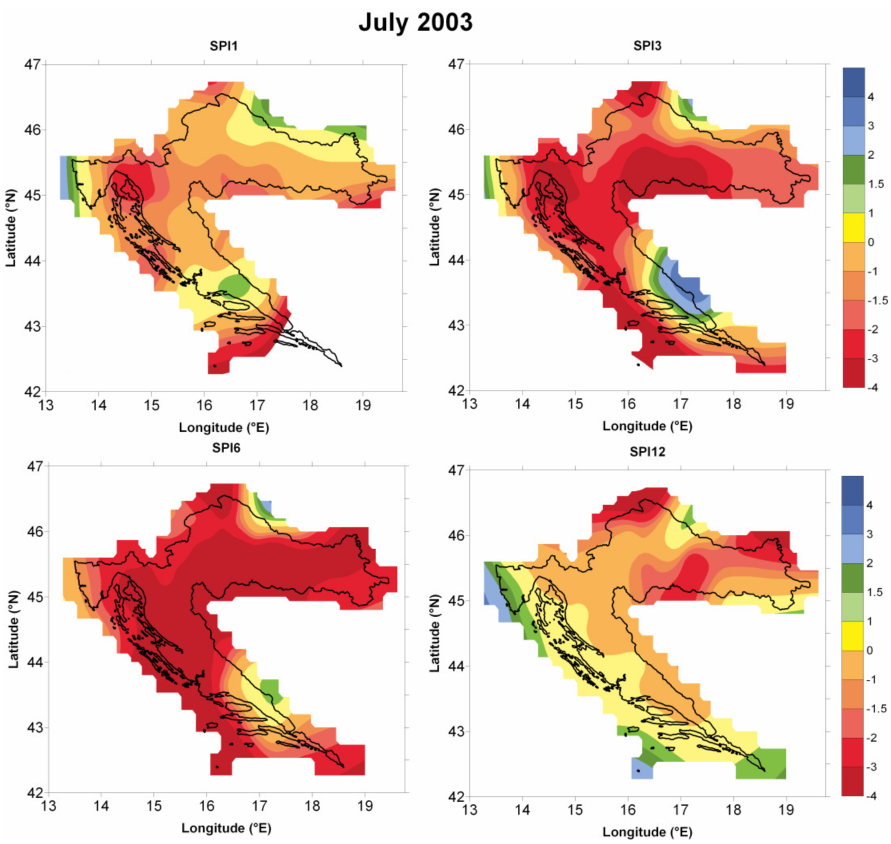


Figure 4.4 a) Spatial distribution map of the SPI and b) Relative frequency of the SPI values at the time scales of 1, 3, 6 and 12 months in June 2003

a)



b)

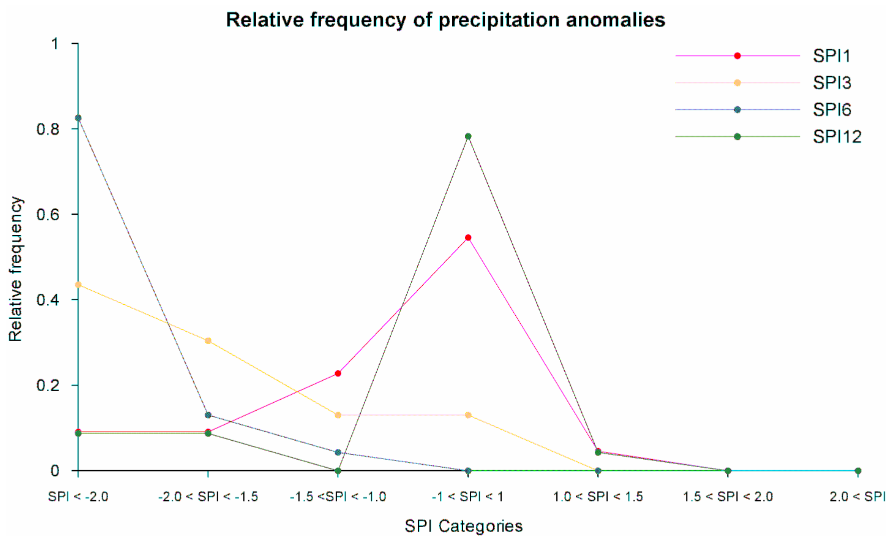
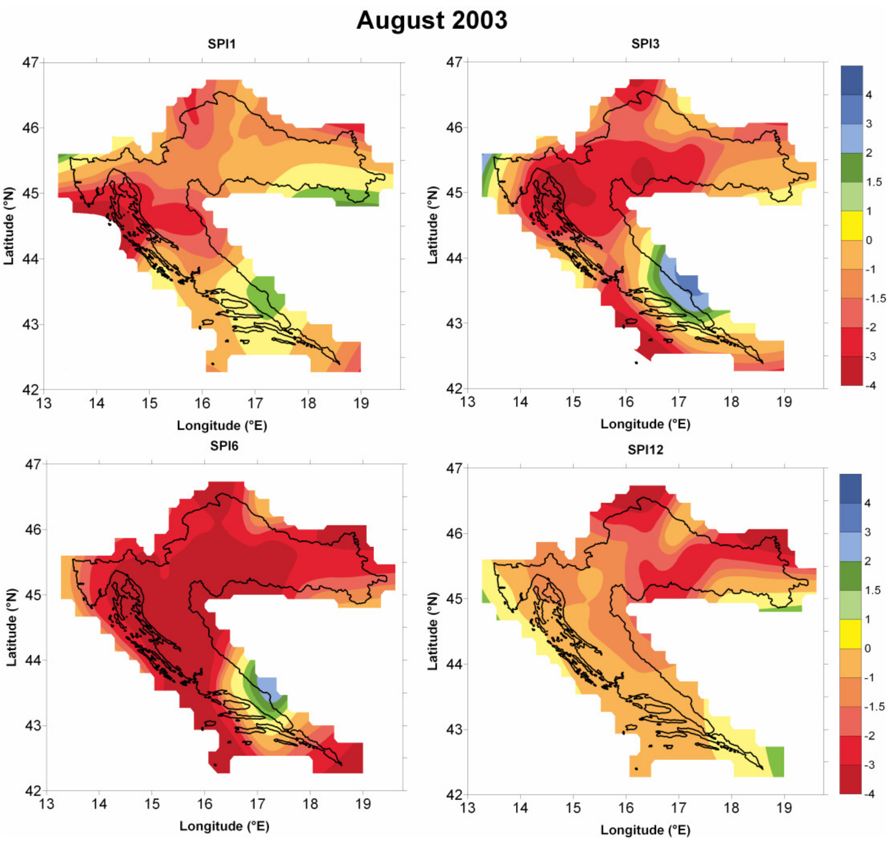


Figure 4.5. a) Spatial distribution map of the SPI and b) Relative frequency of the SPI values at the time scales of 1, 3, 6 and 12 months in July 2003

a)



b)

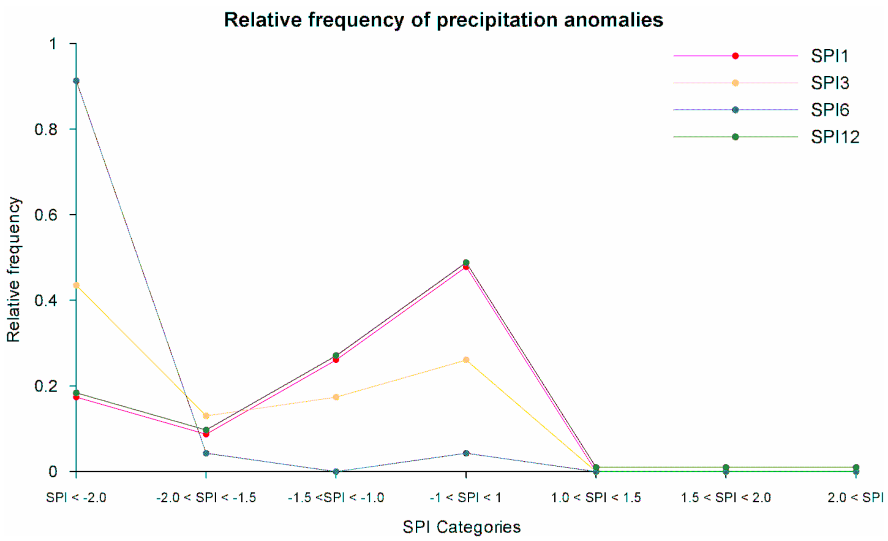


Figure 4.6. a) Spatial distribution map of the SPI and b) Relative frequency of the SPI values at the time scales of 1, 3, 6 and 12 months in August 2003

4.2 Development and implementation of irrigation scheduling system in Croatia

Having in mind the natural potential of the Republic of Croatia – the quality of soil and rich water resources with a favourable climate – it is clear that irrigation is not performed according to the actual potential, significance, and needs. In terms of the size of irrigated area – 9264 hectares or 0.86 percent of exploited agricultural land – the Republic of Croatia is one of the last countries in Europe.

The un-competitiveness of present agriculture is the consequence of a *low technological level of production*, *fragmented agricultural plots*, and *low crops*. Droughts are a common occurrence, and the damage they cause to agriculture is estimated at billions of kunas. At the same time, irrigation of agricultural land is insufficient and uses a negligible part of the water potential.

Some of the problems related to inadequate management of natural resources can and must be systematically solved. Thus the *Project of Irrigation and Management of Agricultural Land and Water in the Republic of Croatia* was launched in 2004 pursuant to the Decision of the Government of the Republic of Croatia. Pursuant to that Decision, the *National Committee* was established; it is presided by Prime Minister Ivo Sanader and the Minister of Agriculture, Forestry and Water Management, Petar Čobanković, was appointed as his deputy. The Minister has appointed an *Expert Team* coordinating the preparation and adoption of the strategy of present and future development of irrigation in Croatia, aimed at improving the management of natural resources, organization of agricultural infrastructure, and market economy of agricultural products. The strategy was prepared and adopted by the Expert Team in July 2005 under the title of the *National Project of Irrigation and Management of Agricultural Land and Water in the Republic of Croatia* – NAPNAV (Project holder: Faculty of Agriculture, the University of Zagreb). The strategy was adopted by the National Committee on October 17, 2005, and by the Government of the Republic of Croatia on November 17, 2005.

It is expected that the measures of systematic *organization of infrastructure in agriculture, consolidation of agricultural land* and *introduction of irrigation and new technologies* of production shall result in a more efficient agricultural production. The change in the structure of production shall be initiated by the introduction of more lucrative crops which are currently mostly imported, and, eventually, the Project shall result in a favourable macroeconomic effect..

4.2.1 National Framework of the Project

The Existing State of Agriculture, Agricultural Land, and Land Policy

Agriculture in Croatia is marked by years-long decrease in production, unbalanced supply and demand, a permanent negative foreign trade balance, and a gradual decrease of its share in the GNP (1999 – 11.58 percent share, and in 2003 – 9.93 percent share). Thus the economic indicators also point to the inefficient use of available resources, slow turnover of capital, and decrease in the productivity of labour in agriculture.

Trends on the national and global markets of agricultural products do not support increase of production in Croatia. Orientation towards sustainable agriculture and laying stronger emphasis on sustainable management of natural resources in the European Union (EU) will be reflected in Croatia as well in such a way that every planned increase in production will be monitored with full attention. Data of the Central Bureau of Statistics show that in 2003 the total of 1,080 million hectares of arable land and gardens (74 percent of the total area of arable land and gardens) were sown. In the structure of sown areas, grain covers 64.1 percent, oil seeds and crops 8.8 percent, potato 5.8 percent, other vegetables 6.0 percent, sugar beet 2.6 percent, forage crops 11.1 percent, tobacco 0.5 percent, and aromatic plants 0.2 percent.

The dominant segment of agrarian structure is agricultural family farms, which own about 80 percent of land. More than 70 percent of these farms have less than 3 hectares of mostly very fragmented agricultural plots. Even among those with larger plots, there are very few productive and market-oriented farms which would, in current conditions, be able to compete with the imported crops. The average area of used agricultural land by production subject is 2.4 hectares. Agricultural households use on average 1.9 hectares and business entities use 159.2 hectares. In order to achieve economical and competitive production, it is imperative to:

• Improve the structure of agricultural farms by consolidation of agricultural land,

• Undertake systematic measures for improvement of agricultural land, which include

construction of irrigation systems, and

• Develop a stimulating legislative and institutional framework for systematic and consistent implementation of the policy of management of agricultural land and water with the goal of increasing the productivity and achieving sustainable management of natural resources.

Rationale, Needs and Potential of NAPNAV

Agricultural areas that are currently irrigated in the Republic of Croatia are relatively small in relation to the needs and possibilities. Rich water potential and fertile soils are not used enough. The average crops of, first of all, vegetables and fruit, but also field crops, are low and fluctuate through the years, which is primarily connected with the occurrence of droughts. In Croatia, droughts occur on average every three to five years and, depending on their intensity and duration, can decrease the crops of various cultures by 20-70 percent. Especially significant were the droughts in 2000 and 2003, when the confirmed damage to agriculture amounted to more than HRK 3.4 billion.

Irrigation is one of the measures by which the damage from droughts can be decreased or completely avoided in certain areas. Reduction of crops of agricultural areas cultivated without irrigation on the territory of the Republic of Croatia amounts to 10 – 60 percent in the average climatic conditions, and in droughty conditions up to 90 percent of the biological potential, depending on the culture, type of soil and area. Along with that, the position of irrigation in the agriculture of the neighboring countries is a sufficient argument for a claim of a better perspective and the position of this measure in Croatian agriculture and economy in general.

One of the important starting points for the planning of irrigation is to identify the availability and quality of water resources and necesities (Figure 4.7). Nowadays, less than 1 percent of renewable water resources is abstracted for all purposes in Croatia. Rational management of water resources for irrigation purposes primarily implies the creation of conditions for ensuring reserves of water for irrigation.

As for land resources, it has been determined that Croatia has about 2.9 million hectares of agricultural land, 244,000 ha of which are suitable for irrigation, and with minor limitations, irrigation can be performed on more than 500,000 hectares.

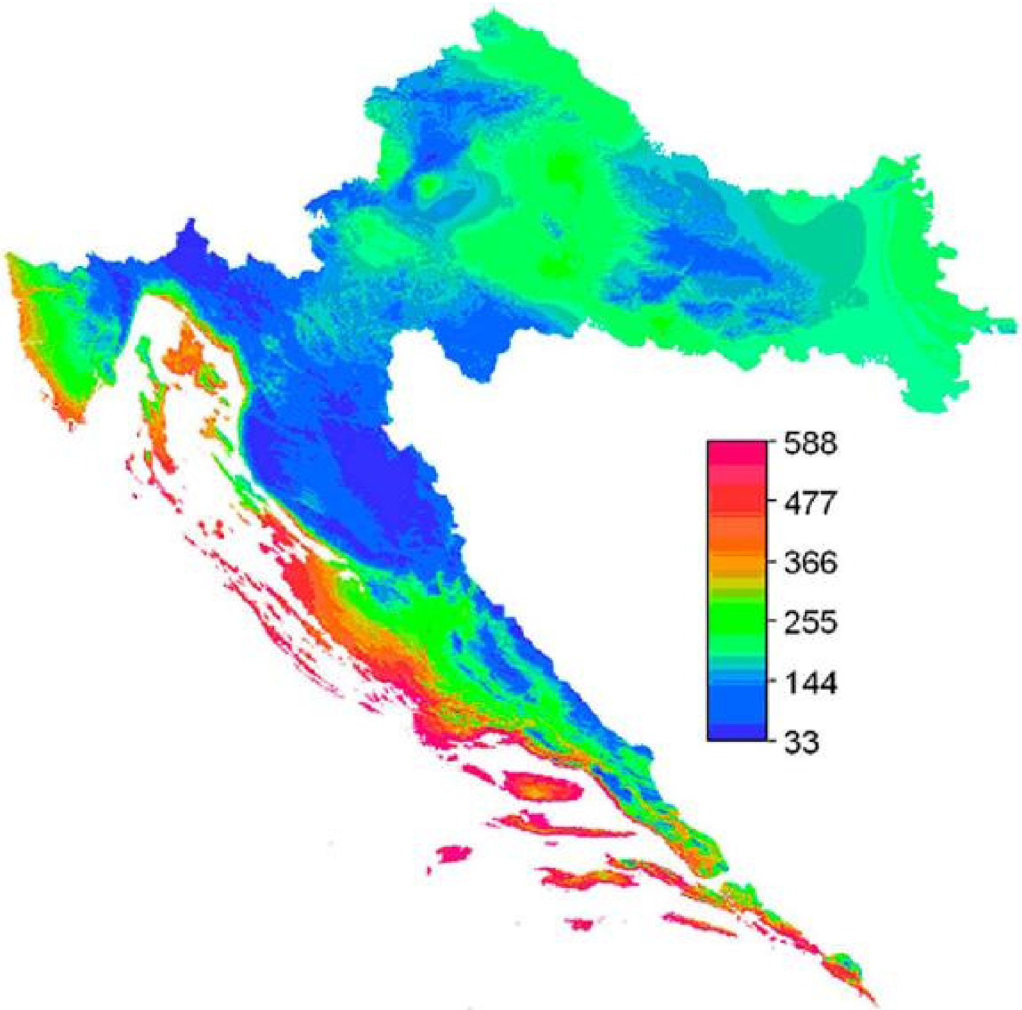


Figure 4.7. Water deficit (milimeters) for tomato in Croatia obtained from mean annual precipitation amounts and mean annual evapotranspiration amounts.

NAPNAV Objectives

The general objectives of NAPNAV as strategic bases for its implementation are the following:

• Analyze and quantify the potential for systematic introduction of irrigation in the Republic of Croatia;

• Define the rights and obligations of all participants in the system;

• The document should be a high-quality basis for planning the introduction of irrigation systems,

construction of infrastructure, and realization of plans of production of agricultural crops in new conditions of organized and monitored application of irrigation.

Specific objectives of NAPNAV are:

1. Short-term:

- preparation of county plans;
- construction of pilot-projects for irrigation;

2. Long-term:

- review and ranking of further projects for implementation of irrigation on the national level;
- definition of organization and the status of institutions for planning, financing, construction and monitoring of the projects;
- proposal of the dynamics of systematic introduction of irrigation in the Republic of Croatia up to the year 2020.

4.2.2 Project Activities

Defining the Criteria for Establishment of Priorities

Ranking of areas according to the priorities on the national level: The process of defining the priority areas was conducted in several stages, and several criteria were used. The most important criteria for irrigation were the natural potential of soil and water, water deficit, and the socio-economic factors. It has been estimated that in the Republic of Croatia there are about 6,000 hectares of soil very highly suitable for irrigation, the majority of which is in the County of Dubrovnik-Neretva. About 500,000 hectares are highly suitable for irrigation, the majority of which are in the Counties of Osijek-Baranja and Vukovar-Srijem (Figure 4.8).

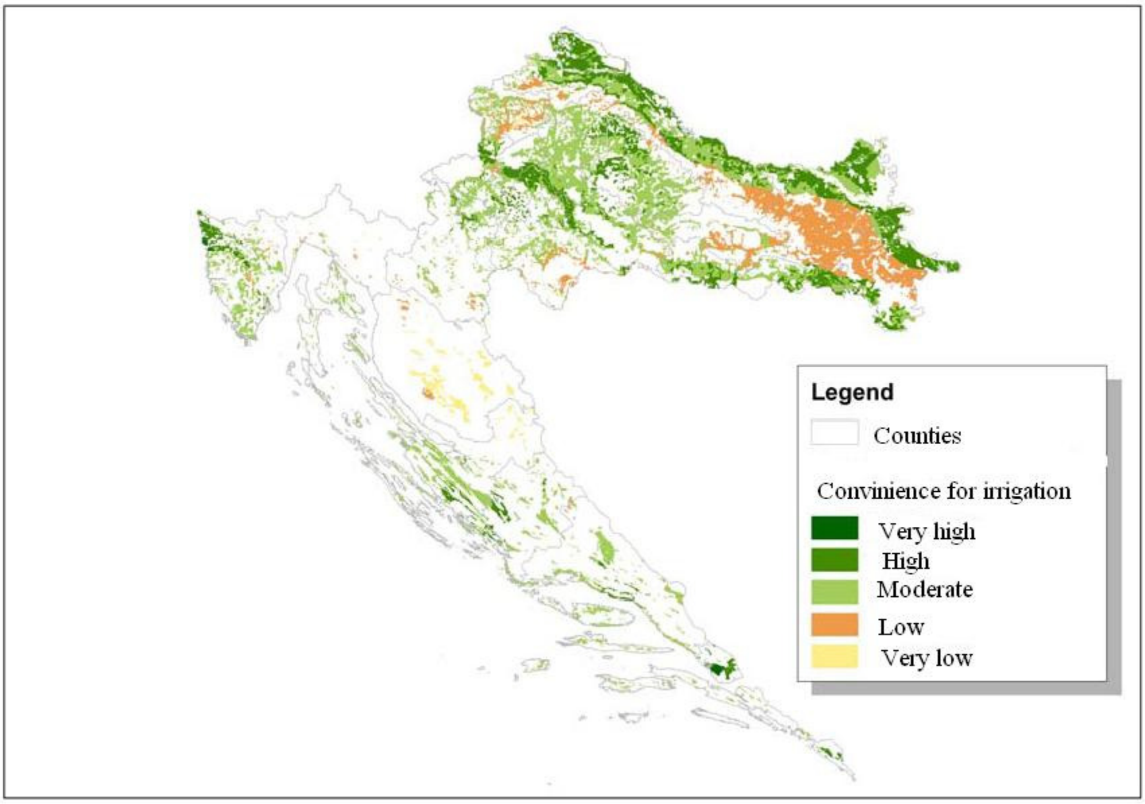


Figure 4.8 Map of priority areas for irrigation in the Republic of Croatia

Establishing priorities in the process of nominating projects for construction: In the process of ranking the nominated projects by priority, along with the criterion of availability of natural resources, the following criteria shall be used:

• Analysis of economic cost-effectiveness (profitability);

• Relative increase of income by surface unit;

• Co-financing;

• Sociological criteria (number of households or other beneficiaries included in the project, possibility of employment, development of rural areas, etc.);

• The degree of development of land where irrigation is planned;

• Consent of the beneficiaries.

Nomination, Evaluation and Monitoring of Project Implementation

Size of systems and potential beneficiaries: The NAPNAV defines the types of irrigation systems and their sizes, which is in direct correlation with potential beneficiaries. Currently the agricultural land in Croatia is mostly owned by family agricultural farms, which make a dominant part of the agrarian structure with the average plot size of 0.45 hectares. Business entities that engage in agricultural production use significantly larger plots per entity in comparison with agricultural households; they have a smaller number of plots per entity and larger average size of

plot. They all may be interested in the application of irrigation.

The category of *very small* systems includes irrigated land of less than 5 hectares in size, and **small** systems are those on the area of 5 – 10 hectares. These are mostly one or more commercial family agricultural farms. Systems of *medium* size refer to irrigated land of 10 to 200 hectares in size, and potential beneficiaries are one or more family agricultural farms, one or more co-ops, and companies. *Large* systems are those that are built for irrigation of surfaces larger than 200 hectares. The NAPNAV precisely defines the institutions involved in Project implementation, i.e. the process of nominating and financing individual projects.

Process of Nomination of Individual Projects: The process of nomination of individual irrigation project is initiated by a final beneficiary or beneficiaries by developing a conceptual design and submitting other documents. The beneficiary at the same time agrees to use the constructed systems and take over the rights and responsibilities associated with it, which shall be regulated by legislative regulations. The nominated projects shall be evaluated and ranked by the institutions involved in Project implementation.

Financing the Construction of Irrigation Systems: In the majority of countries which have organized irrigation systems the main investor of infrastructure construction is the state. This project also recommends that the state cofinance the construction of water supply to the plot, while the infrastructure on the plot is financed by the final beneficiary. The share of the state in co-financing shall depend on the size of the plot for which the water supply system is constructed. Construction of systems for small, fragmented and isolated plots makes the construction, as well as maintenance, more difficult and significantly more expensive. Thus the state should stimulate, by the percentage of co-financing, the aggregation of land and association of agricultural producers, which eventually leads to more rational management of constructed systems.

4.2.3 Sources of Funds

The sources of funds include: State Budget of the Republic of Croatia, EU pre-accession and EU structural funds, the World Bank, Commercial loans with state guarantee, and ***Local*** government.

Dynamics of Construction

By 2010, irrigation systems had to be constructed on new 35,000 hectares of agricultural land, i.e. by 2020, on a total surface of 65,000 hectares (Figure 4.9). Unfortunately there are big dela.y in plan realisation.

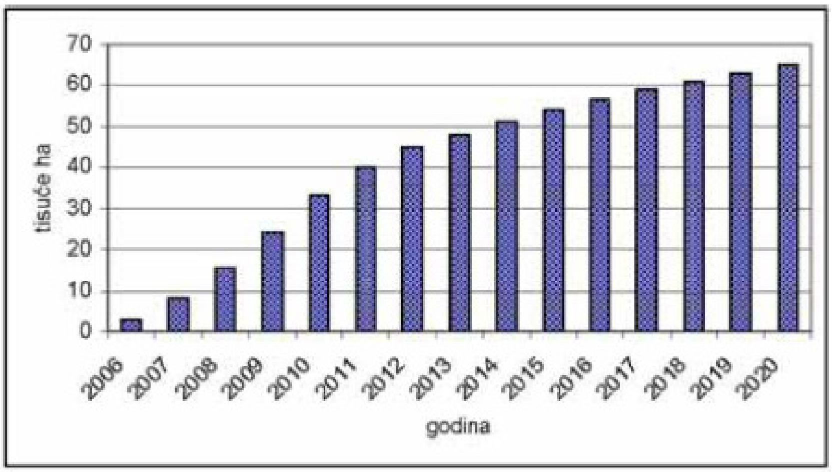


Figure 4.9 Cumulative increase of irrigated agricultural land in the Republic of Croatia by the year 2020

Legal Framework

Irrigation as a form of water use is defined by the Water Act, while the Water Management Financing Act lays down a charge for such form of water use. The acts also prescribe the method of obtaining a concession for ameliorative irrigation. In view of systematic introduction of irrigation, several regulations which would more thoroughly regulate the manner of using and operating irrigation systems, the manner of calculating and collecting prescribed charges, etc. are in preparation.

4.2.4 Overview of the Activities and Investments in Irrigation for the period 2004-2011

The following organizational changes have taken place so far within the activities on NAPNAV's realization:

• Pursuant to the Regulation of the Government of the Republic of Croatia on the internal organization of the MAFWM, the *Department for Ameliorative Irrigation* has been established within the Water Management Directorate –Water Management Sector.

• Pursuant to the Decision of the general manager of Hrvatske vode (HV), a *Working Group for the Implementation of the National Irrigation Program* has been established within Hrvatske vode. This group consists of 4 employees in HV's Head Office, and of 1-2 employees in 4 Water Management Departments (WMD) (WMD Sava, WMD Osijek, WMD Rijeka, and WMD Split).

• Task teams for coordinating and monitoring the preparation of county irrigation plans are established at the level of counties (team members are the representatives of the Ministry, Hrvatske vode, and competent experts from county services: agricultural experts, civil engineers specializing in hydraulic engineering). It is through these task teams that final beneficiaries express their needs and interest in introducing irrigation on their agricultural land.

So far, the NAPNAV has been carried out through the following three stages:

Stage I: County irrigation plans (CIP),

Stage II: Pilot-project of irrigation (PPI),

Stage III A: Project documents for individual irrigation systems (IS), and

Stage III B: Repair/reconstruction of existing and construction of new irrigation systems.

Stage I:

County irrigation plans (CIP) are the key planning documents defining the potential and needs for the irrigation of agricultural areas on the territory of a county. In the previous period the preparation of such plans began in 18 of the 21 counties; 7 county irrigation plans have been adopted, 4 are pending adoption (under review), and 7 plans are in the process of preparation. The plans are expected to be completed and adopted in 2007. Fifty percent of the funds required for the preparation of the above plans are provided by the Ministry of Agriculture, Forestry and Water Management, while the remaining 50 percent are provided by each individual county (Figure 4.10).

Figure 4.10 Counties of Croatia.

Stage II:

Under to the NAPNAV, four national pilot projects of irrigation (PPI) have been defined:

- The multi-purpose Sava – Danube canal (irrigation of the valley of Biđ-Bosut polje);
- The Opatovac irrigation system (the County of Vukovar-Srijem);
- The Kaštela-Trogir-Seget irrigation system (the County of Split-Dalmatia); and
- The lower Neretva irrigation system (the County of Dubrovnik-Neretva);

Expected impacts and benefits of the pilot-project:

• Rapid procedure for analyses of costs and economic justification and of the introduction of irrigation system;

• Optimizing the quantity of research and measurement required for system design and introduction;

• Defining and optimizing management measures under the given agro-ecological conditions;

• Providing the basis for the adoption of legal regulations and subordinate legislation related to problems with construction, maintenance and operation of irrigation systems;

• Training of participants in the system, raising the general level of knowledge, and strengthening the capacity of staff on the local level;

• Testing new irrigation techniques and environmental impacts.

The initiation of works on the construction of the Opatovac reservoir (in the municipality of Lovas) in September 2006 marked the realization of the Opatovac national pilot-project of irrigation. Terms of reference have been defined for the remaining three national pilot projects, and authors of technical documentation (on the level of conceptual design – location permit) have been selected. The funds needed for the realization of these 4 national pilot projects are provided by the Ministry of Agriculture, Forestry and Water Management (Figure 4.11).

Figure 4.11 Locations of the 4 irrigation pilot projects for stage II.

Stage III:

Project documents for individual irrigation systems (IS) are being prepared for the known users and locations of irrigation. Conceptual and main designs are in preparation, and for those which have been prepared the issuance of appropriate location permits is under way. In this stage, 12 counties are covered with 32 projects (Figure 4.12). The projects are supported by the Ministry of Agriculture, Forestry and Water Management with the amount of 50 percent of their value, while the remaining part is provided by the counties and towns or the final beneficiary.

Figure 4.12 Locations of the 32 irrigation pilot projects for stage III.

Pending the preparation of technical documents and issuance of required permits for the construction of new systems, the reparation of the existing irrigation systems was launched. In the period 2004 – 2006 the following two systems were repaired and put into operation:

1. ***Vransko polje irrigation system*** (the County of Zadar) – 483.74 hectares; beneficiary: "Vrana" d.o.o. Biograd n/m, production of vegetables, ensilage corn, and wine grape; the final beneficiary participated in the system's repair with its own funds (Figure 4.12).

Figure 4.12 A photo of Vransko polje irrigation system.

2. ***Grabovo irrigation system*** (the County of Vukovar-Srijem) – stage I, 500 hectares; beneficiary: "Vupik" Vukovar; production of vegetables and field crops; the beneficiary participated in stage I of system's repair with HRK 2 million (Figure 4.13).

Figure 4.13. A photo of Grabovo irrigation system.

Along with the above-mentioned systems, some hydraulic structures used for irrigation (reservoirs, pumping stations and irrigation canals) in Dalmatia underwent partial repair in the previous period.

4.2.5 Problem of Land Fragmentation

The fragmentation of production areas poses great problems and imposes constraints to organizing profitable and efficient agricultural production, and is one of the main limiting factors to more rapid development of agriculture in Croatia. Land consolidation in Croatia has long been known as a measure for combining and developing production areas with the purpose of efficient agricultural production on agricultural farms. From the first modern **Land Consolidation Act** from 1902 to 1990, land consolidation was carried out on economically richer areas, and their

intensity depended on socio-economic circumstances.

This Ministry is, in cooperation with the Swedish Government, implementing a joint project *"Consolidation of Agricultural Land in Croatia"*, whose implementation is based on the following two instruments:

• Consolidation as a measure of development of agricultural land,

• Establishment of a land pool as a measure of improving the market of agricultural land.

The project encompasses 5 pilot projects of agricultural land consolidation at 5 locations in 4 counties:

• The County of Primorje-Gorski kotar,

• The County of Vukovar-Srijem,

• The County of Zagreb, and

• The County of Varaždin.

The purpose of the project is to support the development of national policy of agricultural land consolidation.

4.2.6 The Lower Neretva Irrigation Pilot Project

The valley of the lower course of the Neretva River in the Republic of Croatia (the Lower Neretva) is a specific area of some 12,000 hectares, in which everything has always been adapted to the water regime of the natural environment. Five locations, with the total area of 1,620 hectares, are under protection. According to the Physical Plan of the County of Dubrovnik-Neretva, the entire Lower Neretva area is envisaged for protection within the category of a nature park, while the Parila area and Kuti Lake are proposed to be protected as a specific zoological

(ornithological) reserve.

Agricultural production in the Lower Neretva area takes place at around 5,370 hectares of agricultural land, a larger part within the meliorated system, and a lesser part on an inundated area. Melioration operations, intensification of agricultural production, and introduction of new crops have resulted in rapid socio-economic changes, accompanied with a rise of the standard of living of the inhabitants in the Lower Neretva area.

The salinization of arable land due to the lack of freshwater during droughty periods is an obstacle to agricultural production in these areas. This can be prevented by freshwater irrigation. Water in the Lower

Neretva area is salty and brackish, and the inflow of non-saline water is very low. Within the existing irrigation system, water of proper quality abstracted from the Neretva River upstream of Metković (the territory of Bosnia and Herzegovina) is supposed to be transferred to the profile of the Mala Neretva River in Opuzen, with the aim of preserving a freshwater basin with the area of ca. 2,500 ha (aquatic and wetland) and distributing water to plots on ca. 3,600 ha. The adopted concept has in practice proved as an operationally expensive and inefficient solution which meets the needs of only a part of agricultural areas.

In terms of improving and optimizing the existing status of irrigation, *The Study of Irrigation in the Lower Neretva Area* (The Faculty of Agronomy, 2006) was initiated (Figure 4.14). It analyses agricultural production and irrigation conditions in the Lower Neretva area in detail with alternative solutions for the main water supply line leading to arable land. Seven alternatives and 3 sub-alternatives have been prepared. After several public and expert presentations of the study, **two solutions** were adopted as **optimal**:

- Abstraction of water from the Neretva River at a location downstream of Opuzen through construction of a new cut-off which prevents the salt wedge intrusion,

- Abstraction of water upstream of Metković (out of reach of salt wedge), with optimization and modernization of the existing irrigation system.

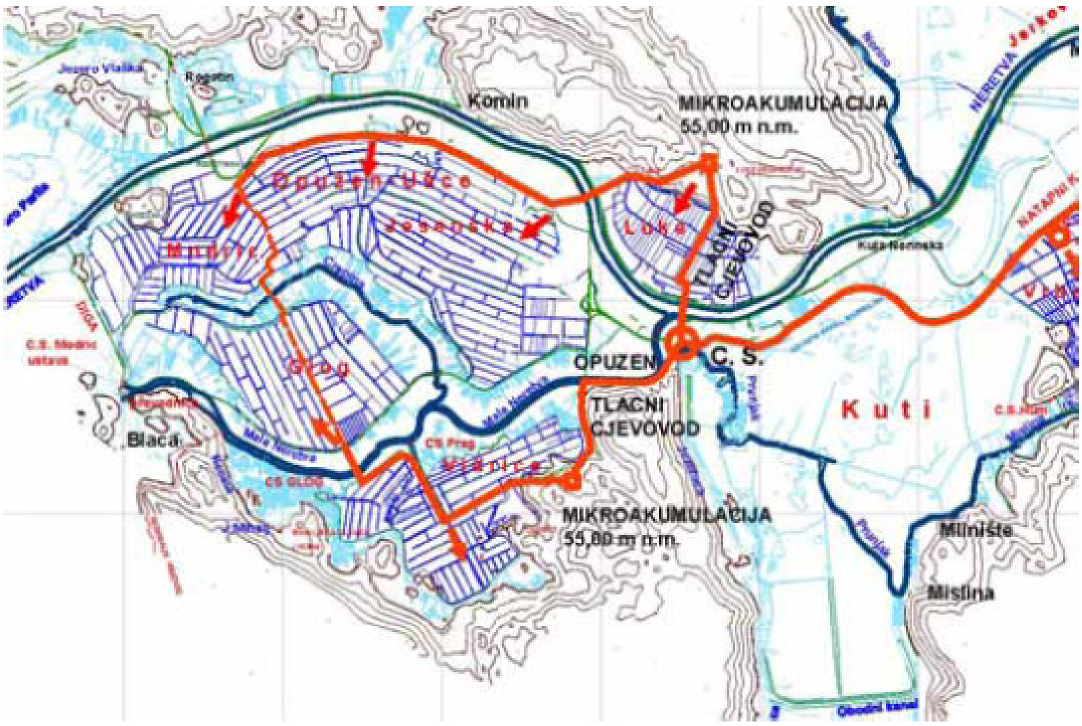


Figure 4.14 Lower Neretva Area.

On the basis of the adopted concepts, terms of reference for the preparation of a preliminary design of the irrigation system for both alternatives were prepared at the end of 2006, i.e. terms of reference for the conceptual design for that alternative which will be selected as the most acceptable following the adoption of preliminary designs. Terms of reference for the preparation of the main design for a part of the Lower Neretva irrigation pilot project in the area of 450 ha have also been prepared.

4.2.7 Conclusion

Winding up the overview of the contents and realization of the National Project of Irrigation and Management of Agricultural Land and Water in the Republic of Croatia (NAPNAV), it is important to point out that this Project is in the first stage of its realization, where emphasis is put on organizational and structural activities, i.e. on the preparation of plans and technical documents. The construction of several new irrigation systems is expected to start in the second stage of the program. Only with the realization of this project it is possible to create preconditions for competitiveness and efficiency of Croatian agriculture on the EU market.

References

Bibliography

Alexandersson H (1986) A homogeneity test applied to precipitation data. J Clim 6:661–675

Cindrić K., Pasarić Z., Gajić-Čapka M., 2009: Spatial and temporal analysis of dry spells in Croatia. Theor. Appl. Climatol., 102 (2010) , 1-2; 171-184

Dobrinić, A. and V. Zabka: "*National Project of Irrigation and Management of Agricultural Land and Water in the Republic of Croatia".* Proceedings of the Regional Workshop on WUAs Development, June 4 – 7, 2007. Bucharest, Romania.

McKee, T.B.; N.J. Doesken; and J. Kleist. 1995. Drought monitoring with multiple time scales. Preprints, 9th Conference on Applied Climatology, pp. 233–236. January 15–20, Dallas, Texas.

McKee, T.B.; N.J. Doesken; and J. Kleist. 1993. The relationship of drought frequency and duration to time scales. Preprints, 8th Conference on Applied Climatology, pp. 179–184. January 17–22, Anaheim, California.

Penzar, B., 1976: Drought severity indices for Zagreb and their statistical forecast (in Croatian). Rasprave i prikazi br. 13, 1-58.

Zaninović, K., Gajić-Čapka, M., Perčec Tadić, M. et al, 2008: Klimatski atlas Hrvatske / Climate atlas of Croatia 1961-1990., 1971-2000. Državni hidrometeorološki zavod, Zagreb, 200 str.

5. Report on historical overview of drought impact records

PROJECT INFORMATION	
Project acronym:	DMCSEE
Project title:	Drought Management Centre for South East Europe
Contract number:	2008-0017-201002
Starting date:	17. 05. 2010
Ending date:	17. 05. 2012
Project WEB site address:	http://meteo.hr/DMCSEE/
Partner organisation:	Meteorological and Hydrological Service of Croatia
Name of representative:	M. Sc. Ivan Čačić, director
Project manager:	dr. Krešo Pandžić
E-mail:	pandzic@cirus.dhz.hr
Telephone number:	+386 (0)1 45 65 684
DELIVERABLE INFORMATION	
Title of the deliverable:	**Historical overview of drought impact records**
WP/activity related to the deliverable:	Act. 4.1 Drought impact reporting
Type (internal or restricted or public):	Public
Location (if relevant):	Zagreb, Croatia
Author:	Mr Milan Mesić, external expert
Deadline	17.04.2012. Draft report

5.1 Introduction

By its position, Croatia belongs to the Central-European, Adriatic-Mediterranean and Panonian-Danube basin group of countries. It borders Slovenia (667.8 km) to the northwest, Hungary (355.5 km) to the north, Serbia (317.6 km) and Montenegro (22.6 km) to the northeast and southeast, and has the longest border with Bosnia and Herzegovina (1011.4 km). The national sea border is 948 km long and stretches along the outer edge of the territorial sea. It is followed by protected ecological and fishing zone reaching the continental shelf border between Croatia and Italy [1] (Figure 5.1a).

- Croatia has a total area of 87,661 km^2 from which the 56,594 km^2 is the land area and the remainder of 31,067 km^2 is water. Croatian coastline is a total of 5,835 km; 30.5% is mainland and 69.5% consists of islands. The most area (around 50%) includes lowlands (below 200 m in height), 25% constitutes hilly area, 15% is mountainous region (above 500 m) and 10% is the coastal area.

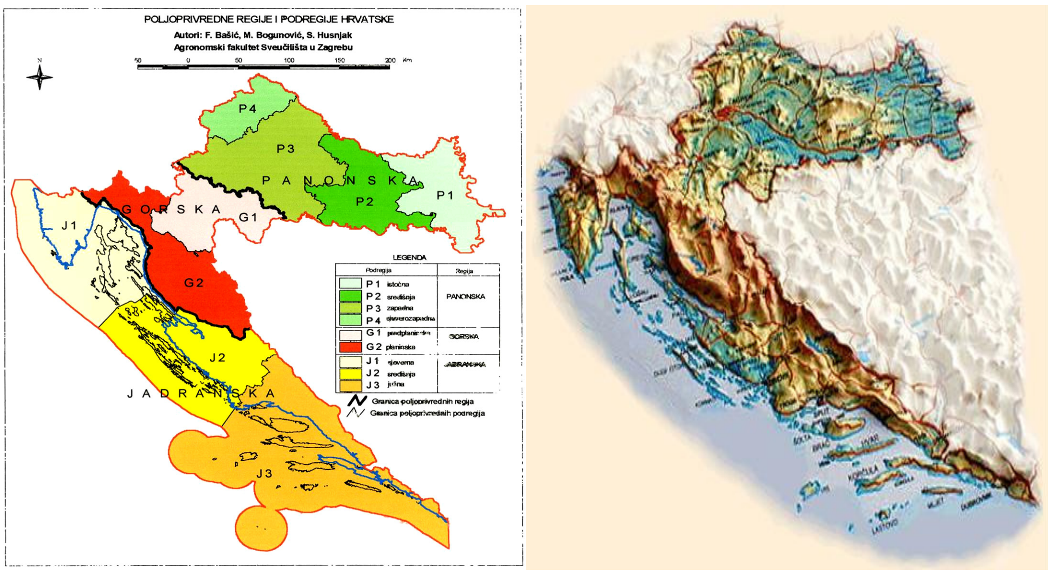


Figure 5.11. a) Agricultural regions and b) relief of Croatia [2]

The area of Croatia can be divided into three major geomorphologic and consequently agricultural regions (Figure 5.1) [2]:

- The Panonian and Peri-Panonian area (P) comprises the lowland and hilly parts of eastern and northwestern Croatia; mountains higher than 500 m are rare and of an insular character. Most of this area is being used for farming and livestock breading. Slavonija and Baranja in the east are the most suitable for growing cereals; the humid valleys and the hills are richly afforested while the northwestern part, which gravitates to Zagreb, is industrially the most developed.

- The hilly and mountainous area (G), which separates Panonian Croatia from its coastal part, is less developed. Its future development will be based on its transit importance, the growth of the already existing wood and timber industry, and the still underexploited potential for the production of healthy food, and winter and rural tourism. The highest mountain peak in Croatia is Dinara (1,831 m).
- The Adriatic area (J) includes the narrow coastal belt separated from the hinterland by high mountains. This is predominantly a karst area with very dry summers. The few streams mainly follow narrow gorges in breaking their way through to the sea. The Croatian coastal area may further be divided into the northern (Istria and Kvarner) and southern part (Dalmatia). The Croatian Adriatic coast is one of the most indented in the world: it has 1185 islands and islets. The largest island is Krk; other large islands include Cres, Brač, Hvar, Pag and Korčula. The largest peninsulas are Istria and Pelješac, and the largest bay is Kvarner Bay

Croatia has 16 rivers longer than 100 km and they all flow either to the Adriatic or the Black Sea basin. The main rivers only partly flow through the Croatian territory; they mostly make the natural borders with the neighboring countries. The longest Croatian rivers are Sava (562 km) and Drava (305 km). There are only 14 lakes in Croatia with the area bigger than 0.5 km^2 and almost half of them are men-made in 20th century. The largest lake Vrana has an area of 30 km^2. The Nature Protection Act (OG 70/05, 139/08) determines nine categories of area protection. The total surface of Croatia's protected areas is 5,088.161 km^2 or 8.99% of the mainland and 410.25 km^2 of the marine area [4].

Utilized agricultural land (arable land, vineyards, meadows and pastures, orchard and olive plantations) covers 46.2% of the Croatian territory while total area of forest land (with macchia and bushes) encompasses 40% of the mainland [2].

The climate of Croatia is determined by its position in the northern mid-latitudes and the corresponding weather processes on a large and medium scale. The most important climate modifiers over Croatia are the Adriatic Sea and the Mediterranean, the Dinaric Alps with their form, altitude and position relative to the prevailing air flow, the openness of the north-eastern parts to the Panonian plain, and the diversity of vegetation. According to the Köppen climate classification [3].most of Croatia has a temperate rainy climate (symbol C) which is the prevailing type for mid-latitudes. Only the highest mountain areas (>1200 m asl) have a snow-forest climate (symbol D). The mean annual air temperature in the lowland area of the northern Croatia is 10-12°C, at the heights above 400 m is lower than 10°C, while in the highland it is 3-4°C. In the coastal area the mean temperature is 12-17°C. The mean annual amount of precipitation in Croatia ranges from 300 mm to slightly over 3500 mm (Figure 5.2). The smallest annual amounts fall on the outer islands of the southern Adriatic (Palagruža, 311 mm) and in the eastern Croatia (Osijek, 650 mm). About 800 mm to 900 mm of precipitation can be expected on the islands and the coast of central and northern Dalmatia as well as on the west coast of the Istrian Peninsula. The precipitation amount in the Panonian area decreases from the west to the east. The precipitation amount is increased from the coast to the inland. Most of the precipitation is recorded on the slopes and peaks of the coastal Dinaric Alps (from 3000 to 3500 mm).

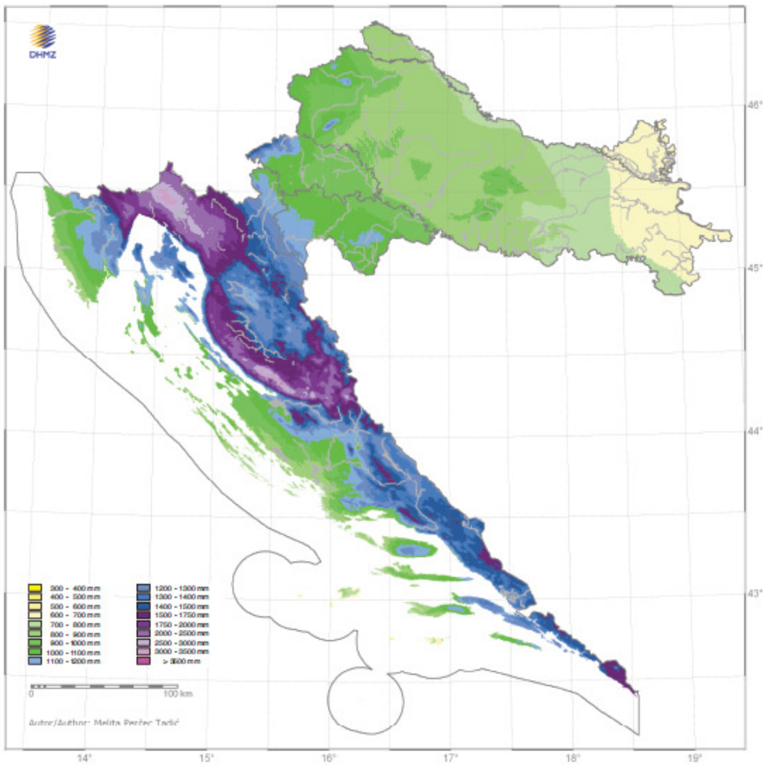


Figure 5.2. Spatial distribution of mean annual precipitation in Croatia, 1961-1990 [3].

According to the Croatian Bureau of Statistics 4.437,460 (2001 census) people live in Croatia. During the last decade of the 20th century the population of Croatia has been stagnating because of the Croatian War of Independence. During the war, large sections of the population were displaced and emigration increased. Table 5.1 gives the data about population and households from censuses from 1953 to 2001. The mid-year estimate of 2009 gives the population of 4.429.000 with the negative natural population growth of -1.8 per 1000 inhabitants. Average population density is 78.4 inhabitants per km^2. Central part of Croatia is the most populated (115 inh./km^2), while the least populated is the mountainous part of Croatia (13 inh./km^2). Within total number of inhabitants, 51.1% lives in 124 cities. The 2051 projection of population is 3.714,300 [1]. Figure 5.2 shows the natural change in population in Croatia from 1975 to 2009 period.

The capital city of Croatia is Zagreb which is situated in the northwest of the country at the altitude of 122 meters. It is the largest city and historically the political, commercial, and cultural center of the Republic of Croatia. The official 2001 census counted 779,145 residents, and the mid-year estimates for 2009 increased this number to 790,208.

Table 5.1. Population and households according to censuses [1]

	Popisi *Censuses*						
	1953.	1961.	1971.	1981.	1991.	2001.[1]	
Stanovništvo	3 936 022	4 159 696	4 426 221	4 601 469	4 784 265	4 437 460	*Population*
Prosječna starost stanovništva							*Average age of population*
Muškarci	29,34	30,53	32,44	33,80	35,37	37,5	*Men*
Žene	31,91	33,26	35,48	37,14	38,71	41,0	*Women*
Očekivano trajanje života pri rođenju							*Life expectancy at birth*
Muškarci	59,05	64,28	65,65	66,64	68,59	71,1	*Men*
Žene	63,20	69,02	72,33	74,15	75,95	78,1	*Women*
Broj kućanstava	1 031 910	1 167 586	1 289 325	1 423 862	1 544 250	1 477 377	*Number of households*
Prosječan broj članova u kućanstvu	3,81	3,56	3,43	3,23	3,10	2,99	*Average number of persons per household*

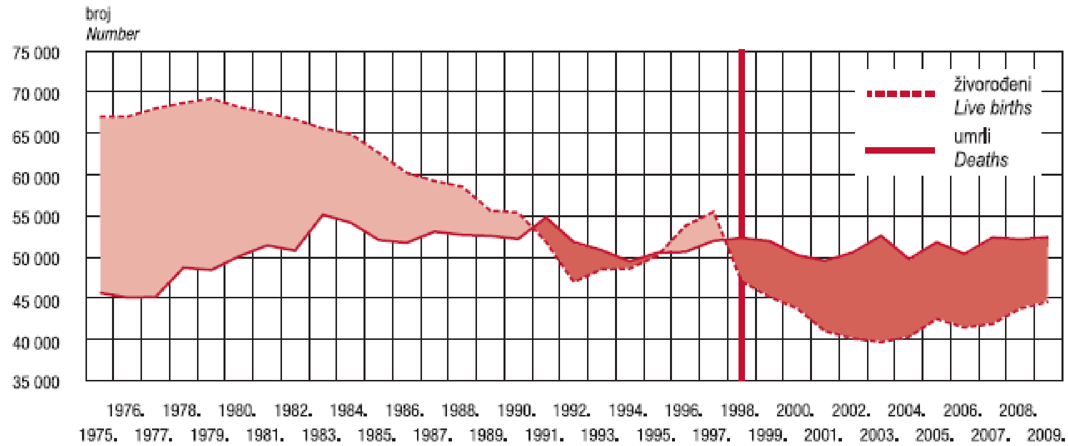


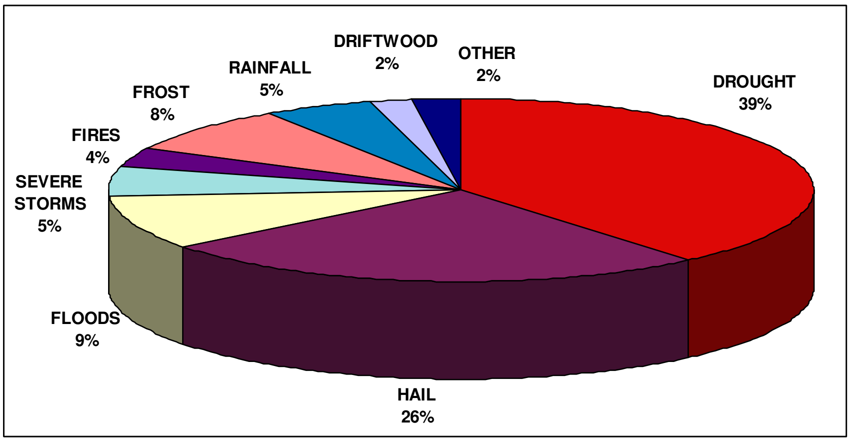
Figure 5.3. Natural change in population, 1975-2009

5.2 Archive of local/regional/national drought periods and impacts based on historical records

5.2.1 Methodology

In Croatia drought causes highest economic losses (39%) among all hydro-meteorological events (Figure 5.4). The greatest damage is found in agriculture, infrastructure, buildings and movable property. The cost and type of damage is different from year to year. Drought is the most frequent hazard and it usually comprises the whole country. In last 14 years the highest damages due to drought impacts were in 2000 (84%), 2003 (90%) and 2007 (80%) [5]. Hence, there is an increasing interest in developing methods for drought risk assessment in Croatia.

a)



b)

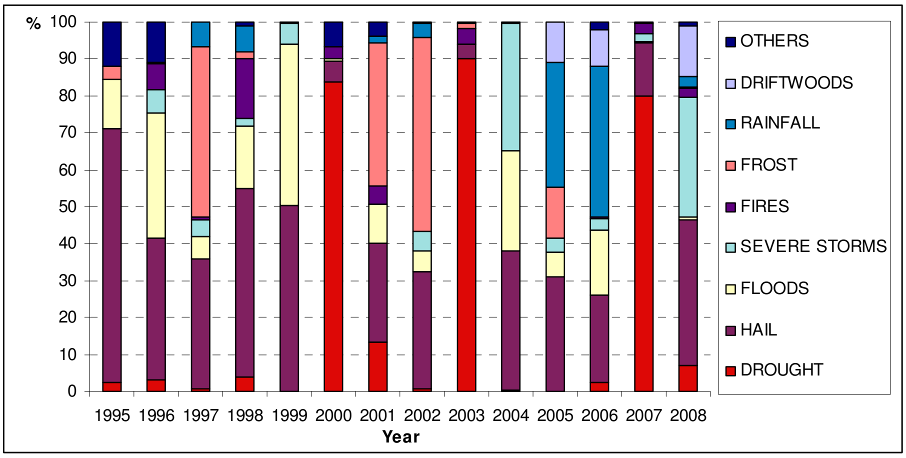


Figure 5.4. Economic losses (in percentages) due to natural hazards in Croatia during the period 1995–2008. a) Average losses during the whole period and b) losses per year.

Atmospheric conditions which cause a considerable water deficit determine a desert climate, or a climate with tendency to desertification. These conditions make the potential evapotranspiration (PET) larger than precipitation (P). When the precipitation can not restore the water deficiency due to evaporation the soil water storage reduces. The long-lasting water shortage can cause the drought and serious damage in water management and agriculture. The precipitation deficit in terms of the ratio P/PET is then a useful aridity index. Smaller values of the ratio correspond to drier areas. The climate assessment in Croatia according to the aridity index shows the prevailing precipitation deficit in the warm part of the year in the whole country, except the mountainous region [2]. In the Panonian region there is no precipitation deficit on the annual scale but a deficit occurs in some months. The precipitation deficit decreases going from the east to the west. Moreover, the duration of deficit is shorter in the west and northwest region (from May to August) than in the east and central mainland (from April to September). The deficit is mostly pronounced in the Adriatic region. In the middle Adriatic region the precipitation deficit usually lasts from April to September while in the south region the deficit is present from February to October. The mean annual precipitation restores only 50% of evaporating water. According to the United Nations Convection to Combat Desertification (UNCCD) definition and criteria accepted by UNEP/GEMS (1992) after recommendation of FAO UNESCO (1977), the next scheme shows the threat to desertification due to climate conditions:

(desertification) $0.05 > P/PET > 0.65$ (no desertification)

The average climatic conditions (1961-1990) in Croatia are not favorable to desertification. However, in the warm half of the year there is a susceptibility to desertification in the eastern Croatia (Slavonia) and in the coastal region (Table 5.2). The eastern Slavonia is in dry-subhumid zone during the warmest months. The vulnerability to desertification is the most pronounced at the Adriatic coast and islands and it increases as one goes to the south.

Operational drought monitoring on different time scales started in Croatia in 2009 (Meteorological and Hydrological Service (DHMZ), http://meteo.hr/). The Standardised Precipitation Index (SPI) is used for this purpose which is useful for determining drought onset, duration and intensity. However, Mihajlović [9] analysed meteorological drought of 2003-2004 over the Panonian part of Croatia as well as the drought characteristics during the 20th century at Zagreb- Grič station. The results of SPI at timescales of 1, 3, 6 and 12 months (SPI1, SPI3, SPI6 and SPI12) showed that the drought in Panonian region started in March 2003 and lasted till April 2004. However, it is shown that the meteorological drought is a regular feature over the Panonian part of Croatia. The meteorological drought of 2003–2004 had an exceptional magnitude at the 1-month timescale and did not have an exceptional magnitude and duration at the 3-, 6- and 12-month timescales. The most severe meteorological drought according to the Zagreb data lasted from July 1990 to August 1993. There are two other extreme drought periods with highest magnitude at a12-month timescale: May 1949 to November 1950 and November 1942 to September 1944.

Table 5.2. Spatio-temporal distribution of aridity index (P/PET) and the categorization due to susceptibility to desertification [2].

Arid zone:	0.05<P/PET<0.20	(orange)
Semiarid zone:	0.20<P/PET<0.50	(dark yellow)
Dry-subhumid zone:	0.50<P/PET<0.65	(light yellow)

ARIDITY INDEX P/PET, 1961.-1990.														
Station	**REG.**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Year**
OSIJEK	P1	4.70	2.50	1.50	1.00	0.69	0.81	0.52	0.51	0.58	0.89	2.71	4.33	0.93
DONJI MIHOLJAC	P1	4.15	2.15	1.35	0.87	0.60	0.60	0.44	0.49	0.49	0.77	2.33	3.87	0.80
SLAVONSKI BROD	P2	4.90	2.53	1.65	1.13	0.95	0.86	0.72	0.66	0.84	1.30	3.05	4.75	1.15
VARAŽDIN	P4	3.46	2.37	1.72	1.27	1.00	0.91	0.75	0.93	1.14	1.64	3.46	3.87	1.27
ĐURĐEVAC	P3	3.92	2.58	1.75	1.21	0.92	0.82	0.67	0.75	0.90	1.41	3.74	4.27	1.20
KOPRIVNICA	P3	4.08	2.63	1.69	1.30	0.96	0.88	0.72	0.81	1.03	1.61	3.63	4.60	1.27
ZGB-MAKSIMIR	P3	3.83	2.33	1.81	1.23	1.00	0.99	0.71	0.92	1.14	1.77	3.68	4.14	1.30
SISAK	P3	4.64	2.94	1.81	1.38	1.03	0.89	0.66	0.85	1.15	1.64	4.14	5.23	1.33
KARLOVAC	G1	7.67	4.40	3.27	2.07	1.45	1.16	0.94	1.20	1.67	2.74	6.67	8.50	1.99
OGULIN	G1	7.07	5.50	3.81	2.60	1.60	1.29	1.00	1.35	1.96	3.16	6.48	8.29	2.33
PARG	G2	11.00	9.07	6.80	4.77	2.76	2.48	1.44	1.97	3.40	6.13	11.58	12.00	4.00
GOSPIĆ	G2	10.70	8.31	4.95	3.00	1.95	1.28	0.73	1.28	2.27	4.25	9.94	14.20	2.80
PAZIN	J1	4.33	3.20	2.49	1.82	1.20	0.97	0.55	0.93	1.38	2.22	4.19	3.91	1.57
PULA	J1	2.41	1.81	1.30	0.99	0.58	0.39	0.22	0.44	0.63	0.90	2.02	2.14	0.77
RIJEKA	J1	3.91	3.05	2.43	1.69	1.05	0.83	0.45	0.66	1.34	2.04	3.37	3.59	1.44
SENJ	J1	1.47	1.29	1.03	0.82	0.57	0.37	0.22	0.36	0.55	0.89	1.85	1.74	0.67
ZADAR	J2	1.75	1.50	1.30	0.77	0.54	0.33	0.17	0.33	0.70	1.12	1.75	1.88	0.73
KNIN	J2	3.11	2.31	1.77	1.24	0.86	0.63	0.25	0.44	0.85	1.48	2.71	3.48	1.03
ŠIBENIK	J2	1.43	1.12	0.89	0.59	0.32	0.25	0.11	0.21	0.36	0.70	1.29	1.35	0.49
SPLIT MARJAN	J3	1.32	1.00	0.89	0.57	0.32	0.21	0.09	0.17	0.28	0.54	1.15	1.43	0.44
HVAR	J3	1.40	1.07	1.00	0.56	0.30	0.21	0.11	0.19	0.33	0.64	0.97	1.42	0.48
DUBROVNIK	J3	2.10	1.83	1.44	0.97	0.50	0.34	0.16	0.35	0.51	0.98	1.64	1.92	0.67

Furthermore, the climatology of dry spells during the second half of 20th century in Croatia has been analysed [10]. Length of dry spell is expressed as number of consecutive dry days with daily precipitation amount less than 1 mm, less than 5 mm and less than 10 mm. The results affirmed the three main climatological regions in Croatia, with the highlands exhibiting shorter dry spells than the mainland, and the coastal region exhibiting longer dry spells. The prevailing positive trend of both mean and maximal durations is detected during winter and spring seasons, while negative trend dominate in autumn for all thresholds. Positive field significant trends of mean dry spell duration with 5 and 10 mm thresholds are found during spring and the same is valid for annual maximum dry spell duration with a 10 mm threshold.

The records of drought impacts in Croatia are systematically assesembled in the report of rare meteorological and hydrological events in the **Meterological and Hydrological Bulletin** of DHMZ (monthly reports). The source for these data are mainly from national newspapers.

5.2.2 Results

At the Adiatic coast it is the dry period that is characteristic during summer months. However, small amounts during summer provide enough soil moisture for cultivating the most important Mediterranean culture, olives and vine. In summer 2008 Zadar archipelago was the most affected by drought at the Adriatic. Namely, because of the extremely small crop this event was proclaimed a natural disaster in the Zadar County. This was the motivation for analyzing the spatial distribution of SPI in the Zadar archipelago [11]. The SPI has the minimum value at 3 months scale (from July to September). The precipitation amount registered in summer 2008 had the second smallest value compared to the last 47-years period (1961-2007). These amounts have return period values of more than 90 years.

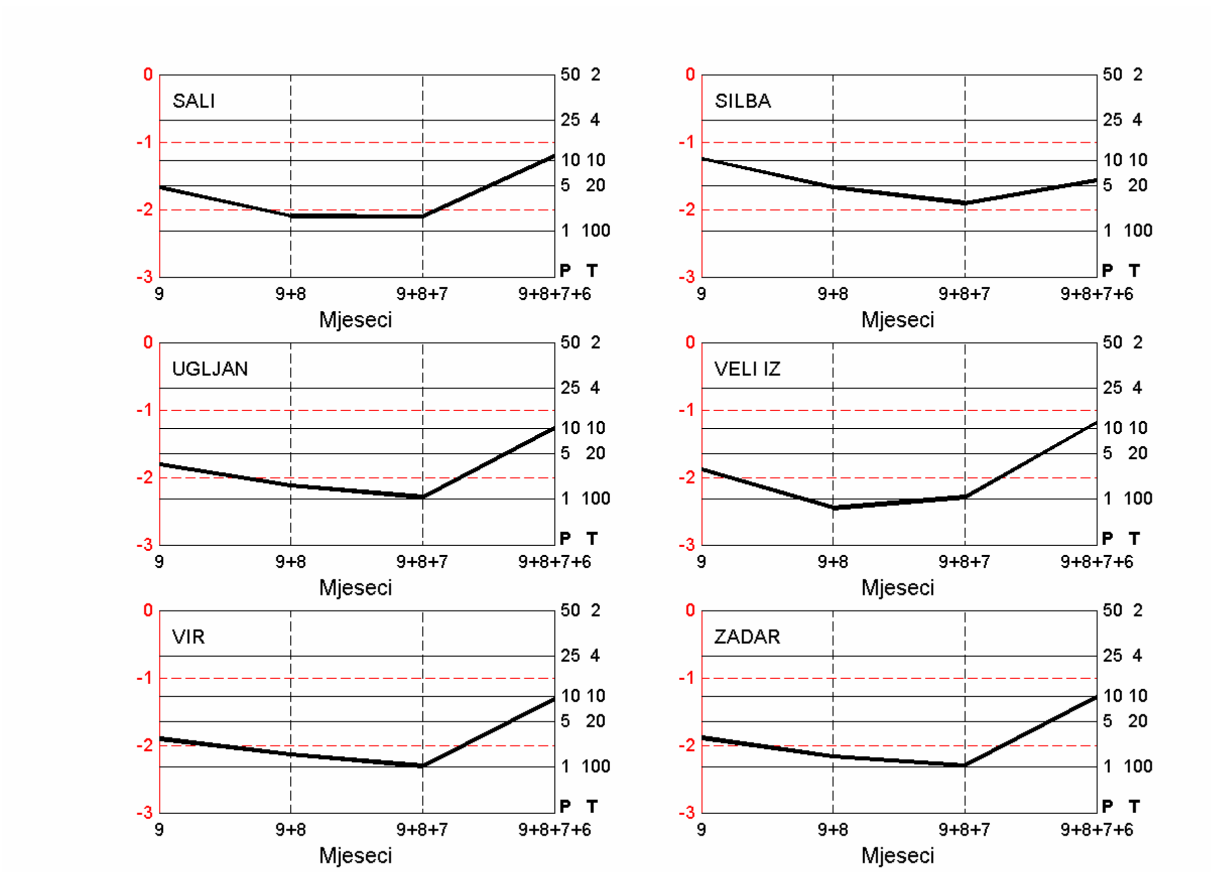


Figure 5.5. Standardised precipitation index (SPI), associated percentiles (P %) and return periods (T years) for time scales from a month (September) to four months (June to September) 2008 at six stations in the Zadar archipelago [11].

Records of drought impacts obtained from the Meteorological and Hydrological Bulletin during the period 2000-2010 are given in Table 5.3. Droughts in 2003 and 2007 lasted the whole year and all the Croatia was affected. Drought had impacts on agriculture, hydropower, water supply, river traffic was stopped; it increased forest fires danger and drying of rivers and wells. The natural disaster was proclaimed for many areas.

Table 5.3. Drought chronology for the period 2000 to 2010.

Country	*Location*	Source	Date/period	Abstract
Croatia	***All Croatia***	Newspaper articles	Spring - Summer 2000.	Drought threatening agriculture, livestock, fresh water fisheries, hydropower, water supply, tourism, increasing forest fires danger, rivers and wells dried, natural disaster proclaimed for many areas
Croatia	***Korčula island***	Newspaper articles	Spring 2001	2 to 5 litre rain in 50 days
Croatia	***NW Croatia, Dalmatia,***	Newspaper articles	Summer 2001	Drought threatening agriculture, water supply
Croatia	***Imotski region***	Newspaper articles	Autumn 2001	Drought threatening agriculture, water supply, Blue lake dried
Croatia	***Adriatic coast region***	Newspaper articles	Winter 2001/2002	Drought threatening agriculture, hydropower, water supply
Croatia	***Northern Dalmatia***	Newspaper articles	Spring/summer 2002	Drought threatening agriculture, water supply, fresh water fisheries, tourism, natural disaster proclaimed for some areas
Croatia	***All Croatia***	Newspaper articles	Year 2003	Drought threatening agriculture, livestock, fresh water fisheries, hydropower, water supply, tourism, river traffic stopped, increasing forest fires danger, rivers and wells dried, natural disaster proclaimed for many areas
Croatia	***Istria***	Newspaper articles	Summer 2004	Drought threatening agriculture

Croatia	***Šibenik region***	Newspaper articles	Summer 2005	Drought threatening agriculture, livestock
Croatia	***All Croatia***	Newspaper articles	July 2006	Drought threatening agriculture, livestock
Croatia	***All Croatia***	Newspaper articles	Year 2007	Drought threatening agriculture, hydropower, water supply, river traffic stopped, increasing forest fires danger, rivers and wells dried, natural disaster proclaimed for many areas
Croatia	***All Croatia***	Newspaper articles	Winter 2007/2008	Drought threatening agriculture, livestock, fresh water fisheries, hydropower, water supply, tourism, river traffic difficult
Croatia	***Dalmatia, Lika***	Newspaper articles	Summer/autumn 2008	Drought threatening agriculture, water supply, tourism, increasing forest fires danger, state of natural disaster proclaimed for some areas
Croatia	***Slavonia, Dalmatia, Istria***	Newspaper articles	Winter to autumn 2009	Drought threatening agriculture, livestock, water supply, some wells dried, natural disaster proclaimed for some areas
Croatia	***Some Dalmatian islands (Korčula)***	Newspaper articles	Summer 2010	Drought threatening olives, Vela Luka 40 days without rain

5.3 Conclusions and remarks

In a globally changing climate, the region of Croatia belongs to the transitional area between northern Europe with an increase in average precipitation and a drying Mediterranean. During the 20th century, there has been a decreasing trend in precipitation and an increasing trend in temperature for most places in Croatia, during most seasons. In the future, Croatia is expected to be hotter and drier – especially in the summer [12]. Precipitation affects economic development in many ways. Water is an essential factor in many sectors of economy like agriculture, hydro-power, tourism and fisheries; and reductions in the availability of water can lead to serious damages in those sectors.

Hence, it is necessary to develop good system of drought monitoring in Croatia. In the Meteorological and Hydrological Service of Croatia monitoring of meteorological drought has been set up in 2009 and it is still in progress. There is still necessity for systematic meteorological drought research in Croatia. Furthermore, requirements for the monitoring of agricultural and hydrological drought in Croatia are obvious. There are not available data of drought impacts in quantitative way.

5.4 Mitigation practices and drought management from all countries/regions added to the archive

5.4.1 Methodology

The Republic of Croatia signed the UN Convention to combat desertification in countries experiencing serious drought and/or desertification. The Croatian Government established the National Committee to Combat Desertification. The basic task of the Committee is the monitoring and participation in the preparation and implementation of a National Action Programme (NAP) [2]. In 2003 the Committee started to work on the preparation of a project under the title "National Action Programme to Mitigate the Effects of Drought and Combat Land Degradation" which was adopted in 2007. In 2004 National Project of Irrigation and Land and Water Management in the Republic of Croatia (NAPNAV) is launched. Its aim was to organize irrigation and concentration of agricultural land and introduce income crops, in order to ensure the conditions for the application of new technologies. This should result in better utilization of natural resources for more efficient agricultural production, and finally bring about the development of rural areas. Under this project, within four years from the project implementation period, irrigated areas should have been expanded from the current 7200 hectares of irrigated land to a minimum of 30000 hectares.

Irrigation as a solution to agricultural drought impact mitigation. Irrigation is a melioration measure for a compensation of water deficit in agricultural production. Generally speaking, irrigation systems in Croatia are quite disorganized. Farmers usually finance the irrigation infrastructure on their own.

The highest development in irrigation was reached before the War of Independence. In 1989 13,290 ha of agriculture land was irrigated. In 1990s only 5,790 ha of land was irrigated (0.28% of cultivated land and 0.44% of sown land). Today, the official data about methods and infrastructure used in practice in Croatia are scarce and with poor precision [2]. The irrigated area of agricultural land in Croatia is one of the smallest in Europe. According to the agricultural census from 2003 it is estimated that from total of 1,077.403 ha agricultural area only 0.86% is irrigated [13].

The most affected water regions are Dalmatia, especially the River Neretva valley, and Zadar – Biograd region. In the rest of country irrigated areas are dispersed and depend on the cultivation of specific cultures.

5.4.2 Results

One of the most important questions about irrigation is what are the actual demands and potentials for irrigation of agriculture land in Croatia. Table 5.4 gives the estimated water deficit for exploitation of full biological potential of particular crops. Climate characteristics and optimal cultivated methods have been taken into account for this purpose.

Table 5.4 Water deficit according to climate-plant relation of some particular agriculture crops cultivated in the average climatic condition of particular water basins [2]

River basin	Meteorol. station	Annual R (mm)	Annual demands (mm)					
			Maize	Sugar beet	Potato	Watermelon	Tomato	Agrum
Drava-Dunav	Osijek	721	105	161		96	147	
	Varaždin	727	23		43		73	
Sava	Slav. Brod	700	56	110			102	
Littoral	Pula	910	132			191	243	
	Gospić	666	21		46		81	
Dalmatia	Zadar	1022				201	301	
	Dubrovnik	1202				213	310	213

We can see that under the average climatic conditions there is a water shortage of 21mm to 310 mm for the cultivation of analysed crops. From the agricultural point of view drought can start when a plant does not have enough water during the vegetation season which can affect the crop yield. Drought in Croatia occurs every three to five years and it reduces the yield of some crops from 20% to 40% depending on the intensity and duration of drought [2].

Although there are many possibilities for irrigation in Croatia they are rarely used. The water source used for irrigation is usually surface water (rivers, lakes) and sometimes underground water. There are many water reservoirs made but the water for irrigation purposes is almost not used. The quality of water is satisfying in the continental part of Croatia, in watersheds of rivers Dunav, Drava and Sava and in Istrian peninsula. However, at the coast and in Dalmatia the water for irrigation is often salinized and alkaline.

The potential irrigation development in water regions in Croatia is given in table 5.5.

Table 5.5. Short and long term estimation of irrigation development and annual water demands in river basins in Croatia according to NAP [2].

River basins	Planned area **2009.**, ha	Annual water demands , 10^6 m^3	Planned area **2015.**, ha	Annual water demads, 10^6 m^3
Drava - Dunav	14 650	19,85	36 800	50,57
Sava	5 070	6,37	13 200	16,78
Littoral - Istria	3 250	7,92	5 950	14,45
Dalmatia	6 150	17,69	11 750	33,94
Total	29 120	51,83	67 700	114,84

5.5 Conclusions and remarks

For the successful combat to drought impacts a great water reserves are needed for irrigation of vulnerable area. As it is mentioned above Croatia is reach in water and there exist basic preconditions for advanced irrigation systems then it is today. However, more detailed hydrological analysis showed that in the natural conditions there is not enough water storage for irrigation during low water period and especially when drought occurs. The preventive possibility to mitigate drought impacts can include the water transport from the region with excess water to region with temporary water deficit as well as collecting and storing the water for irrigation purposes. This includes building canals, water supply systems and surface water reservoirs as storages during dry periods.

Bibliography

[1] Statistical Yearbook of the Republic of Croatia 2010. Croatian Bureau of Statistics, ISSN 1333-3305 Zagreb, 2010; 588 pp.

[2] National Action Programme to Mitigate the Effects of Drought and Combat Land Degradation (in Croatian). Ministry of Environmental Protection, Physical Planning and Construction, Zagreb, 2007.

[3] Zaninović, K., Gajić-Čapka, M., Perčec-Tadić, M. et al, 2008: Klimatski atlas Hrvatske / Climate atlas of Croatia 1961-1990., 1971-2000. Državmi hidrometeorološki zavod, Zagreb, 200 str.

[4] Fifth National Communication of the Republic of Croatia under the United Nation Framework Convention on the Climate Change. Republic of Croatia, Ministry of Environmental Protection, Physical Planning and Construction, 2009. http://unfccc.int/national_reports/annex_i_natcom/submitted_natcom/items/4903.php

[5] Economic losses from natural hazards in Croatia during the period 1995–2008. Državno povjerenstvo za procjenu štete od elementarnih nepogoda, 2009.

[6] FAO/UNESCO, 1977. World of desertification. United Nations Conference on Desertification (UNCOD), 1977

[7] UNEP/GEMS, 1992. Global reassessment of desertification

[8] UNEP, 1997. World Atlas of desertification, Second edition, pp 182

[9] Mihajlović, D., 2005: Monitoring the 2003-2004 meteorological drought over the Panonian part of Croatia. Int. J. Climatol., Vol 26, 15, 2213-22215

[10] Cindrić, K., Pasarić, Z., Gajić-Čapka, M., 2010: Spatial and temporal analysis of dry spells in Croatia. Theor. Appl. Climatol., Vol 102, No 1-2, 171-184

[11] Juras J., Cindrić K., 2009: Spatial distribution of *SPI* on the Zadar archipelago in the summer 2008 (in Croatian). Jadranska meteorologija, 13, 54-58

[12] United Nations Development Programme (UNDP), 2008: A climate for change – Climate change and its impacts on society and economy in Croatia, UNDP in Croatia Zagreb, pp 282

[13] National Project of Irrigation and Land and Water Management (in Croatian), 2005. Ministry of Agriculture, Forestry and Water Management, Zagreb

6. Report on drought vulnerability estimates based on climatological and geomorfological data

PROJECT INFORMATION	
Project acronym:	DMCSEE
Project title:	Drought Management Centre for South East Europe
Contract number:	2008-0017-201002
Starting date:	17. 05. 2010
Ending date:	17. 05. 2012
Project WEB site address:	http://meteo.hr/DMCSEE/
Partner organisation:	Meteorological and Hydrological Service of Croatia
Name of representative:	M. Sc. Ivan Čačić, director
Project manager:	dr. Krešo Pandžić
E-mail:	pandzic@cirus.dhz.hr
Telephone number:	+386 (0)1 45 65 684
DELIVERABLE INFORMATION	
Title of the deliverable:	**Drought vulnerability estimates based on climatological and geomorfological data**
WP/activity related to the deliverable:	Act. 4.2 Drought vulnerability and risk assessment
Type (internal or restricted or public):	Public
Location (if relevant):	Zagreb, Croatia
Author:	Mr Ivica Kisić, external expert
Deadline	17.04.2012. Draft report

6.1 INTRODUCTION

Following the recommended procedure within WP4 in the project "Drought Management Centre for South East Europe" (DMCSEE-OMSZ, 2011), the map of vulnerability to drought for Croatia is prepared using the maps of necessary parameters: slope, irradiation, and precipitation as well as available optional parameters: soil type and land use, as inputs.

Compared with the OMSZ proposal some modifications are introduced that are going to be described in the document. The input maps are presented and discussed at first, followed by the three versions of the vulnerability map, the first one dependent on climatological inputs only, the second one modified by soil type and the final one based on the necessary and the two optional parameters of soil type and land use class.

6.2 SLOPE

The slope map presents the slope angle based on the digital elevation model (DEM). The SRTM DEM of 100 m resolution is used. Calculated angles range from 0° on the flat terrain to 74° in some river canyons and on the mountain slopes (Fig. 6.1), but mostly the slope belongs to the lowest category classes of 0.2 and 0.4 (Tab. 7.1).

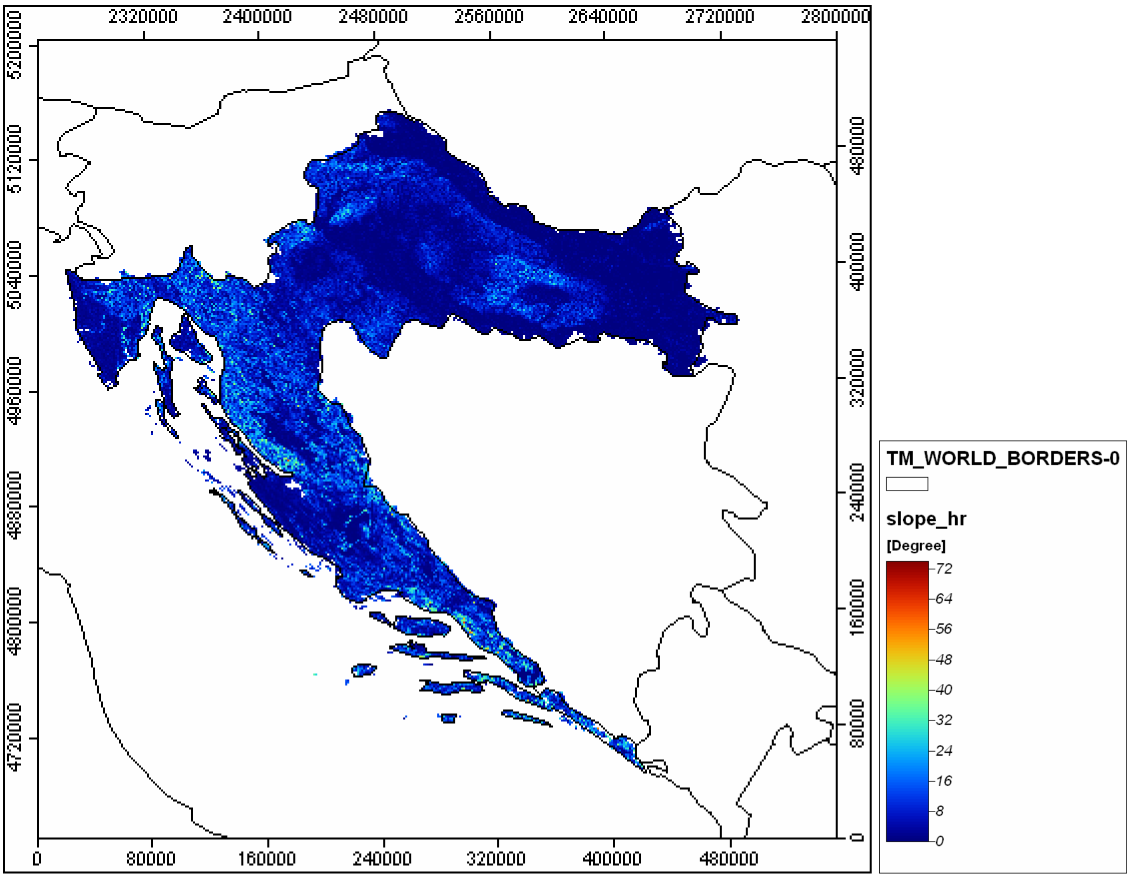


Fig. 6.11: The slope map of Croatia.

6.3 SOLAR IRRADIATION

The potential solar irradiation map (PISR) for the vegetation period calculated with RSAGA rsaga.pisr module (Brenning, 2011) is presented for Croatia in Fig. 6.2. This algorithm is implementation of the Saga GIS module Potential Incoming Solar Radiation (Conrad, 2010) for R statistical computing and visualisation framework (www.r-project.org). PISR was calculated for one year with four hours temporal resolution and clear sky conditions.

It can be seen that maximum values are predicted for the southern slopes while minima are on the northern slopes. Furthermore, the range of values is greater (126.7–1552.6 kWh/m^2) compared to the irradiation map from the observations (Fig. 6.3) since there is a number of pixels with very low irradiation values (<500 kWH/m^2). With the proposed classification procedure, with five equidistant classes, the resulting category map is dominated with the higher vulnerability classes. The map was filtered to reduce this problem but suggestion is that this irradiation vulnerability classes should be connected with some vegetation related thresholds.

The proposed methodology from OMSZ to use the potential solar radiation, calculated by the SAGA GIS module and for the vegetation period, as an input parameter in determining vulnerability to drought in Croatia, gave the results that were inconsistent with the physical characteristics of Croatian climate which could cause drought.

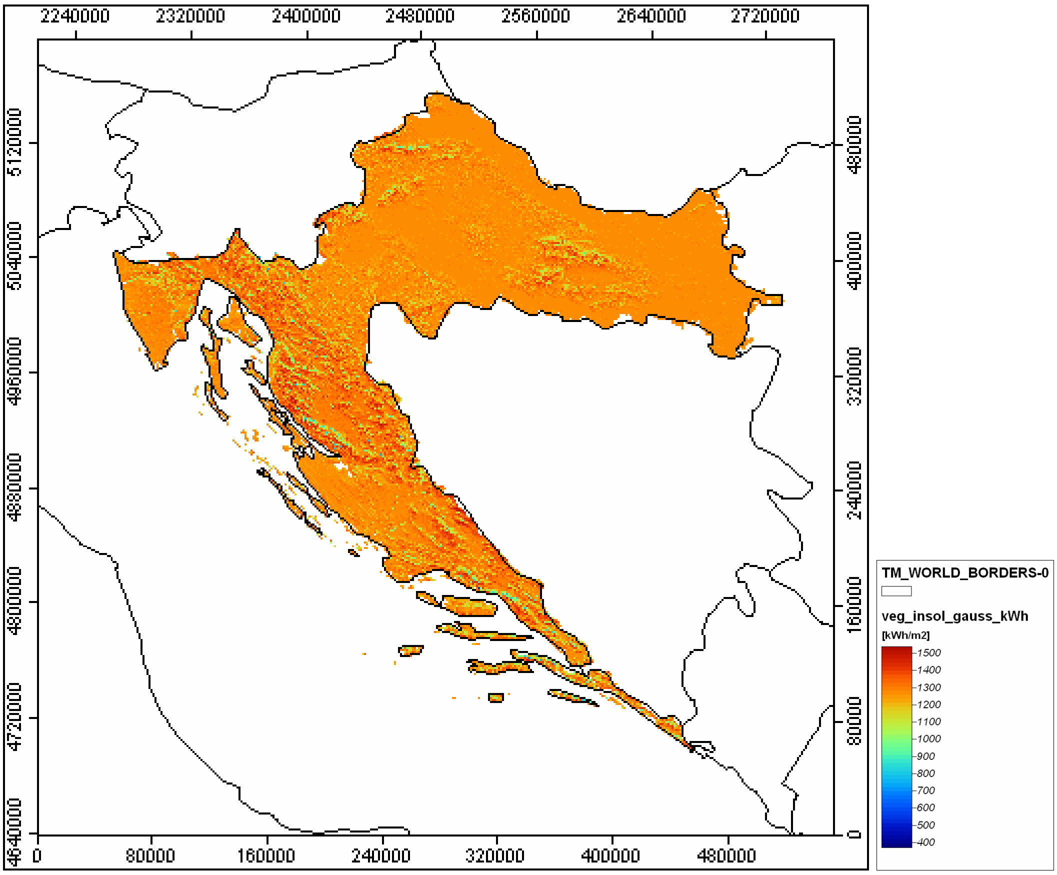


Fig. 6.2: Map of potential solar irradiation for the vegetation period for Croatia

Namely, the irradiation on the territory of Croatia depends significantly on the cloudiness regime and relief. It ranges from 1164.9 to 1635.3 kWh/m^2 (Fig. 6.3) as estimated from the Croatian solar irradiation map for the available 1961–1980 period (Perčec Tadić 2004, Zaninović et al. 2008). The irradiation rises from the north to the south and it is larger on the coast than inland. Also, the values are lower on the mountain tops due to the increased cloudiness in summer. This is opposite to the distribution of potential irradiation which shows maximum values on the mountain summits (Fig. 6.2). It could not be expected that the vulnerability to drought in the vegetation period, due to solar radiation, would be the highest on the mountain tops.

For these reasons the irradiation map, calculated from the measured data in the 1961-1980 period, was used as input parameter that influence vulnerability to drought. Most of the territory belongs to the lowest category classes of 0.2 and 0.4 (Tab. 7.1).

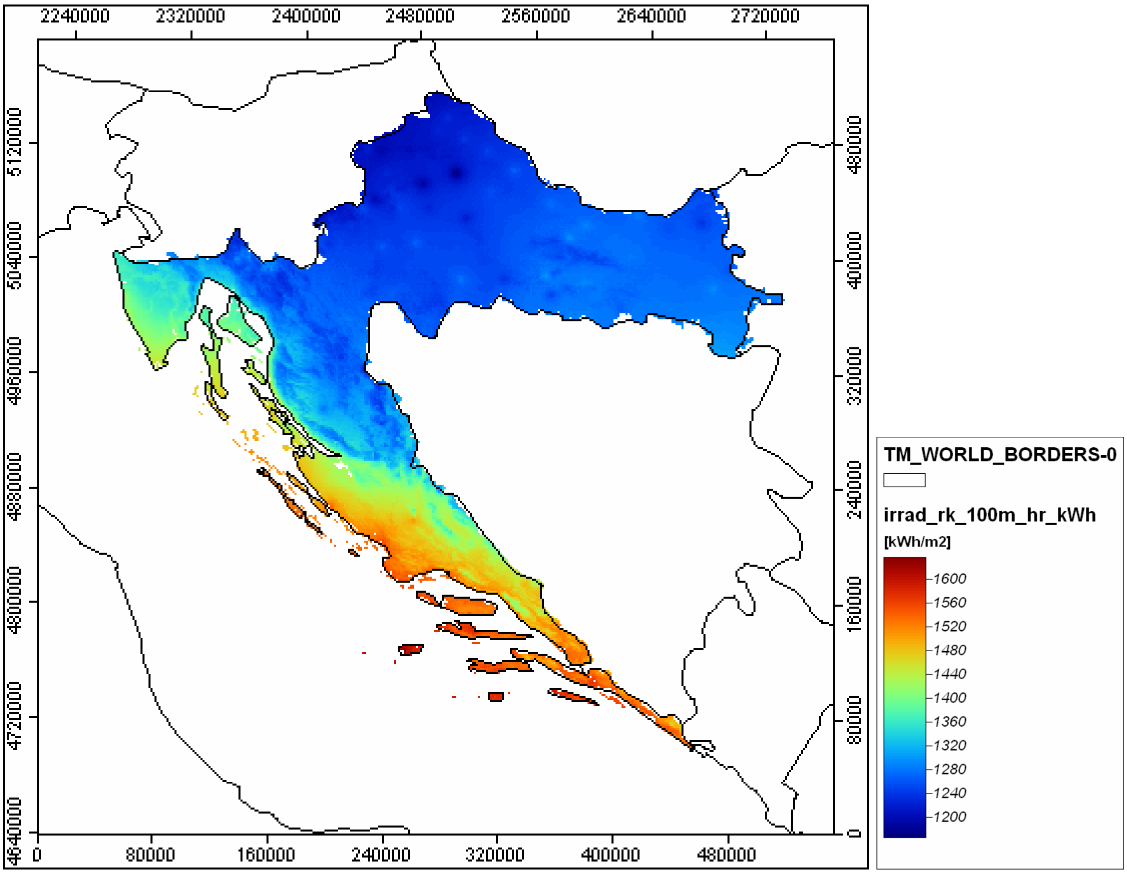


Fig. 6.3: Solar irradiation map of Croatia based on the measured irradiation data in the 1961-1980 period.

6.4 PRECIPITATION

6.4.1 Mean annual precipitation for the 1971–2000 period

Average annual precipitation in Croatia for the period 1971–2000 ranges from about 3900 mm on the summits of the southern Velebit Mountain located along the northern Croatian Adriatic coast to about 300 mm on the outlying islands in the middle Adriatic. The quite dry areas are also the eastern lowland (Slavonia), the middle and southern Adriatic islands and the coastal flat zone of the western Istrian peninsula and middle Adriatic coast. The mountainous hinterland of the Kvarner bay in the northern Adriatic (Gorski kotar) and of the southern Dalmatia as well as the southern Velebit Mountain, are the areas with the highest precipitation amounts in the country.

This map was created by applying the regression kriging framework, as described in Perčec Tadić (2010). Average annual precipitation data from the period 1971–2000 collected on 562 meteorological stations have been used in the geostatistical analysis. The correlation with the climatic factors such as altitude, weighted distance to the sea, latitude and longitude has been established and the residuals (differences of observation and regression prediction) were modelled for the spatial correlation. Final prediction of the average annual precipitation was calculated as a raster map in 1 km resolution. This map was resampled to 100 m resolution for the estimation of the drought vulnerability map.

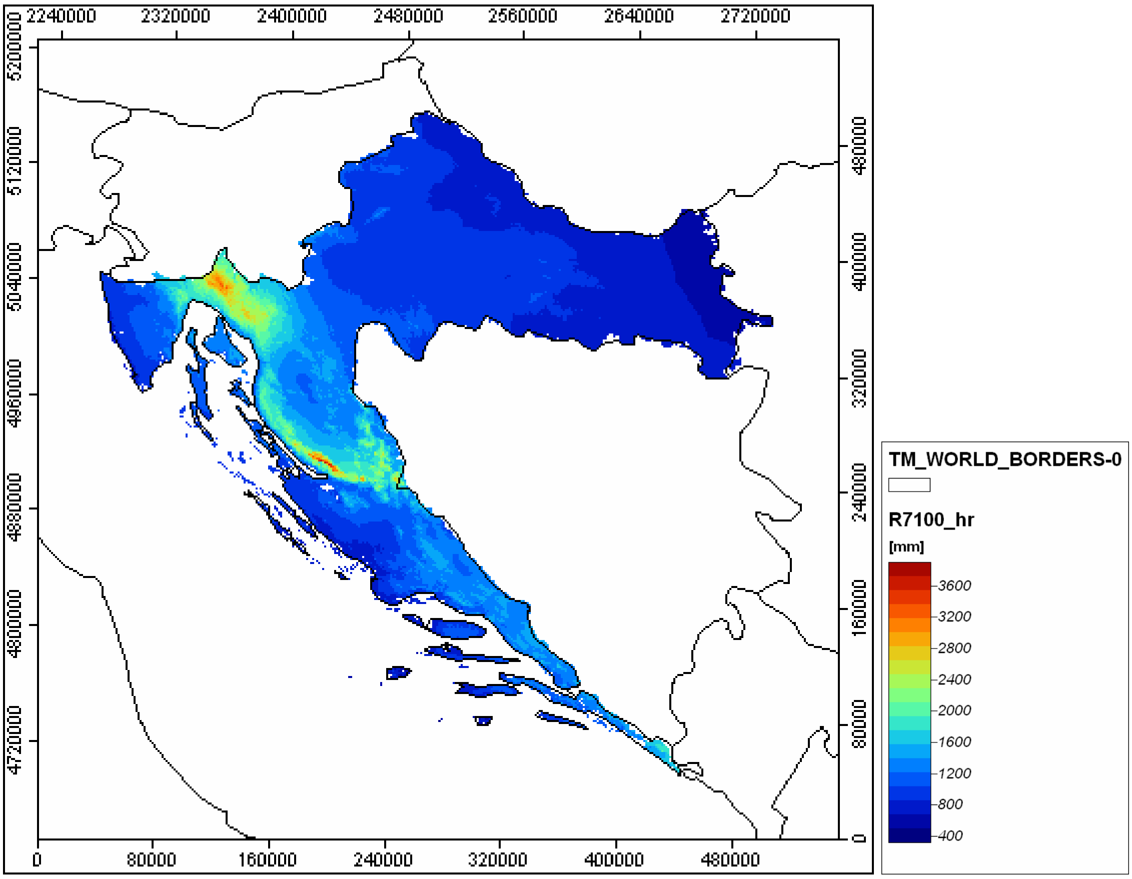


Fig. 6.4: Average annual precipitation for the 1971–2000 period.

6.4.2 Standard deviation of precipitation for the 1971–2000 period

Standard deviation of precipitation was calculated with the same method as precipitation (and solar irradiation), that is regression kriging. Values of standard deviation range from 99 mm to 455 mm. The lowest values are on the western continental part of the country, on the lowland of the eastern continental region and on some coastal areas (western Istria peninsula in the northern Adriatic and the plain Ravni kotari beyond the middle Adriatic coast). Precipitation is the most variable on the mountain areas.

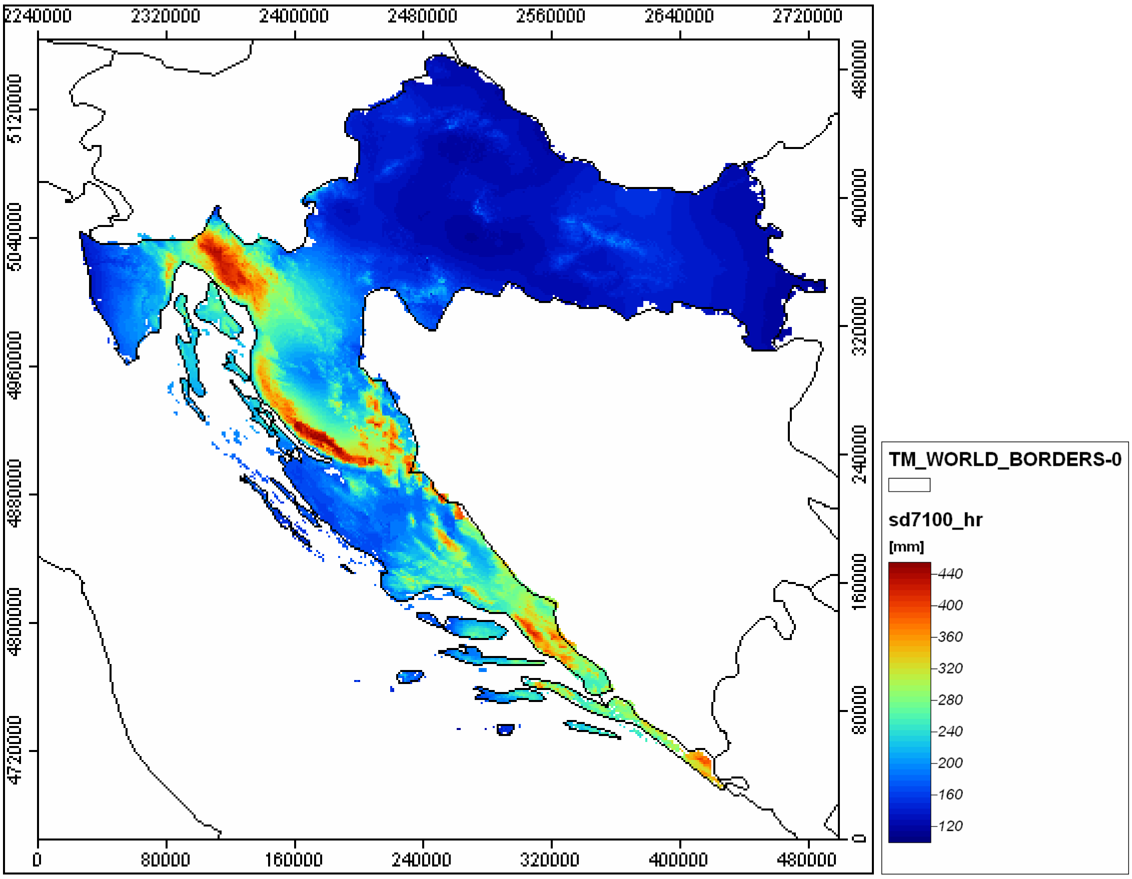


Fig. 6.5: Standard deviation of the annual precipitation for the 1971–2000 period

6.4.3 Ratio of precipitation and standard deviation

The last version of output standards for drought vulnerability (DMCSE-OMSZ, 2011) proposed the ratio of precipitation and standard deviation as the parameter that was intending to represent the extremity of precipitation. The map of this parameter (Rsd) for Croatia is presented in Fig. 6.6. According to this map, the lowest values of this parameter, that correspond to the least vulnerable areas to drought, would be in the areas with the lowest annual precipitation. This is hard to accept. Firstly, it was the discussion about modifying the proposed precipitation parameter by reversing the definition of vulnerability classes. Finally, the coefficient of variation (c_v) (the inverse of the suggested Rsd parameter) was used to define the extremity in precipitation amounts while the vulnerability classes were left as proposed.

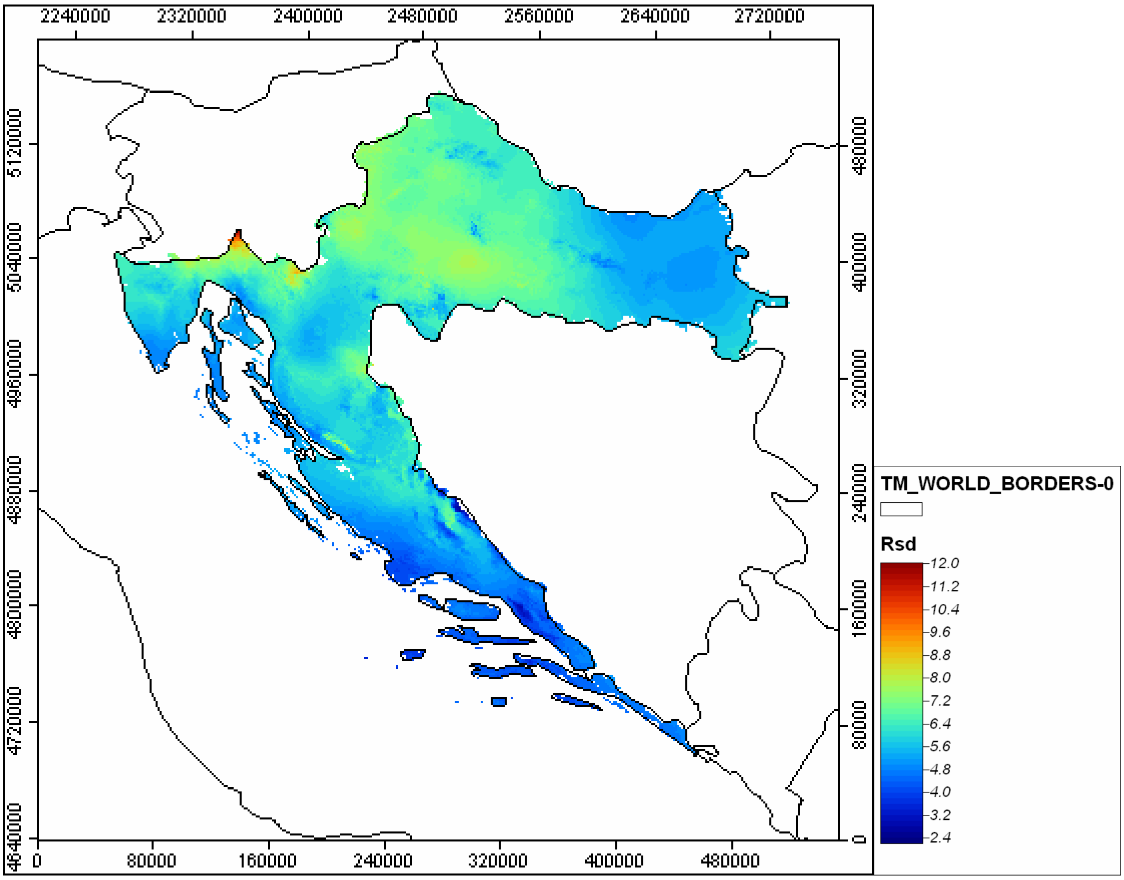


Fig. 6.6: Ratio of precipitation and standard deviation for the 1971–2000 period.

6.4.4 Coefficient of variation

Coefficient of variation, c_v, is defined as the ratio of standard deviation and precipitation. Higher values of c_v are connected with the higher vulnerability to drought (Fig. 6.7). For Croatia, the most sensitive areas are on the southern coast. Coefficient of variation ranges from 8% to 48% of the average annual precipitation amount. With the proposed classification procedure with five equidistant classes the resulting category map is dominated with the lowest category classes of 0.2 and 0.4 (Tab.7.1).

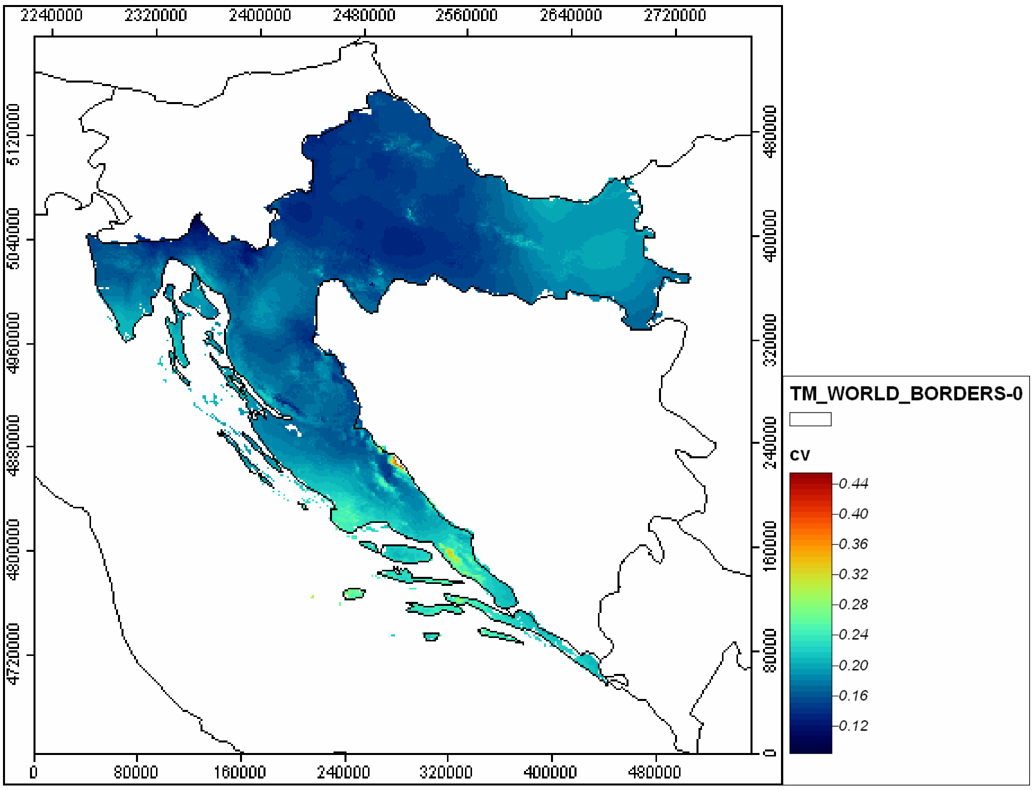


Fig. 6.7: Coefficient of variation of precipitation for the 1971–2000 period.

6.5 SOIL CLASS MAP

The Map of World Soil Resources (WRB) is available from the FAO web page at the scale 1:25.000.000 as a World Soil Resources Coverage (WSRC). It was completed in 1990 from the FAO/UNESCO Soil Map of the World at the scale 1:5.000.000 (FAO, 1971-1981) and from some additional information (WRB). There are 32 soil classes for the world and four of them can be found in Croatia. Luvisols dominate in the continental part of the country, with some Cambisols and Phaeozems. Cambisols dominate in Istria peninsula and the mountainous Lika region, while the rest of the coastal area is covered with Leptosol soils (Fig. 6.8). Widespread are the Luvisols (category 0.4), then Leptosols (category 1.0) and Cambisols (category 0.6) while the rarest are Phaeozems (category 0.8) (Tab. 7.1).

Luvisols (LV) are most common in flat or gently sloping land in cool temperate regions (Central Europe) and in warm regions (e.g. Mediterranean) with distinct dry and wet seasons. Most Luvisols are fertile soils and suitable for a wide range of agricultural uses. They are characterized with a clay-rich subsoil (IUSS Working Group WRB, 2006).

Cambisols (CM) generally make good agricultural land and they are used intensively. Cambisols with high base saturation in the temperate zone are among the most productive soils on earth. Because of the generalisations made on the WSRC, it can be suspected that in the northern part of the mountainos district of Gorski kotar, the WSRC Cambisols are missclasified as Leptosols (Bakšić et al, 2008) while on Medvednica mountain in NW Croatia, beside Luvisols, the Cambisols are also present (Pernar et al, 2009).

Pheaeozems (PH) are more common in America and Asia. In Europe, mostly discontinuous areas are found in Central Europe, notably the Danube area of Hungary and adjacent countries. Wind and water erosion are serious hazards. There can be periods in which the soil dries out (IUSS Working Group WRB, 2006).

Leptosols, LP are the world's most extensive soils (IUSS Working Group WRB, 2006). They are very shallow soils over continuous rock and soils that are extremely gravelly and/or stony (IUSS Working Group WRB, 2006).

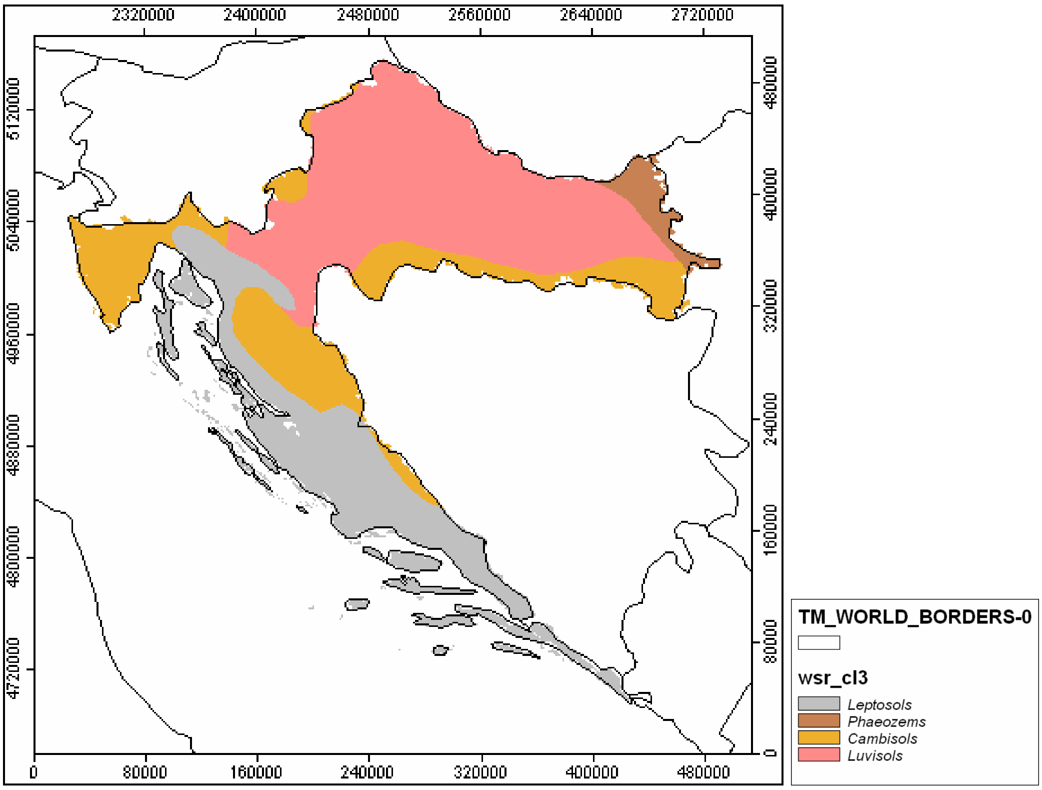


Fig. 6.8: Soil classes (adapted from the Map of World Soil Resources (WSRC)

6.6 LAND USE MAP

Land use classes for the part of the Croatian territory covered with vegetation have been analysed from the Corine Land Cover raster data (CLC 2006). There are 50864.3 km^2 (90%) of the Croatian territory that is covered with some kind of vegetation.

The largest part of the Croatian land (56.4%) is mostly covered with forest and transitional woodland-shrub or occupied by agriculture that has significant areas of natural vegetation belonging to the lowest category class of 0.2. These types of vegetation are not so vulnerable to drought. Vineyards occupy 0.5% of the area and they are slightly more sensitive to drought. Complex cultivation patterns, natural grasslands and sclerophyllous vegetation are the second most spread land cover types that occupy 26.2% of the territory. They belong to the 0.6 vulnerability class. Fruit trees and berry plantations are quite sensitive to drought but grow on only 0.2% of the land. Most sensitive to drought is arable land (6.7%) and unfortunately in Croatia it is mostly non-irrigated (6.5%) according to the CLC 2006 data (Tab. 6.1).

When available, the CLC 2006 data were compared with the national sources. According to the CBS (2011), forests occupy 39.5% of the territory. According to the National Agricultural census Report (CBS 2003), Croatia has 0.5% of vineyards, 0.6% of orchards, 14.2% arable land and gardens and only 0.2% of irrigated arable land.

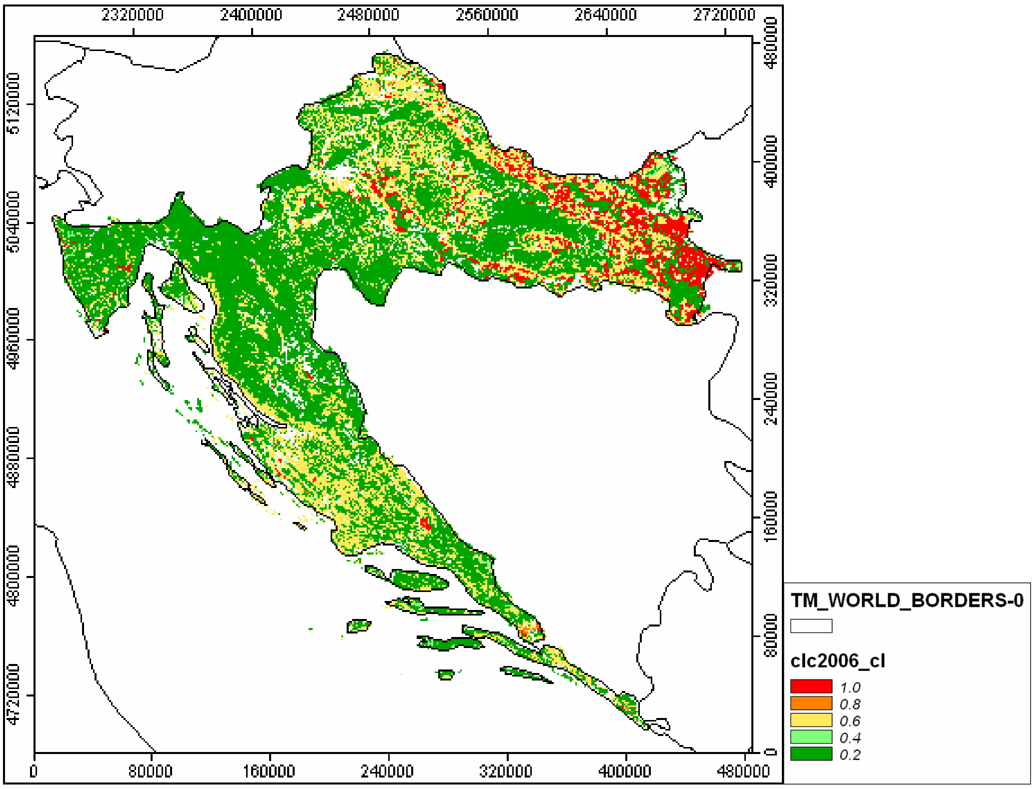


Fig. 6.9 Land use map

Table 6.1: Description of the classes for the land use map

Vulnerability class	Description	Code	Area [%]
0.2	Olive groves, Land principally occupied by agriculture, with significant areas of natural vegetation, Broad-leaved forest, Coniferous forest, Mixed forest, Transitional woodland-shrub	223, 243, 311, 312, 313, 324	56.4%
0.4	Vineyards	221	0.5%
0.6	Complex cultivation patterns, Natural grasslands, Moors and heathland, Sclerophyllous vegetation, Sparsely vegetated areas	242, 321, 322, 323, 333	26.2%
0.8	Fruit trees and berry plantations	222	0.2%
1.0	Non-irrigated arable land, Permanently irrigated land	211, 212	6.7%
	Without vegetation, water area		10.1%

Bibliography

Bakšić D, Pernar N, Vukelić J, Baričević D (2008) Properties of cambisol in beech-fir forests of Velebit and Gorski Kotar. Period biol, Vol 110, No 2, 119-125.

Brenning (2011) Package 'RSAGA', http://cran.r-project.org/web/packages/RSAGA/index.html

CBS (2003) Agricultural Census 2003, Croatian Bureau of Statistics http://www.dzs.hr/Eng/censuses/Agriculture2003/census_agr.htm

CBS (2011) Croatia in Figures, 2011. Croatian Bureau of Statistics http://www.dzs.hr/Hrv_Eng/CroInFig/croinfig_2011.pdf

CLC (2006) Corine Land Cover 2006 raster data - version 15 http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2006-raster-1/

Conrad (2010) Modul for the Potencial Solar Radiation in SAGA GIS, http://www.saga-gis.org

DMCSE-OMSZ (2011) Output_standard_drought_vulnerability_v31.doc

FAO-Unesco 1971 – 1981. Soil Map of the World. Legend and 9 volumes. Unesco, Paris.

IUSS Working Group WRB (2006) *World reference base for soil resources 2006*. 2nd edition. World Soil Resources Reports No. 103. FAO, Rome.

Perčec Tadić M (2004) Digitalna karta srednje godišnje sume globalnog Sunčeva zračenja i model proračuna globalnog Sunčeva zračenja na nagnute, različito orijentirane plohe. *Hrvatski meteorološki časopis*. 39; 41-50.

Perčec Tadić M (2010) *Gridded Croatian climatology for 1961-1990.* Theor Appl Climatol 102 (1-2):87-103

Perčec Tadić M, Gajić-Čapka M, Cindrić K,Zaninović K (2012) Spatial differences in drought vulnerability, European Geophisical Union, General Assembly 2012, 22-27 April 2012, Vienna, Austria.

Pernar N, Vukelić J, Bakšić D, Baričević D, Perković I, Miko S, Vrbek B (2009) Soil properties in beech-fir forests on Mt. Medvednica (NW Croatia). *Periodicum biologorum*. 111 (4); 427–434

Zaninović K, Gajić-Čapka M, Perčec Tadić M, Vučetić M, Milković J, Bajić A, Cindrić K, Cvitan L, Katušin Z, Kaučić D, Likso T, Lončar E, Lončar Ž, Mihajlović D, Pandžić K, Patarčić M, Srnec L, Vučetić V (2008) *Klimatski atlas Hrvatske / Climate atlas of Croatia 1961-1990., 1971-2000*. Zagreb, Državni hidrometeorološki zavod. 200 pp

WRB Map of World Soil Resources 1:25 000 000 - January 2003 http://www.fao.org/ag/agl/agll/wrb/soilres.stm

WSRC World Soil Resources Coverage ftp://ftp.fao.org/agl/agll/faomwsr/wsrll.zip

7. Report on drought vulnerability maps

PROJECT INFORMATION	
Project acronym:	DMCSEE
Project title:	Drought Management Centre for South East Europe
Contract number:	2008-0017-201002
Starting date:	17. 05. 2010
Ending date:	17. 05. 2012
Project WEB site address:	http://meteo.hr/DMCSEE/
Partner organisation:	Meteorological and Hydrological Service of Croatia
Name of representative:	M. Sc. Ivan Čačić, director
Project manager:	dr. Krešo Pandžić
E-mail:	pandzic@cirus.dhz.hr
Telephone number:	+386 (0)1 45 65 684
DELIVERABLE INFORMATION	
Title of the deliverable:	**Drought vulnerability maps**
WP/activity related to the deliverable:	Act. 4.2 Drought vulnerability and risk assessment
Type (internal or restricted or public):	Public
Location (if relevant):	Zagreb, Croatia
Author:	Mr Marinko Oluić, external expert
Deadline	17.04.2012. Draft report

7.1 DROUGHT VULNERABILITY MAPS

The first version of the drought vulnerability map (Fig. 7.1) is calculated from the category maps of slope, irradiation and coefficient of variation of precipitation. It is dominated with the lowest vulnerability classes of “not vulnerable” and “slightly vulnerable” since the lowest class categories of 0.2 and 0.4 are the most common on the category maps of slope, coefficient of variation of precipitation and solar irradiation.

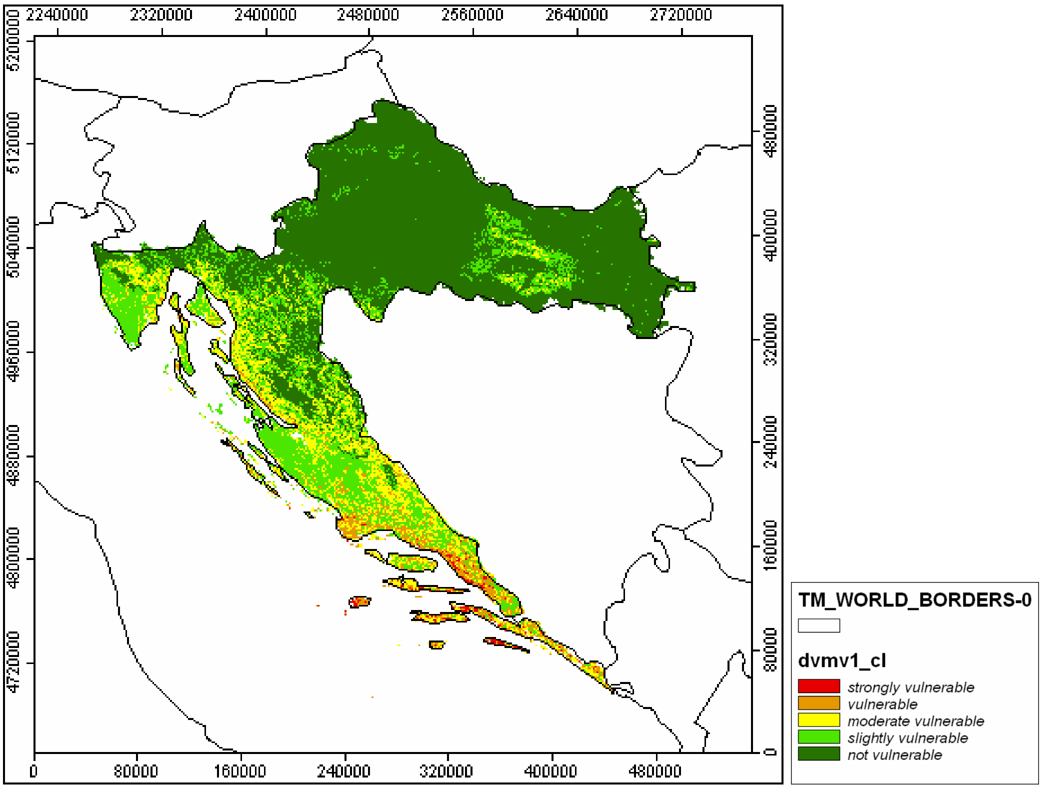


Fig. 7.1: Categorical drought vulnerability map calculated from the category maps of slope, irradiation and coefficient of variation of precipitation.

Inclusion of soil information rises the drought vulnerability most evidently on the coast and on the Dinaric mountains as well as in the very eastern lowland of Slavonia (Fig. 7.2). Coastal zone is dominated by the Leptosols (class 1.0, tab. 6.1). The excessive internal drainage and the shallowness of many Leptosols can cause drought even in a humid environment (IUSS Working Group WRB, 2006).

Continental part of the country mostly belongs to the vulnerability class “not vulnerable”. Only dryer (east of Croatia) or steeper mainland (Slavonian Mountains) can be “slightly vulnerable”. “Slightly vulnerable” are also the Istria peninsula and the mountainous Lika region where only some smaller parts are in the classes “not vulnerable” or “moderately vulnerable”. Along the coast vulnerability rises to the south, from “moderately vulnerable” and “vulnerable” on the northern Adriatic coast and over the nearby Velebit Mountain, to the predominant class “vulnerable” on the southern Adriatic coast. “Strongly vulnerable” can be on some steeper slopes with higher irradiation and/or higher precipitation variability.

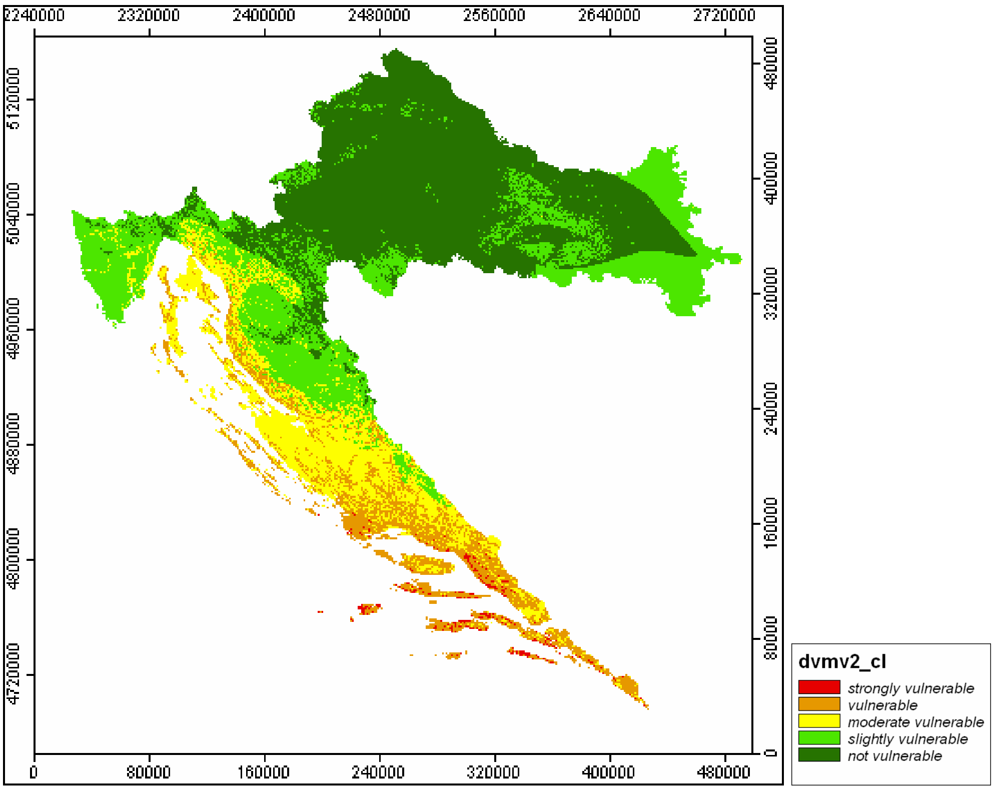


Fig. 7.2: Categorical drought vulnerability map calculated from the category maps of slope, irradiation, coefficient of variation of precipitation and soil type.

Final version of the drought vulnerability map (Fig. 7.3) is calculated from the category maps of slope, irradiation, coefficient of variation of precipitation, soil classes and the land cover classes.

It has been calculated for the areas with vegetation.

The most eastern inland part of Croatia is considered the “moderately vulnerable” to drought. That area is mainly associated with arable land or complex cultivation patterns. Forests in this area belong to the classes “not vulnerable“ and “slightly vulnerable”. On the north-western inland area the woods are mainly “not vulnerable”, while the arable land and cultivated areas are “slightly vulnerable”. “Slightly vulnerable” are also the Istria peninsula and Lika region where only some smaller parts are in the classes “not vulnerable” (mixed forests) or “moderately vulnerable” (cultivated land or pastures). On the northern Adriatic coast vulnerability rises, and becomes “moderately vulnerable” (forests) and “vulnerable” (cultivated areas, sparse vegetation or shrub). On the middle Adriatic coast the “moderately vulnerable” are mostly transitional woodlands while grassland and cultivated areas are “vulnerable”. Some smaller areas can be also “strongly vulnerable”

Inclusion of the land use map in the analysis, modified the vulnerability map compared with the second version of the map. The vulnerability increased mainly on the cultivated land, natural grassland and arable land, but decreased mainly in the forests and on olive groves which are adapted to the dryness.

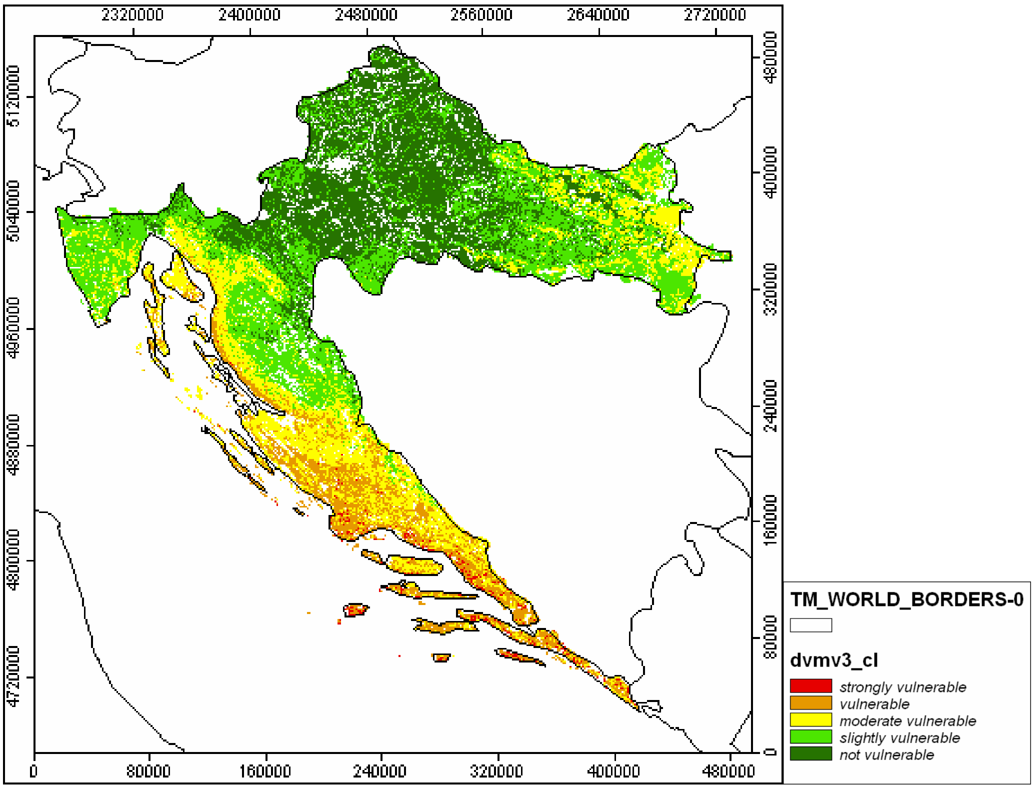


Fig. 7.3: Categorical drought vulnerability map for the areas covered with vegetation. It is calculated from the category maps of slope, irradiation, coefficient of variation of precipitation, soil type and land cover type.

7.2 STATISTICAL ANALYSIS OF THE MAPS

One of the attempts to summarize complex interactions of terrain, soil and climatological properties in only one parameter that would be capable to describe the sensitivity to drought is the calculation of the drought vulnerability map. According to these preliminary results, 28.1% of the territory of Croatia is not vulnerable to drought (Tab. 7.2). Slightly vulnerable is 29.5% of the area, and 21.1% is moderately vulnerable. Vulnerable to drought is 10.3% and only 1% of the territory is strongly vulnerable. The 10% of the land without vegetation or water bodies has not been classified.

The major concern in this kind of analysis is how to set the limiting values for the vulnerability classes. Beside the already mentioned problem of the skewed distribution, there can also be the disadvantage in setting the equal intervals for the classes on the input maps as well on the vulnerability map. The equal intervals can tell where the values are smaller or larger. Further research should be oriented to the definition of the actual vulnerability classes that would have to be established on some real drought data. Solving these relations could also allow for an expert decision on how to treat a land that belongs to a certain vulnerability class.

Table 7.1: Proportion of the necessary and optional parameter classes related to the vulnerability classes over the territory of Croatia expressed in km^2. Soil classes: LV - Luvisol, CM - Cambisol, PH - Phaeozem, LP – Leptosol. Land cover code according to Tab. 6.1.

Vlb.	Slope		Irradiation		Coeff. of variation c_v		World soil		Land cover	
class	Limits [°]	Area [km^2]	Limits [kWh/m^2]	Area [km^2]	Limits	Area [km^2]	Type	Area [km^2]	Code	Area [km^2]
0.2	0–5	32325.6	1164.9-1259.0	18609.2	0.08-0.16	21582.5	-	-	223,243,311,312,313,324	31879.2
0.4	5–12	14482.4	1259.0-1353.1	22763.5	0.16-0.24	33802.6	LV	24923.5	221	289.0
0.6	12–20	6699.3	1353.1-1447.2	6526.7	0.24-0.32	1130.2	CM	13508.0	242,321,322,323,333	14803.6
0.8	20–35	2875.2	1447.2-1541.3	7485.7	0.32-0.40	37.6	PH	1824.6	222	95.5
1.0	35–90	172.2	1541.3-1635.4	1169.6	0.40-0.48	1.9	LP	16298.8	211,212	3797.0

Table 7.2: Proportion of drought vulnerability classes over the territory of Croatia expressed in km^2 and percents. Drought vulnerability classes: NV - “not vulnerable”, SlV - “slightly vulnerable”, MV - “moderately vulnerable”, V - “vulnerable” and StV - “strongly vulnerable”.

Vulnerability class	Drought Vulnerability Fig 9		Drought Vulnerability Fig 10		Drought Vulnerability Fig 11		
	limits	area [km^2]	limits	area [km^2]	limits	area [km^2]	area [%]
NV	0.6-1.0	33015.3	1.00-1.52	24744.9	1.2-1.8	15891.7	28.1
SlV	1.0-1.4	12445.1	1.52-2.04	16016.1	1.8-2.4	16678.3	29.5
MV	1.4-1.8	7852.8	2.04-2.56	9095.5	2.4-3.0	11925.1	21.1
V	1.8-2.2	2784.3	2.56-3.08	6241.7	3.0-3.6	5797.2	10.3
StV	2.2-2.6	457.3	3.08-3.60	456.5	3.6-4.2	571.9	1.0

Bibliography

Bakšić D, Pernar N, Vukelić J, Baričević D (2008) Properties of cambisol in beech-fir forests of Velebit and Gorski Kotar. Period biol, Vol 110, No 2, 119-125.

Brenning (2011) Package ‘RSAGA’,

http://cran.r-project.org/web/packages/RSAGA/index.html

CBS (2003) Agricultural Census 2003, Croatian Bureau of Statistics

http://www.dzs.hr/Eng/censuses/Agriculture2003/census_agr.htm

CBS (2011) Croatia in Figures, 2011. Croatian Bureau of Statistics

http://www.dzs.hr/Hrv_Eng/CroInFig/croinfig_2011.pdf

CLC (2006) Corine Land Cover 2006 raster data - version 15

http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2006-raster-1/

Conrad (2010) Modul for the Potencial Solar Radiation in SAGA GIS, http://www.saga-gis.org

DMCSE-OMSZ (2011) Output_standard_drought_vulnerability_v31.doc

FAO-Unesco 1971 – 1981. Soil Map of the World. Legend and 9 volumes. Unesco, Paris.

IUSS Working Group WRB (2006) *World reference base for soil resources 2006*. 2nd edition. World Soil Resources Reports No. 103. FAO, Rome.

Perčec Tadić M (2004) Digitalna karta srednje godišnje sume globalnog Sunčeva zračenja i model proračuna globalnog Sunčeva zračenja na nagnute, različito orijentirane plohe. *Hrvatski meteorološki časopis*. 39; 41-50.

Perčec Tadić M (2010) *Gridded Croatian climatology for 1961-1990.* Theor Appl Climatol 102 (1-2):87-103

Perčec Tadić M, Gajić-Čapka M, Cindrić K,Zaninović K (2012) Spatial differences in drought vulnerability, European Geophisical Union, General Assembly 2012, 22-27 April 2012, Vienna, Austria.

Pernar N, Vukelić J, Bakšić D, Baričević D, Perković I, Miko S, Vrbek B (2009) Soil properties in beech-fir forests on Mt. Medvednica (NW Croatia). *Periodicum biologorum*. 111 (4); 427–434

Zaninović K, Gajić-Čapka M, Perčec Tadić M, Vučetić M, Milković J, Bajić A, Cindrić K, Cvitan L, Katušin Z, Kaučić D, Likso T, Lončar E, Lončar Ž, Mihajlović D, Pandžić K, Patarčić M, Srnec L, Vučetić V (2008) *Klimatski atlas Hrvatske / Climate atlas of Croatia 1961-1990., 1971-2000*. Zagreb, Državni hidrometeorološki zavod. 200 pp

WRB Map of World Soil Resources 1:25 000 000 - January 2003 http://www.fao.org/ag/agl/agll/wrb/soilres.stm

WSRC World Soil Resources Coverage ftp://ftp.fao.org/agl/agll/faomwsr/wsrll.zip