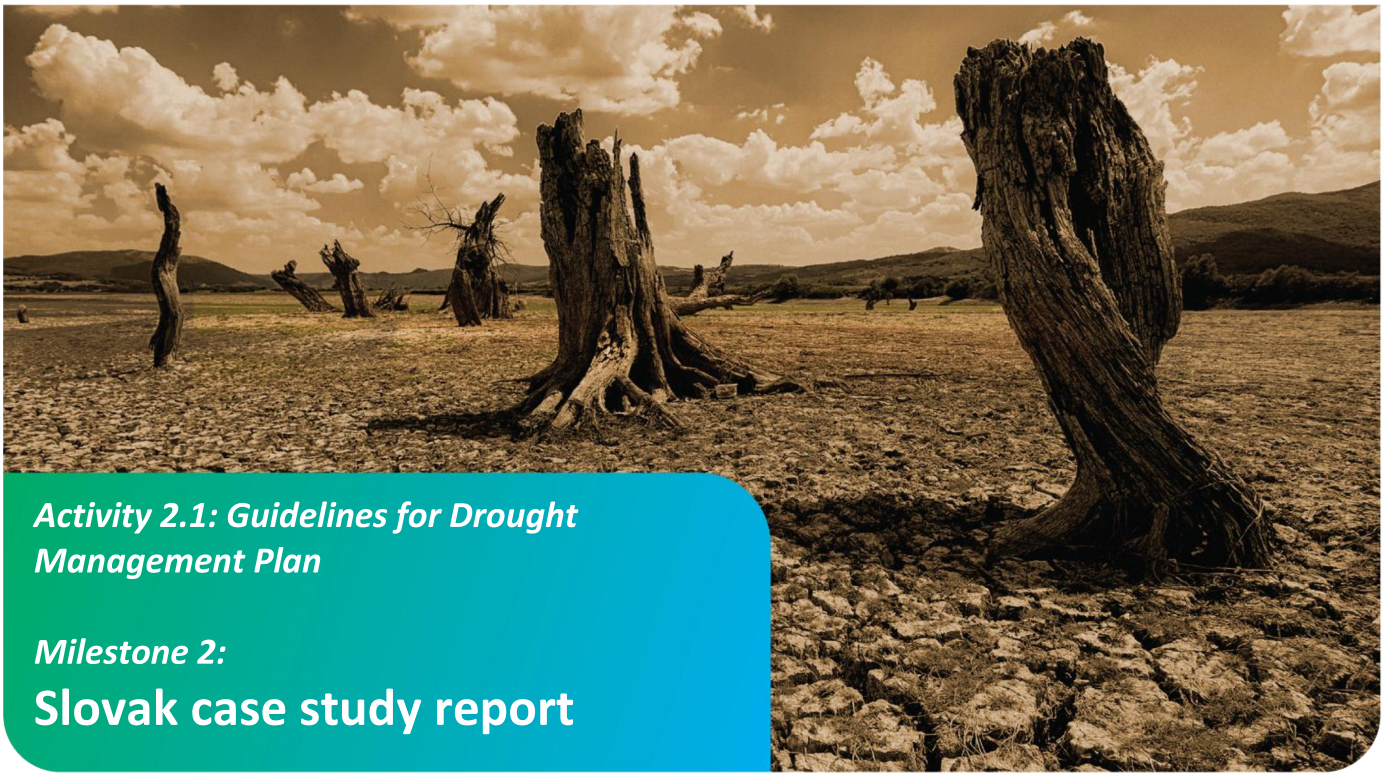
Integrated Drought Management

Programme in Central and Eastern Europe



Activity 2.1: Guidelines for Drought Management Plan

Milestone 2:

Slovak case study report

WP:	WP2: National planning processes
Activity:	Act. 2.1: Guidelines for Drought Management Plans
Activity leader:	Elena Fatulova; GWP Slovakia
Participating partners:	Slovak Hydrometeorological Institute (SHMU) Soil Science and Conservation Research Institute (VUPOP) NPPC
Name of the output	**Slovak Study Report**
Purpose of the output:	*Assessment of one drought period (2011/2012) with the aim to develop a national drought indicator system, early warning system and further basic elements (thresholds for classification of drought stages, mitigation measures) for the production of Drought management Plan. Output will be used as a basis for activity 2.1. Guidelines for Drought Management Plans.*

ABBREVIATIONS

CEE	Central and Eastern Europe
CIS	Common Implementation Strategy for the WFD
EC	European Commission
EU	European Union
GWP	Global Water Partnership
DMP	Drought Management Plan
DWG	Drought Working Group
ED	Environmental department
IDMP	Integrated Drought Management Programme
NAP	National Action Programme
VUPOP	Soil Science and Conservation Research Institute
MARD	Ministry of Agriculture and Rural Development
ME	Ministry of Economy
MoE	Ministry of the Environment of the Slovak Republic
SVP	River Basin Management Plan
SIZP	Slovak Environmental Inspectorate
SHMU	Slovak Hydrometeorological Institute
SK	Slovakia
SOP	State Nature Protection
SRBE	Slovak River Basin Enterprise
UNCCD	United Nations Convention to Combat Desertification
WS&D	Water scarcity and drought
WFD	Water Framework Directive
WRMP	Water Resources Management Programm

1. INTRODUCTION

In September 2013 GWP CEE countries have launched an ambitious program under the name "Integrated Drought Management Programme in the central and Eastern Europe (IDMP CEE). The programme has been developed under challenges of „Water and Climate Programme". The general objective of the IDMP CEE is to support regional initiatives associated with effort to develop an integrated drought policy built on the principles of drought risk management through the application of preparedness and mitigation measures.

The specific objectives of the IDMP CEE are as follows:

- To create a scientific platform with the aim to share the best practices and knowledge relating to all aspects of drought policy (management, planning, professional experiences),
- To develop a Guidelines for production of Drought management plans,
- To join the public into the process of development of a national drought management policy (through national consultations and international workshops).

A part of IDMP CEE work packages is the Activity 2.1 ***Guidelines for Drought Management Plans.*** The aim of this activity is to develop Guidelines for production of Drough management Plans (DMP) taking into account the national and regional particularities of CEE region. DMP presents an administrative tool for implementation and enforcement of a new drought policy moving from crisis management to risk management based approach.

The Guidelines shall be primarily oriented on the national level utilising all practical expriences of the involved countries. One of the main sources for the Guidelines development is a Slovak case study providing example for step by step process intended to provide a roadmap that countries can follow in the development of a national drought management policy and drought preparadness/mitigations plans (DMP) at the national level.

2. PURPOSE AND SCOPE OF THE STUDY

General objective of the study is to provide methodologies for drough assessment used in Slovakia and design all necessary steps for development of functioning drought management system through implementation of DMP.

The following specific objectives have been set to achieve this general objective:

- To select a national indicator system consisting of meteorological, hydrological, agricultural and forestry indicators suitable for identification of drought events and assessment of the drought severity,
- To evaluate the last serious drought episode occurred in Slovankia during the years 2011 – 2012 on the base of available data from the state monitoring network,
- On the base of the detailed assessment of monitored meteorological data in a spatio-temporal scale to set a thresholds for the chosen indicators with the aim to define a different drought stages reflecting drought severity,
- To design an early warning system tailored on Slovak conditions,
- To suggest a framework program of measures for each drought stage with the aim to minimalize a drought impacts (part of DMP),
- To develop an organizational structure for drought management ensuring coordination among drought affected sectors and stakeholders on all levels (part of DMP),
- To identify gaps and uncertainties preventing further actions for development of effective drought policy,

- To specify a measures for removing of identified shortcomings.

The following principles have been taken into account during the study execution:

- Suggested procedures are in line with the European drought policy based on the risk based approach. The main principles are summarised in the policy documents issued by EC (e.g. "***Addressing the challenge of water scarcity and droughts in the European Union"*** (COM (2007)414 final, 18 July 2007), ***"A Blueprint to Safeguard Europe's Water Resources"*** (COM (2012) 673 final) (further Blueprint),
- Drought issues are solved in accordance with the principles of integrated drought management in the context of Water Framework Directive (WFD),
- Applied methodologies for development of DMP are based on recommendations provided in the technical report ***"Drought Management Plan Report Including Agricultural, Drought Indicators and Climate Change"*** (Report 2007). The document presenting general guidelines was approved by Water Directors in 2007 within the process of Common Implementation Strategy for Implementation of WFD (CIS).
- The study is part of the National Action Programme of the Slovak Republic (NAP) to combat drought (UNCCD) as a strategic material identifying the causes and factors leading to the drying out of the land and its subsequent degradation. This will include a comprehensive definition of measures to improve the situation.

In accordance with long-term (10-year) strategy to combat desertification UNCCD NAP fundamental objective is to define measures to mitigate drying of the land. As implementation tools are given:

- Permanent monitoring of drought in soils and land
- Information System on the occurance and consequences of drought in Slovakia
- Involvement in monitoring of drought in Europe
- Development of risk management plans caused by drought.

In accordance with above mentioned EU guidelines (Report 2007) and pursuant to Article 13.5 of WFD, DMP shall be produced voluntarily as an additional planning document and included into River basin management plans (RBMPs). Even though the DMP is not obligation of Member States, it should be developed in cases when drought is considered to be a relevant water management issue (e.g. documented by meteorological monitoring). Member States were encouraged to produce a DMP within the first planning cycle by December 2009. The implementation of drought policy within the second cycle of RBMPs (December 2015) is strongly supported by EC through measures included in the Blueprint.

A possible content for the documents integrating the DMP may include (Report 2007):

- General basin characterisation under drought conditions,
- The river basin's experience on historical droughts,
- Characterization of droughts within the basin,
- Drought warning system implementation,
- Program of measures for preventing and mitigating droughts linked to indicators systems,
- Organizational structure of the DMP (identification of competent entity, committee or working group to identify drought impacts and propose management measures),
- Update and follow-up of the DMP,
- Public supply specific plans,
- "Prolonged drought" management as required in article 4.6 of WFD.

The main items needed to develop a Drought Management Plan are summarised in Report 2007 as follows:

- Indicators and thresholds establishing onset, ending, and severity levels of the exceptional circumstances (prolonged drought),

- Measures to be taken in each drought phase in order to prevent deterioration of water status and to mitigate negative drought effects,
- Organizational framework to deal with drought and subsequent revision and updating of the existing drought management plan.

As stated above the first step in the process is identification of a national drought indicator system consisting of suitable meteorological, hydrological and agricultural indicators. Based on their comparison and correlations reasonable thresholds for determination of different drought stages shall be derived. The following drought stages are recommended in the Report 2007:

- ***Normal status***: this phase should be seen as the hydrological planning one, in which strategic and long term measures are applied. These measures concern water demand management (water efficiency measures) and might include hydraulic infrastructures for improving the storage and regulation capacity of the river basin, infrastructures that promote the use of non-conventional resources (e.g. treatment and reuse facilities) and any other measures that might need extended time frames to be implemented.
- ***Pre-alert status***: the objective is to prevent the deterioration of water bodies while ensuring the activation of specific drought management measures, and continuing to meet water demands. These are mainly informative and control measures, as well as voluntary water saving measures.
- ***Alert status***: it is an intensification of the pre-alert status, since drought progresses as well as measures to apply. It is a priority to continue preventing the deterioration of water bodies status. These types of measures should be focused on saving water. Demand restrictions might be applied, depending on the socio-economic impacts, and by consensus of the affected stakeholders. Areas with high ecological value should be monitored more intensively to prevent their deterioration,
- ***Emergency or extreme status***: when all previous prevention measures have been applied, but the drought situation prevails to a critical status, when no water resources are sufficient for the essential demands (even affecting and restricting public supply), additional measures might be used to minimize impacts on water bodies and ecological impacts.

Measures to be taken during hydrological droughts can be grouped as follows:

- ***Preventative or strategic measures*** are developed and used under the normal status. They belong to the hydrological planning domain and their main objective is reinforcing the structural system to increase its response capacity (to meet supply guarantees and environmental requirements) towards droughts. These are measures to be taken in RBMP.
- ***Operational measures*** are those that are typically applied when droughts occur (during pre-alert and alert statuses). These are mainly control and information measures in pre-alert and conservation resources measures. If the drought is prolonged excessively, the status of water resources can deteriorate to a point in which emergency operational measures might be needed, consisting essentially of applying water restrictions. Severe Water conservation measures and restrictions, to be adopted if drought worsens to extreme status, should be ranked according to parameters such as: priorities among different uses, environmental requirements, status of drought etc.
- ***Organizational measures*** establish competent agents and an appropriate organization to develop and follow-up the DMP; create coordination protocols among administrations and public and private entities directly linked to the problem, in particular to those entities in charge of public supply
- ***Follow-up measures*** serve in the process of watching out for the compliance and application of the DMP and its effects.
- **R*estoration or exit drought measures*** include the deactivation of adopted measures and the activation of restoration ones over the water resources effects and the aquatic ecosystem.

Slovak case study and Activity 2.1 "*Guidelines for Drought Management Plans"* are closely connected with the IDMP Activity 1.2 „***Review of the current status of the implementation of Drought Management plans***

and measures within RBMP according to WFD". The survey carried out in ten CEE countries showed that the current status of elaboration of all three DMP basic components (early warning system, minigating measures and organizational structure) generaly is not satisfactory.
Therefore the emphasis of Slovak case study was primarily focused on elaboration on the mentioned elements in Slovak conditions.

3. ASSESSMENT OF DROUGHT INDICATORS DURING 2011 – 2012

3.1 Introduction

The choice of years 2011 and 2012 for the analysis of drought has a very good reason. These years represent one of the driest periods in the recent years which followed immediately after one of the wet years in the history of measurement. In the year 2010, especially in May and June, most of the Slovak territory was hit by floods. Despite the floods, this year has only partially alleviated the drought of the upcoming years. Although the precipitation throughout the year 2012 was more intense than in the year before, the lack of precipitation from the year 2011 was brought forward to year 2012, impacting mainly the surface and the ground water resources.

The amount of atmospheric precipitation (resp. the lack of it) is the main reason of drought in the environmental conditions of Slovakia. The air temperature (being a main indicator of the evaporation) can increase or decrease the intensity of the drought impact on the land. Therefore the beginning of the chapter is dedicated to the analysis of the air temperature and precipitation and afterwards we analyse several indicators of the drought, which are mostly the function of the two. Hence we continue with the analysis of the water discharge on the water basins of Slovakia and the analysis of the water levels of the ground water and spring yields.

The measurements of the hydrometeorological components are in the competence of the Slovak hydrometeorological institute (SHMI). Therefore it was possible (in the chapters 3.1-3.3) to assess the drought and its manifestations not only in the years 2011 and 2012, but also to offer the solution for monitoring of the current drought and prediction of its future occurrences. Because SHMI does not monitor the soil humidity, the other two chapters (3.4 and 3.5) were prepared on the Soil Fertility Research Institute.

3.2 Precipitation and air temperature

3.2.1 Meteorological station network

National station network of meteorological stations (Fig. 1) has been used for qualitative and quantitative evaluation of air temperature and precipitation for the period of years 2011 a 2012). This station network is regularly controlled and managed by professional staff of Slovak hydrometeorological institute and outputs of observers and Instruments are stored, revised and updated in the database.

3.2.2 Air temperature

Annual air temperature in the year 2011

Annual air temperature in the year 2011 (Fig. 2) was statistically high significant (criterion 80-percentile) at the most of the meteorological stations of Slovakia.

Air temperature for warm part (IV-IX) of the year 2011

Air temperature for warm part (IV-IX) of the year 2011 (**Chyba! Nenašiel sa žiaden zdroj odkazov.**) was statistically high significant at the most of the meteorological stations of Slovakia, at some places at a record level.

Annual air temperature in the year 2012

Annual air temperature in the year 2012 (Fig. 4) was statistically high significant at the most of the meteorological stations of Slovakia.

Air temperature for warm part (IV-IX) of the year 2012

Air temperature for warm part (IV-IX) of the year 2012 (**Chyba! Nenašiel sa žiaden zdroj odkazov.**) was statistically high significant at the most of the meteorological stations of Slovakia, at many places at a record level.

Comparison of the annual air temperatures of the years 2011 and 2012

Annual air temperature of the year 2011 was 0,15°C colder than the year 2012.

Fig. 1

Sieť meteorologických staníc / Meteorological station network

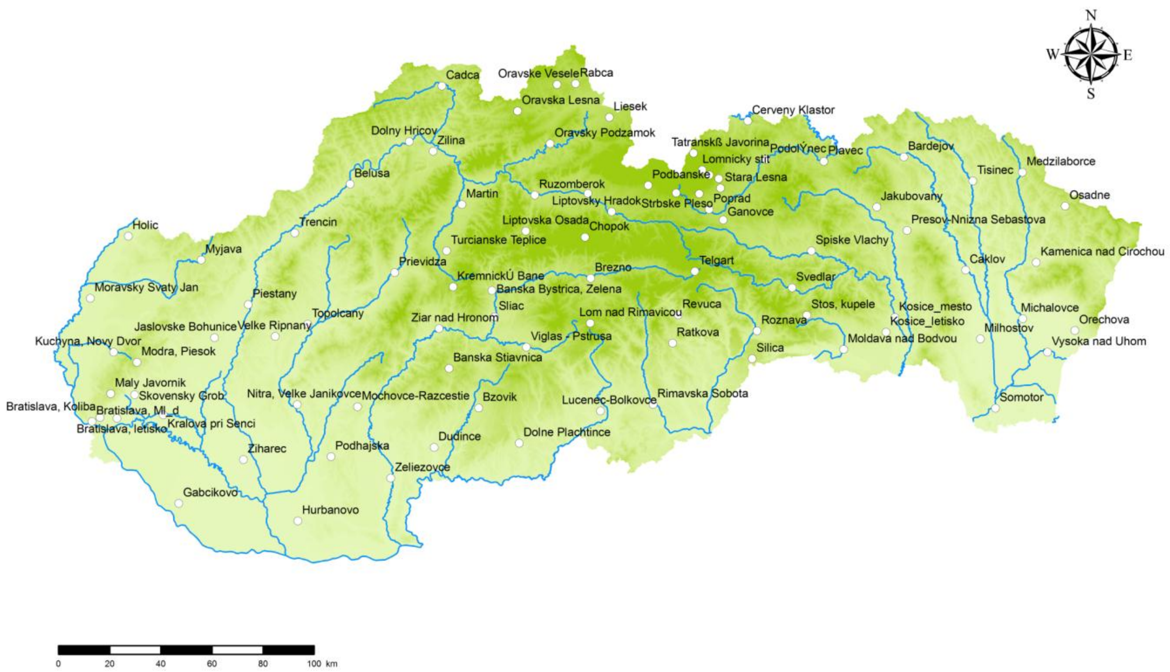


Fig. 2

Hodnotenie meteorologických prvkov / Evaluation of meteorological elements
Teplota vzduchu (ročný priemer) 2011
Air temperature (yearly) 2011

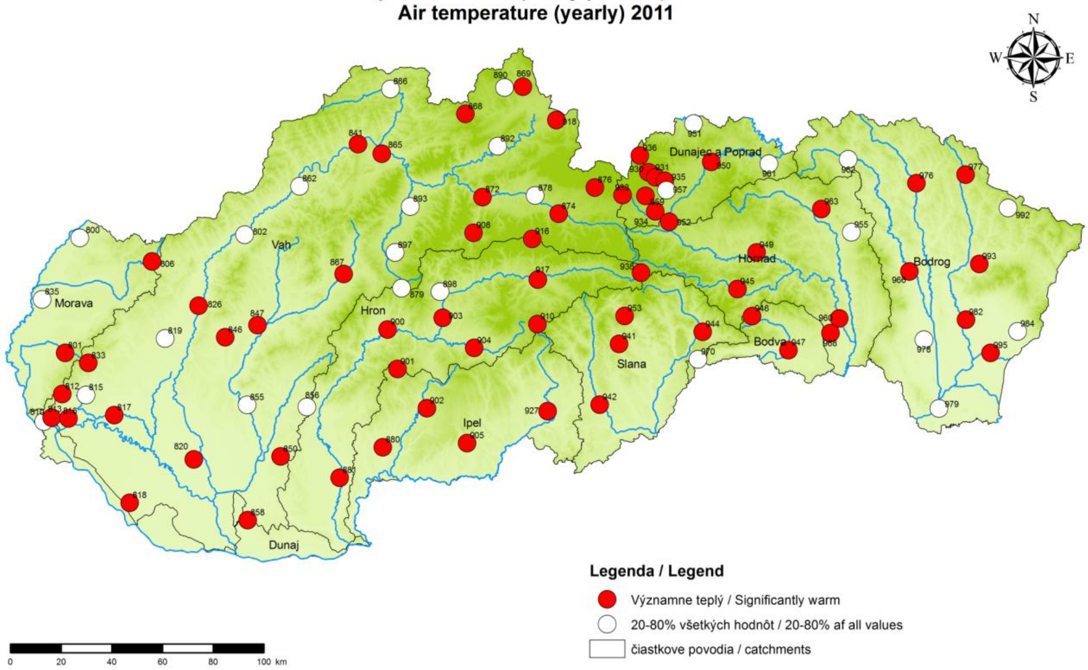


Fig. 3

Hodnotenie meteorologických prvkov / Evaluation of meteorological elements
Teplota vzduchu (IV-IX) 2011
Air temperature (IV-IX) 2011

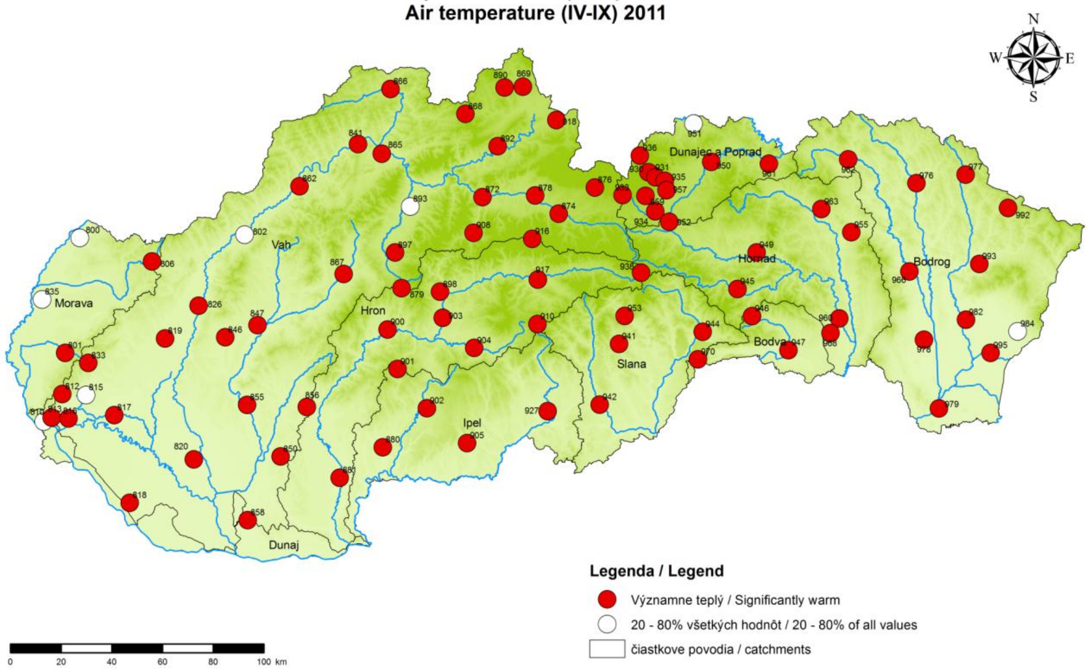


Fig. 4

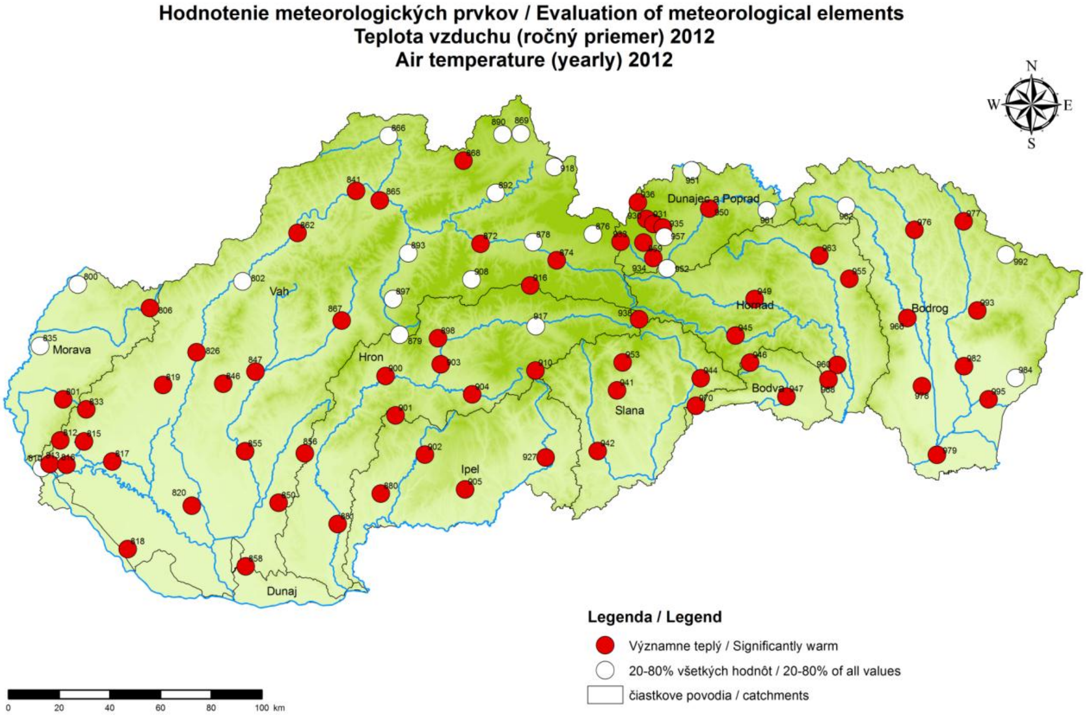
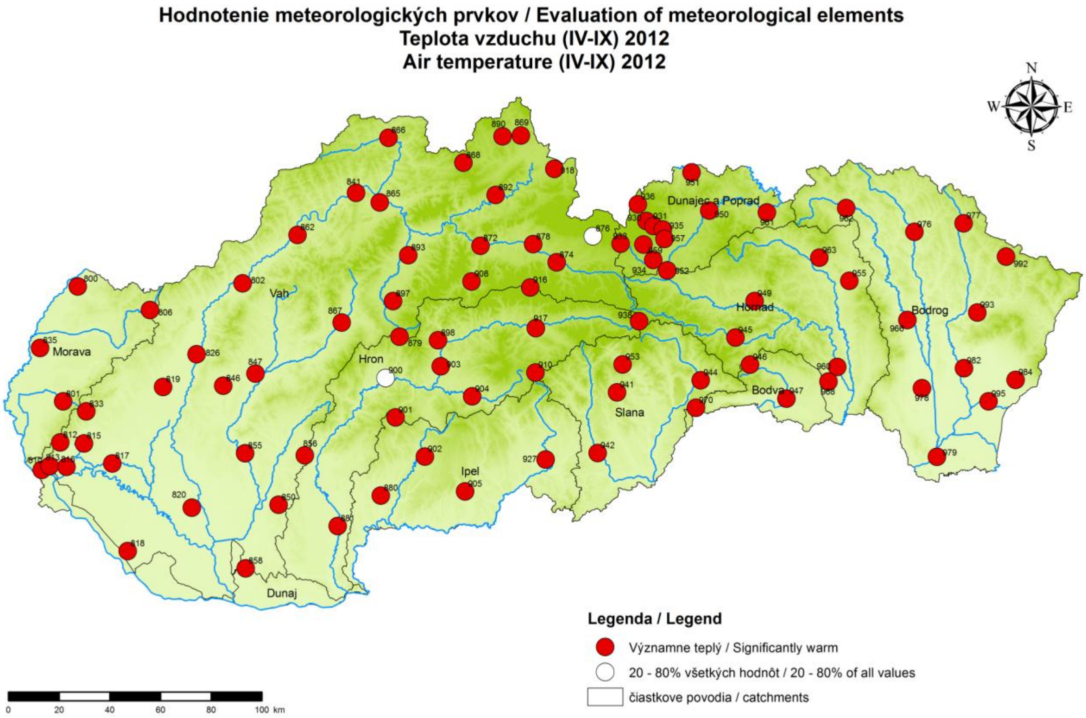

Hodnotenie meteorologických prvkov / Evaluation of meteorological elements
Teplota vzduchu (ročný priemer) 2012
Air temperature (yearly) 2012
Morava
Váh
Hron
Dunaj
Ipeľ
Slaná
Hornád
Bodva
Bodrog
Dunajec a Poprad
Legenda / Legend
Významne teplý / Significantly warm
20-80% všetkých hodnôt / 20-80% of all values
čiastkove povodia / catchments
0 20 40 60 80 100 km

Fig. 5


Hodnotenie meteorologických prvkov / Evaluation of meteorological elements
Teplota vzduchu (IV-IX) 2012
Air temperature (IV-IX) 2012
Morava
Váh
Hron
Dunaj
Ipeľ
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Dunajec a Poprad
Legenda / Legend
Významne teplý / Significantly warm
20 - 80% všetkých hodnôt / 20 - 80% of all values
čiastkove povodia / catchments
0 20 40 60 80 100 km

3.2.3 Precipitation

Yearly precipitation total in the year 2011

Yearly precipitation total was poor in total amount of precipitation in the year 2011 (**Chyba! Nenašiel sa žiaden zdroj odkazov.**), at some places (localities) at a record level.

Warm part of the year 2011

Warm part of the year 2011 precipitation were not so clearly expressed as in yearly amount (Fig.). Statistically significant low amounts of precipitation were observed and measured at the south and east region of Slovakia. On the other hand statistically significant high precipitation totals for warm part of the year 2011 were measured at Bratislava town and around as well as at southerly regions of Malé Karpaty, Žiar nad Hronom and mountain chain of High Tatras due to storm activity.

Yearly precipitation total in the year 2012

Yearly precipitation total were poorer in total amount of precipitation in the year 2012 (Fig.), significantly low at western region of Slovakia and at middle Slovakia in the Tatras region, locally in some places of east north and south parts of Slovakia. Statistically significant high has been observed only in Prievidza town.

Warm part of the year 2012

Warm part of the year 2012 precipitation (Fig.) were statistically significant low especially at west and north-west and north regions of Slovakia and at some regions of river basin Slaná.

Fig. 7

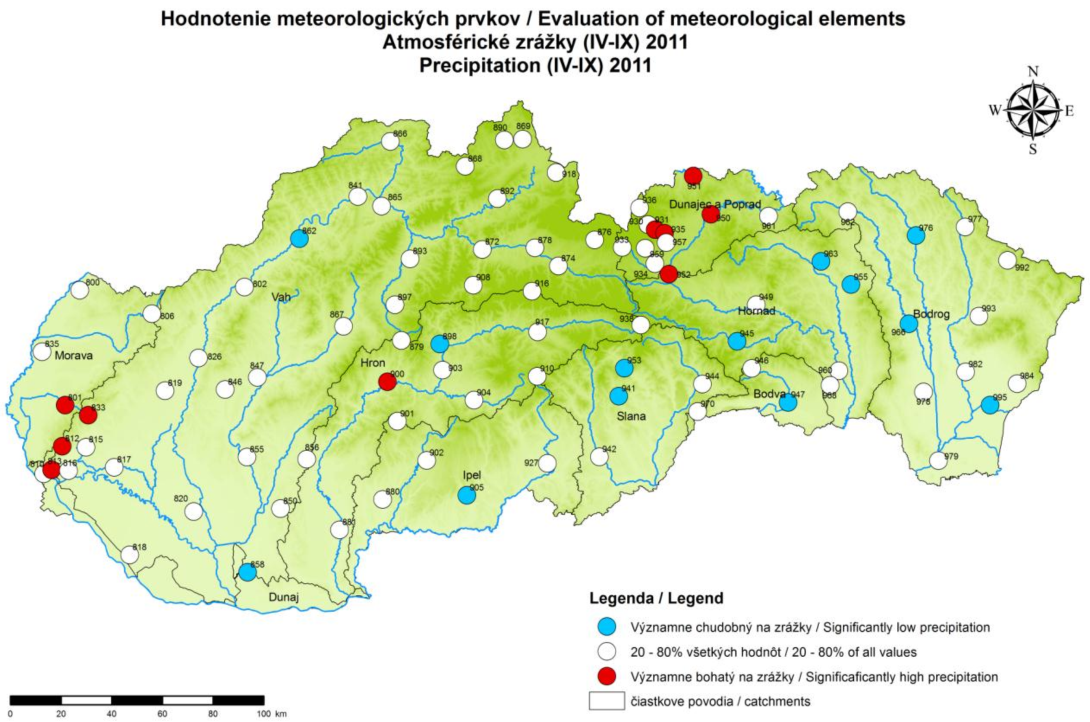


Fig. 8

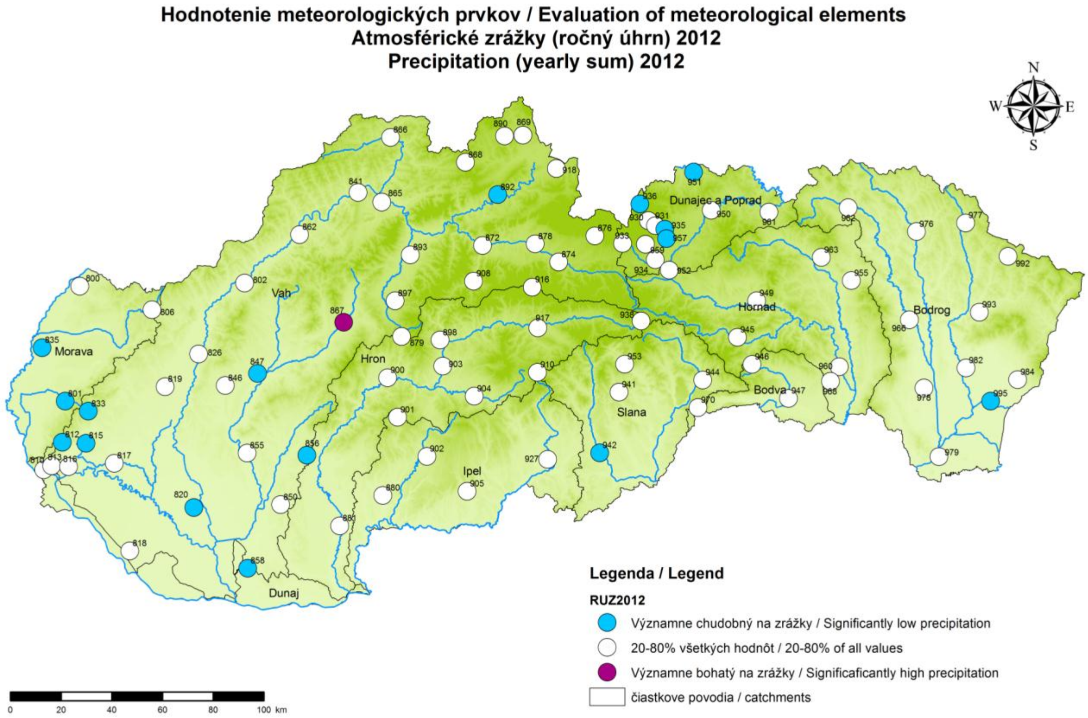
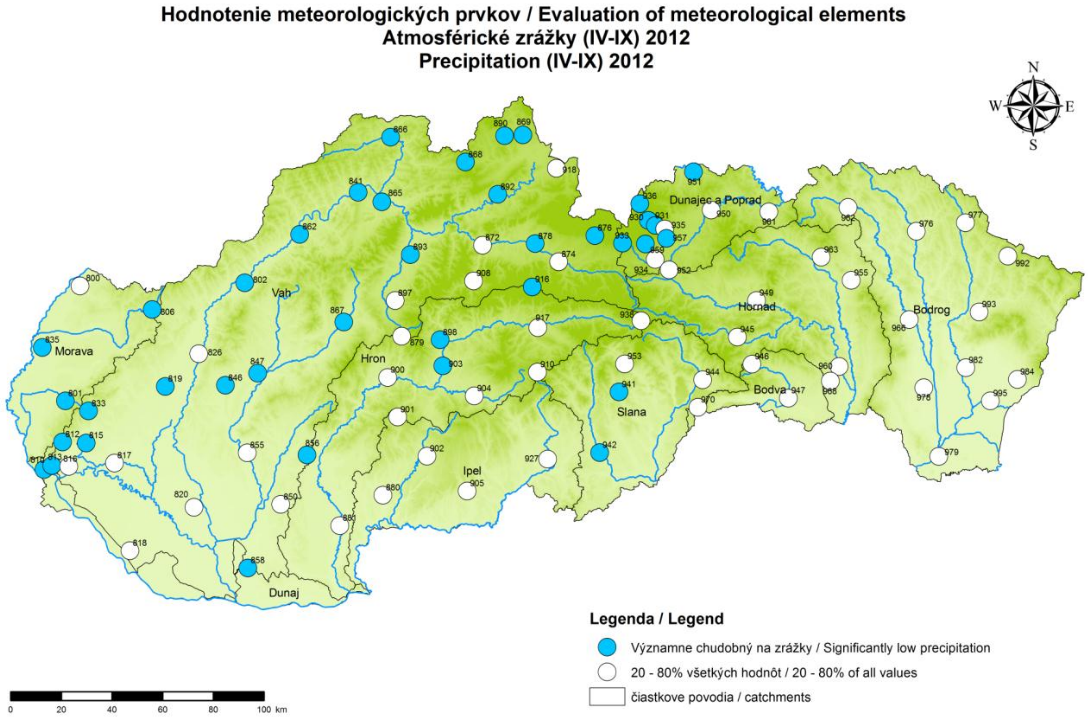

Hodnotenie meteorologických prvkov / Evaluation of meteorological elements
Atmosférické zrážky (ročný úhrn) 2012
Precipitation (yearly sum) 2012
N
W
E
S
Morava
Váh
Hron
Dunajec a Poprad
Hornád
Bodrog
Bodva
Slaná
Ipeľ
Dunaj
Legenda / Legend
RUZ2012
Významne chudobný na zrážky / Significantly low precipitation
20-80% všetkých hodnôt / 20-80% of all values
Významne bohatý na zrážky / Significaficantly high precipitation
čiastkove povodia / catchments
0
20
40
60
80
100 km

Fig. 9


Hodnotenie meteorologických prvkov / Evaluation of meteorological elements
Atmosférické zrážky (IV-IX) 2012
Precipitation (IV-IX) 2012
N
W
E
S
Morava
Váh
Hron
Dunajec a Poprad
Hornád
Bodrog
Bodva
Slaná
Ipeľ
Dunaj
Legenda / Legend
Významne chudobný na zrážky / Significantly low precipitation
20 - 80% všetkých hodnôt / 20 - 80% of all values
čiastkove povodia / catchments
0
20
40
60
80
100 km

3.2.4 Methodology of air temperature and precipitation evaluation at Slovak territory

Standard data processing of monthly values (mean or amount) coming from daily values (for air temperatures as a daily mean calculated by formula (t7+t14+2*t21)/4, for precipitation as a daily amount). Homogenized monthly values were compared to the normal period 1961-1990 recommended by World meteorological organization (WMO) as an etalon. Monthly values were adjusted by homogenization software MASH. Quartile deviation c has been used for qualitative air temperature evaluation. The character of the month has been established by the interval to which the value has taken place.

$$c=0,5(\tilde{x}_3 - \tilde{x}_1)$$

where:
$\tilde{x}_1$ and $\tilde{x}_3$ means first and third quartile for the period 1961-1990

Scheme used in practice:

Interval	***% appearance***	***event is***	***symbol***
$<x_{(1961-1990)}-3c$	2,15	extremely below normal	EPN
$x_{(1961-1990)}-3c$ to $x_{(1961-1990)}-2c$	8,87	deeply below normal	SPN
$x_{(1961-1990)}-2c$ to $x_{(1961-1990)}-c$	13,98	below normal	PN
$x_{(1961-1990)}-c$ to $x_{(1961-1990)}+c$	50,0	normal	N
$x_{(1961-1990)}+c$ to $x_{(1961-1990)}+2c$	13,98	above normal	NN
$x_{(1961-1990)}+2c$ to $x_{(1961-1990)}+3c$	8,87	high above normal	SNN
$> x_{(1961-1990)}+3c$	2,15	extremely above normal	ENN

Percentage of normal (1961-1990) for precipitation totals have been used as a criterion for qualitative evaluation of the month:

Interval %N [%]	***event is***
<10	extra dry
>10 a <50	excessively dry
>50 a <75	dry
>75 a <125	normal
>125	wet
>125 a <150	excessively wet
>150	extra wet

Color scale enable us qualitatively evaluate character of the concrete month and meteorological element at the Slovak territory.

Mean monthly air temperatures and air temperature deviations from normal (1961-1990) for quantitative evaluation of temperature conditions..

Precipitation deficit (difference between actual and normal (1961-1990) value) was calculated for quantitative precipitation evaluation and also for drought index as a qualitative indicator was calculated for complex evaluation of precipitation conditions at Slovak territory.

MONTHLY AIR TEMPERATURE EVALUATION FOR THE YEARS 2011 AND 2012

Tab. 1 Mean monthly air temperatures and deviations from normal at selected meteorological stations of Slovakia, 2011

		2011											
Station name	Char.	1	2	3	4	5	6	7	8	9	10	11	12
Bardejov	t_mpr	-1.8	-3.7	3.6	10.0	13.3	17.8	18.3	19.3	15.1	7.1	0.8	0.5
	Dev from N	2.5	-1.6	1.4	1.9	0.2	1.6	0.7	2.5	2.1	-0.9	-1.8	2.7
Bolkovce	t_mpr	-2.4	-1.0	5.4	12.5	15.8	19.4	19.5	20.9	17.8	8.8	1.5	0.8
	Dev from N	1.0	-0.4	1.2	2.8	1.3	1.9	0.3	2.4	3.1	-0.3	-1.9	2.2
Bratislava, airport	t_mpr	0.1	-0.2	6.7	13.4	16.3	20.4	19.9	21.4	18.5	10.5	2.9	3.1
	Dev from N	1.5	-1.1	1.7	3.2	1.2	2.1	-0.2	2.1	3.1	0.6	-1.5	2.7
Čadca	t_mpr	-2.2	-3.0	3.1	8.7	12.0	16.2	16.2	17.7	13.2	6.8	1.3	0.5
	Dev from N	1.5	-1.0	1.3	1.9	0.1	1.4	0.0	2.2	1.1	-0.9	-1.4	2.3
Červený Kláštor	t_mpr	-3.5	-3.3	1.8	6.8	9.8	15.0	15.9	16.5	13.1	5.7	0.0	-0.4
	Dev from N	1.7	-0.3	1.0	0.5	-1.4	0.9	0.4	1.8	1.6	-1.3	-1.8	2.8
Hurbanovo	t_mpr	-0.2	-0.3	6.4	13.2	16.7	20.7	20.3	21.6	18.4	10.1	3.2	2.9
	Dev from N	1.3	-1.2	1.1	2.6	1.1	2.0	0.0	2.2	2.9	-0.1	-1.5	2.5
Kamenica/Cir.	t_mpr	-0.8	-2.8	4.5	10.8	14.7	18.9	18.9	19.8	15.8	7.9	0.7	2.1
	Dev from N	2.8	-1.7	1.1	1.6	0.7	2.0	0.6	2.3	2.1	-0.8	-3.0	3.4
Košice, airport	t_mpr	-1.2	-2.5	5.0	12.1	15.8	19.5	19.5	20.9	18.0	8.8	1.9	1.2
	Dev from N	2.3	-1.6	1.5	2.6	1.4	2.1	0.5	2.6	3.5	-0.2	-1.3	2.7
Liptovský Hrádok	t_mpr	-3.2	-2.2	3.4	8.9	13.0	16.3	16.8	18.0	14.2	6.5	0.0	-0.2
	Dev from N	1.7	0.5	2.2	2.4	1.4	1.7	0.9	2.9	2.6	-0.2	-1.6	2.9
Michalovce	t_mpr	-0.8	-2.5	5.2	12.5	16.4	20.3	20.3	21.3	18.1	8.8	1.5	1.9
	Dev from N	2.4	-1.8	1.3	2.4	1.4	2.3	0.8	2.5	3.2	-0.7	-2.4	2.7
Moldava/Bodvou	t_mpr	-1.6	-2.1	4.7	11.8	15.5	19.3	19.6	20.5	17.3	8.6	1.1	0.8
	Dev from N	2.1	-1.2	1.0	2.3	0.9	1.8	0.6	2.3	3.0	-0.2	-2.0	2.4
Myjava	t_mpr	-1.1	-1.6	5.7	12.3	15.0	18.8	18.5	20.6	17.4	8.7	3.0	1.1
	Dev from N	1.7	-0.9	2.3	3.8	1.7	2.5	0.7	3.1	3.7	-0.2	-0.1	2.2
Nitra	t_mpr	-0.9	-0.7	5.9	12.6	15.7	19.5	19.5	21.3	18.0	10.0	2.9	2.2
	Dev from N	1.1	-1.4	1.1	2.6	0.8	1.6	0.1	2.3	2.9	0.0	-1.5	2.2
Oravská Lesná	t_mpr	-3.6	-4.3	1.0	6.3	10.5	14.2	14.6	16.0	11.8	5.1	0.1	-1.0
	Dev from N	2.0	-0.1	1.9	2.2	0.8	1.5	0.5	2.6	1.9	-0.5	-0.6	2.7
Plaveč	t_mpr	-3.3	-4.2	2.4	8.2	11.7	16.1	16.7	17.7	13.8	6.2	0.2	-0.4
	Dev from N	2.0	-1.2	1.2	1.4	0.0	1.4	0.7	2.5	1.9	-1.0	-1.5	2.8
Podbánske	t_mpr	-4.6	-4.7	1.3	7.4	11.6	14.2	14.3	16.2	14.0	4.8	0.9	-1.4
	Dev from N	0.6	-0.8	2.1	3.3	2.2	1.7	0.4	2.7	3.9	-0.7	0.7	2.4
Poprad	t_mpr	-4.2	-3.9	2.3	8.8	12.3	15.6	16.2	17.2	13.9	6.1	-0.6	-0.2
	Dev from N	0.8	-0.6	1.6	2.7	1.2	1.5	0.6	2.3	2.4	-0.6	-2.0	2.9
Ratková	t_mpr	-3.0	-2.4	3.7	10.9	14.5	18.4	18.8	20.5	17.3	8.2	1.0	0.4
	Dev from N	1.5	-0.5	1.3	2.7	1.1	1.8	0.9	3.6	4.5	0.8	-1.2	3.0
Rimavská Sobota	t_mpr	-2.5	-1.6	5.0	12.1	16.6	20.5	20.3	21.3	18.5	8.9	1.0	0.8
	Dev from N	1.2	-0.9	1.0	2.2	1.9	2.8	0.8	2.7	3.9	-0.1	-2.3	2.4
Rožňava	t_mpr	-2.0	-2.3	5.0	12.4	15.9	19.3	19.6	20.9	17.8	8.8	1.3	0.7
	Dev from N	1.7	-1.5	1.5	3.1	1.8	2.1	0.8	3.1	3.8	0.0	-1.8	2.6
Somotor	t_mpr	-1.0	-2.4	4.9	12.3	15.9	19.7	19.9	21.1	18.1	8.4	1.3	1.8
	Dev from N	2.2	-1.8	0.6	1.9	0.4	1.2	-0.2	1.7	2.7	-1.2	-2.5	2.7
Štrbské Pleso	t_mpr	-4.9	-5.4	-0.3	5.5	9.3	12.5	12.6	14.7	11.9	4.1	0.6	-3.0
	Dev from N	0.3	-1.0	1.5	2.7	1.5	1.7	0.3	2.6	2.9	-1.1	0.9	0.8
Telgárt	t_mpr	-3.9	-4.4	1.0	7.1	10.7	14.1	14.7	15.9	13.1	5.1	0.0	-2.2
	Dev from N	1.5	-0.5	1.6	2.6	1.0	1.5	0.5	2.4	2.8	-0.7	-0.3	1.8
Vígľaš	t_mpr	-3.2	-1.7	4.4	10.8	13.6	17.5	18.0	19.5	15.9	7.5	0.7	0.0
	Dev from N	0.9	-0.4	1.5	2.5	0.7	1.7	0.7	2.7	2.7	-0.6	-2.1	1.9

Legend : t_mpr-mean air temperature, Dev from N-Deviation from Normal

Tab. 2 Mean monthly air temperatures and deviations from normal at selected meteorological stations of Slovakia, 2012

		2012											
Station name	Char.	1	2	3	4	5	6	7	8	9	10	11	12
Bardejov	t_mpr	-2.4	-4.1	4.1	9.4	14.4	18.0	20.0	18.5	14.4	8.5	5.5	-3.0
	Dev from N	2.0	-2.0	1.9	1.4	1.3	1.8	2.4	1.8	1.4	0.6	2.9	-0.8
Bolkovce	t_mpr	-0.9	-3.0	6.4	11.8	17.0	20.4	21.9	21.4	17.1	10.0	6.2	-3.2
	Dev from N	2.5	-2.5	2.3	2.0	2.4	2.9	2.7	2.9	2.4	0.9	2.8	-1.9
Bratislava, airport	t_mpr	2.1	-2.6	8.6	11.6	17.3	21.3	22.8	22.6	17.7	10.6	7.0	-0.7
	Dev from N	3.5	-3.5	3.5	1.4	2.2	2.9	2.7	3.3	2.3	0.7	2.6	-1.2
Čadca	t_mpr	-2.5	-3.1	2.1	8.2	13.2	16.5	18.6	16.9	13.0	7.5	5.9	-3.3
	Dev from N	1.2	-1.2	0.4	1.5	1.2	1.6	2.4	1.3	0.8	-0.2	3.1	-1.4
Červený Kláštor	t_mpr	-3.6	-4.6	2.4	7.3	11.6	15.8	17.2	15.9	12.5	7.5	4.7	-5.0
	Dev from N	1.6	-1.6	1.6	1.1	0.4	1.7	1.8	1.1	0.9	0.5	2.9	-1.7
Hurbanovo	t_mpr	1.7	-2.3	7.8	12.5	18.1	21.4	23.1	22.4	17.7	11.0	7.7	-0.5
	Dev from N	3.3	-3.3	2.5	1.8	2.5	2.7	2.8	2.9	2.2	0.8	3.1	-0.9
Kamenica/Cir.	t_mpr	-1.4	-3.4	4.8	10.9	15.5	19.4	21.7	19.2	15.8	9.4	6.7	-1.2
	Dev from N	2.2	-2.2	1.4	1.7	1.6	2.4	3.4	1.7	2.0	0.7	3.0	0.0
Košice, airport	t_mpr	-0.7	-3.7	6.3	11.1	16.3	19.9	22.2	21.6	17.0	10.0	6.1	-2.0
	Dev from N	2.8	-2.8	2.7	1.6	1.9	2.5	3.3	3.3	2.6	1.0	2.9	-0.5
Liptovský Hrádok	t_mpr	-3.2	-4.4	3.2	8.5	13.8	17.4	18.7	17.5	13.8	7.8	5.3	-3.5
	Dev from N	1.7	-1.7	2.0	2.0	2.2	2.7	2.8	2.4	2.3	1.0	3.6	-0.4
Michalovce	t_mpr	-0.5	-3.4	6.4	11.3	16.7	20.1	23.0	21.1	17.0	10.1	6.6	-1.1
	Dev from N	2.7	-2.7	2.4	1.2	1.7	2.1	3.5	2.2	2.1	0.6	2.8	-0.3
Moldava/Bodvou	t_mpr	-1.8	-2.9	5.7	10.6	16.0	19.4	21.4	20.6	16.1	9.6	5.4	-2.3
	Dev from N	2.0	-2.0	2.0	1.1	1.5	1.9	2.4	2.5	1.8	0.8	2.3	-0.7
Myjava	t_mpr	-0.2	-3.3	5.7	9.9	16.2	18.9	21.6	21.6	16.6	9.7	6.5	-1.9
	Dev from N	2.6	-2.6	2.3	1.4	2.8	2.6	3.8	4.2	2.9	0.9	3.3	-0.8
Nitra	t_mpr	1.4	-2.7	7.2	11.8	17.2	20.6	22.8	22.2	17.4	10.7	7.6	-1.0
	Dev from N	3.4	-3.4	2.4	1.8	2.3	2.7	3.4	3.2	2.2	0.7	3.1	-1.0
Oravská Lesná	t_mpr	-4.3	-5.6	0.1	5.3	11.5	15.0	17.2	15.3	11.3	5.9	4.4	-4.3
	Dev from N	1.3	-1.3	1.1	1.2	1.8	2.2	3.1	1.9	1.4	0.3	3.7	-0.6
Plaveč	t_mpr	-4.0	-4.4	2.9	8.5	12.6	16.7	18.5	16.9	13.4	8.1	5.1	-4.5
	Dev from N	1.3	-1.3	1.8	1.7	0.9	2.0	2.5	1.8	1.5	0.9	3.5	-1.2
Podbánske	t_mpr	-4.8	-4.3	0.4	5.2	10.8	13.6	16.0	15.4	11.4	5.8	2.5	-5.1
	Dev from N	0.4	-0.4	1.2	1.1	1.4	1.1	2.1	1.9	1.3	0.3	2.3	-1.3
Poprad	t_mpr	-4.5	-3.7	3.0	7.8	12.7	16.7	17.9	17.0	13.4	7.6	4.7	-4.8
	Dev from N	0.5	-0.5	2.3	1.7	1.6	2.5	2.4	2.1	1.9	0.8	3.3	-1.7
Ratková	t_mpr	-2.0	-4.5	4.6	10.3	15.6	19.0	20.4	19.1	14.8	8.6	5.2	-3.7
	Dev from N	2.6	-2.6	2.3	2.0	2.2	2.5	2.5	2.3	2.0	1.2	3.0	-1.1
Rimavská Sobota	t_mpr	-1.3	-3.1	5.7	11.3	16.8	20.3	21.9	21.3	16.5	9.7	5.9	-3.2
	Dev from N	2.4	-2.4	1.8	1.5	2.1	2.6	2.5	2.6	2.0	0.7	2.6	-1.7
Rožňava	t_mpr	-1.8	-2.8	6.1	11.0	16.1	19.7	21.4	20.6		9.4	5.5	-2.4
	Dev from N	1.9	-1.9	2.6	1.7	2.0	2.6	2.7	2.9		0.7	2.4	-0.6
Somotor	t_mpr	-0.4	-3.4	6.2	11.5	16.7	20.2	23.1	21.6	17.0	10.2	6.0	-1.5
	Dev from N	2.8	-2.8	1.9	1.1	1.1	1.7	3.0	2.2	1.7	0.7	2.2	-0.6
Štrbské Pleso	t_mpr	-6.0	-3.5	-0.5	4.4	10.0	13.1	15.0	14.3	11.0	5.6	2.6	-5.0
	Dev from N	-0.9	0.9	1.3	1.7	2.1	2.3	2.7	2.1	2.0	0.4	2.9	-1.2
Telgárt	t_mpr	-4.5	-4.8	1.5	6.3	11.6	14.9	16.7	16.0	12.2	6.6	3.5	-4.7
	Dev from N	0.9	-0.9	2.1	1.7	1.9	2.3	2.5	2.5	2.0	0.9	3.2	-0.8
Vígľaš	t_mpr	-2.1	-3.2	5.2	9.9	14.7	18.4	20.0	19.0	15.3	8.9	5.8	-4.6
	Dev from N	2.0	-2.0	2.3	1.6	1.7	2.5	2.6	2.2	2.1	0.8	3.1	-2.8

QUALITATIVE AND QUANTITATIVE PRECIPITATION EVALUATION
Year 2011 (Tab. 3, Fig. 10)

January
Percentage of monthly precipitation normal (1961-1990) describes this month from dry to excessively dry especially in the middle of Slovakia and in southerly regions of western Slovakia. Precipitation normal was January at the rest of Slovakia.
Monthly precipitation deficit compared with normal value from the period 1961-1990 reached up to 20,6 mm in southern part of West Slovakia, up to 38,9 mm in the Middle Slovakia.
February
Percentage of monthly precipitation normal describes this month from dry to extra dry at the whole territory of Slovakia.
Monthly precipitation deficit compared with normal value reached in average 26,5 mm.
March
Percentage of monthly precipitation normal describes this month from wet to extra wet at outer western Slovakia and at southern half of Slovakia.
Precipitation surplus reached at outer western part of Slovakia up to 24 mm and at southern part of Slovakia up to 26,1 mm.
Precipitation deficit occurred preferentially at northern regions of Slovakia with the minimum of 47,4 mm.
April
Percentage of monthly precipitation normal describes this month from dry to excessively dry except some localities like Bratislava and surrounding, middle part of Vah river basin and Tatra region where it looks like from wet to excessively wet.
The most deficit of precipitation (48,8 mm) this month was at south eastern part of Slovakia, the most surplus (16,2 mm)was in outer western part of Slovakia.
May
Percentage of monthly precipitation normal describes this month as normal only at middle and upper Váh river basin and at some localities of Liptov region and at Dunaj river basin as excessively wet, resp. wet at southern districts were from dry to excessively dry.
The most deficit of precipitation this month (46,6 mm) was in the south eastern part of Slovakia, the most surplus of precipitation (13,9 mm) was in the northern part of Slovakia.
June
Percentage of monthly precipitation normal describes this month from wet to excessively up to extra wet.
The most precipitation deficit this month (39,7 mm) was in the south eastern part of Slovakia and the most precipitation surplus (78,9 mm) was in south western part of Slovakia.
July
Percentage of monthly precipitation normal describes this month from wet to excessively wet practically at the whole territory of Slovakia.
The most precipitation surplus (212,4 mm) was in north part of Slovakia, the lowest precipitation surplus (13,8 mm) was in eastern part of Slovakia.
August
Percentage of monthly precipitation normal describes this month from dry to excessively dry practically at the whole territory of Slovakia.
The most precipitation deficit this month (58,9 mm) was in north part of Slovakia, the most precipitation surplus (26,5 mm) in outer western part of Slovakia.
September
Percentage of monthly precipitation normal describes this month as dry, excessively dry up to extra dry (especially in the southern regions).
The most precipitation deficit (65,1 mm) this month was in High Tatras region, the most precipitation surplus (5,5 mm)was in the eastern part of Slovakia.
October
Percentage of monthly precipitation normal describes this month as excessively dry especially at southern regions of middle and eastern parts of Slovakia, dry at outer east of west Slovakia, at Middle of Slovakia and at East of Slovakia at Košice town and surrounding.
The most precipitation deficit this month (31,0 mm) was in the Middle of Slovakia and the most precipitation surplus (21,7 mm) was in northern part of East of Slovakia.
November
Percentage of monthly precipitation normal describes this month as excessively dry at the whole territory of Slovakia.
The most precipitation deficit (82,4 mm) this month was in northern part of Slovakia, the low precipitation deficit (40,3 mm) in northern part of east of Slovakia.
December
Percentage of monthly precipitation normal describes this month as dry at western part of Slovakia, excessively wet at southern districts of middle and eastern Slovakia, from wet to excessively wet at middle Slovakia.

The most precipitation deficit (30,9 mm) this month was in outer west part of Slovakia, the most precipitation surplus (38,2 mm) was in southern part of East Slovakia.

Tab. 3 Monthly precipitation totals and percentage of normal at selected meteorologicalstations of Slovakia, 2011

		2011											
Station name	Char.	1	2	3	4	5	6	7	8	9	10	11	12
Bardejov	MT	20.5	9.6	19.4	23.5	47.8	63.9	205.4	45.1	6.9	46.8	0.1	30.1
	PN	52.7	25.9	55.1	47.0	55.3	65.1	209.2	52.3	11.1	91.3	0.2	57.8
	ML	D	ED1	D	ED1	D	D	EW2	D	ED1	N	ED2	D
	Deficit	-18.5	-27.4	-15.6	-26.5	-38.2	-34.1	107.4	-40.9	-55.1	-4.2	-48.9	-21.9
Bratislava, airport	MT	25.0	11.3	36.1	51.2	36.1	127.8	83.0	42.5	13.4	30.6	0.0	19.1
	PN	57.7	26.2	96.2	146.0	64.8	194.0	153.8	69.1	33.6	82.6	0.0	38.4
	ML	D	ED1	N	W	D	EW2	EW1	D	ED1	N	ED2	ED1
	Deficit	-18.0	-31.7	-0.9	16.2	-19.9	61.8	29.0	-19.5	-26.6	-6.4	-54.0	-30.9
Čadca	MT	38.8	16.3	22.0	76.8	98.7	81.0	163.6	51.7	27.4	45.1	0.4	63.7
	PN	62.8	31.3	44.3	121.5	107.6	68.3	144.5	48.7	39.2	79.9	0.6	88.6
	ML	D	ED1	ED1	N	N	D	W	ED1	ED1	N	ED2	N
	Deficit	-23.2	-35.7	-28.0	13.8	6.7	-38.0	50.6	-54.3	-42.6	-10.9	-70.6	-8.3
Červený Kláštor	MT	27.2	10.0	8.0	52.5	100.9	165.7	312.4	58.1	12.2	57.4	1.0	21.1
	PN	68.9	30.9	22.7	106.1	116.1	145.9	310.9	59.8	19.6	130.4	2.2	48.7
	ML	D	ED1	ED1	N	N	W	EW2	D	ED1	W	ED2	ED1
	Deficit	-11.8	-22.0	-27.0	3.5	13.9	51.7	212.4	-38.9	-49.8	13.4	-45.0	-21.9
Hurbanovo	MT	13.4	5.3	28.4	16.4	24.6	63.0	83.7	22.4	15.4	19.7	0.1	31.4
	PN	39.4	15.5	106.8	42.2	44.1	103.4	165.0	38.8	39.6	61.1	0.2	78.8
	ML	ED1	ED1	N	ED1	ED1	N	EW1	ED1	ED1	D	ED2	N
	Deficit	-20.6	-28.7	1.4	-22.6	-31.4	2.0	32.7	-35.6	-23.6	-12.3	-53.9	-8.6
Košice, airport	MT	23.8	13.4	35.7	8.4	68.1	100.1	149.9	31.0	14.6	20.9	3.0	55.2
	PN	85.9	50.2	113.0	19.8	95.1	119.3	178.6	42.1	27.6	49.0	6.2	158.6
	ML	N	D	N	ED1	N	N	EW1	ED1	ED1	ED1	ED2	EW1
	Deficit	-4.2	-13.6	3.7	-33.6	-3.9	16.1	65.9	-43.0	-38.4	-22.1	-45.0	20.2
Myjava	MT	55.9	11.4	62.0	50.8	51.6	100.2	88.2	40.1	21.6	34.0	0.7	52.7
	PN	119.9	24.6	161.3	105.9	78.8	126.1	135.3	65.7	43.2	70.3	1.1	89.2
	ML	N	ED1	EW1	N	N	W	W	D	ED1	D	ED2	N
	Deficit	8.9	-34.6	24.0	2.8	-13.4	21.2	23.2	-20.9	-28.4	-14.0	-61.3	-6.3
Oravská Lesná	MT	55.2	44.1	15.6	79.8	61.7	148.9	205.3	55.1	39.3	58.4	0.6	105.1
	PN	69.0	67.7	24.8	110.8	57.8	121.1	159.1	48.3	43.4	78.6	0.7	110.6
	ML	D	D	ED1	N	D	N	EW1	ED1	ED1	N	ED2	N
	Deficit	-24.8	-20.9	-47.4	7.8	-45.3	25.9	76.3	-58.9	-51.7	-15.6	-82.4	10.1
Plaveč	MT	15.1	7.2	18.1	27.0	65.1	84.5	215.5	36.6	18.4	62.7	0.7	24.6
	PN	50.1	27.6	65.3	57.7	80.2	88.3	230.3	42.1	32.4	152.1	1.7	68.9
	ML	D	ED1	D	D	N	N	EW2	ED1	ED1	EW1	ED2	D
	Deficit	-14.9	-18.8	-9.9	-20.0	-15.9	-11.5	122.5	-50.4	-38.6	21.7	-40.3	-11.4
Ratková	MT	14.3	8.3	60.3	10.2	39.4	53.3	144.3	27.5	8.1	38.2	0.6	59.6
	PN	38.2	18.2	143.3	17.3	45.6	57.4	188.7	41.2	15.5	75.6	0.9	120.2
	ML	ED1	ED1	W	ED1	ED1	D	EW1	ED1	ED1	N	ED2	N
	Deficit	-22.7	-37.7	18.3	-48.8	-46.6	-39.7	68.3	-39.5	-43.9	-12.8	-65.4	9.6
Somotor	MT	30.4	8.6	35.7	20.5	27.5	92.1	114.2	9.4	48.5	17.8	2.5	76.2
	PN	99.0	30.5	104.7	48.8	46.9	124.9	177.8	14.3	112.6	48.9	5.6	200.2
	ML	N	ED1	N	ED1	ED1	N	EW1	ED1	N	ED1	ED2	EW2
	Deficit	-0.6	-19.4	1.7	-21.5	-31.5	18.1	50.2	-56.6	5.5	-18.2	-41.5	38.2

Legend

Char. - Characteristics, MT - Monthly Total, PN - Percentage of Normal, ML - Monthly Label, D - Deficit, D - Dry, ED1 - Excessively Dry, ED2 - Extra Dry, W - Wet, EW1 - Excessively Wet, EW2 - Extra Wet

Year 2012 (Tab. 4, Fig. 11)

January

Percentage of monthly precipitation normal describes this month from wet to excessively wet.

The most precipitation surplus (150,1 mm) this month was in northern part of Slovakia, the most precipitation deficit (14,2 mm)was in southern east part of Slovakia.

February

Percentage of monthly precipitation normal describes this month from excessively to extra wet especially at northern districts of Slovakia, from dry to excessively dry in Middle Slovakia Region, normal at outer west and east of Slovakia.

The most precipitation surplus (55,6 mm) this month was in northern part of Slovakia, the most deficit of precipitation (33,9 mm) was in south part of Middle Slovakia.

March

Percentage of monthly precipitation normal describes this month from dry to extra dry.

The most precipitation deficit (42 mm) in this month was in south middle part of Slovakia, the lowest deficit (2,7 mm) in northern part of Slovakia.

April

Percentage of monthly precipitation normal describes this month as normal, only outer west and north part of Slovakia as very dry, resp. dry.

The most precipitation deficit (31,6 mm) in this month was in northern part of west Slovakia, the most precipitation surplus (3,0 mm) this month was in eastern part of outer Middle Slovakia.

May

Percentage of monthly precipitation normal describes this month from dry (the most part of Slovakia) only at outer east part of Slovakia and around Bratislava (West Slovakia) as normal.

The most precipitation deficit (75,6 mm) in this month was in eastern part of outer Middle Slovakia Region, the most precipitation surplus (36,5 mm) in this month was in south western part of Slovakia.

June

Percentage of monthly precipitation normal describes this month as normal only in some regions of middle Váh river basin and Upper Nitra river basin as well as Liptov, Orava, Šariš, Spiš region and around Košice and Upper and Lower Zemplín from wet to extra wet due to storm activity as well.

The most precipitation surplus (68,9 mm) was in this month in the outer part of north region of Slovakia, the most deficit (39,8 mm) was in middle of Slovakia.

July

Percentage of monthly precipitation normal describes this month as a wet, especially in south as extra wet, in northern part of Slovakia as a normal month.

The most precipitation surplus (114,8 mm) was in south eastern part of Slovakia, the most precipitation deficit (27,9 mm) was in northern region of Slovakia.

August

Percentage of monthly precipitation normal describes this month as dry to extra dry at all territory of Slovakia.

The most precipitation deficit (76,8 mm) was in northern part of Slovakia, the lowest precipitation deficit (4,6 mm) was in middle part of Slovakia.

September

Percentage of monthly precipitation normal describes this month as normal only in outer south and north part of Slovakia and partly in some regions of West Slovakia as dry up to very dry.

The most precipitation deficit (45,8 mm) was in the High Tatra mountain region, the most precipitation surplus (26,0 mm) in southern region of east part of Slovakia.

October

Percentage of monthly precipitation normal describes this month as an extra wet almost at the whole territory of Slovakia.

The most precipitation surplus (102,0 mm) was in north westerly part of Slovakia, the most precipitation deficit (2,4 mm) in northern part of east Slovakia..

November

Percentage of monthly precipitation normal describes this month as normal, only in outer west and south west of Slovakia from dry to very dry.

The most precipitation deficit (40,1 mm) was observed in northern part of West Slovakia, the most precipitation surplus (11,4 mm) in southern part of Middle Slovakia.

December

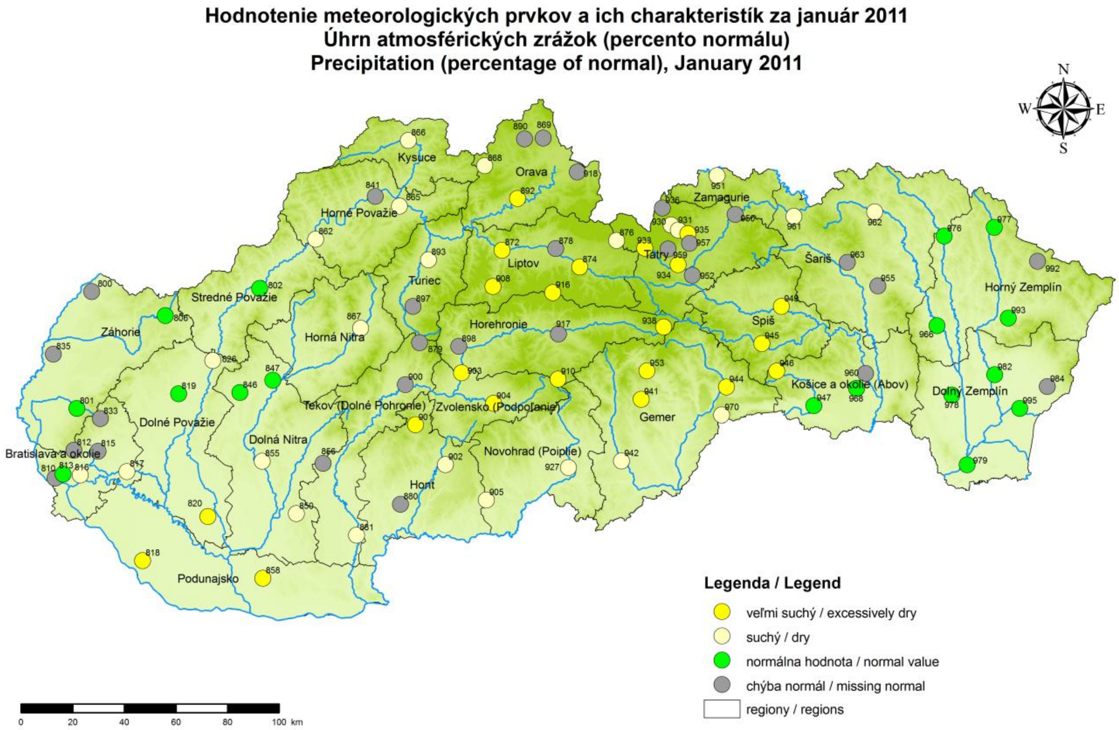
Percentage of monthly precipitation normal describes this month as normal, only in some parts of West Slovakia and some southern regions of Middle and East Slovakia as wet, in middle of Slovakia especially in central and northern part as dry, especially as very dry.

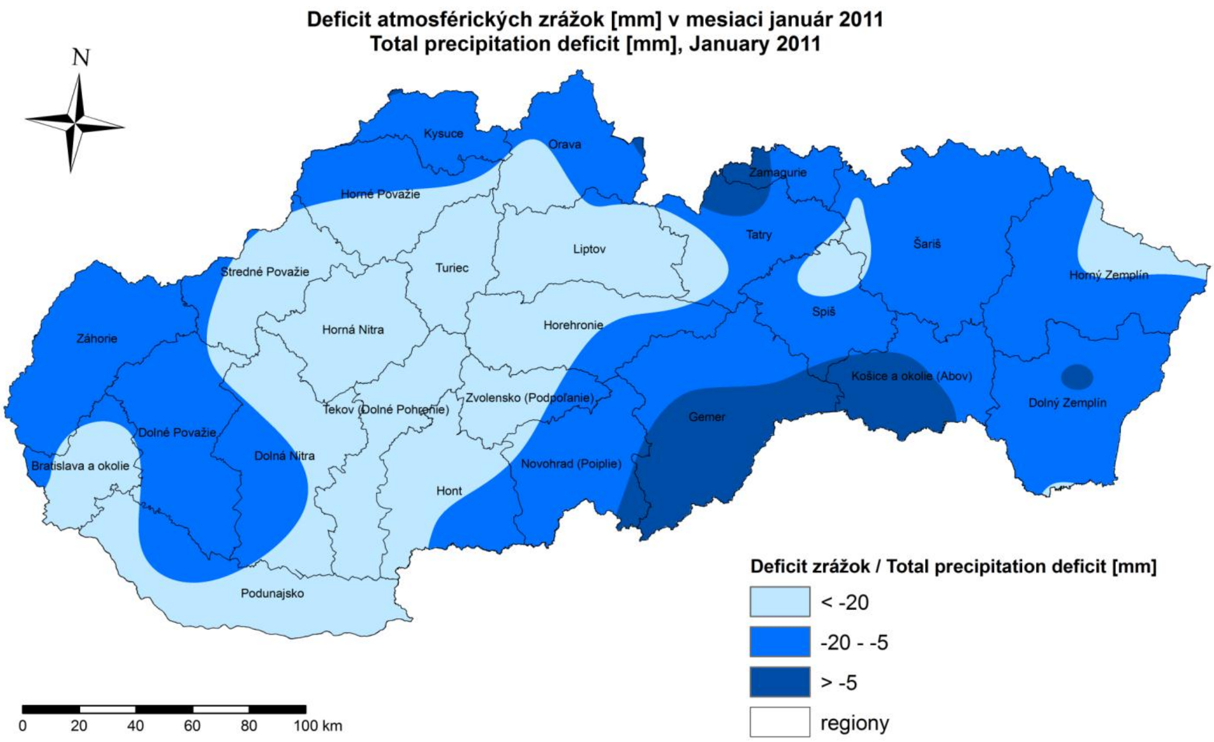
The most precipitation surplus (20,5 mm), the most precipitation deficit (47,5 mm) in northern part of Slovakia.

Tab. 4: Monthly precipitation totals and percentage of normal at selected meteorological stations of Slovakia, 2012

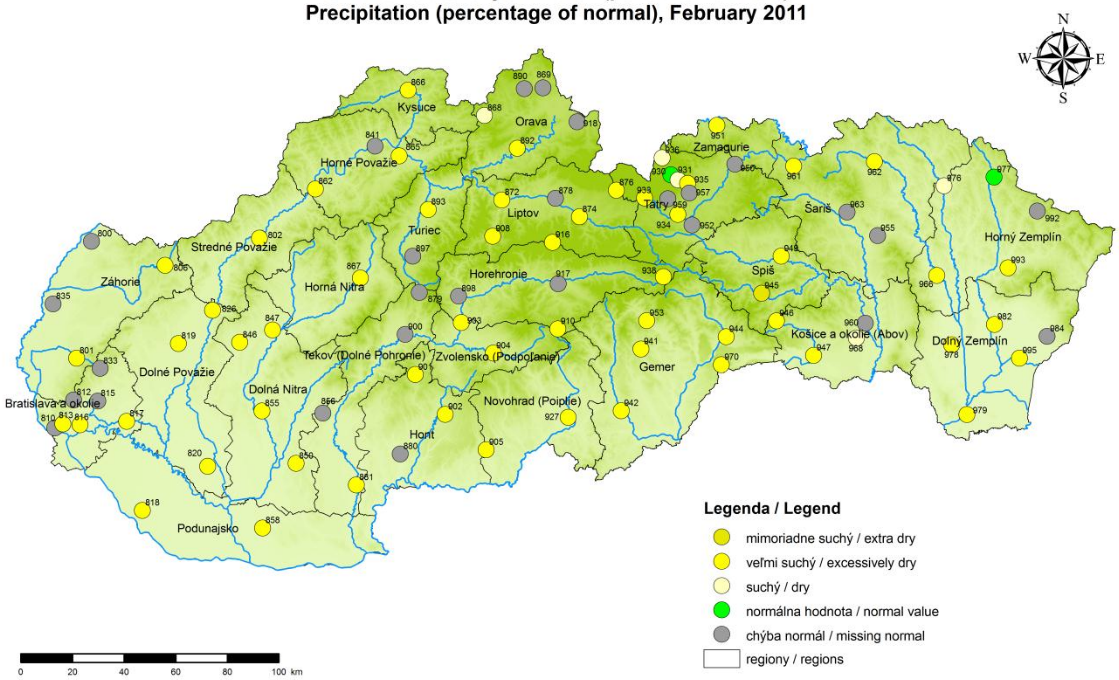
		2012											
Station name	Char.	1	2	3	4	5	6	7	8	9	10	11	12
Bardejov	MT	49.9	42.2	18.2	35.0	82.7	74.7	156.7	40.9	32.5	48.6	36.1	24.9
	PN	128.4	113.8	51.7	70.0	95.6	76.1	159.6	47.4	52.3	94.9	74.2	47.8
	ML	W	N	D	D	N	N	EW1	ED1	D	N	D	ED1
	Deficit	10.9	5.2	-16.8	-15.0	-3.3	-23.3	58.7	-45.1	-29.5	-2.4	-12.9	-27.1
Bratislava, airport	MT	77.1	34.5	8.8	18.2	92.5	36.6	85.9	30.9	25.3	79.6	28.4	49.5
	PN	177.9	80.1	23.4	51.9	166.1	55.6	159.2	50.2	63.5	214.9	52.4	99.6
	ML	EW1	N	ED1	D	EW1	D	EW1	D	D	EW2	D	N
	Deficit	34.1	-8.5	-28.2	-16.8	36.5	-29.4	31.9	-31.1	-14.7	42.6	-25.6	-0.5
Čadca	MT	142.0	77.6	45.7	33.7	34.4	127.0	85.1	38.1	78.6	116.2	60.8	37.8
	PN	229.9	149.2	92.1	53.3	37.5	107.1	75.2	35.9	112.4	205.8	86.0	52.5
	ML	EW2	W	N	D	ED1	N	N	ED1	N	EW2	N	D
	Deficit	80.0	25.6	-4.3	-29.3	-57.6	8.0	-27.9	-67.9	8.6	60.2	-10.2	-34.2
Červený Kláštor	MT	77.5	53.6	24.6	37.6	65.3	100.6	99.8	20.2	40.4	53.6	27.3	22.4
	PN	196.4	165.4	69.9	76.0	75.1	88.6	99.3	20.8	64.8	121.7	59.7	51.7
	ML	EW2	EW1	D	N	N	N	N	ED1	D	N	D	D
	Deficit	38.5	21.6	-10.4	-11.4	-21.7	-13.4	-0.2	-76.8	-21.6	9.6	-18.7	-20.6
Hurbanovo	MT	48.9	16.1	2.5	37.1	23.2	58.9	87.3	5.8	24.7	64.0	24.7	41.4
	PN	143.7	47.2	9.4	95.5	41.6	96.7	172.1	10.1	63.4	198.6	45.9	103.9
	ML	W	ED1	ED2	N	ED1	N	EW1	ED1	D	EW2	ED1	N
	Deficit	14.9	-17.9	-24.5	-1.9	-32.8	-2.1	36.3	-52.2	-14.3	32.0	-29.3	1.4
Košice, airport	MT	18.0	6.2	2.9	44.4	39.9	83.1	127.6	8.1	37.2	90.3	35.7	55.5
	PN	65.0	23.2	9.2	104.6	55.7	99.0	152.0	11.0	70.3	211.8	73.7	159.5
	ML	D	ED1	ED2	N	D	N	EW1	ED1	D	EW2	D	EW1
	Deficit	-10.0	-20.8	-29.1	2.4	-32.1	-0.9	43.6	-65.9	-15.8	47.3	-12.3	20.5
Myjava	MT	98.2	60.5	9.9	16.4	37.1	57.5	103.0	16.7	53.9	94.4	21.9	53.7
	PN	210.6	130.5	25.8	34.2	56.7	72.4	158.0	27.3	107.8	195.3	35.2	90.9
	ML	EW2	W	ED1	ED1	D	D	EW1	ED1	N	EW2	ED1	N
	Deficit	51.2	14.5	-28.1	-31.6	-27.9	-21.5	38.0	-44.3	3.9	46.4	-40.1	-5.3
Oravská Lesná	MT	230.1	120.6	58.3	50.1	48.6	154.0	103.8	41.0	80.2	125.6	60.7	47.5
	PN	287.7	185.1	92.7	69.6	45.5	125.2	80.4	36.0	88.6	169.0	73.5	50.0
	ML	EW2	EW1	N	D	ED1	W	N	ED1	N	EW1	D	D
	Deficit	150.1	55.6	-4.7	-21.9	-58.4	31.0	-25.2	-73.0	-10.8	51.6	-22.3	-47.5
Plaveč	MT	45.4	34.6	25.3	40.1	78.7	164.9	136.0	41.2	41.1	52.9	35.1	26.0
	PN	150.6	132.9	91.2	85.7	96.9	172.3	145.3	47.4	72.4	128.3	85.2	72.8
	ML	EW1	W	N	N	N	EW1	W	ED1	D	W	N	D
	Deficit	15.4	8.6	-2.7	-6.9	-2.3	68.9	43.0	-45.8	-15.9	11.9	-5.9	-10.0
Ratková	MT	35.8	12.1	0.0	47.7	25.7	69.0	154.1	10.5	32.4	110.3	77.4	55.8
	PN	95.6	26.6	0.0	80.8	29.8	74.4	201.5	15.7	61.9	218.4	116.8	112.5
	ML	N	ED1	ED2	N	ED1	D	EW2	ED1	D	EW2	N	N
	Deficit	-1.2	-33.9	-42.0	-11.3	-60.3	-24.0	78.1	-56.5	-19.6	59.3	11.4	5.8
Somotor	MT	34.4	22.8	3.4	38.5	49.6	63.0	61.3	4.1	69.0	47.5	28.5	58.2
	PN	112.1	80.9	10.0	91.7	84.6	85.4	95.4	6.3	160.2	130.4	64.1	152.9
	ML	N	N	ED2	N	N	N	N	ED2	EW1	W	D	EW1
	Deficit	3.4	-5.2	-30.6	-3.5	-9.4	-11.0	-2.7	-61.9	26.0	11.5	-15.5	20.2

Fig. 10 Precipitation 2011

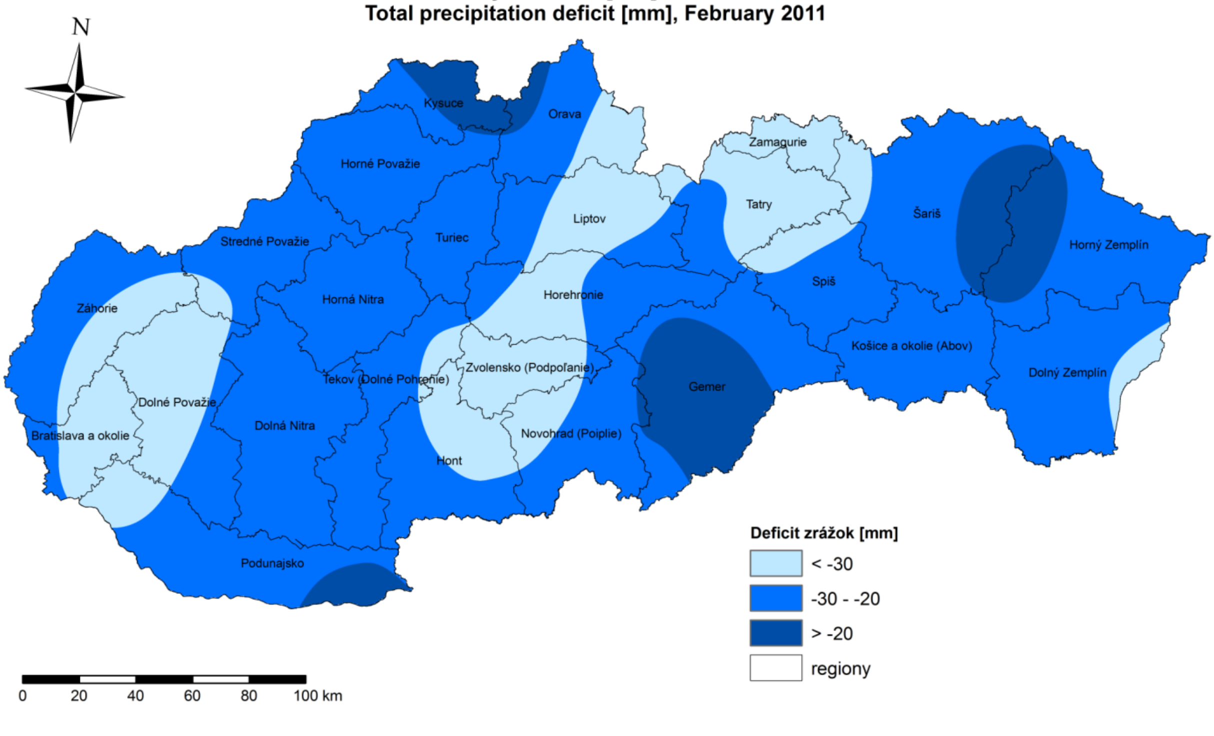




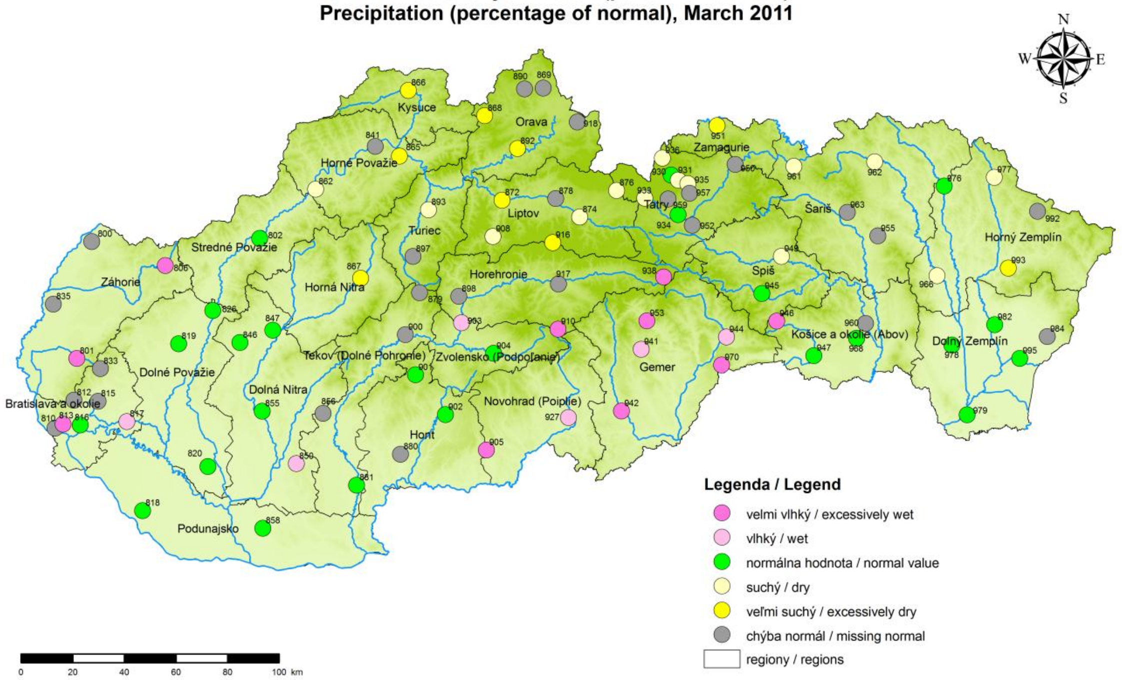
Hodnotenie meteorologických prvkov a ich charakteristík za február 2011
Úhrn atmosférických zrážok (percento normálu)
Precipitation (percentage of normal), February 2011



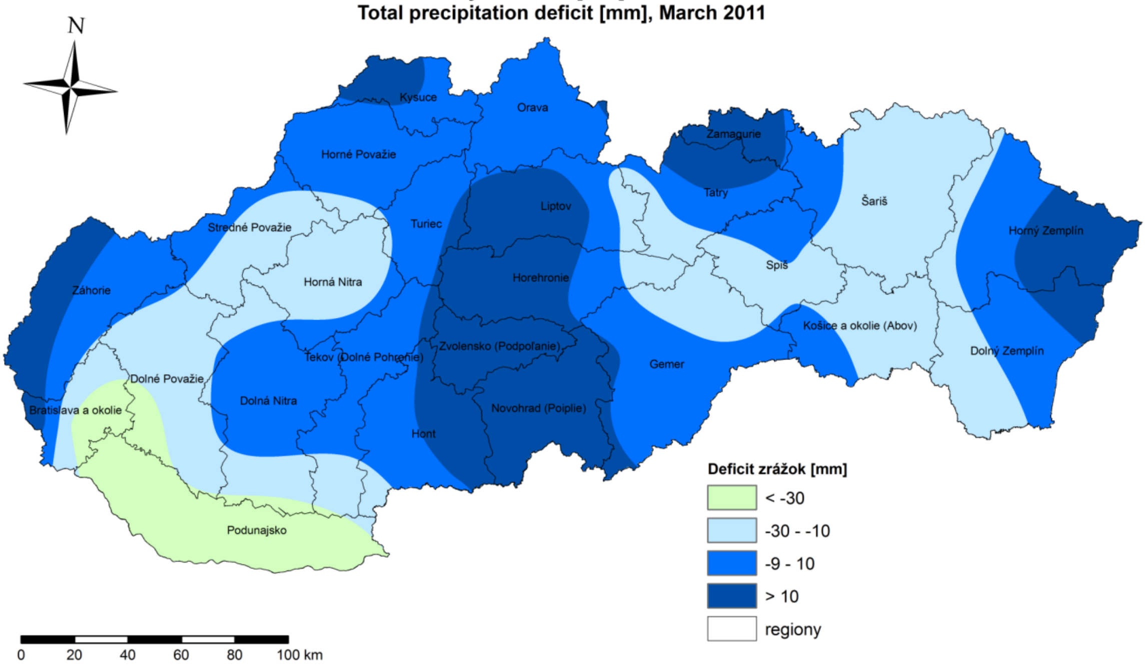
Deficit atmosférických zrážok [mm] v mesiaci február 2011
Total precipitation deficit [mm], February 2011



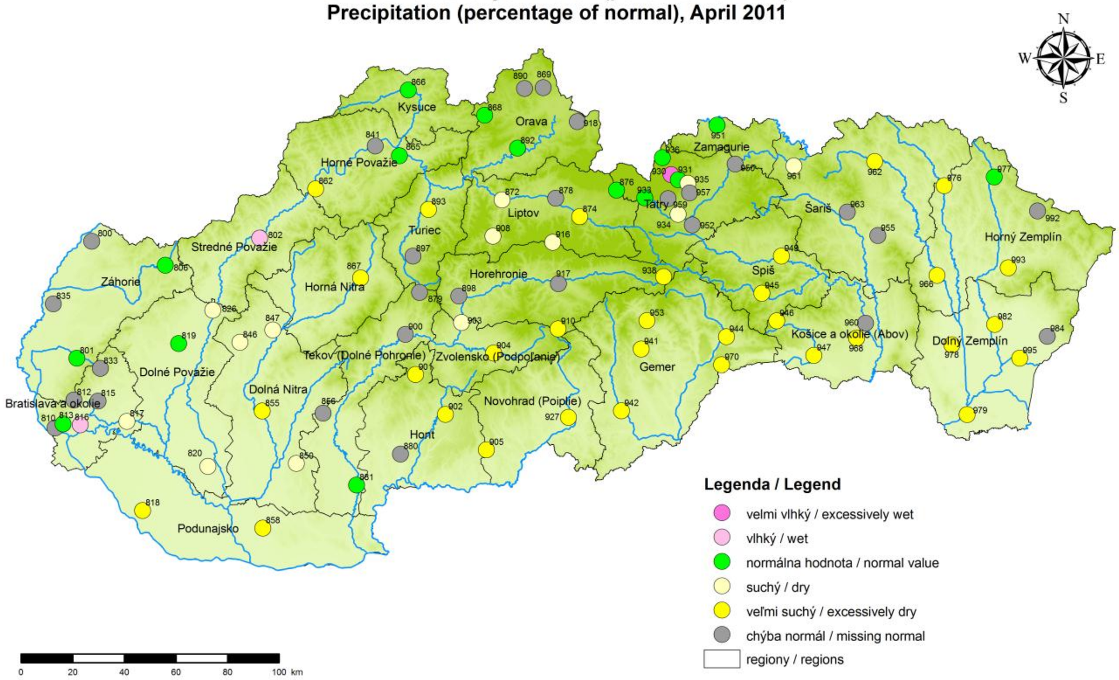
Hodnotenie meteorologických prvkov a ich charakteristík za marec 2011
Úhrn atmosférických zrážok (percento normálu)
Precipitation (percentage of normal), March 2011



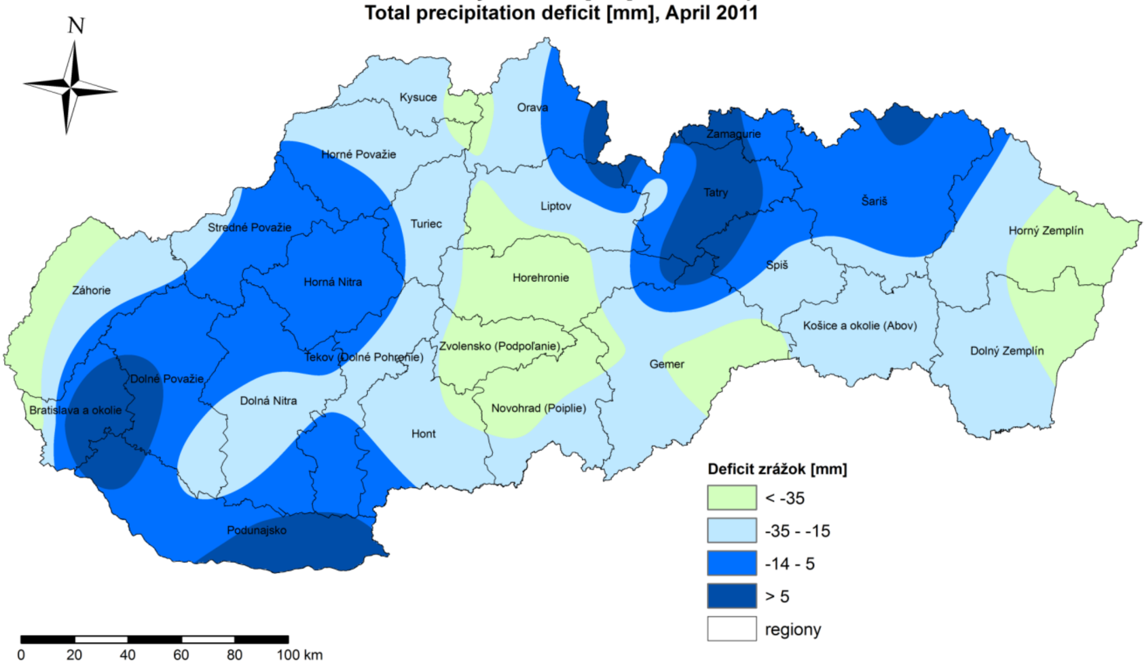
Deficit atmosférických zrážok [mm] v mesiaci marec 2011
Total precipitation deficit [mm], March 2011



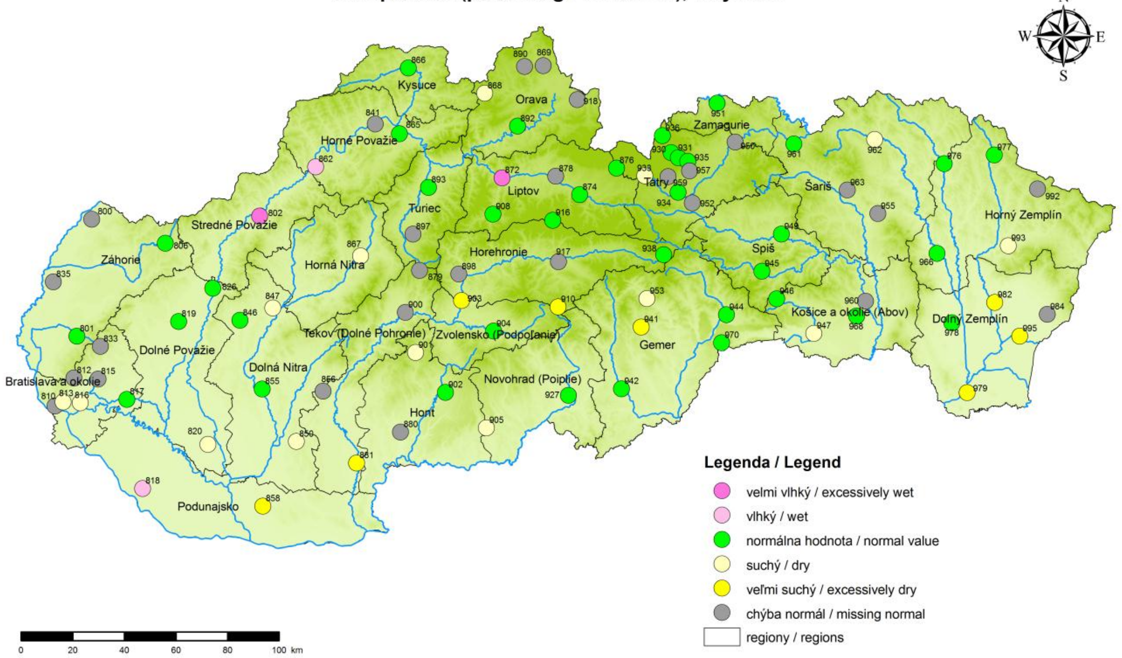
Hodnotenie meteorologických prvkov a ich charakteristík za apríl 2011
Úhrn atmosférických zrážok (percento normálu)
Precipitation (percentage of normal), April 2011



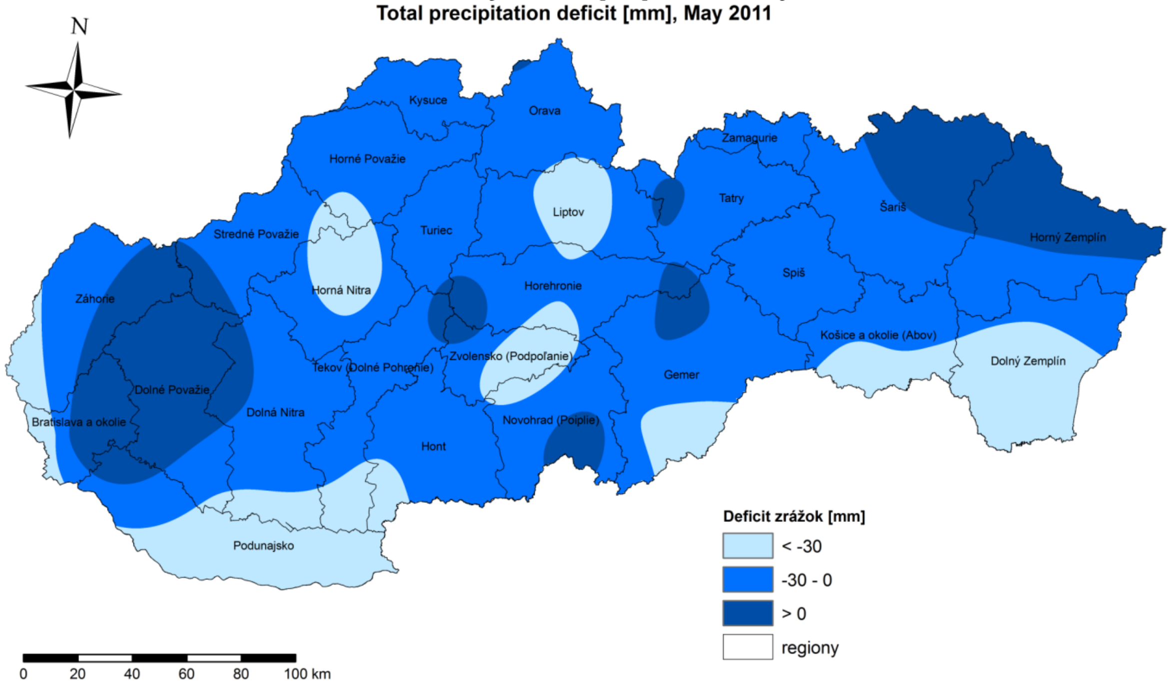
Deficit atmosférických zrážok [mm] v mesiaci apríl 2011
Total precipitation deficit [mm], April 2011



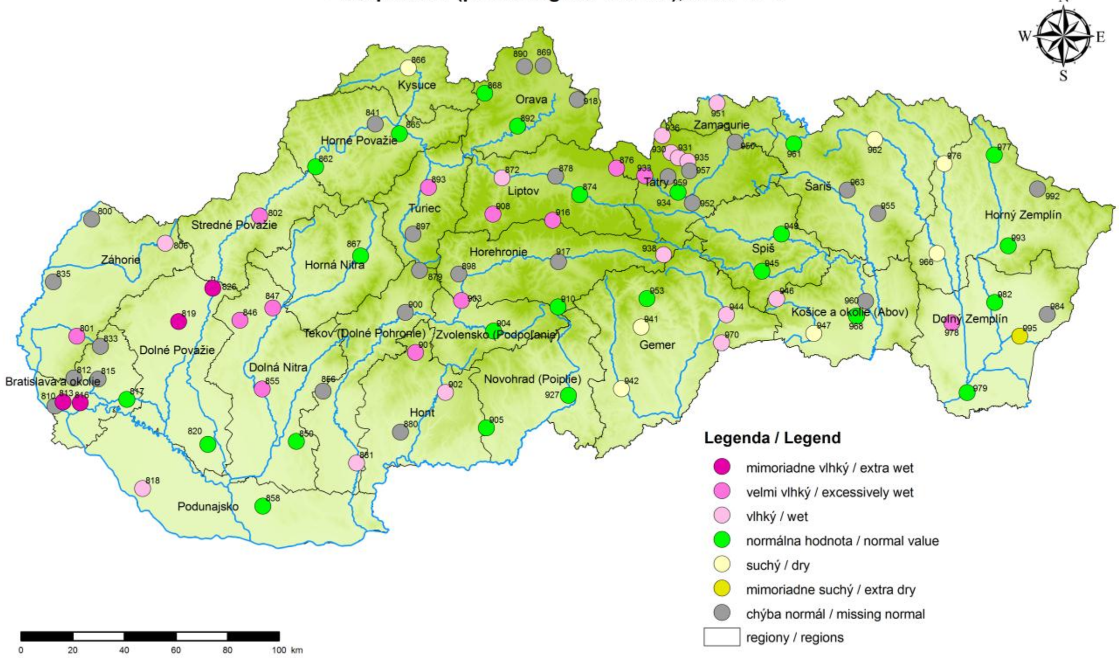
Hodnotenie meteorologických prvkov a ich charakteristík za máj 2011
Úhrn atmosférických zrážok (percento normálu)
Precipitation (percentage of normal), May 2011



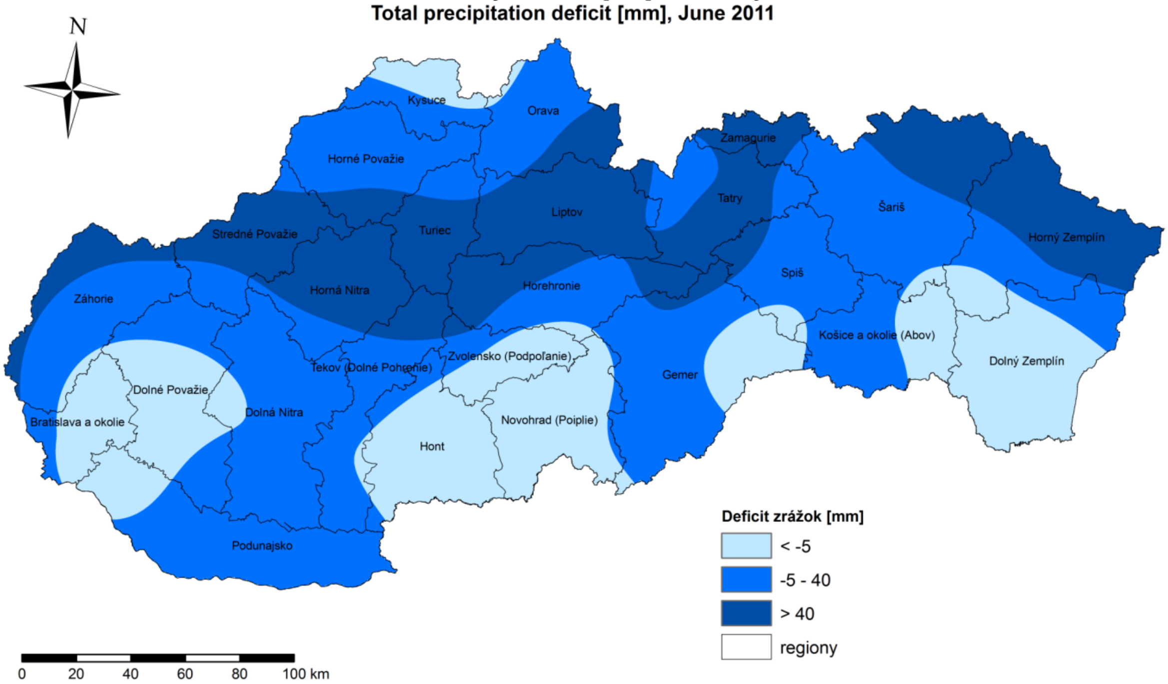
Deficit atmosférických zrážok [mm] v mesiaci májl 2011
Total precipitation deficit [mm], May 2011



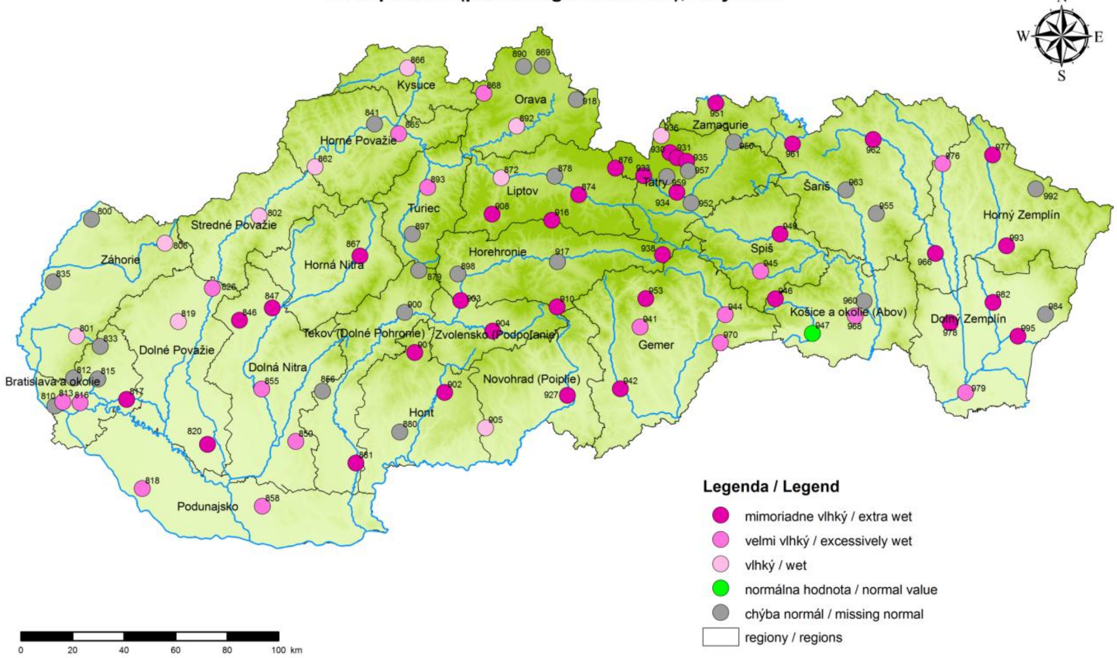
Hodnotenie meteorologických prvkov a ich charakteristík za jún 2011
Úhrn atmosférických zrážok (percento normálu)
Precipitation (percentage of normal), June 2011



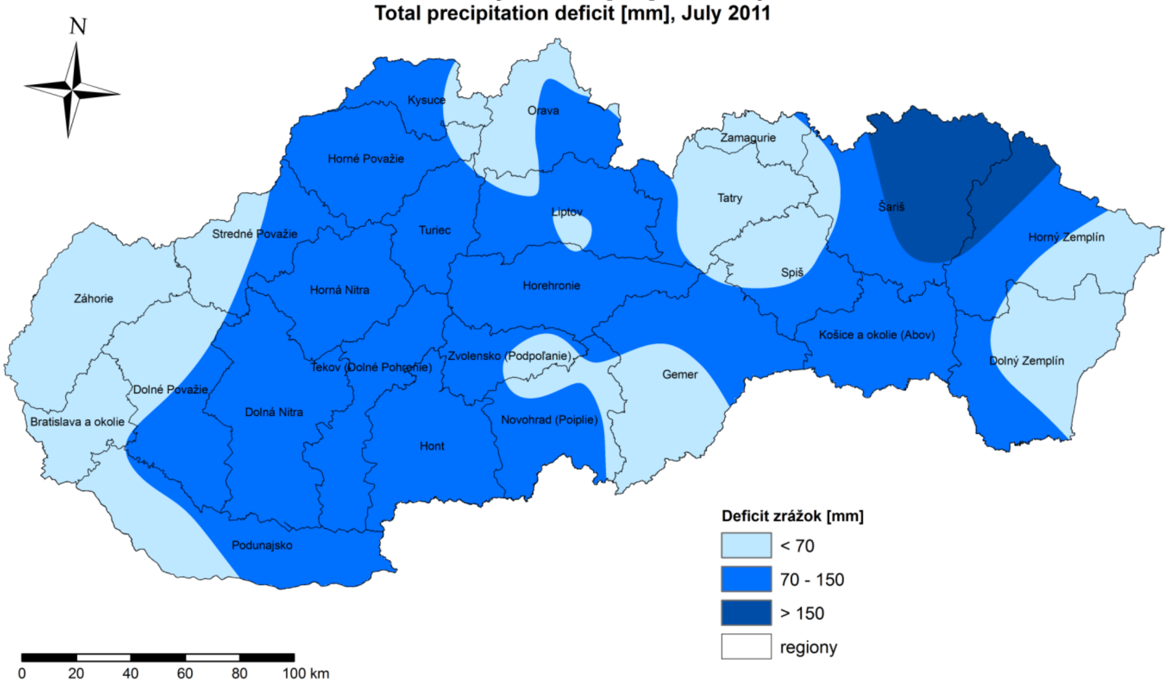
Deficit atmosférických zrážok [mm] v mesiaci jún 2011
Total precipitation deficit [mm], June 2011



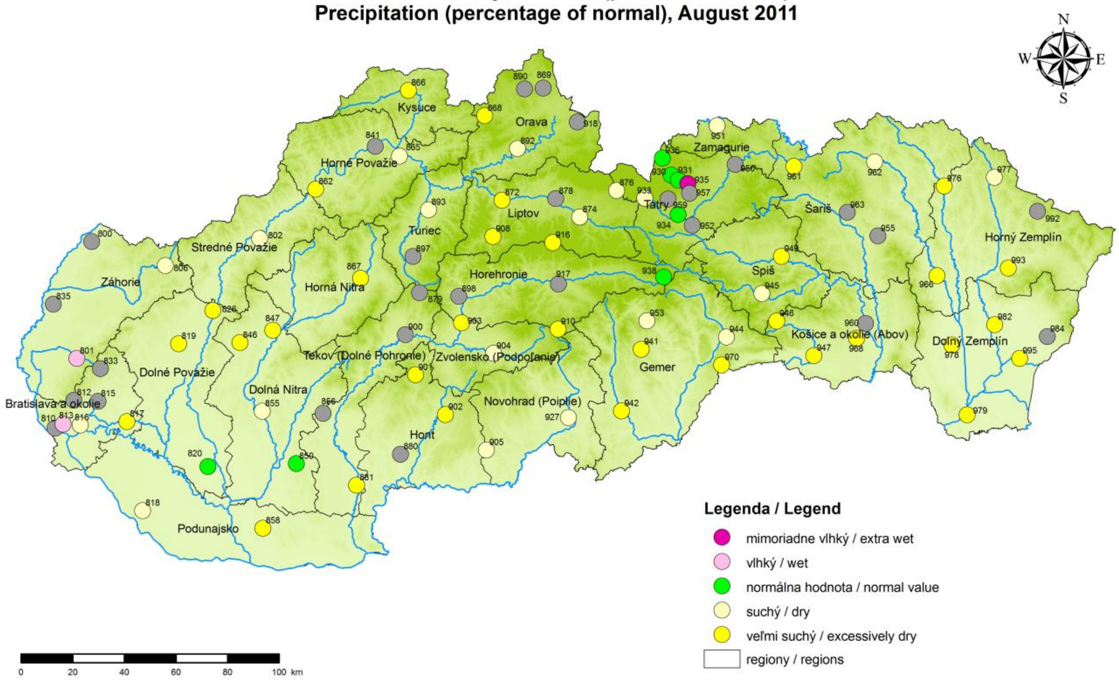
Hodnotenie meteorologických prvkov a ich charakteristík za júl 2011
Úhrn atmosférických zrážok (percento normálu)
Precipitation (percentage of normal), July 2011



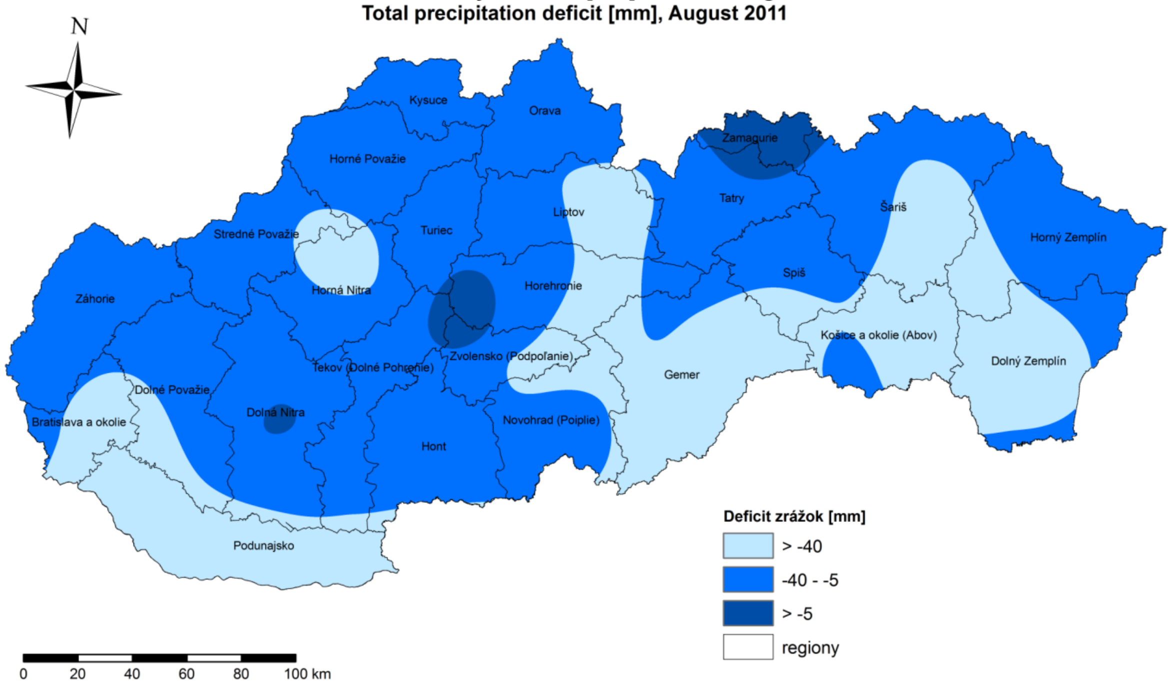
Deficit atmosférických zrážok [mm] v mesiaci júl 2011
Total precipitation deficit [mm], July 2011



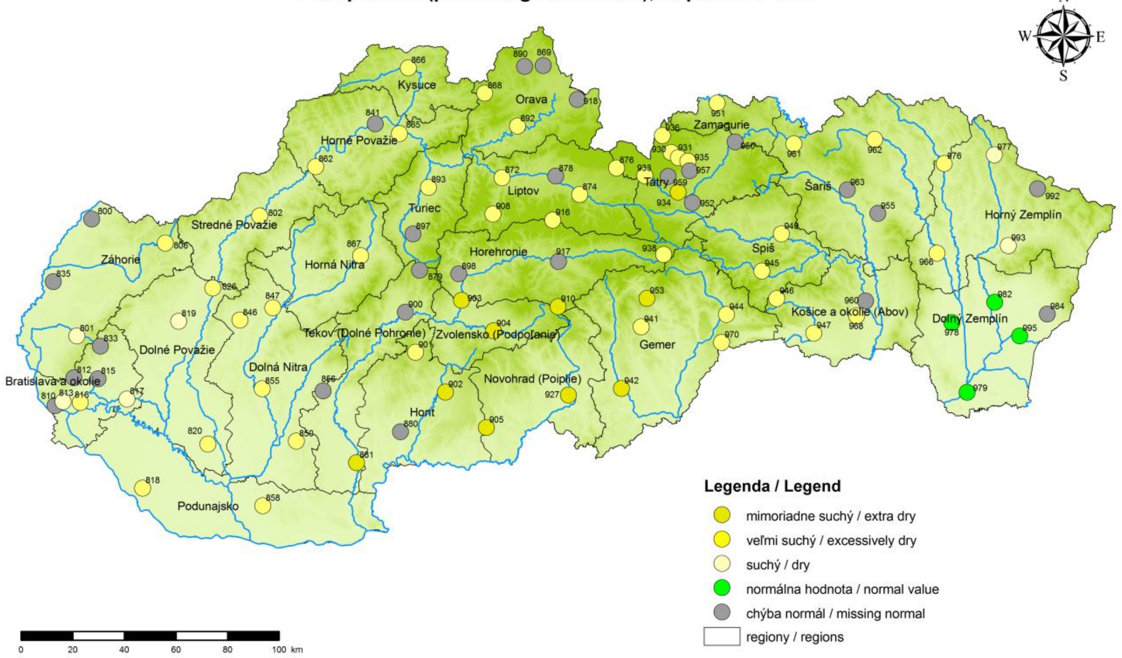
Hodnotenie meteorologických prvkov a ich charakteristík za august 2011
Úhrn atmosférických zrážok (percento normálu)
Precipitation (percentage of normal), August 2011



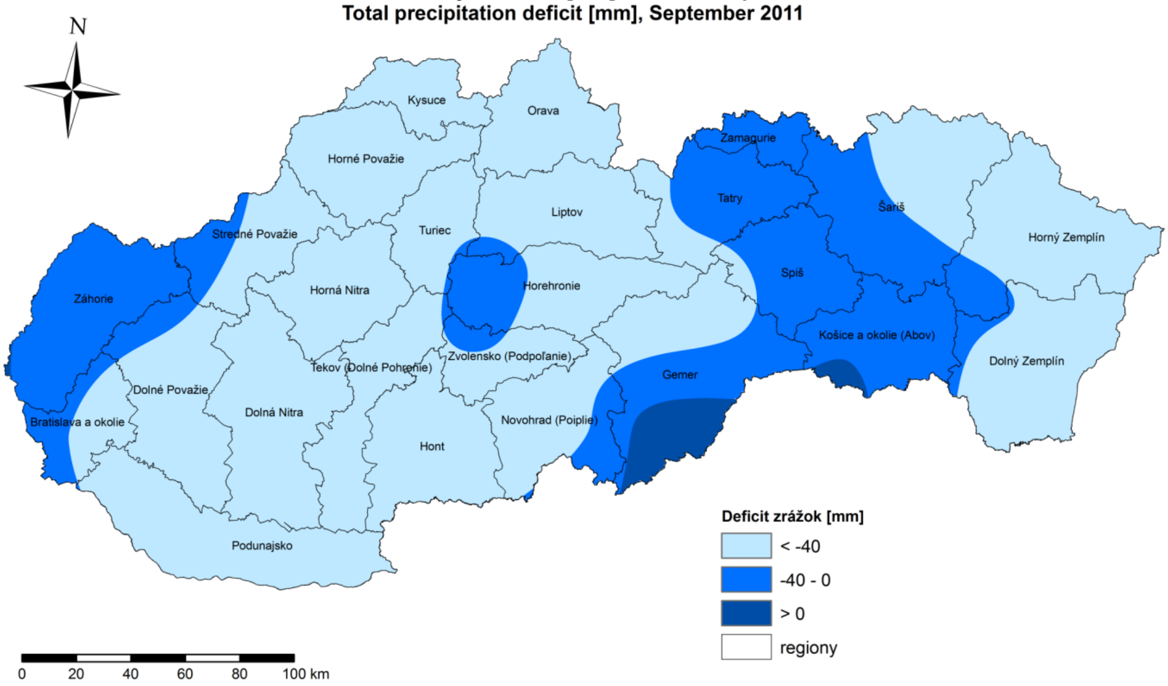
Deficit atmosférických zrážok [mm] v mesiaci august 2011
Total precipitation deficit [mm], August 2011



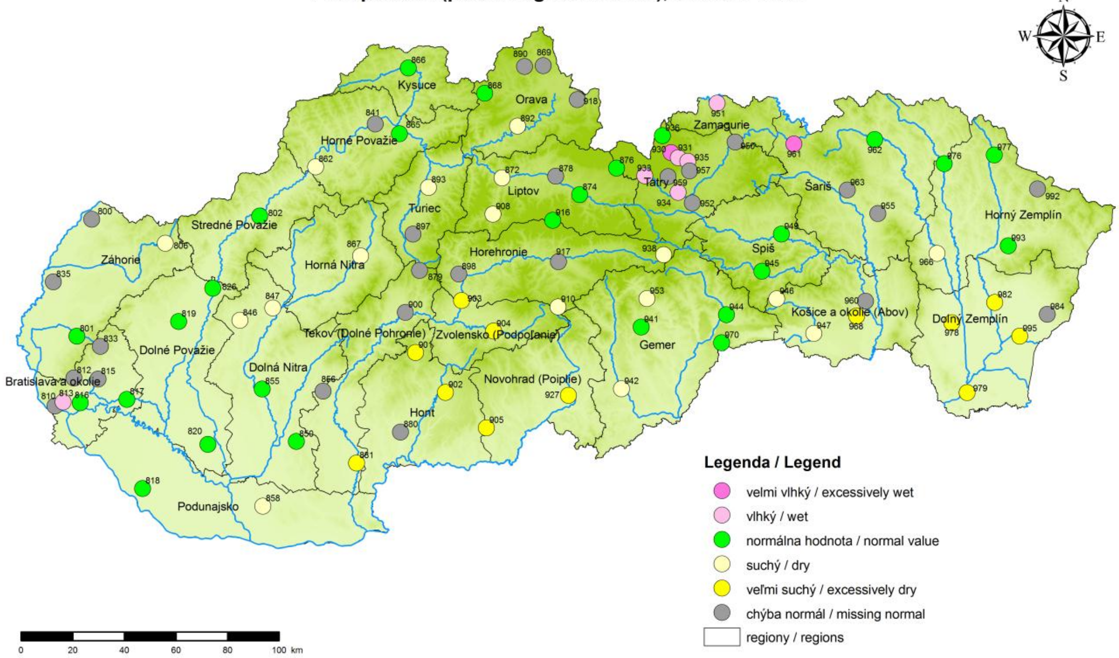
Hodnotenie meteorologických prvkov a ich charakteristík za september 2011
Úhrn atmosférických zrážok (percento normálu)
Precipitation (percentage of normal), September 2011



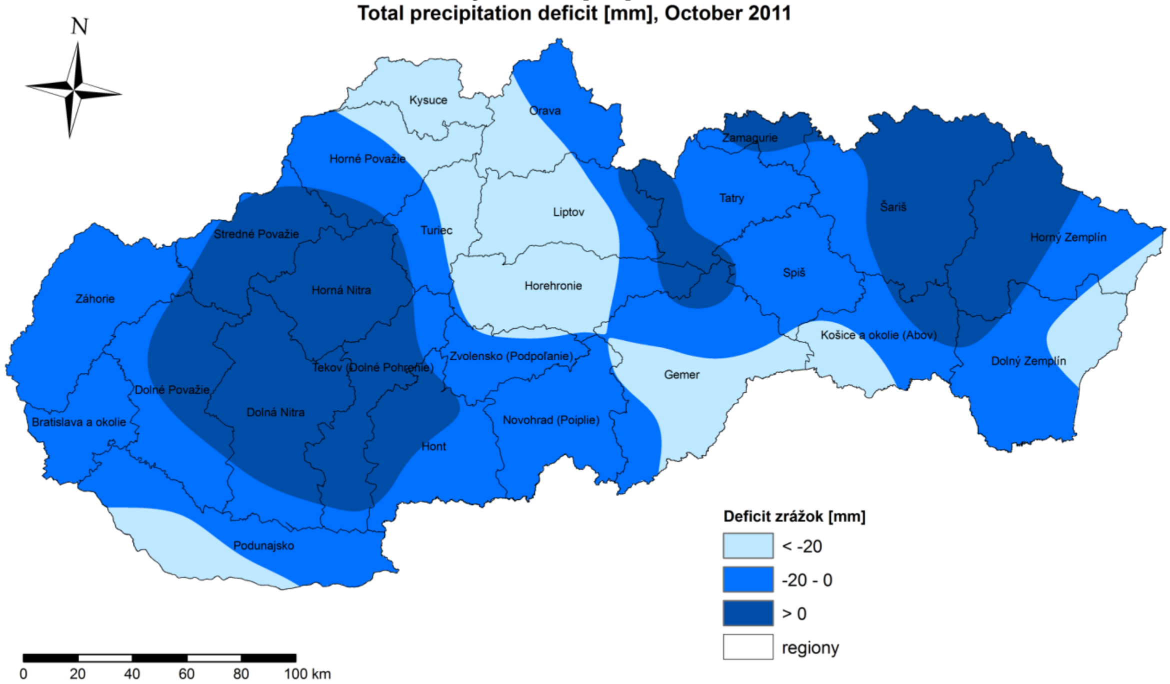
Deficit atmosférických zrážok [mm] v mesiaci september 2011
Total precipitation deficit [mm], September 2011



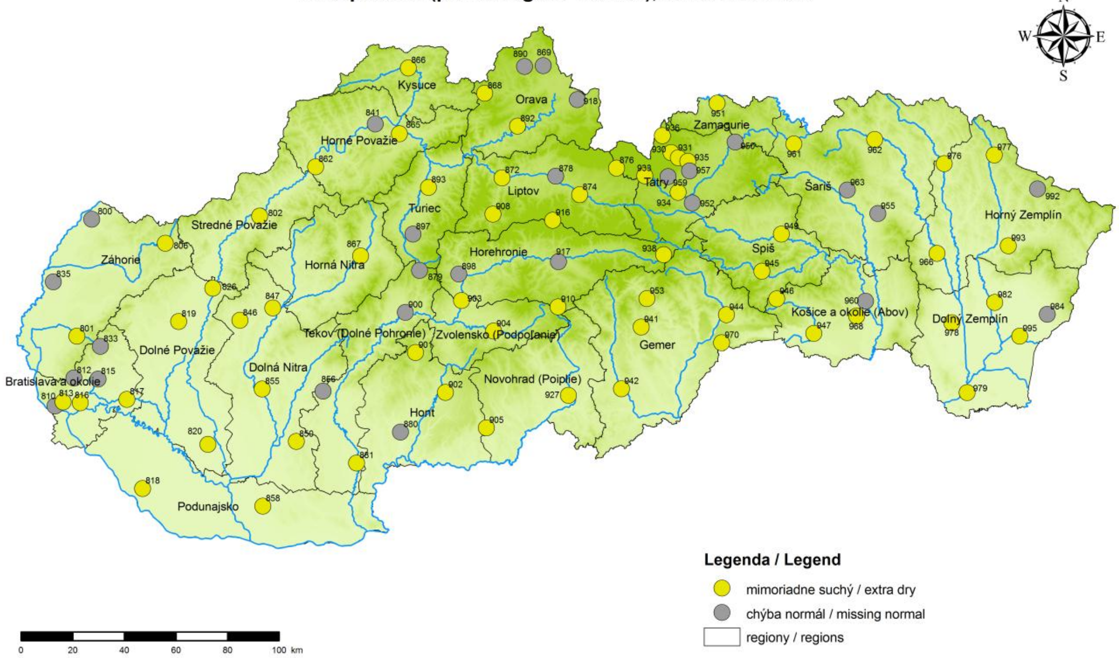
Hodnotenie meteorologických prvkov a ich charakteristík za október 2011
Úhrn atmosférických zrážok (percento normálu)
Precipitation (percentage of normal), October 2011



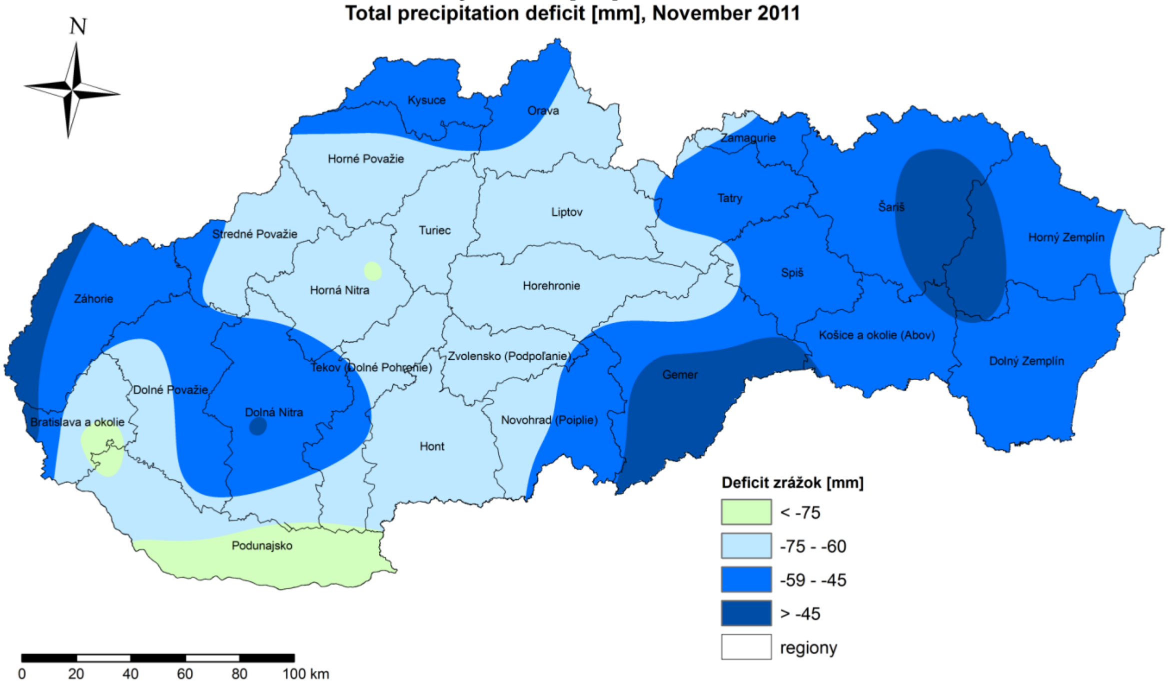
Deficit atmosférických zrážok [mm] v mesiaci október 2011
Total precipitation deficit [mm], October 2011



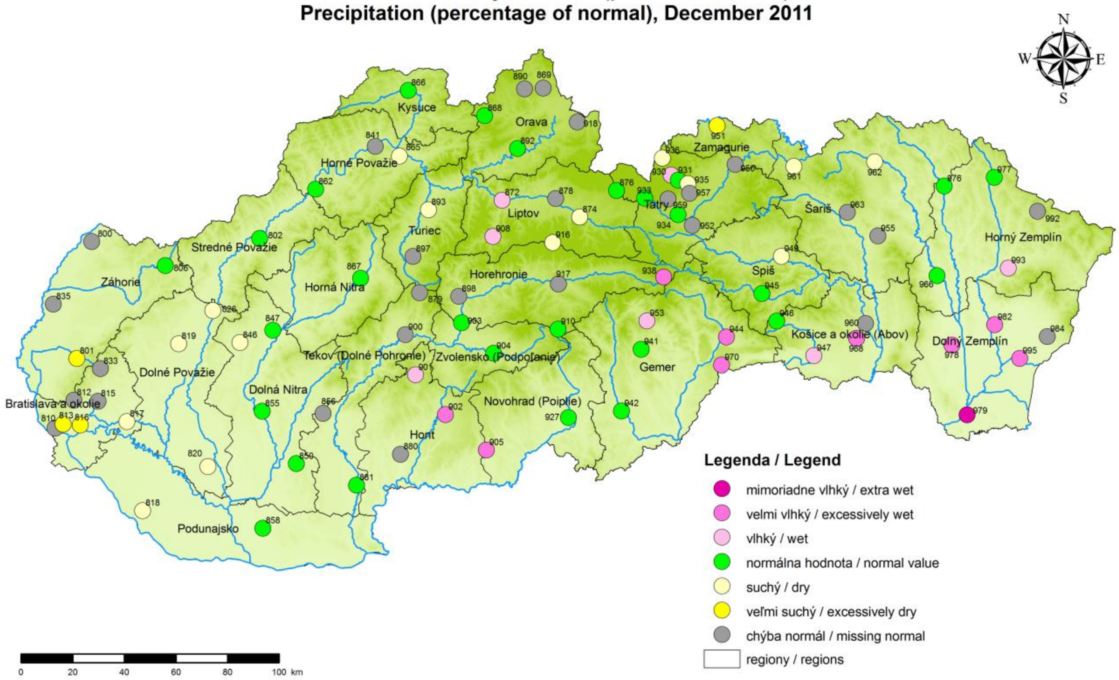
Hodnotenie meteorologických prvkov a ich charakteristík za november 2011
Úhrn atmosférických zrážok (percento normálu)
Precipitation (percentage of normal), November 2011



Deficit atmosférických zrážok [mm] v mesiaci november 2011
Total precipitation deficit [mm], November 2011



Hodnotenie meteorologických prvkov a ich charakteristík za december 2011
Úhrn atmosférických zrážok (percento normálu)
Precipitation (percentage of normal), December 2011



Deficit atmosférických zrážok [mm] v mesiaci december 2011
Total precipitation deficit [mm], December 2011

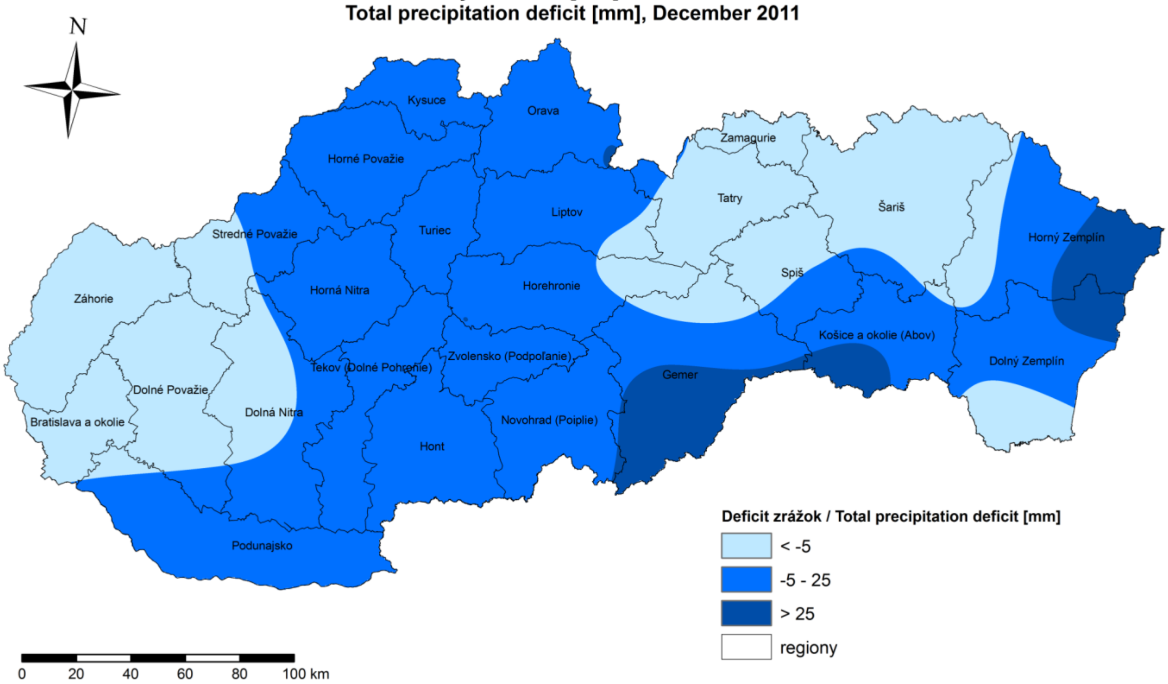
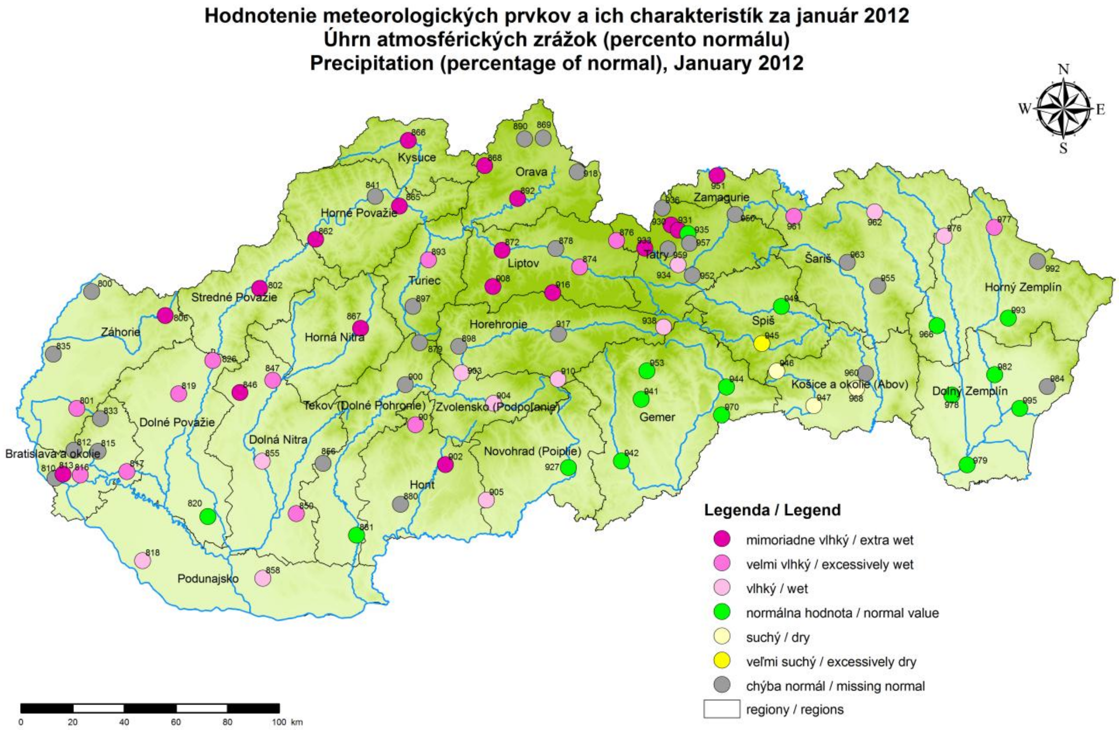
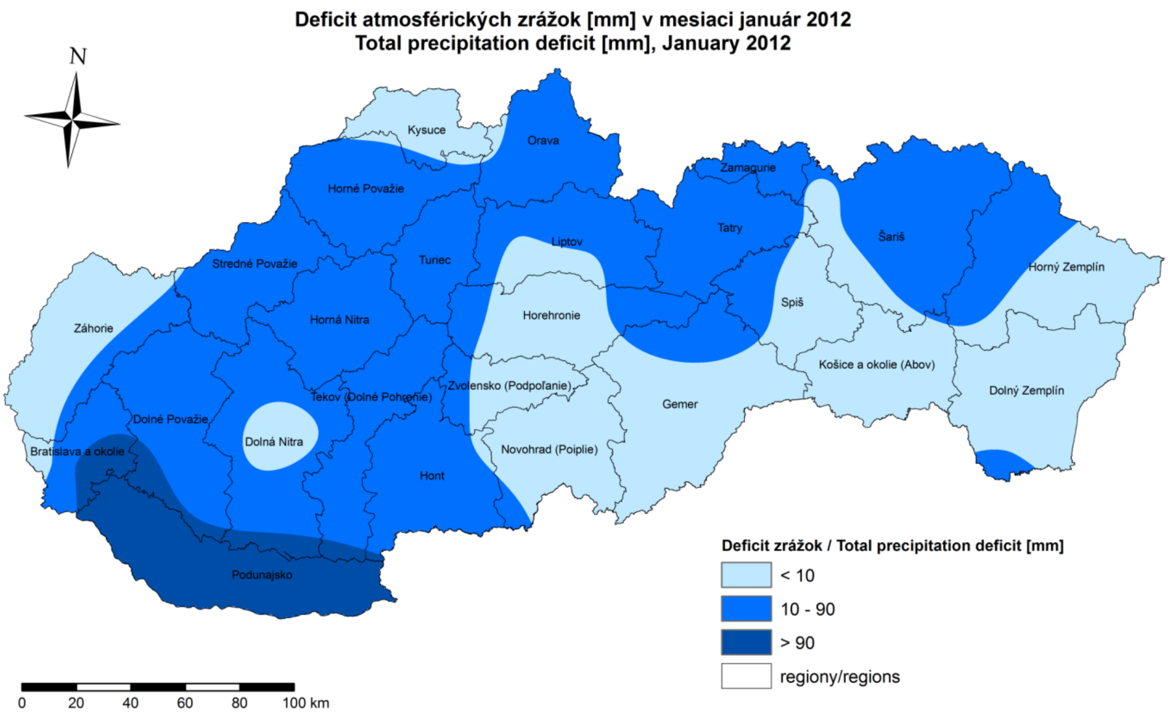
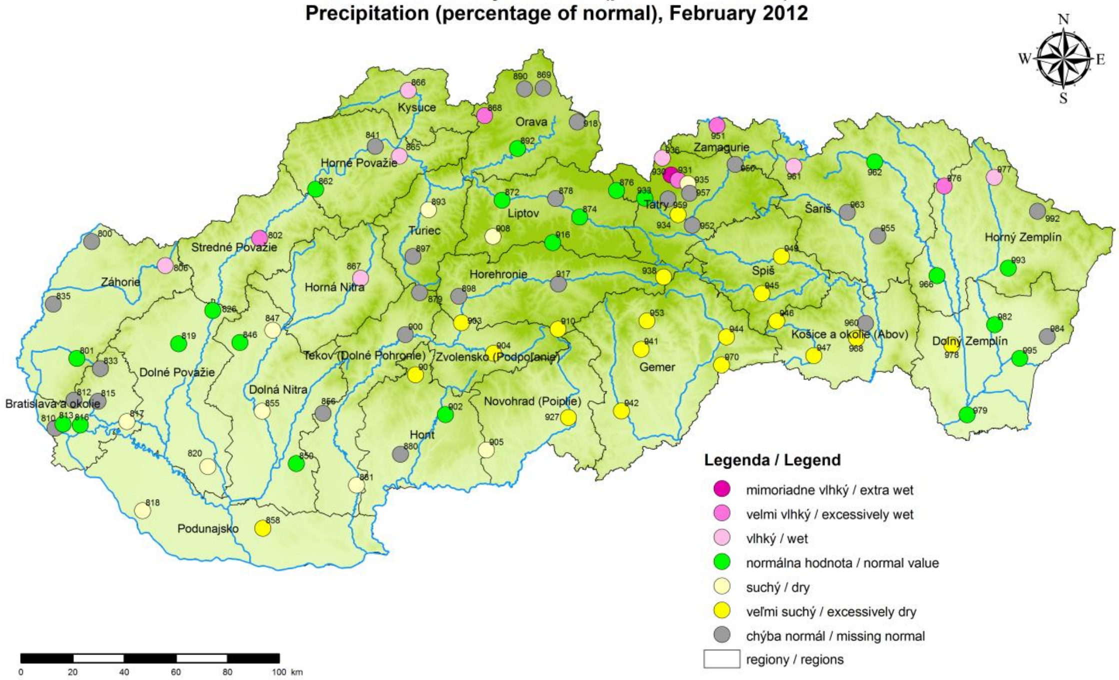


Fig. 11 Precipitation 2012

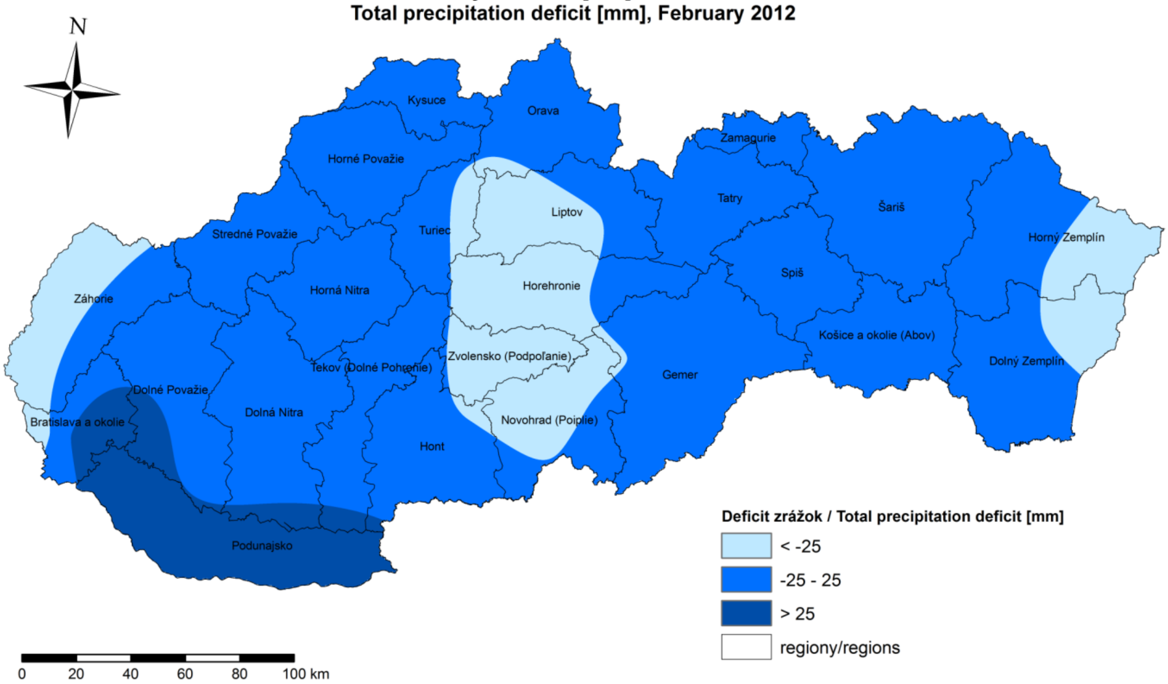




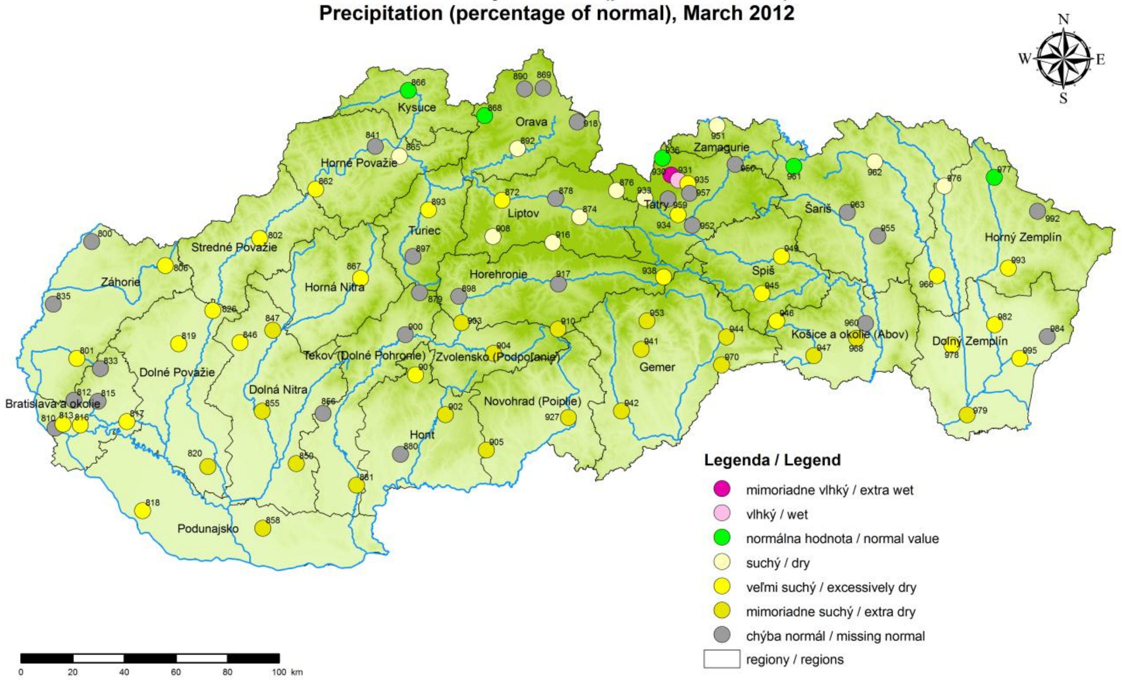
Hodnotenie meteorologických prvkov a ich charakteristík za február 2012
Úhrn atmosférických zrážok (percento normálu)
Precipitation (percentage of normal), February 2012



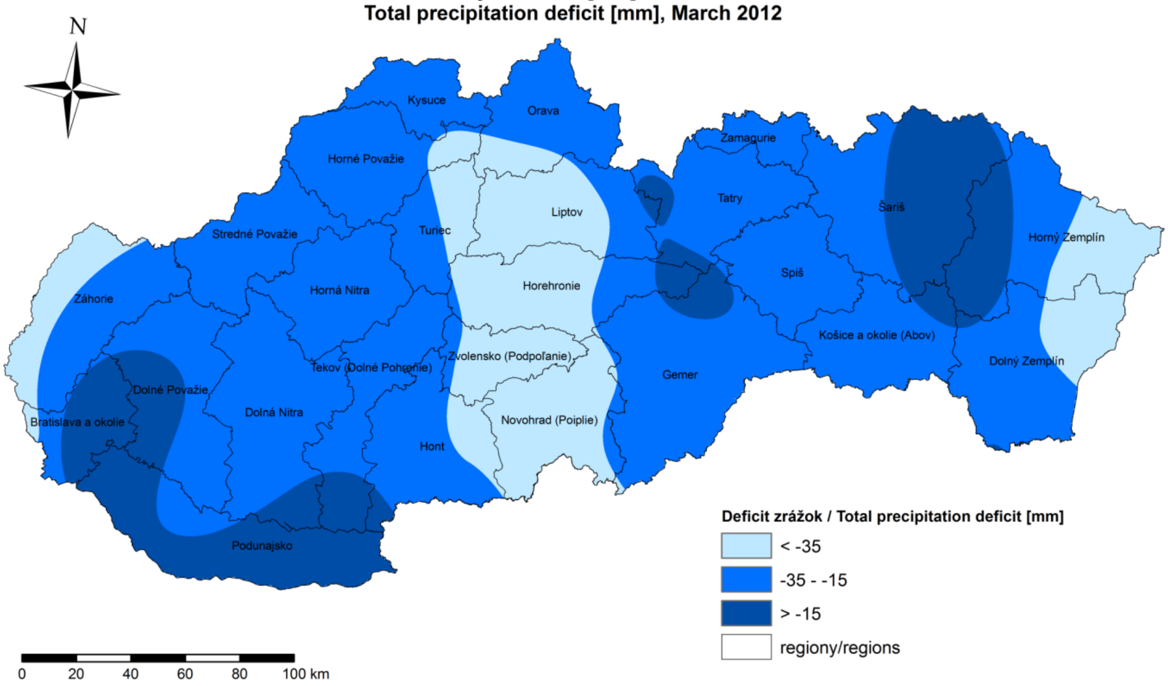
Deficit atmosférických zrážok [mm] v mesiaci február 2012
Total precipitation deficit [mm], February 2012



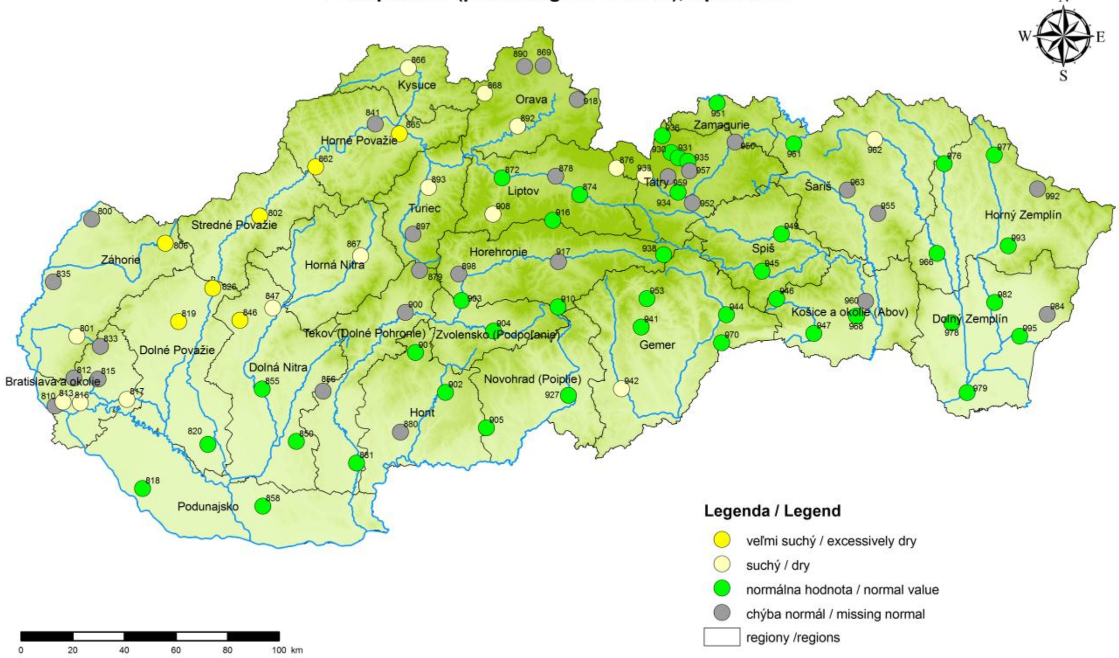
Hodnotenie meteorologických prvkov a ich charakteristík za marec 2012
Úhrn atmosférických zrážok (percento normálu)
Precipitation (percentage of normal), March 2012



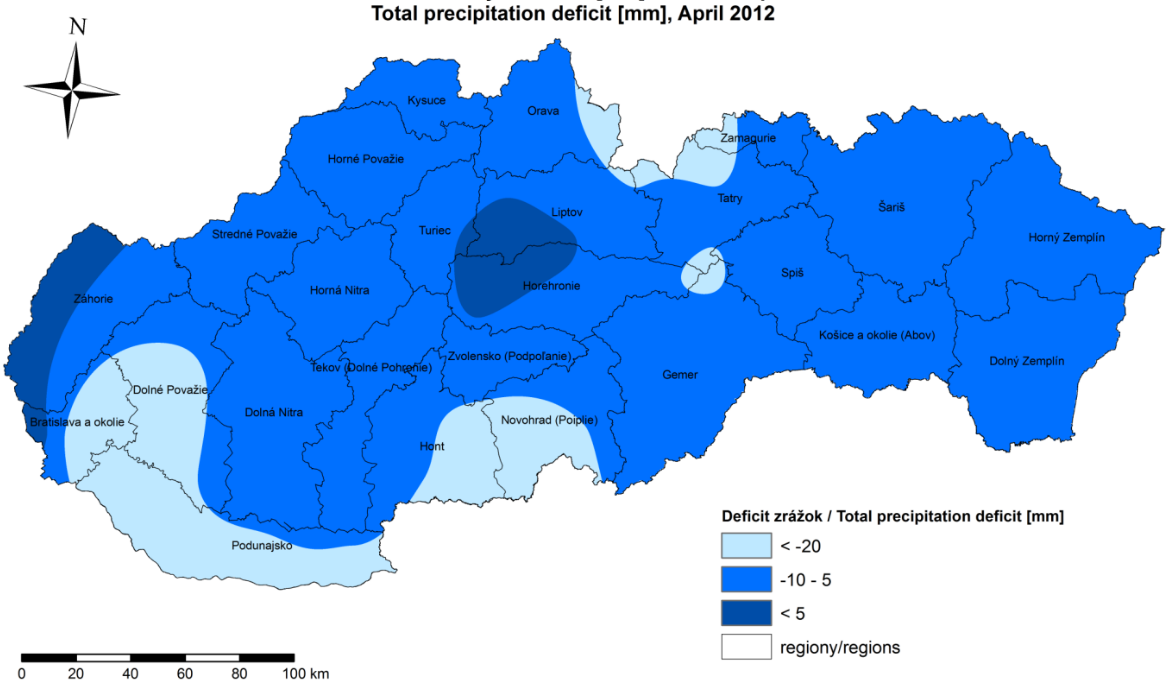
Deficit atmosférických zrážok [mm] v mesiaci marec 2012
Total precipitation deficit [mm], March 2012



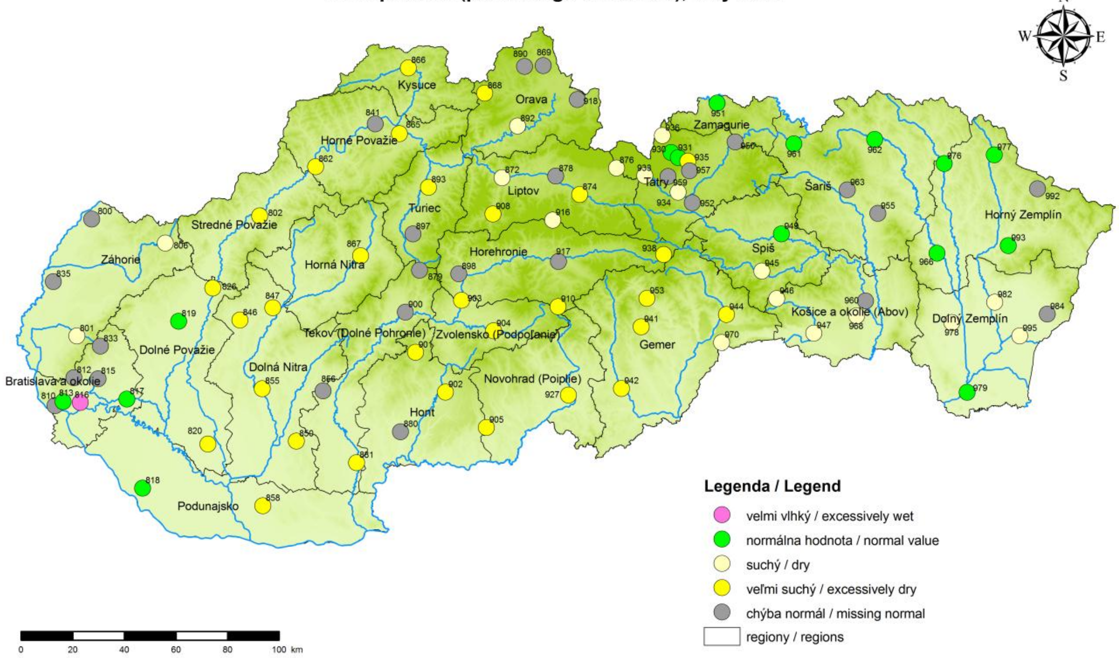
Hodnotenie meteorologických prvkov a ich charakteristík za apríl 2012
Úhrn atmosférických zrážok (percento normálu)
Precipitation (percentage of normal), April 2012



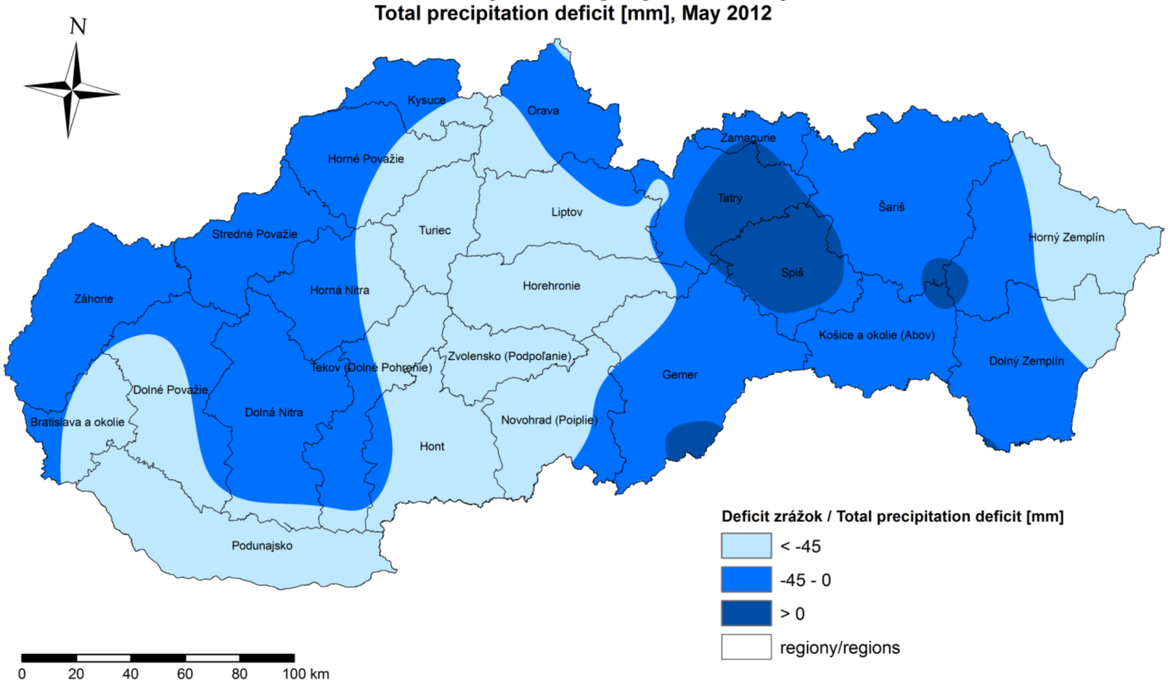
Deficit atmosférických zrážok [mm] v mesiaci apríl 2012
Total precipitation deficit [mm], April 2012



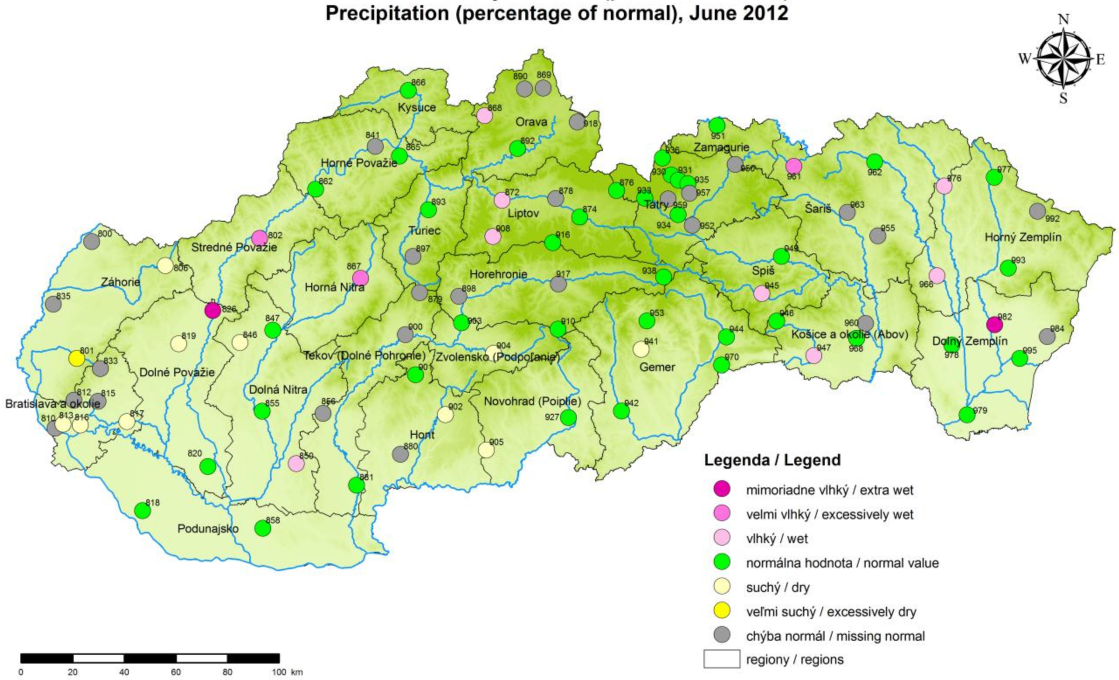
Hodnotenie meteorologických prvkov a ich charakteristík za máj 2012
Úhrn atmosférických zrážok (percento normálu)
Precipitation (percentage of normal), May 2012



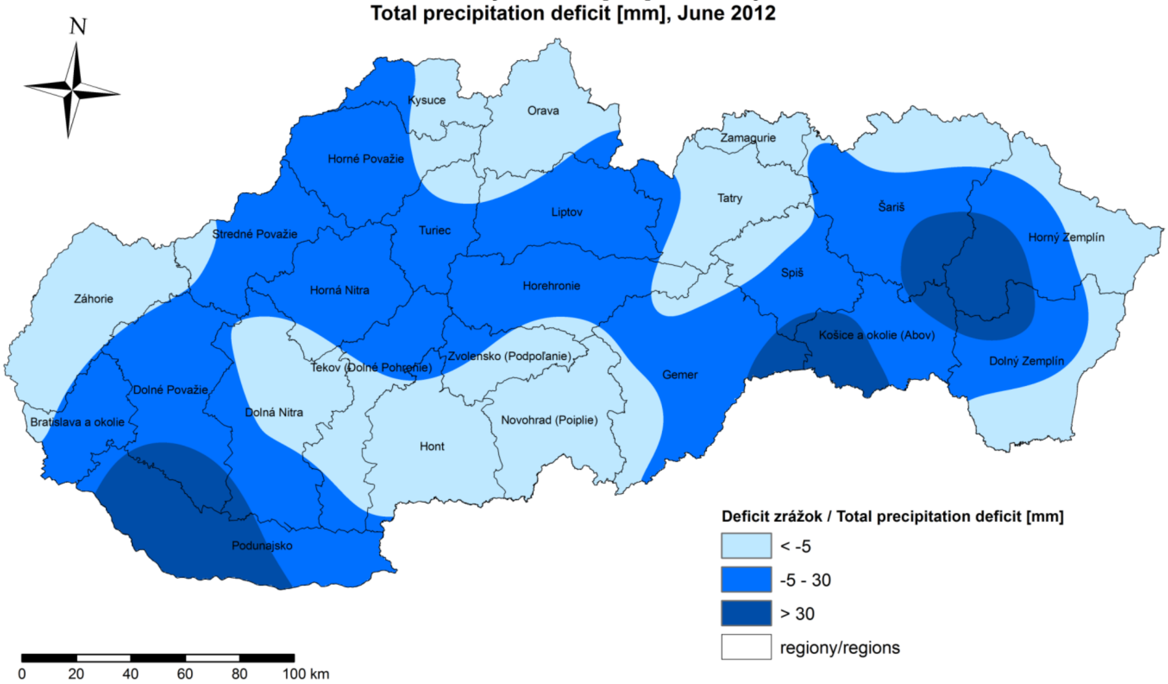
Deficit atmosférických zrážok [mm] v mesiaci máj 2012
Total precipitation deficit [mm], May 2012



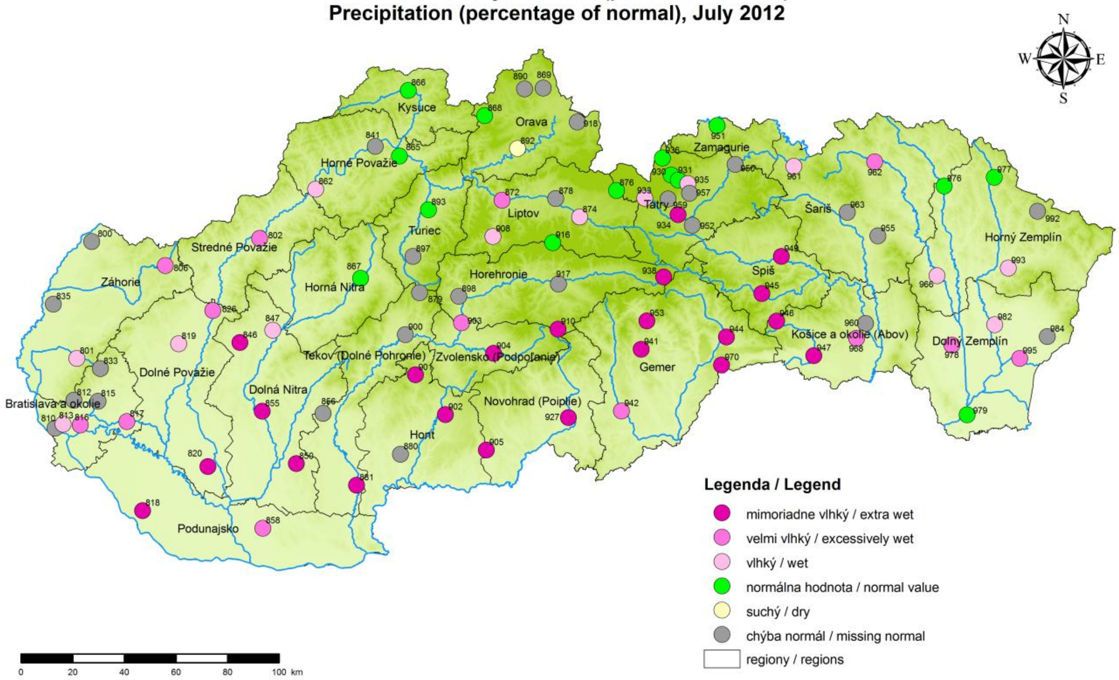
Hodnotenie meteorologických prvkov a ich charakteristík za jún 2012
Úhrn atmosférických zrážok (percento normálu)
Precipitation (percentage of normal), June 2012



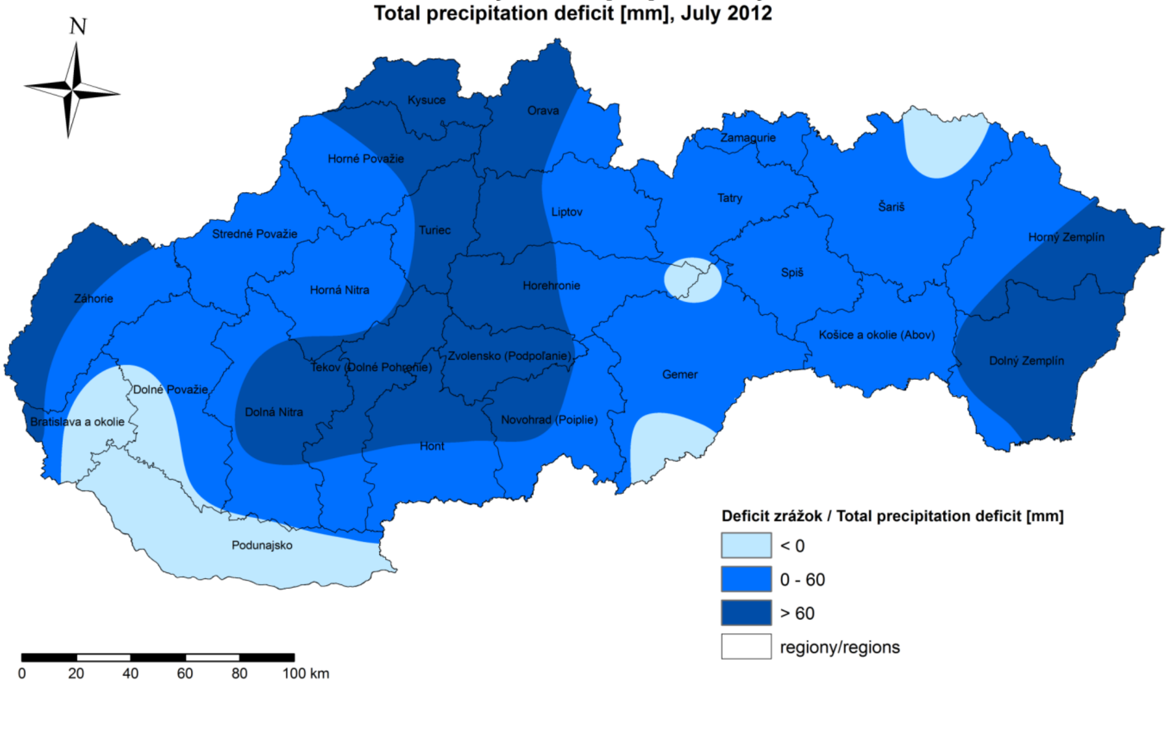
Deficit atmosférických zrážok [mm] v mesiaci jún 2012
Total precipitation deficit [mm], June 2012



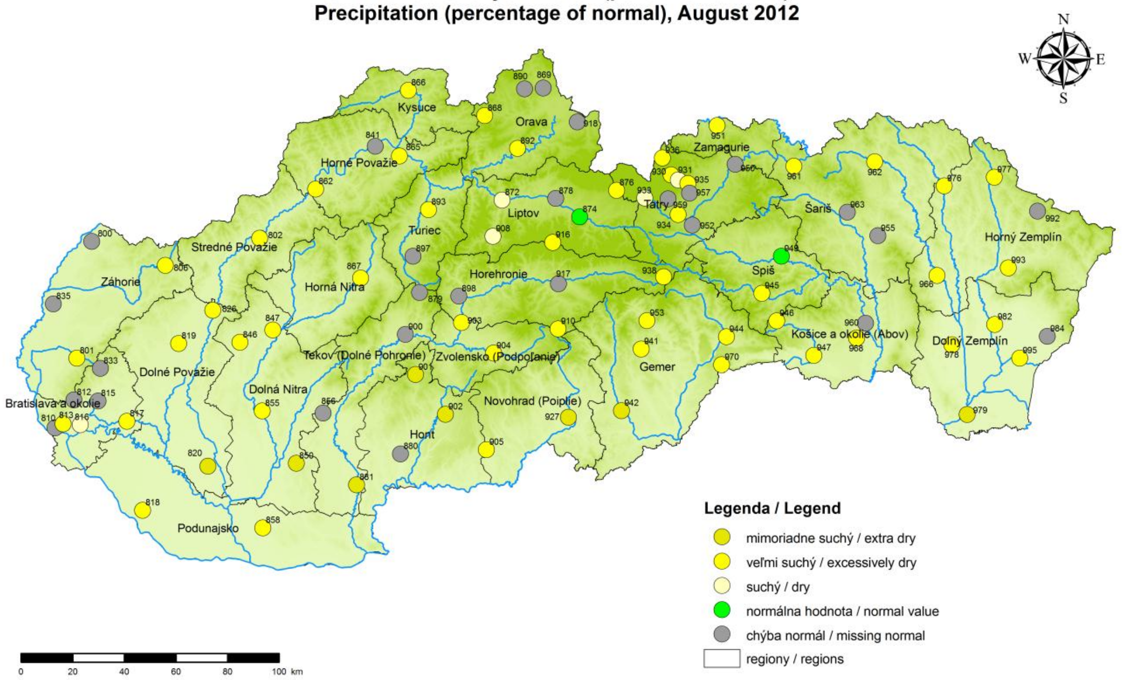
Hodnotenie meteorologických prvkov a ich charakteristík za Júl 2012
Úhrn atmosférických zrážok (percento normálu)
Precipitation (percentage of normal), July 2012



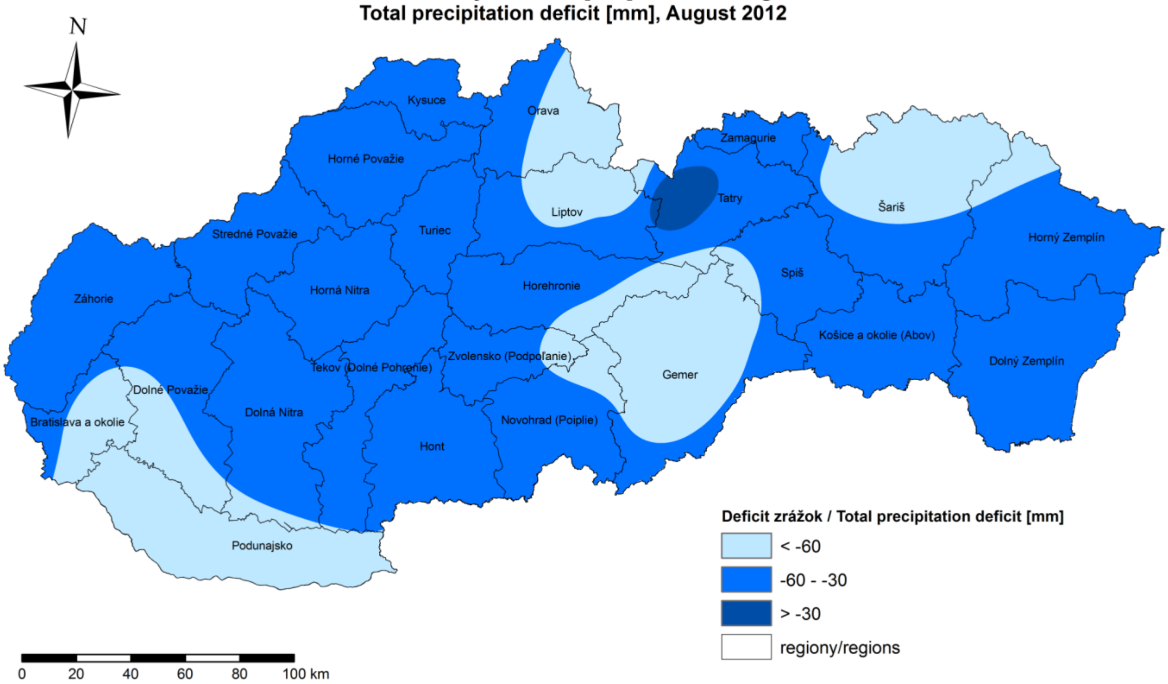
Deficit atmosférických zrážok [mm] v mesiaci júl 2012
Total precipitation deficit [mm], July 2012



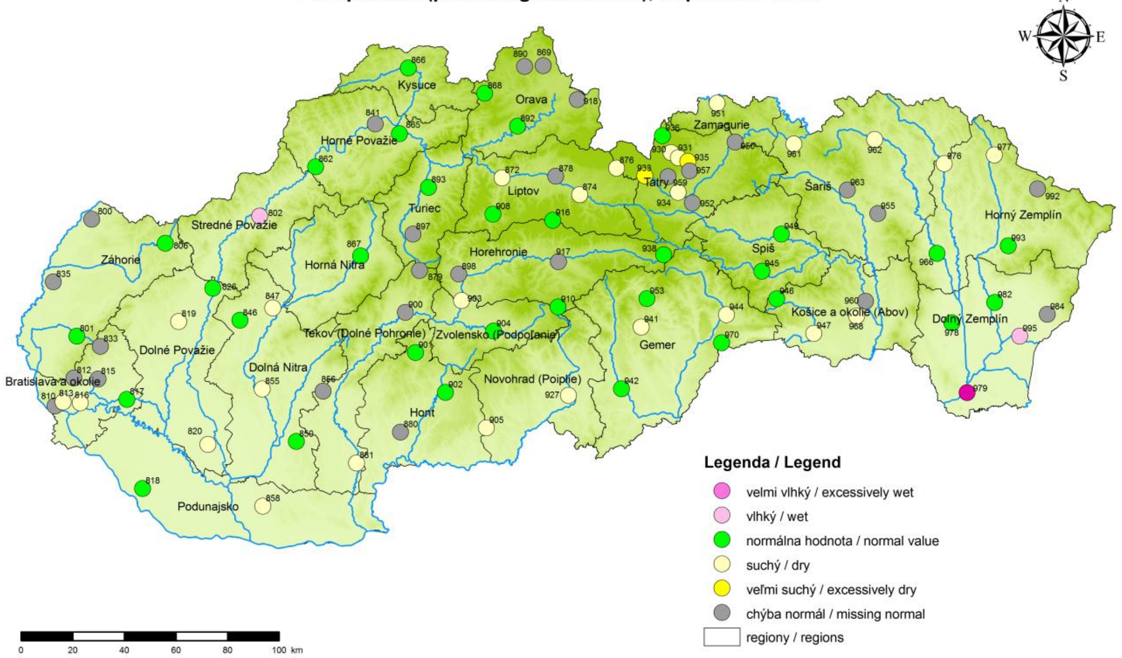
Hodnotenie meteorologických prvkov a ich charakteristík za august 2012
Úhrn atmosférických zrážok (percento normálu)
Precipitation (percentage of normal), August 2012



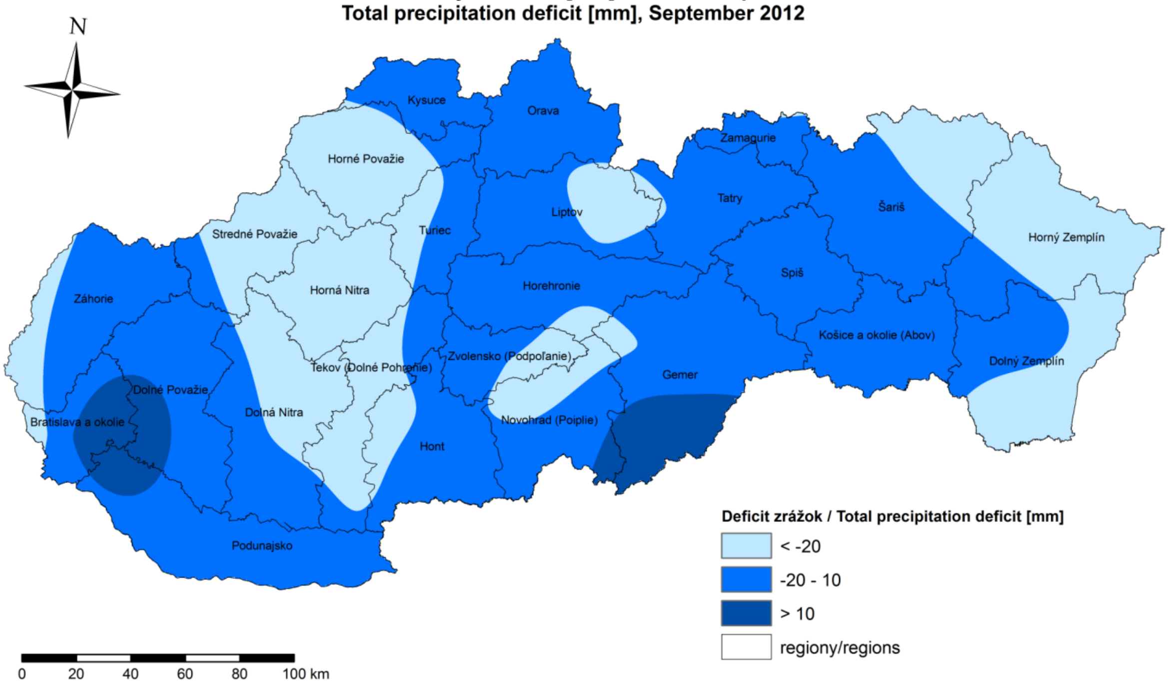
Deficit atmosférických zrážok [mm] v mesiaci august 2012
Total precipitation deficit [mm], August 2012



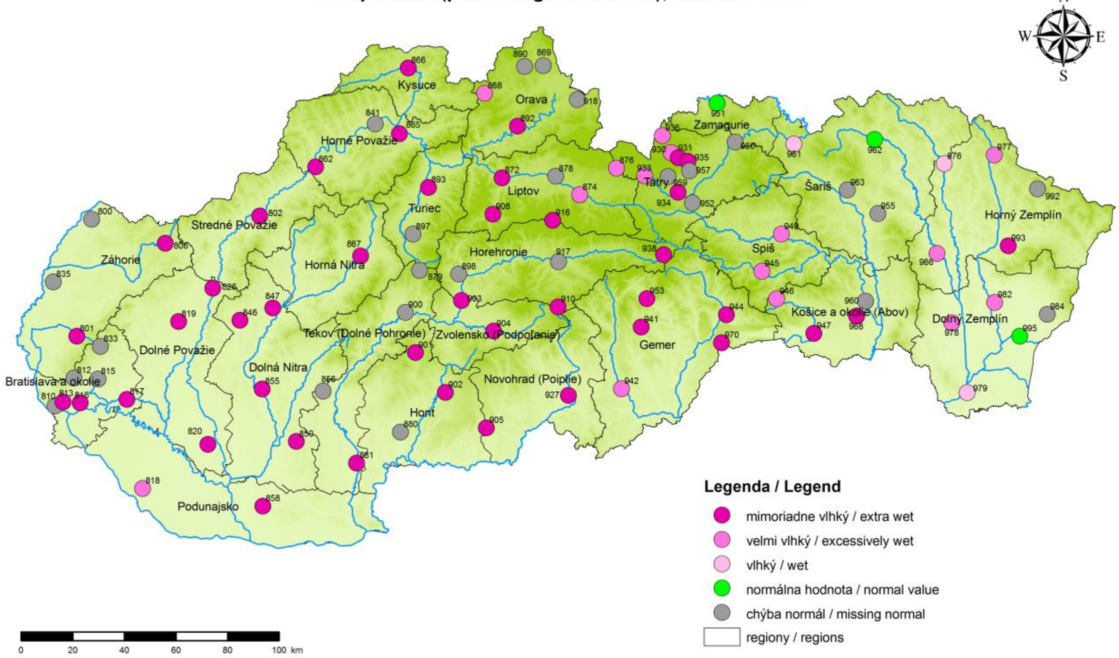
Hodnotenie meteorologických prvkov a ich charakteristík za september 2012
Úhrn atmosférických zrážok (percento normálu)
Precipitation (percentage of normal), September 2012



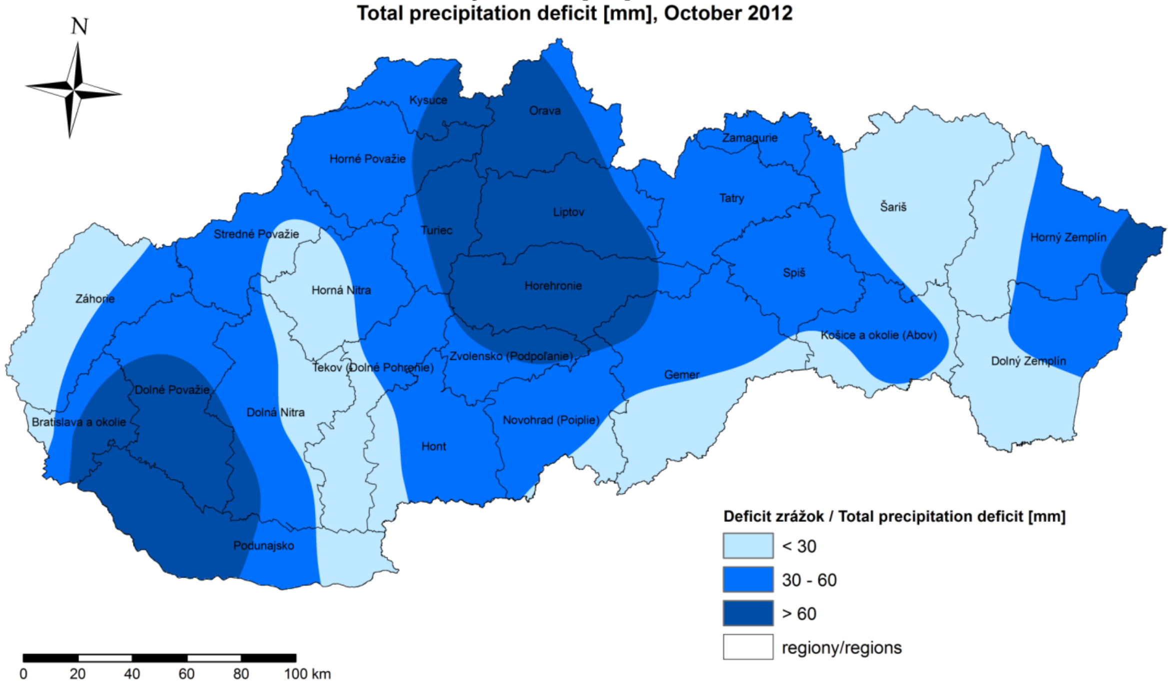
Deficit atmosférických zrážok [mm] v mesiaci september 2012
Total precipitation deficit [mm], September 2012



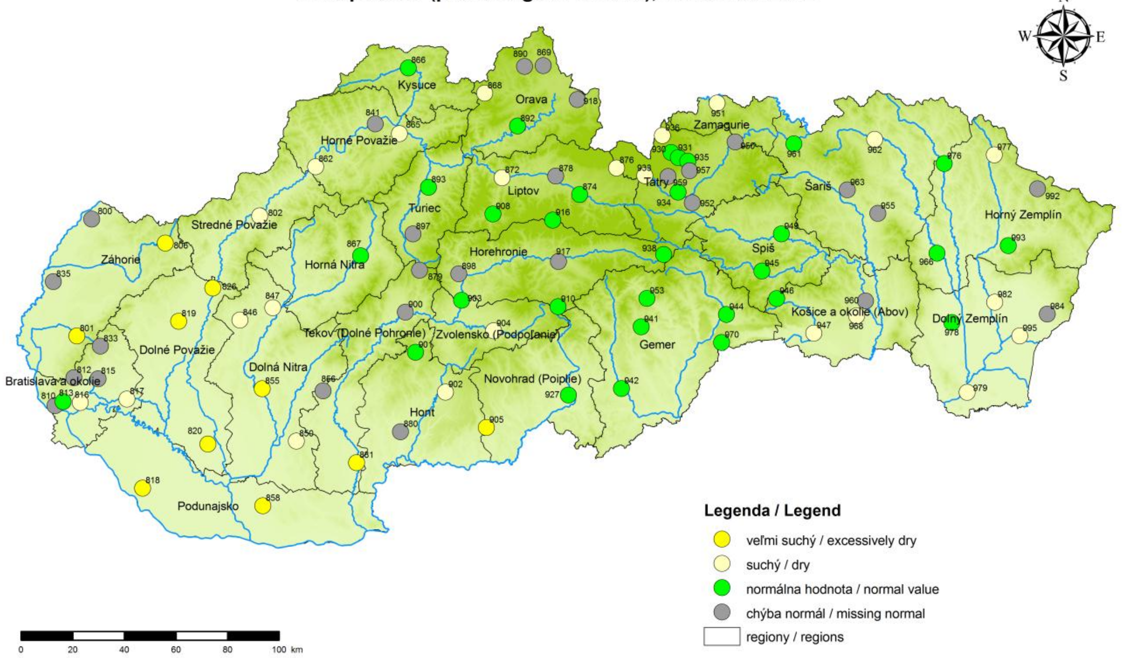
Hodnotenie meteorologických prvkov a ich charakteristík za október 2012
Úhrn atmosférických zrážok (percento normálu)
Precipitation (percentage of normal), October 2012



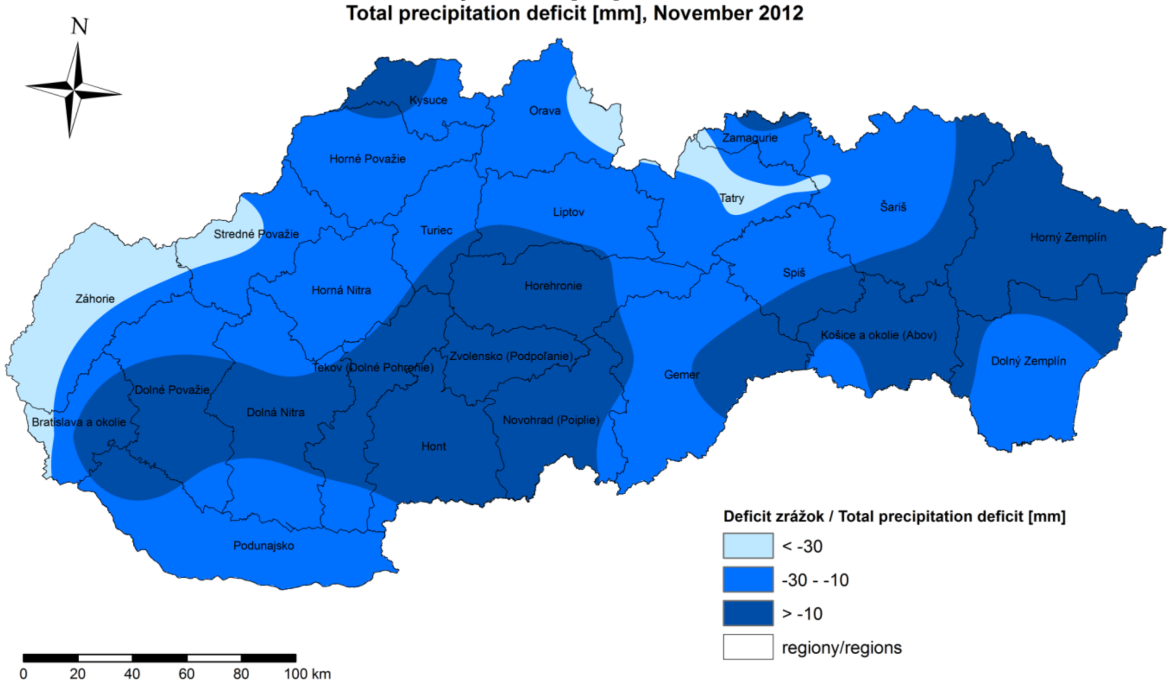
Deficit atmosférických zrážok [mm] v mesiaci október 2012
Total precipitation deficit [mm], October 2012



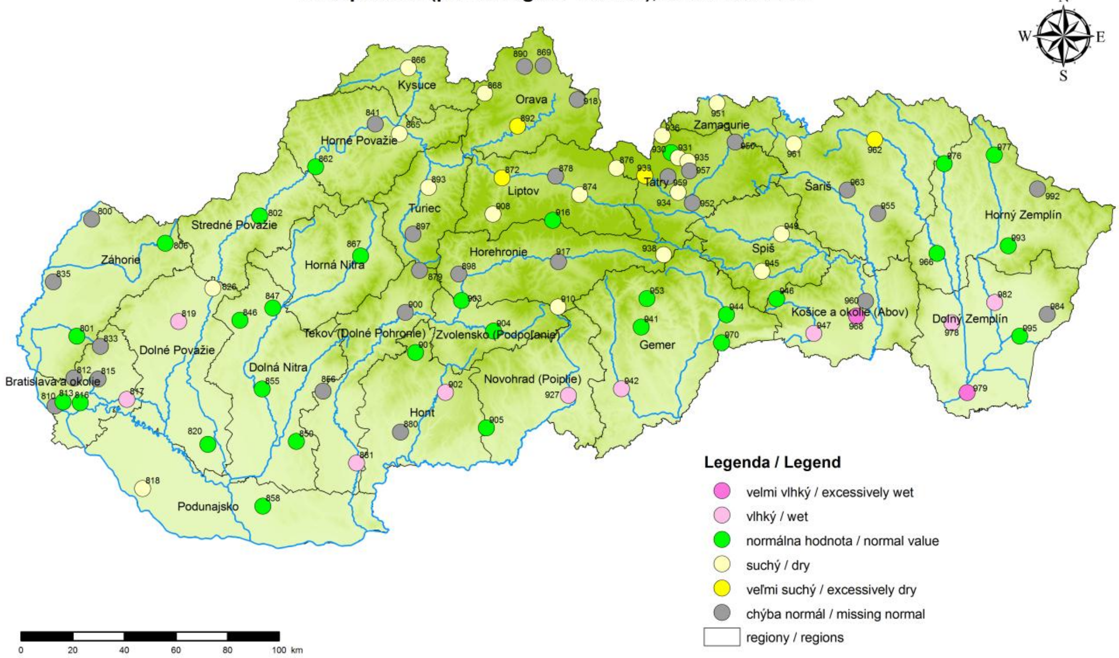
Hodnotenie meteorologických prvkov a ich charakteristík za november 2012
Úhrn atmosférických zrážok (percento normálu)
Precipitation (percentage of normal), November 2012



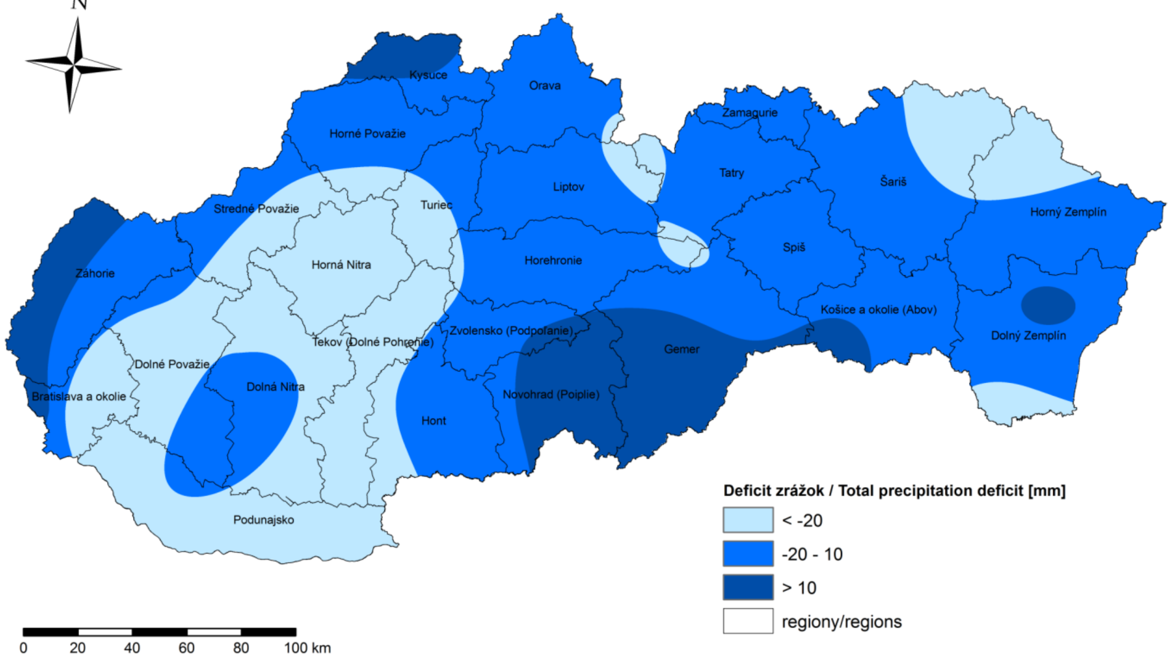
Deficit atmosférických zrážok [mm] v mesiaci november 2012
Total precipitation deficit [mm], November 2012



Hodnotenie meteorologických prvkov a ich charakteristík za devember 2012
Úhrn atmosférických zrážok (percento normálu)
Precipitation (percentage of normal), December 2012



Deficit atmosférických zrážok [mm] v mesiaci december 2012
Total precipitation deficit [mm], December 2012



3.2.5 Warning system of drought prediction

Part: Climatology

Air temperature and precipitation are important indicators of drought development. Their occurrence and duration qualify other parts of living environment to focus on them. In the following text we concentrated on evaluation of possibility to take part in to a preparation of Warning system of drought prediction. This contribution is a part of comprehensive report which aim was also appreciate climatological conditions for drought evaluation in the years 2011 and 2012.

Climatological department (service) is able to offer real time evaluation according to daily reports (INTER message) at 58 meteorological stations and at 29 automatic weather stations (see

Fig. 12). Both sources come thru the control partly, it means that INTER message is controlled by professional staff at regional centers in Bratislava, Banská Bystrica and Košice and stored into the database daily, while data from automatic weather stations are controlled immediately at the station according to sophisticated algorithms and directly reporting to the database. Al above mentioned meteorological elements are stored thru the Climatological and meteorological information system (KMIS) into the database.

Information about air temperature course and cumulative precipitation totals are reachable at web page of Slovak hydrometeorological institute just now in section of climatological reporting (service) in Slovak and English version as well, see URL:
http://www.shmu.sk/en/?page=1&id=klimat_operativneudaje1

According to the daily operative reporting and according to the statistical evaluation, it means calculation of standard behavior of cumulative values during the year separately for air temperature where thresholds were 1st and 3rd quartile (Q1, Q3) and for precipitation 1 standard deviation (StDev) from normal where 68,26% of data are inside the belt defined normal values, other values lying between boundary 1StDev and 2StDev or -1StDev and -2StDev are values statistically significant (let us say mild drought), in the belt of (+/-) 2StDev are 95,35% of all the values, in the position of the belt 2StDev to 3StdEV or -1StDev to -3StDev are statistically more significant (let us say medium drought), in the belt of (+/-) 3StDev are 99,73% of all the values and finally values above (+/-3) values are the most significant (let us say extra drought). There is a line cumulative course of air temperature (Fig. and

Fig.) and precipitation (Fig. and Fig.) in the next graphical projection in daily step as a part of Warning system of drought prediction. This part of the warning system enables to compare actual cumulative values to standard values and period recommended by World meteorological organization and period 1961-1990 and after connecting them to weather prediction (air temperature and precipitation total for selected meteorological stations) possibility to prognosticate possible deviation or re-entry from or to delimited borders (Q1, Q3, StDev). Retrospectively there is an example of the year 2011 (Fig. , Fig.), 2012 (

Fig. ,

Fig.) at locality Hurbanovo for both air temperature and precipitation, respectively precipitation deficit for the period 2010 – 2013 (Fig.). There is a monthly color distinction for better recognition during the year. The aim of such prepared templates is to get possibility identify course of air temperature and precipitation for different period then month statistics (e.g. crossing of month, beginning of one month can be wet but the end part of the same month can be dry so total precipitation total can be normal, but if the beginning of the next month is dry the period of the end and the beginning can be characterized as a dry and quite long period which could cause problems with awaited precipitation rain in particular location.

Fig. 12

Sieť meteorologických staníc s denným spravodajstvom INTER a/alebo hodinovým zasielaním údajov ako automatická meteorologická stanica
Meteorological station network with daily report INTER or as an automatic weather station with or without daily report INTER

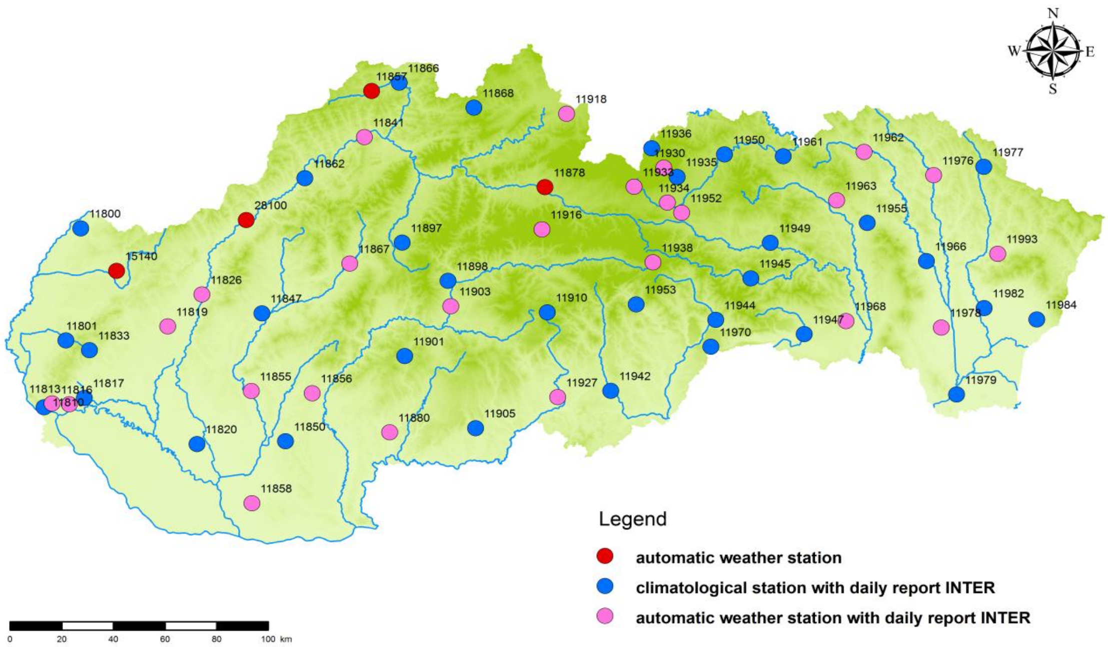


Fig. 13

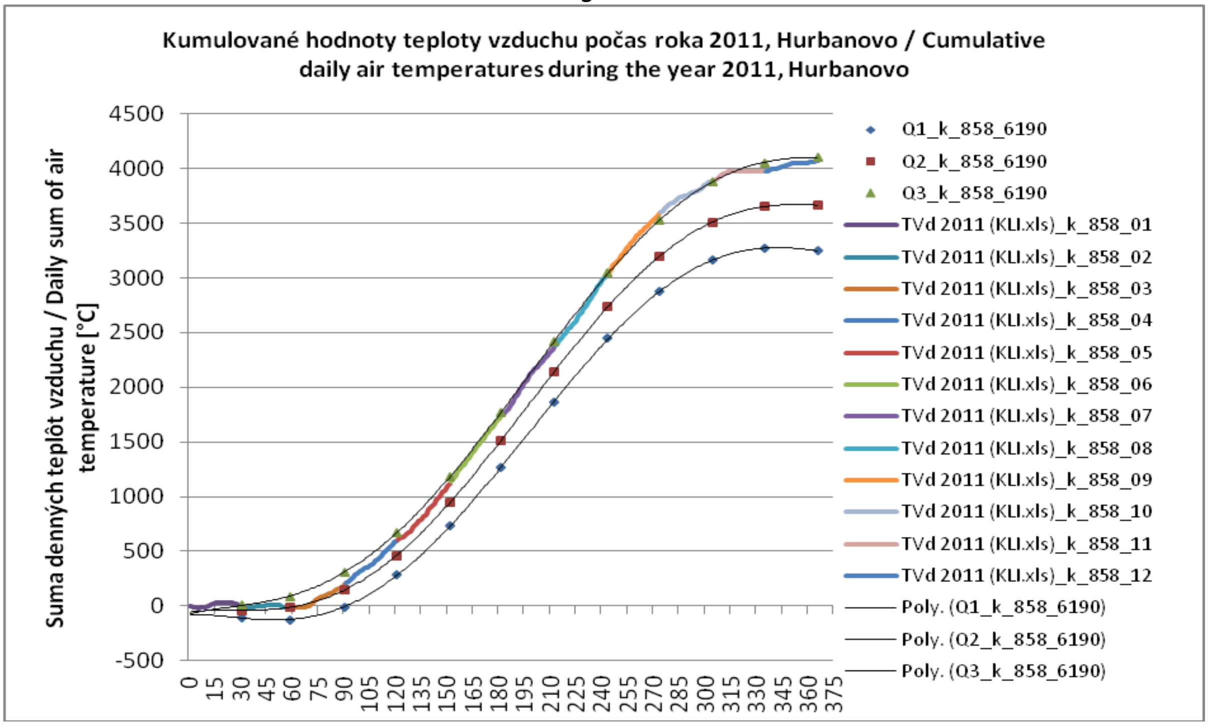


Fig. 14

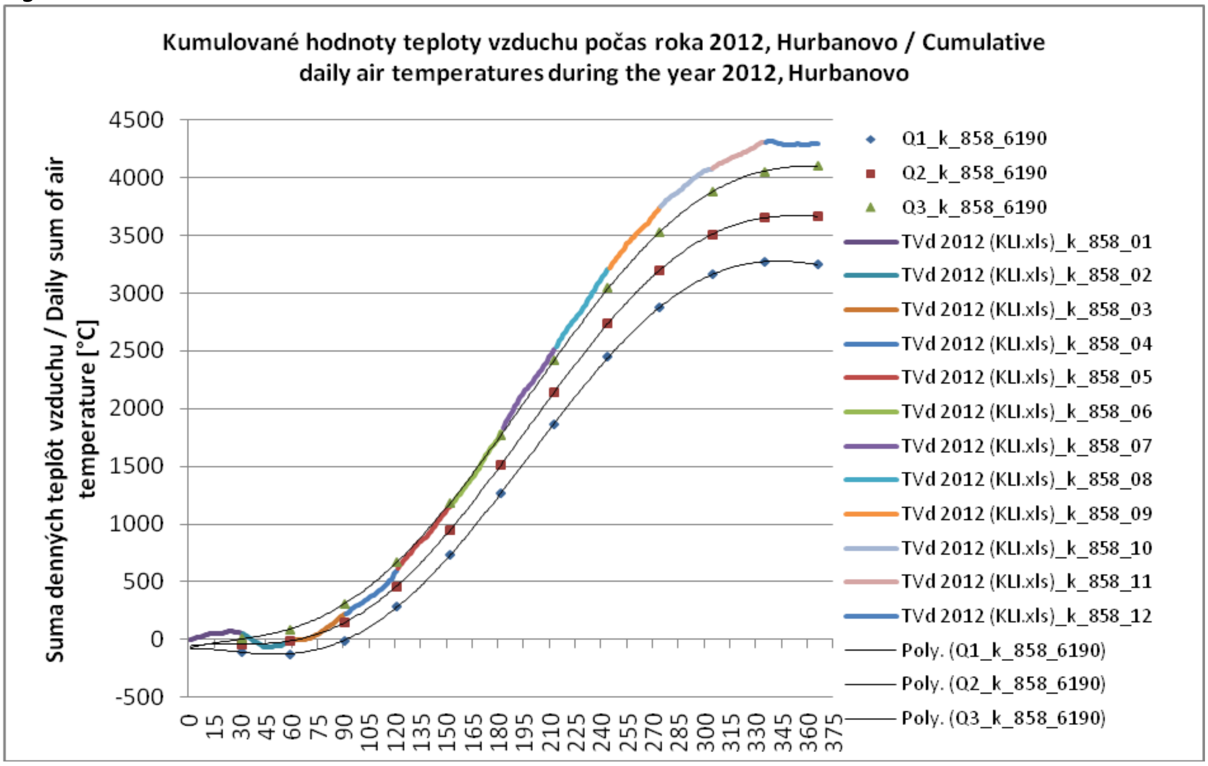

Kumulované hodnoty teploty vzduchu počas roka 2012, Hurbanovo / Cumulative daily air temperatures during the year 2012, Hurbanovo
Suma denných teplôt vzduchu / Daily sum of air temperature [°C]
Q1_k_858_6190
Q2_k_858_6190
Q3_k_858_6190
TVd 2012 (KLI.xls)_k_858_01
TVd 2012 (KLI.xls)_k_858_02
TVd 2012 (KLI.xls)_k_858_03
TVd 2012 (KLI.xls)_k_858_04
TVd 2012 (KLI.xls)_k_858_05
TVd 2012 (KLI.xls)_k_858_06
TVd 2012 (KLI.xls)_k_858_07
TVd 2012 (KLI.xls)_k_858_08
TVd 2012 (KLI.xls)_k_858_09
TVd 2012 (KLI.xls)_k_858_10
TVd 2012 (KLI.xls)_k_858_11
TVd 2012 (KLI.xls)_k_858_12
Poly. (Q1_k_858_6190)
Poly. (Q2_k_858_6190)
Poly. (Q3_k_858_6190)

Fig. 15

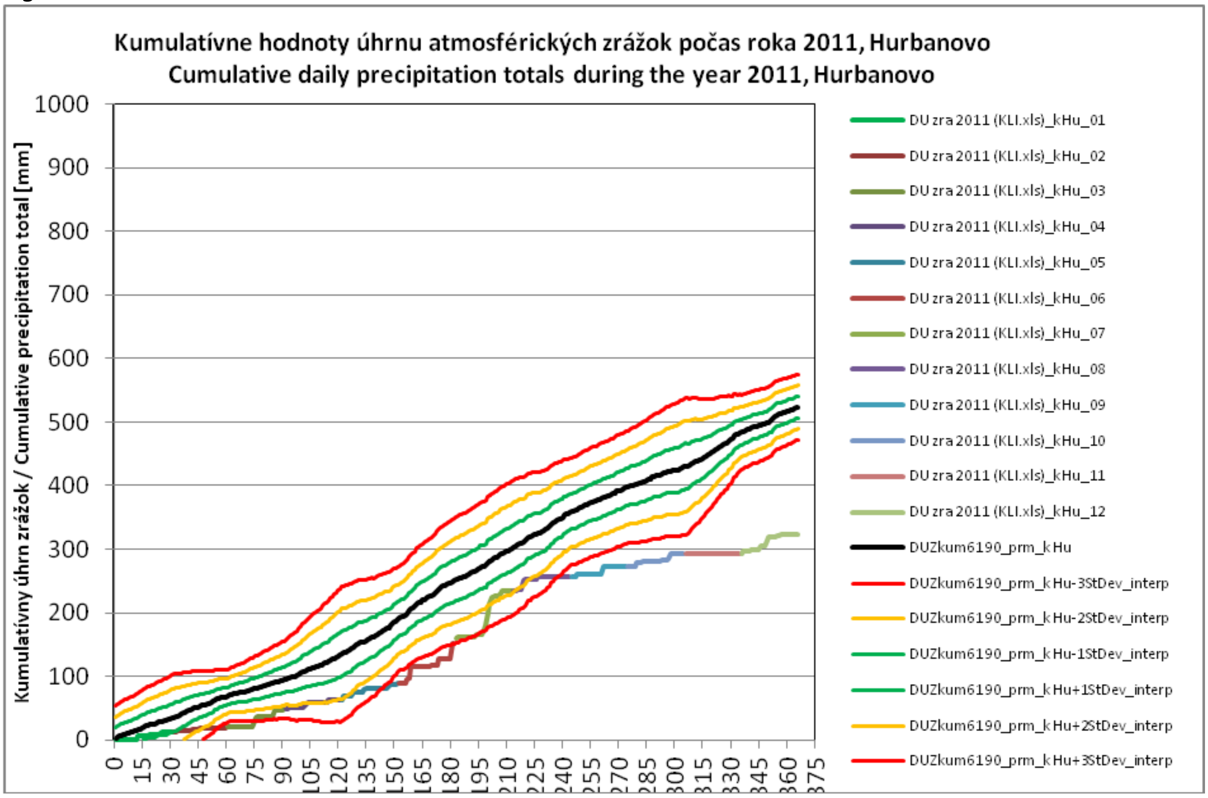

Kumulatívne hodnoty úhrnu atmosférických zrážok počas roka 2011, Hurbanovo
Cumulative daily precipitation totals during the year 2011, Hurbanovo
Kumulatívny úhrn zrážok / Cumulative precipitation total [mm]
DU zra 2011 (KLI.xls)_kHu_01
DU zra 2011 (KLI.xls)_kHu_02
DU zra 2011 (KLI.xls)_kHu_03
DU zra 2011 (KLI.xls)_kHu_04
DU zra 2011 (KLI.xls)_kHu_05
DU zra 2011 (KLI.xls)_kHu_06
DU zra 2011 (KLI.xls)_kHu_07
DU zra 2011 (KLI.xls)_kHu_08
DU zra 2011 (KLI.xls)_kHu_09
DU zra 2011 (KLI.xls)_kHu_10
DU zra 2011 (KLI.xls)_kHu_11
DU zra 2011 (KLI.xls)_kHu_12
DUZkum6190_prm_kHu
DUZkum6190_prm_kHu-3StDev_interp
DUZkum6190_prm_kHu-2StDev_interp
DUZkum6190_prm_kHu-1StDev_interp
DUZkum6190_prm_kHu+1StDev_interp
DUZkum6190_prm_kHu+2StDev_interp
DUZkum6190_prm_kHu+3StDev_interp

Fig. 16

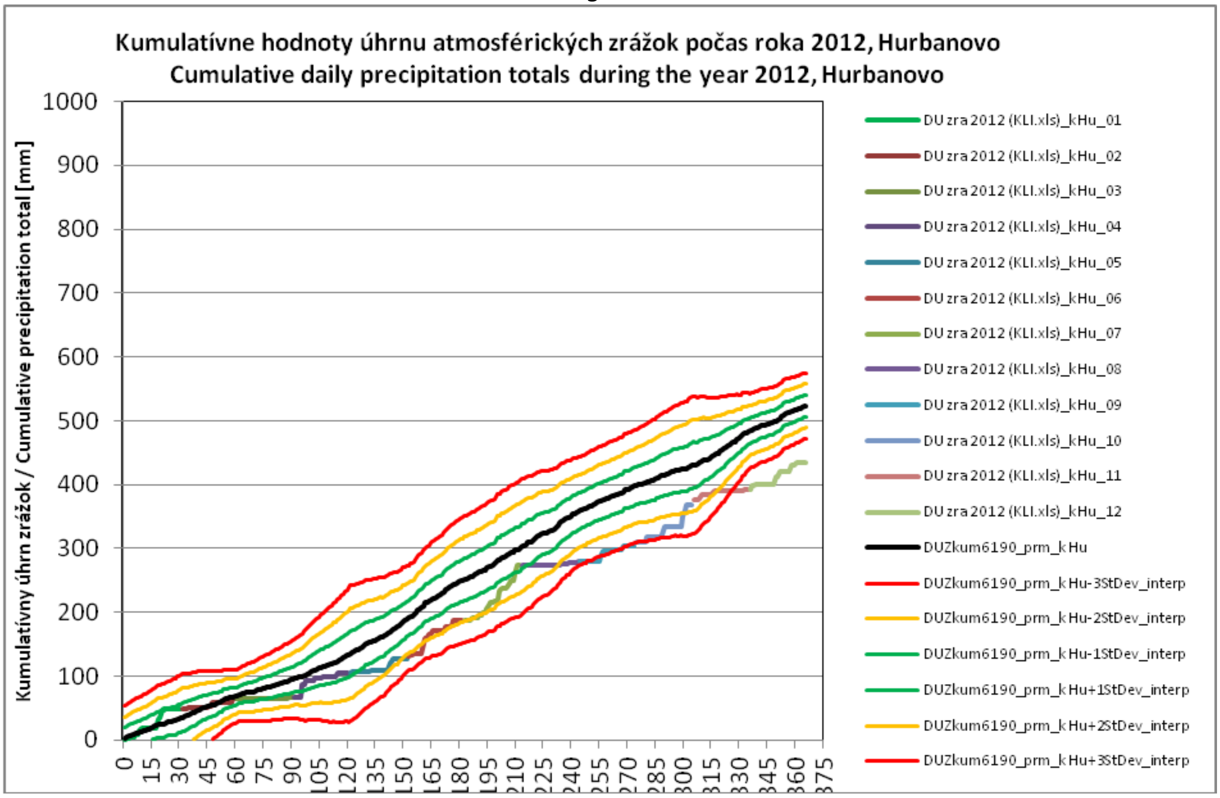
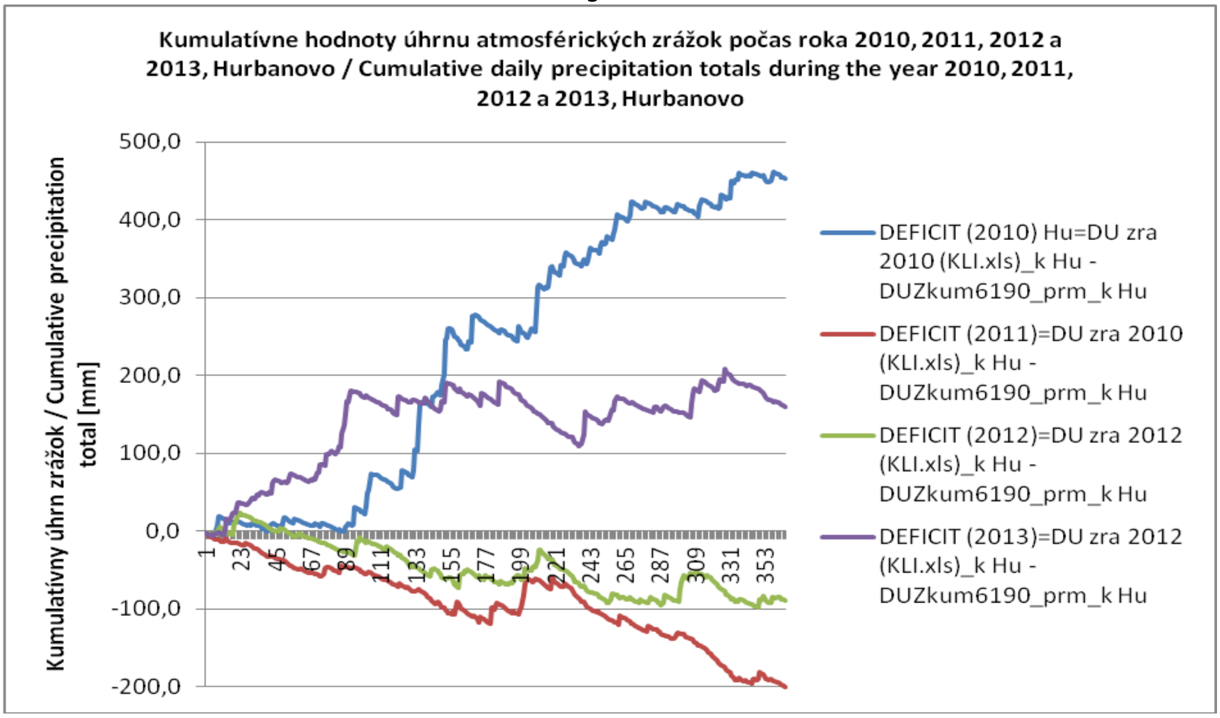


Fig. 17



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3.2.6 Evaluation of indexes on the base of precipitation and air temperature

The evaluation of 2011 and 2012 years by drought indices

Monitoring network

Tab.1 List of meteorological stations used for the evaluation of drought indices

Indicative	Station	Latitude	Longitude	Elevation
11962	Bardejov	49°17´05´´	21°16´14´´	305
11927	Boľkovce	48°20´20´´	19°44´11´´	214
11813	Bratislava, Koliba	48°10´07´´	17°06´38´´	286
11816	Bratislava,Ivanka	48°10´13´´	17°12´27´´	128
11866	Čadca	49°25´37´´	18°48´23´´	432
11966	Čaklov	48°54´09´´	21°37´52´´	140
11951	Červený Kláštor	49°23´14´´	20°25´27´´	469
11858	Hurbanovo	47°52´24´´	18°11´40´´	115
11993	Kamenica nad Cir.	48°56´05´´	21°59´39´´	176
11968	Košice, airport	48°40´14´´	21°14´19´´	229
11874	Liptovský Hrádok	49°02´21´´	19°43´31´´	640
11982	Michalovce	48°44´21´´	21°56´35´´	110
11947	Moldava nad Bod.	48°39´11´´	20°32´15´´	204
11806	Myjava	48°45´14´´	17°33´42´´	349
11855	Nitra	48°16´50´´	18°08´08´´	135
11868	Oravská Lesná	49°22´05´´	19°10´57´´	785
11826	Piešťany	48°36´47´´	17°49´58´´	163
11961	Plaveč	49°15´37´´	20°50´34´´	485
11876	Podbanské	49°08´24´´	19°54´32´´	978
11934	Poprad	49°04´05´´	20°14´58´´	695
11867	Prievidza	48°46´11´´	18°35´38´´	256
11941	Ratková	48°35´34´´	20°05´37´´	311
11942	Rimavská Sobota	48°22´26´´	20°00´38´´	215
11944	Rožňava	48°39´08´´	20°32´07´´	311
11903	Sliač	48°38´33´´	19°08´31´´	313
11979	Somotor	48°25´17´´	21°49´06´´	97
11933	Štrbské Pleso	49°07´04´´	20°03´44´´	1322
11938	Telgárt	48°50´55´´	20°11´21´´	901
11904	Vígľaš	48°32´39´´	19°19´19´´	389
11936	Ždiar-Javorina	49°15´50´´	20°08´22´´	1017
11820	Žihárec	48°04´13´´	17°52´55´´	111

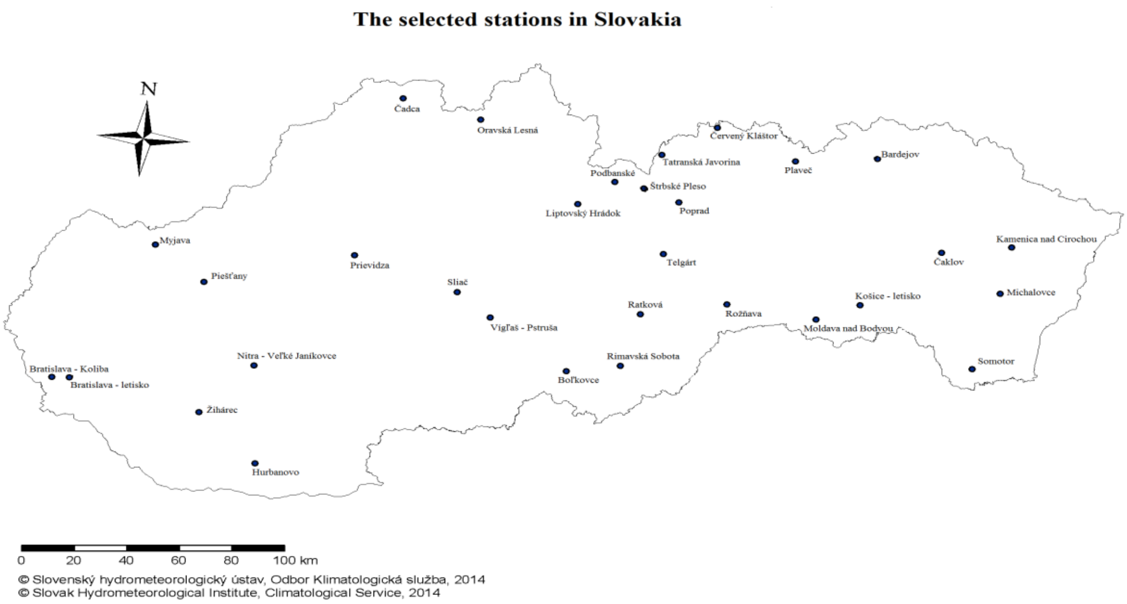
The computation of drought indices is mostly based on the precipitation, air temperature, eventually on other climatological variables.

Air temperature is measured by the network of the climatological stations, which consists of 104 stations with the climatological program. 27 stations are integrated in the network of the professional synoptic stations and 77 stations are voluntary ones. Measurements of the air temperature are performed by a classical way at 7., 14., 21.o´clock measuring terms.

The network of SHMI precipitation stations consists of 568 stations (without synoptic and climatological ones). The precipitation and the snow cover are measured at 7 o´clock, the appearance of precipitation and dangerous meteorological events are noted constantly.

Number of 31 climatological stations was selected for an evaluation of the air temperature, precipitation and drought indices (Tab.1, Fig. 1). The criteria for the station selection were the high quality of data without breaks for the period 1961-2012. These selected stations are sufficiently representative for main country units of Slovakia.

Fig. 1 The set of 31 selected stations in Slovakia used by the counting of drought indices



Methodology

The procedure of the evaluation of the drought is based on the using of combination of drought indices which are based on the precipitation, or indices using the link between the air temperature and the water balance of the upper soil layer, or indices with evapotranspiration and runoff too. The main drought index, used for the evaluation is SPI (Standardized Precipitation Index), which is completed by other indices based not only on the precipitation deficit, but also taking into account the influence of other components of water balance in the upper soil layer.

Standardized Precipitation Index (SPI)

This index is based on the probability of appearance of the concrete amount of the precipitation in the various time range. Mostly is used the time range of 1-,2-,3-,6-,9-,12- and 24- months [5]. We used 1-monthly SPI to evaluate the driest month, 6-monthly for the vegetation season (the end of September) and 12-monthly for the whole year (the end of December). The gamma distribution is used by the computation of probability density distribution. One value of cumulative probability of recurrence of the concrete time range belongs to each value of SPI [5]. If we add next months for evaluation, the gamma distribution is computed again and the previous values of SPI would be changed too. This index has some disadvantages. The first one, that it is based on the precipitation only and don´t include the hydrological, radiation and energetic conditions. The second one, that the values of SPI are representative for the concrete station only, thus we can qualify its deficit in a consideration of its long-term average of precipitation at this station only. We can´t say by the values of SPI how high is the deficit at this station in a consideration of other stations (in our case, the area of Slovakia). The time period is characterized by the interval of SPI values in the Tab.2. In the next Tab.3 there is the rarity of a current drought with the severity of event too [6].

Tab. 2 Intervals of SPI values and their appropriate characterization for the period

SPI	Characterization
2,0 +	extremely wet
1,5 to 1,99	very wet
1,0 to 1,49	moderately wet
-0,99 to 0,99	near normal
-1,0 to -1,49	moderately dry
-1,5 to -1,99	severely dry
-2,0 and less	extremely dry

Tab. 3 The rarity of a current drought by SPI

SPI	category	number of times in 100 years	severity of event
0 to -0,99	mild dryness	33	1 in 3 yrs.
-1,00 to -1,49	moderate dryness	10	1 in 10 yrs.
-1,5 to -1,99	severe dryness	5	1 in 20 yrs.
< -2,00	extreme dryness	2,5	1 in 50 yrs.

In our work we carried out the progress of SPI values in 1-, 6- and 12- monthly time range in 2011 and 2012 for the representative Slovak station representing the area average of all monthly sums of precipitation from 31 stations in the period 1961 – 2012.

Palmer Drought Severity Index (PDSI)
PDSI is very complex model built for a computing of the precipitation deficit in the soil profile. In the process of the evaluation of PDSI we also use the air temperature, evapotranspiration and available water capacity (AWC). In the original Palmer methodology the soil profile is divided to two soil layers. The thickness of the upper layer is designed for containing 1 inch of water, meanwhile the field water capacity is achieved [4]. The thickness of the lower layer depends on the soil characteristics of the concrete locality. The evapotranspiration in the original Palmer work is computed by the Thornthwaite method from 1948 [3]. The input data used by the computation of PDSI were air temperature, precipitation, available water capacity (AWC) and geographical latitude. The output data were available for every month in the period 1961 – 2012. PDSI is cumulative, thus the impact of the hydrological surplus/deficit would be shown in next long-term period. In the Tab.4 we can see the classification and the characteristics of the month by PDSI values presented by Palmer in 1965 [3].

Tab. 4 Intervals of PDSI values and their appropriate characterization for the period

PDSI (interval)	characterization
4,00 +	extremely wet
3,00 to 3,99	very wet
2,00 to 2,99	moderately wet
1,00 to 1,99	slightly wet
0,50 to 0,99	incipient wet spell
-0,49 to 0,49	near normal
-0,50 to -0,99	incipient dry spell
-1,00 to -1,99	mild drought
-2,00 to -2,99	moderate drought
-3,00 to -3,99	severe drought
-4,00 and less	extreme drought

In our work we used the original PDSI, in spite of the fact, that other authors frequently use the self-calibrated PDSI.
For the better illustration we mentioned the progress of PDSI values in 2011 and 2012 computed for a representative Slovak station, which is a country average of monthly air temperatures and sums of precipitation in 1961 – 2012 with average value of the available water capacity and mean latitude for selected 31 stations.

Tomlain climatic indicator of irrigation

Tomlain climatic indicator of irrigation K_Z is defined by the formula,

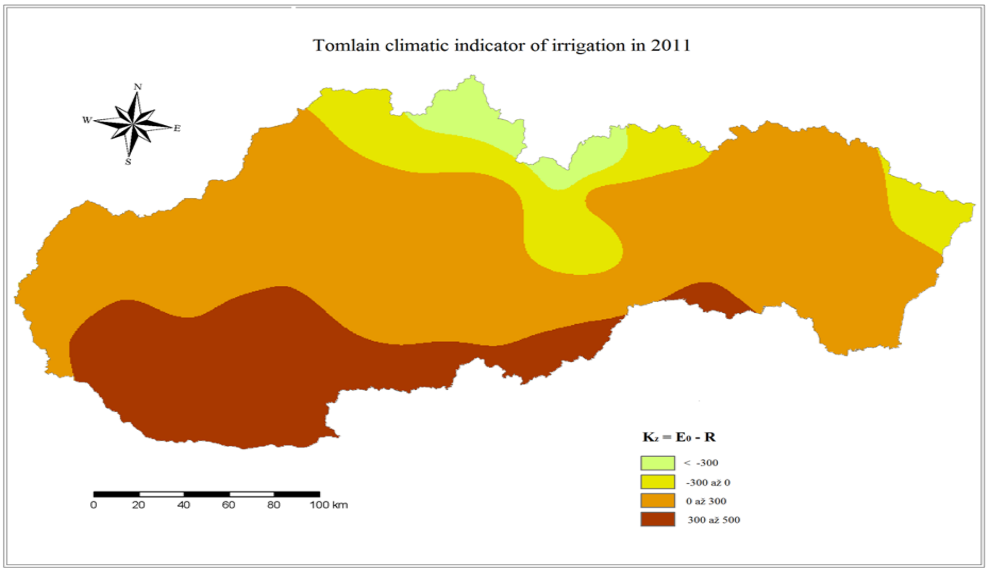
$$K_Z = E_0 - R,$$

where E_0 is the potential evapotranspiration from the grass surface computed by the Budyko-Zubenokova method and R is the precipitation. In this case, the indicator is also useful for quantification of the individual locality to the concrete climatic area defined by the long-term averages of E_0 and R [2]. The positive K_Z value shows, that the evapotranspiration was higher than the precipitation in the concrete period and it represents the amount of water in mm, which is important to add to soil by irrigation for compensation of water deficit. The localities with the negative values are humid and the precipitation sufficiently compensates the losses caused by evapotranspiration and the irrigation isn´t important here.

In the period 1961 – 2012 the annual values of K_Z varied from +200,6 in Hurbanovo in the southwest to -864,2 in Ždiar-Javorina in the north. The typical values for lowlands are about +200 and for mountains about -1000 [2].

In the Fig. 2 there is the map of K_Z values in Slovakia in 2011. The highest values were in the south of the Podunajska lowland and exceeded 300 mm. Reversely, the lowest values below –300 mm were in the north. But this map doesn´t show us the deviations from long-term average of K_Z in concrete localities, and SPI values show us these deviations, so that we decided to use the principle of deviations by K_Z. For the comparison of SPI with K_Z, we computed deviations of K_Z values in the years 2011 and 2012 from the reference period 1961 – 2012. We used Tomlain climatic indicator of irrigation for the evaluation of drought in the vegetation season too. But it has disadvantage, because it was used in the works from Slovakia only and it isn´t better applied abroad even nowadays.

Fig. 2 Tomlain climatic indicator of irrigation in 2011



Konček index of irrigation

Konček index of irrigation was originally proposed for the determination of the climatic areas in Czechoslovakia. Along with an mean air temperature and a number of summer days (the highest daily air temperature is 25,0°C and higher) it was used for the original climatological classification in Slovakia designed by Konček in the 50ies. This index is successfully used for the evaluation of longer periods, for example the normal 30-years period. In our work we used this index for quantification of water balance of the individual year and to compare it with the normal.

Konček index of irrigation I_Z is based on the Thornthwaite methodology and defined by the formula,

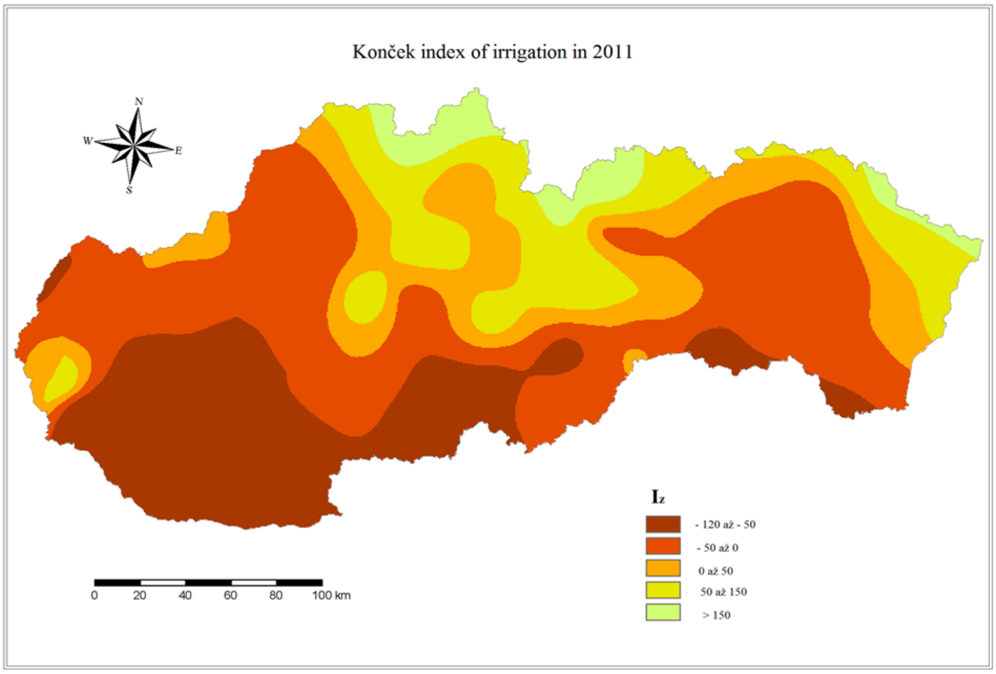
$$I_Z = 0{,}5.R + \Delta r - 10.T - (30 + v^2)$$

where *R* is the precipitation in the vegetation season (IV-IX) in mm, ⍰*r* is the surplus of precipitation in the winter season (XII-II) over the sum of 105 mm. In the case, if the precipitation is lower than 105 mm, ⍰*r* =0. Further, *T* is the average air temperature in the vegetation season in °C and *v* is the average wind speed in m/s measured at 14:00 climatic term in the vegetation season [1].

The value I_Z = 0 gives the normal water balance of irrigation, values I_Z from -20 to 0 characterize mild dry area, 0 to 60 mild moist, 60 to 120 moist, over 120 very moist, from -40 to -20 dry area and below -40 very dry area. The very dry area didn´t exist in Slovakia to 1960, but to 1980 it was identified only in Hurbanovo, and to 2010 it expanded further to the north and east [1]. For the period 1961 – 2012 the values varied from -58,6 in Hurbanovo to 395,6 in Ždiar-Javorina. The advantage of Konček index of irrigation is its simplicity. Its disadvantage is, that it´s limited only in Slovakia. Furthermore, this index doesn´t consider the various conditions of runoff over a year and among various orographic types.

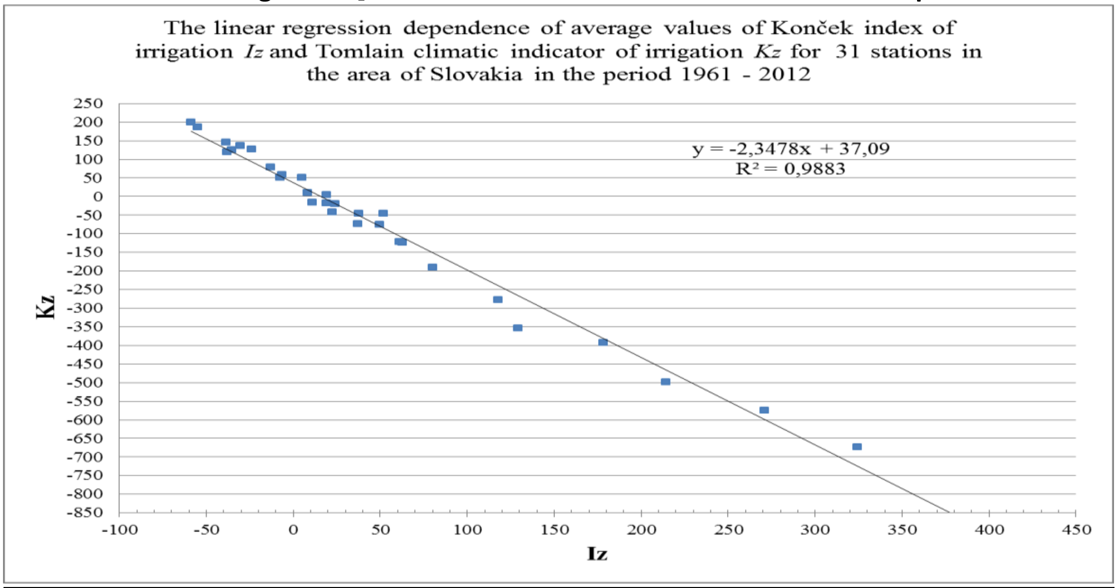
In the Fig. 3 we can see, that the lowest values of I_Z in 2011 were in the southwest and partly in the southern part of the middle Slovakia. These localities were the driest by the I_Z values. Reversely, the highest values were in the north. This map can´t to compare this index with SPI for the evaluation of drought in 2011 and 2012. Therefore, we used the principle of deviations from average values in 1961 – 2012, and it could be useful for the comparison with K_Z too.

Fig. 3 Konček index of irrigation in 2011



In the Fig. 4 there is the graph of the linear regression dependence of Konček and Tomlain indicators. This dependence is decreasing and dependable with the value of coefficient R^2 = 0,9883.

Fig. 4 The linear regression dependence of average values of Konček index of irrigation I_z and Tomlain climatic indicator of irrigation K_z for 31 stations in the area of Slovakia in the period 1961 - 2012



The evaluation of drought in 2011 and 2012 by drought indices
The evaluation of drought by SPI in 2011 and 2012

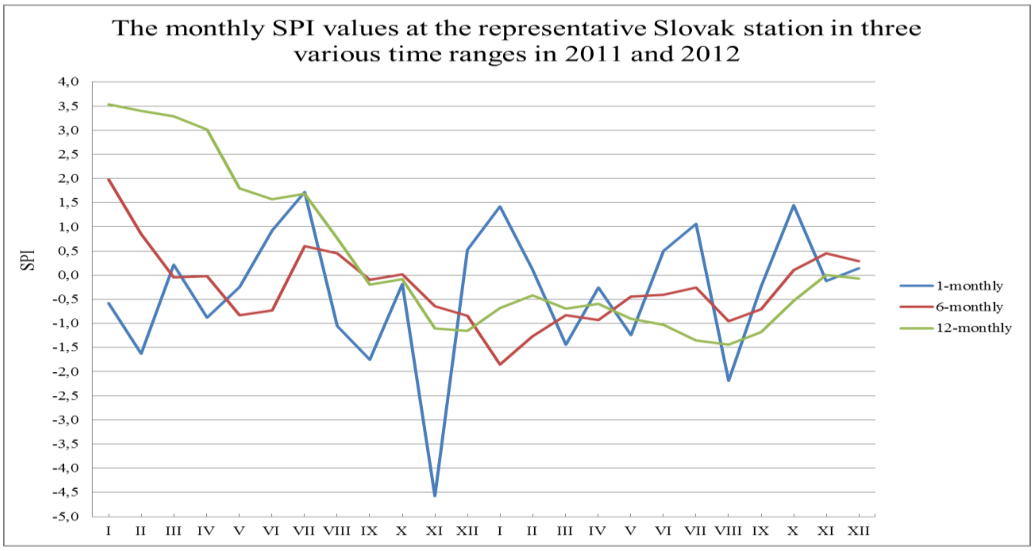
Year 2011

In the Fig. 5 there is the course of monthly SPI values in 1-, 6- and 12- monthly time range at the selected Slovak station, using the mean areal monthly sums of precipitation averaged from detected 31 stations in Slovakia for the period 1961 – 2012. In year 2011 the highest value of 1-monthly SPI was in July 2011 and exceeded 1,50. The lowest value was in November 2011 below -4,50. Generally, the highest mean deficit of precipitation in year 2011 was in November and the highest surplus of precipitation was in July. Starting values of 6-monthly SPI were influenced by extremely rainy year 2010, but they gradually decreased to the value -1,00, but during summer, in July, they increased over 0,50. Later, values of SPI were decreasing till December affected by dry autumn months. The values of 12-monthly SPI were decreasing slowly during the whole year 2011.

In the Fig. 6 there are the values of 12-monthly SPI at the end of December 2011. We can see, that the lowest values below -2,00 appeared mainly in the southern half of Slovakia, in the west and east, and singularly in the northwest too. In these localities there was the highest deficit of annual sum of precipitation in the comparison with the period 1961 – 2012. Reversely, the highest value, over 0,01, was very rare.

In the Fig. 7 there are the values of 6-monthly SPI at the end of September 2011. Values of 6-monthly SPI were higher than values of 12-monthly SPI and decreased below -1,50 were at two stations only. The highest value of SPI exceeded 1,00 only at one station.

Fig. 5 The monthly SPI values at the representative Slovak station in three various time ranges in 2011 and 2012



Year 2012

In the Fig. 8 there are the values of 12-monthly SPI at the end of December 2012. The lowest values decreased below -1,00 and appeared at two stations. In the comparison with the year 2011, the year 2012 was more humid and no extreme drought appeared. The highest value of SPI exceeded the value 0,50 and appeared at the single station only.

In the Fig. 9 there are the values of 6-monthly SPI at the end September 2012. The values lower than -1,50 appeared in the north of Slovakia at two stations, but they didn´t exceed the criteria of extreme drought. The vegetation season in 2012 year was drier like in 2011 and the values of 6-monthly SPI at the end of September 2012 were generally lower like at the end of September 2011. The highest surplus of precipitation with positive values of SPI appeared at three stations lying in the eastern part of Slovakia.

In an accordance with the Fig. 4, August 2012 was the driest month of this year by the 1-monthly SPI, when the majority of stations had SPI below -2,00. Reversely, the most humid month in 2012 was October, with SPI values almost 1,50.

The 6-monthly SPI achieved the lowest value in January 2012, and it was mainly caused by extreme dry November 2011. The 12-monthly SPI has longer response time and the drought in dry autumn months in 2011 and spring months in 2012 was resulted with the minimum in August 2012. This analyze shows, that the driest month was November 2011 and the most humid one was July 2011 during both years 2011 and 2012. Dry months with SPI values below -1,00 were also February, August and September 2011 and March, May and August 2012.

Fig. 6 The 12-monthly SPI values at the end of December 2011

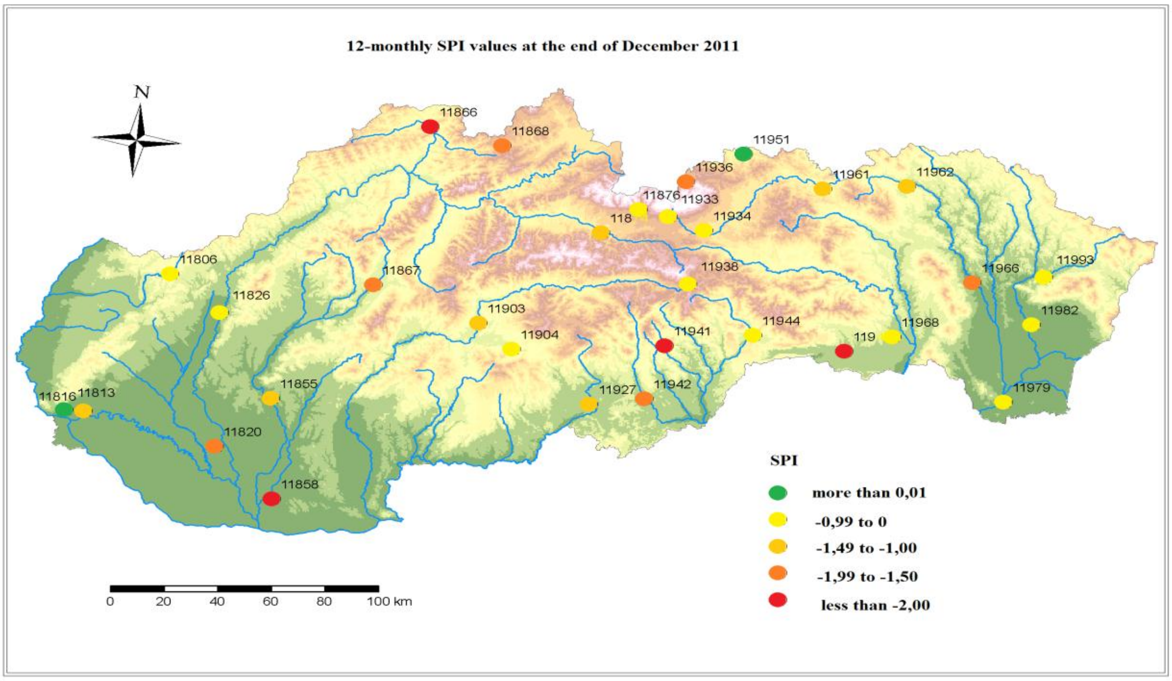


Fig. 7 The 6-monthly SPI values at the end of September 2011

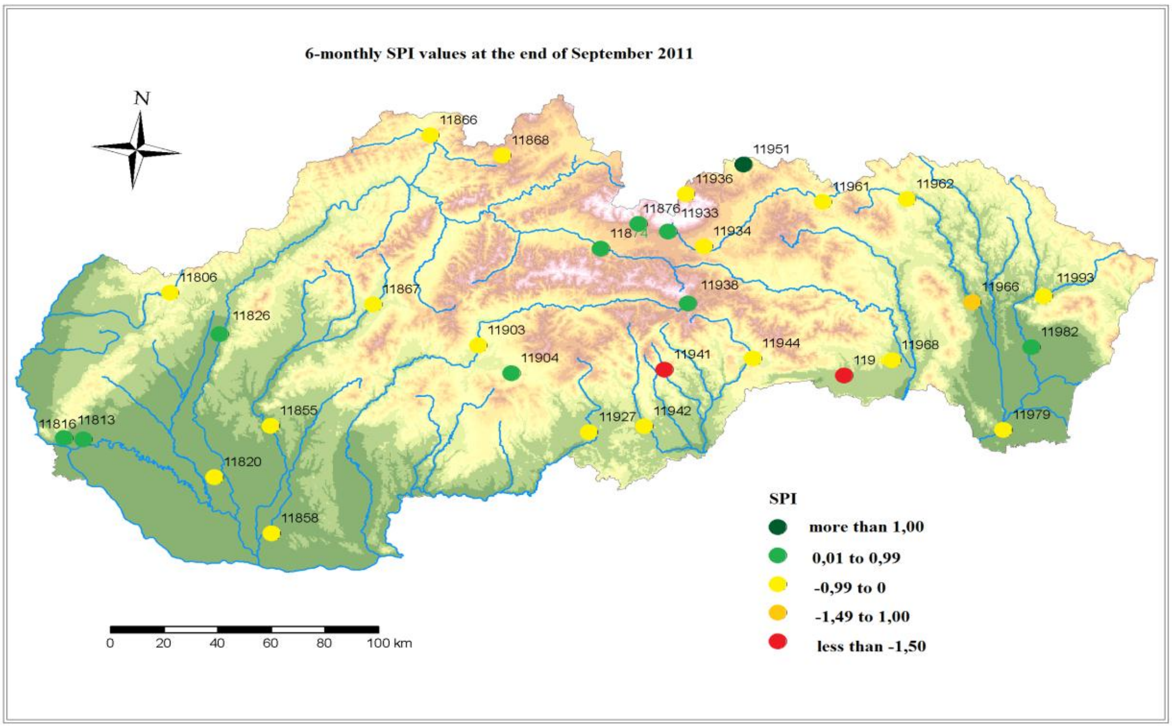


Fig. 8 The 12-monthly SPI values at the end of December 2012

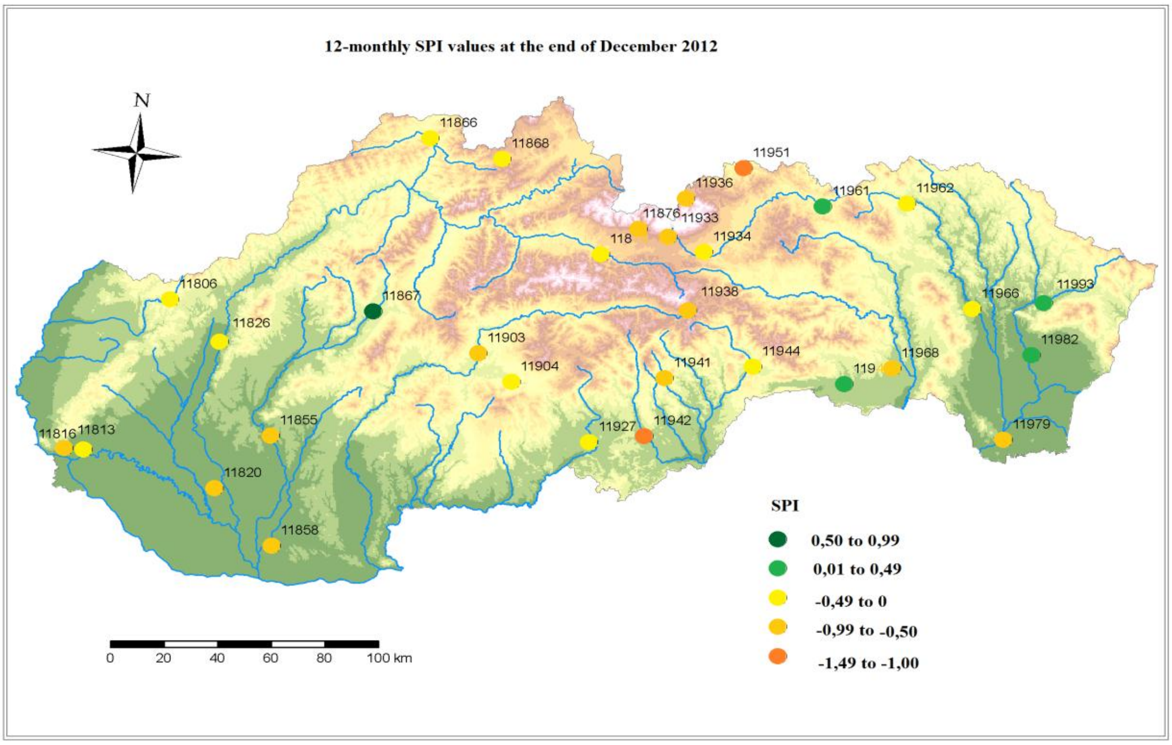
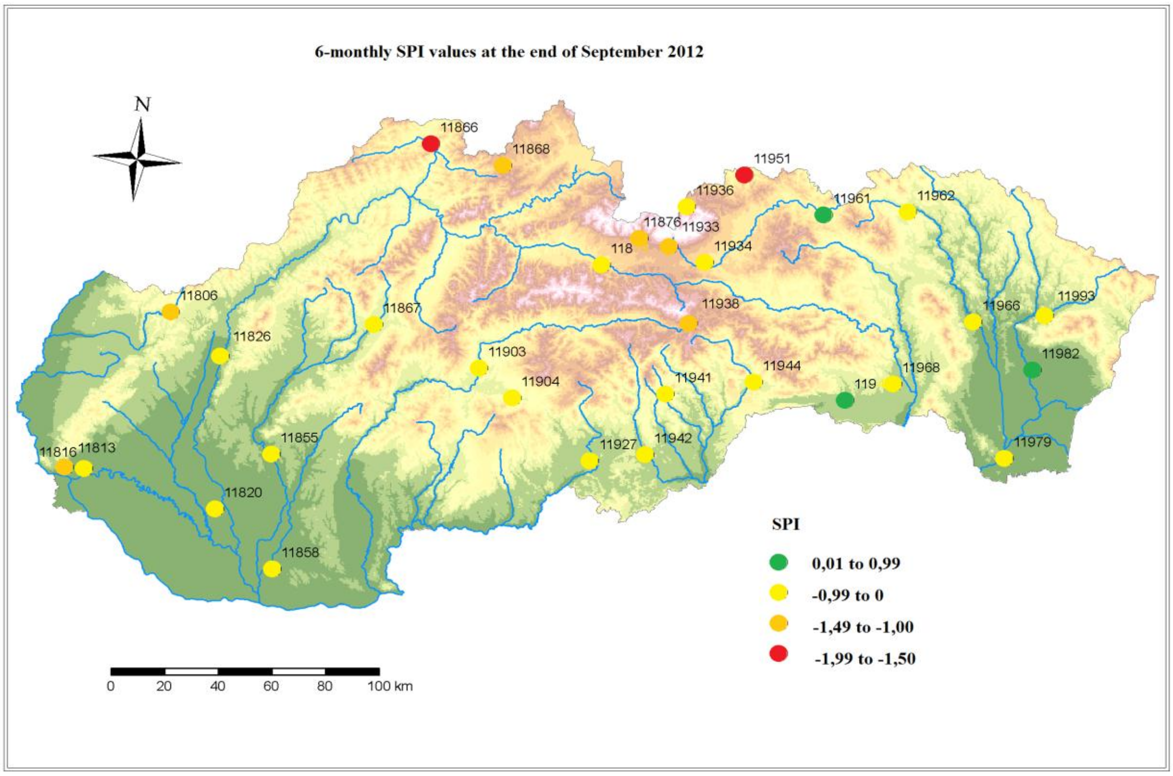


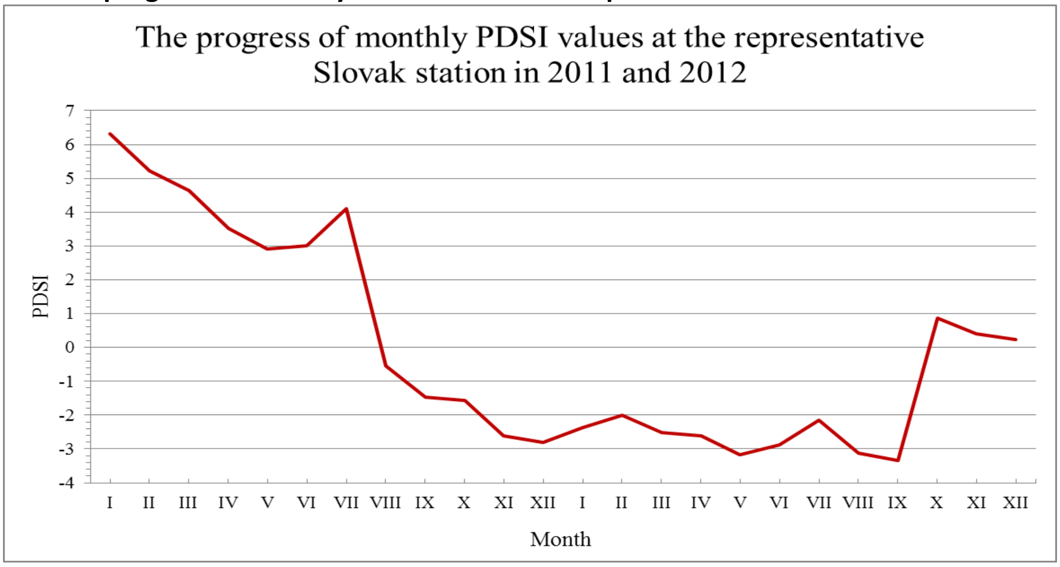
Fig. 9 The 6-monthly SPI values at the end of September 2012



The evaluation of drought in 2011 and 2012 by PDSI

In the Fig. 10 there is the progress of monthly PDSI values at the representative Slovak station in 2011 and 2012. At the beginning of the time period, the high values were influenced by the moist year 2010 and then they decreased from 6,32 in January 2011 to 2,91 in May 2011. But the sufficient amount of water was still in soil and the drought wasn´t appeared. The situation became better in June and July, but in August the values decreased from 4,10 in July 2011 to -0,54 in August 2011. The August 2011 was the first severe dry month, and the dry period became after it. The values were decreasing and reached -2,80 at the end of December 2011. The little increase of values became after the moist winter season 2011/2012, but the influence of dry November 2011 was still expressive. The vegetation season in 2012 was dry and characteristic by the deficit of precipitation at the majority of stations. PDSI achieved the minimum in September 2012 and its value ended -3,33. October 2012 brought rich precipitation and PDSI began to increase. At the end of December 2012, PDSI was close to zero.

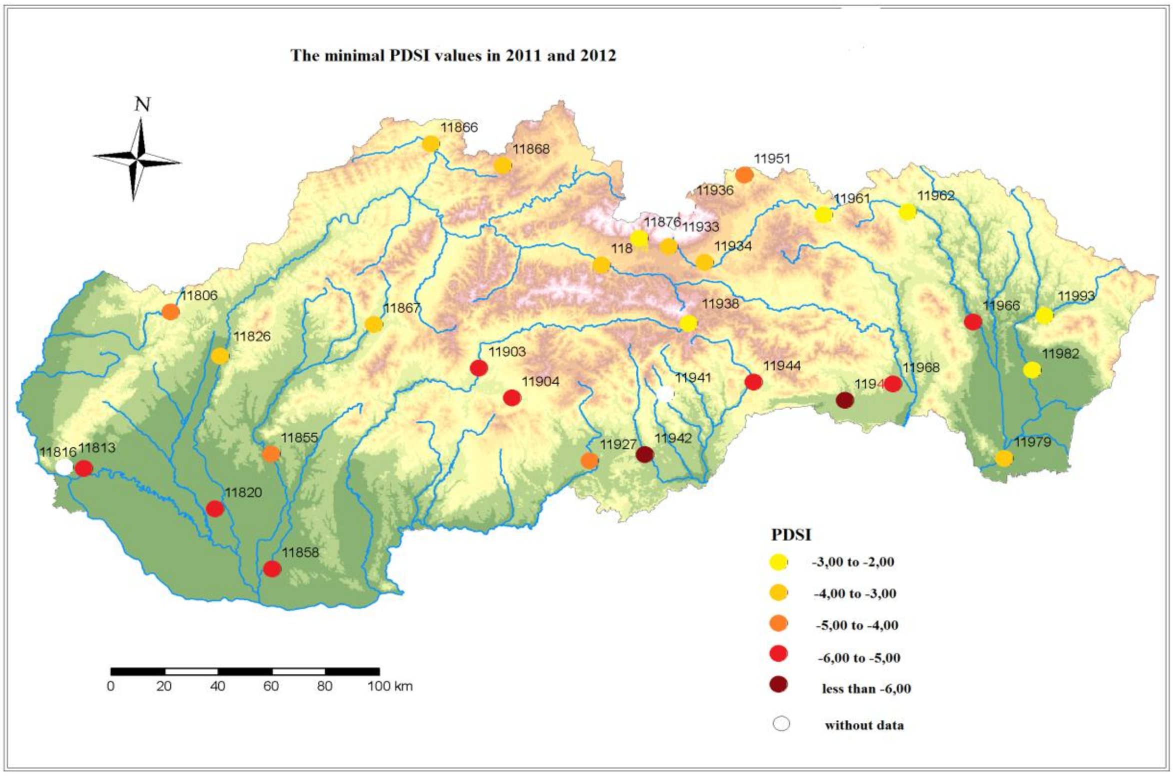
Fig. 10 The progress of monthly PDSI values at the representative Slovak station in 2011 and 2012



The course of PDSI is similar to course of monthly values of 12-monthly SPI. In the contrast to PDSI, the minimum of 12-monthly SPI values was in August 2012. This difference was caused by the different methodology of computation, because the computation PDSI includes not only precipitation, but also the potential evapotranspiration. Both indices shows, that in the first half of 2011 there was a lot of water in soil, but with respect to very hot and dry August 2011, the decrease of soil water appeared in the next period of autumn and the drought was stronger in next dry autumn months (specially November). The normal state appeared in October 2012, which was a quite moist month.

In the Fig. 11 there are the minimal monthly PDSI values in Slovakia in both years 2011 and 2012. The prevailing part of minimal values was in summer months in 2012. The lowest values of PDSI decreased below -6,00 at two stations.

Fig. 11 The minimal PDSI values in 2011 and 2012



The evaluation of drought in 2011 and 2012 by Tomlain climatic indicator of irrigation

Year 2011

In the Fig. 12 there are the deviations of Tomlain climatic indicator of irrigation K_Z in 2011 from the annual average in the period 1961 – 2012. The highest deviations above 300 mm we recorded at two stations. Reversely, the lowest negative deviation was at one station lying in the north of Slovakia. The negative deviations mean the wet condition in a comparison with the reference period. This indicator shows the similar drought situation like 12-monthly SPI values at the end of December (Fig. 6). The difference is again caused by the different methodology of computation, because the K_Z indicator considers the potential evapotranspiration.

In the Fig. 13 there are the deviations of Tomlain climatic indicator of irrigation K_Z in 2011 from the average values in the vegetation season in the period 1961 – 2012. In this case, the highest deviation was at single station lying in the basin of the Bodva river. Reversely, the lowest deviation was at the same station, where minimum of annual values of K_Z was. The results are similar comparing method of the 6-monthly SPI (Fig. 7).

Year 2012

In the Fig. 14 there are the deviations of Tomlain climatic indicator of irrigation K_Z in 2012 from the annual averages values in the period 1961 – 2012. The highest values of deviations were in the interval of 200 – 300 mm and they appeared at five stations. The negative deviations didn´t appear in 2012.

In the Fig. 15 there are the deviations of Tomlain climatic indicator of irrigation K_Z in 2011 from the average values in the vegetation season in the period 1961 – 2012. The highest deviations were mainly in the north of Slovakia, with value higher than 300 mm at one station. This drought situation is relevant with 6-monthly SPI values at the end of September 2012 too (Fig. 9).

Both years 2011 and 2012 can be shown using cumulative sums of monthly value of K_Z at the representative Slovak station (Fig. 16), when K_Z value for an individual month is the average value of K_Z from all 31 stations in the period 1961 – 2012. The cumulative sums in 2011 and 2012 we compared with corresponding values in the period 1961 – 2012. At the beginning of the year 2011, the deficit of precipitation wasn´t such expressive. The K_Z value the closest to the 1961 – 2012 mean was in July 2011. In this approach, the wet year 2010 didn´t affect the results, because it wasn´t included into the computations. We can see that the difference between cumulative sums of individual months of 2011 – 2012 and the monthly mean of the period 1961 – 2012 was high except of July 2011, when the cumulative sum of K_Z was close normal state. From August 2011, the precipitation didn´t compensate the evapotranspiration and the difference started to increase. The situation became better in the winter season 2011/12, but the deficit of the precipitation increased in next dry months of the vegetation season 2012 till September 2012. The wet October 2012, caused the decrease of the difference of K_Z. The progress of the deficit of K_Z have some tight coherence with the progress of monthly values of 12-monthly SPI in the Fig. 5 and PDSI in the Fig. 10.

Fig. 16 The progress of monthly cumulative sums of Tomlain climatic indicator of irrigation at the representative Slovak station in 2011 and 2012 and in the period 1961 - 2012

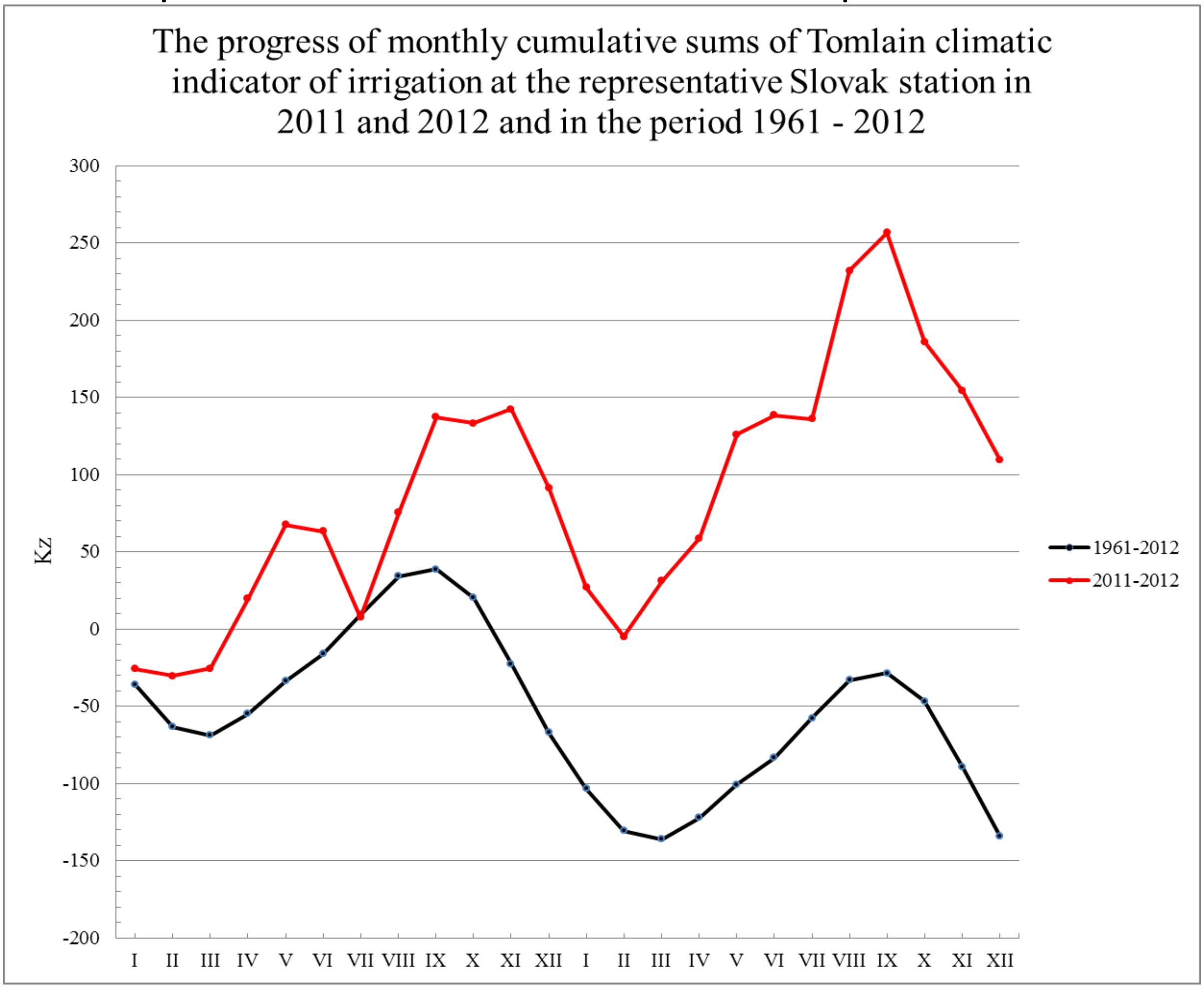


Fig. 12 The deviations of Tomlain climatic indicator of irrigation in 2011 from the period 1961 – 2012

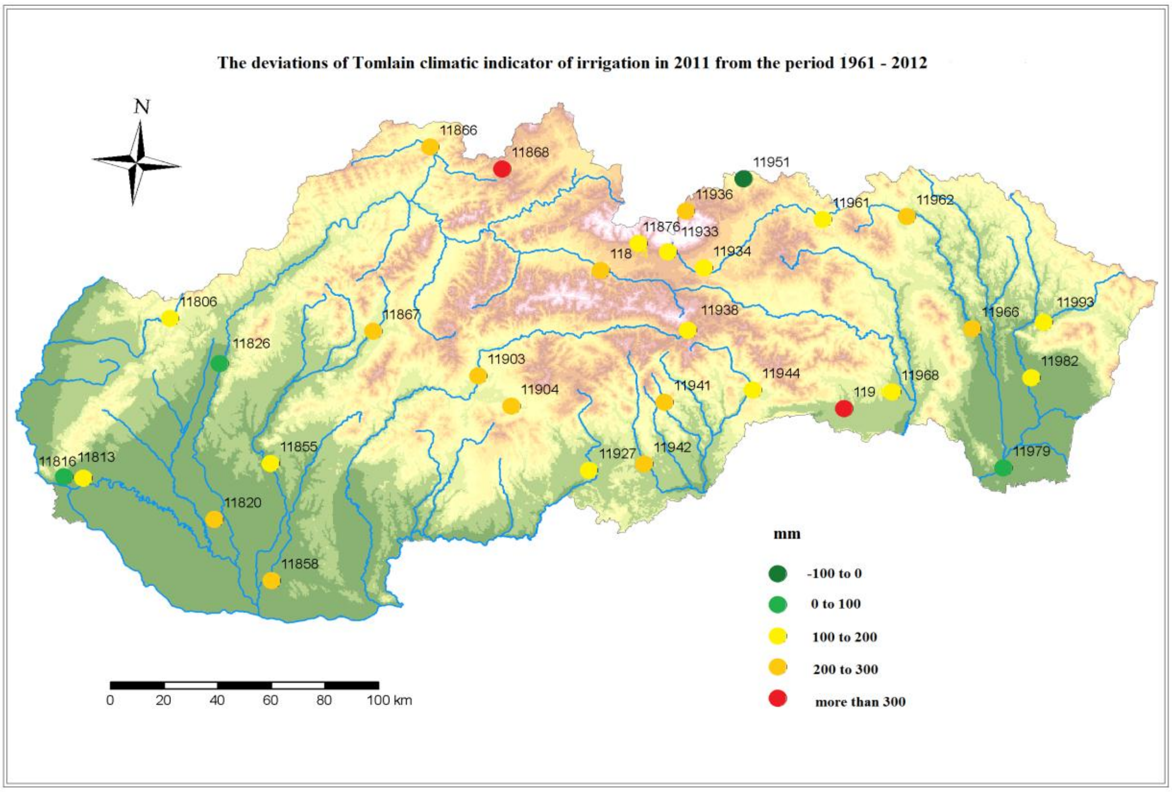


Fig. 13 The deviations of Tomlain climatic indicator of irrigation in the vegetation season in 2011 from the period 1961 – 2012

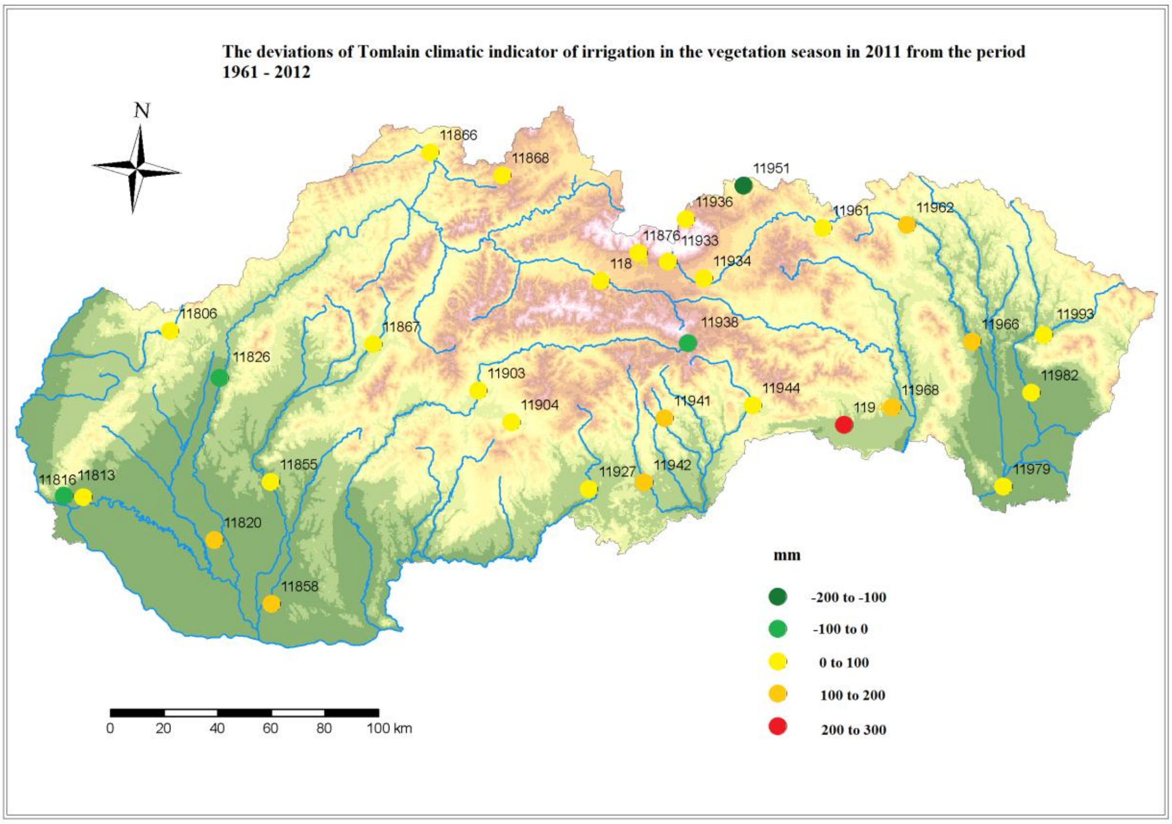


Fig. 14 The deviations of Tomlain climatic indicator of irrigation in 2012 from the period 1961 – 2012

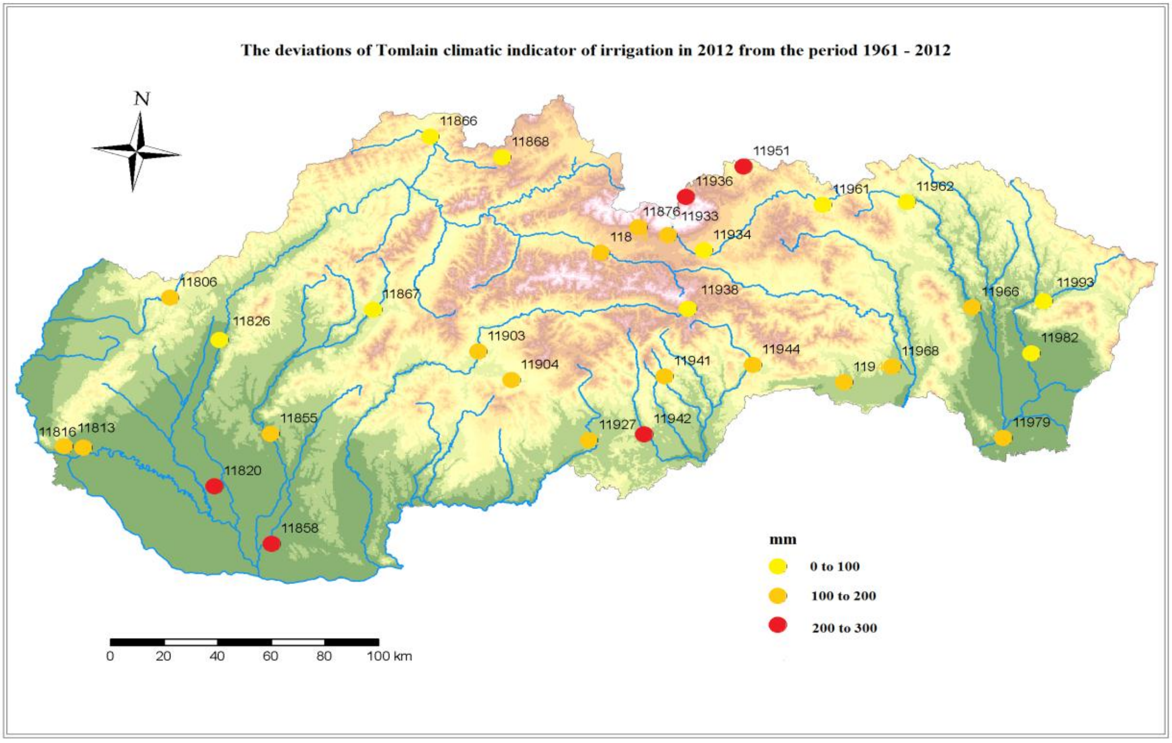
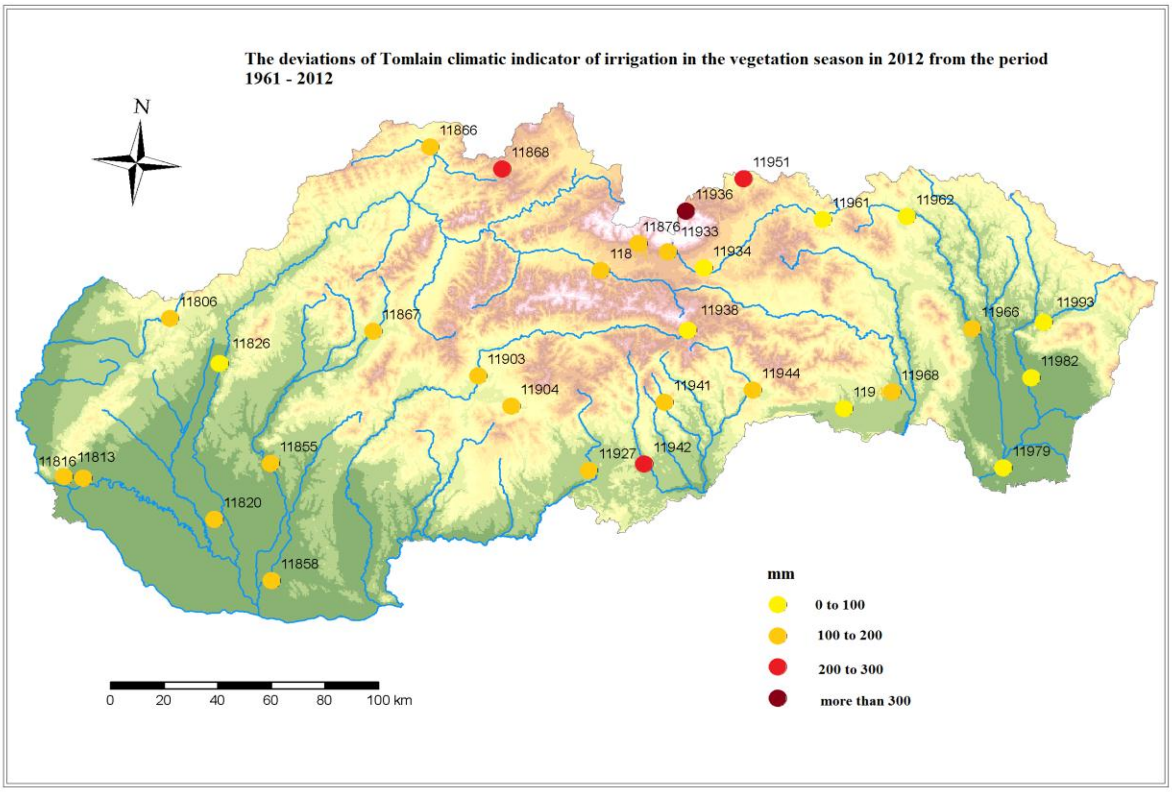


Fig. 15 The deviations of Tomlain climatic indicator of irrigation in the vegetation season in 2011 from the period 1961 – 2012



Konček index of irrigation in 2011 and 2012

In the Fig. 17 there are the deviations of Konček index of irrigation in 2011 from average values in the period 1961 – 2012. The highest deviation, higher than 50, was at the single station lying in the northeast of Slovakia. The lowest value decreased below -100 at the single station lying in the south of the middle Slovakia.

In the Fig. 18 there are the deviations of Konček index of irrigation in 2012 from average values in the period 1961 – 2012. The highest deviation, higher than 100, was at the single station lying in the northwest, where there was very wet winter season 2011/12 which was involved to the final result of I_Z. The deviations lower than -100 didn´t appear in year 2012. The lowest value -89,9 appeared at the same station like in the year 2011, which is lying in the south of the middle Slovakia.

We can say from the results of I_Z, that year 2012 was wetter like the year 2011, it was caused mainly by the wet winter season 2011/12, which had the greatest influence in the northwestern part of Slovakia.

Fig. 17 The deviations of Konček index of irrigation in 2011 from the period 1961 – 2012

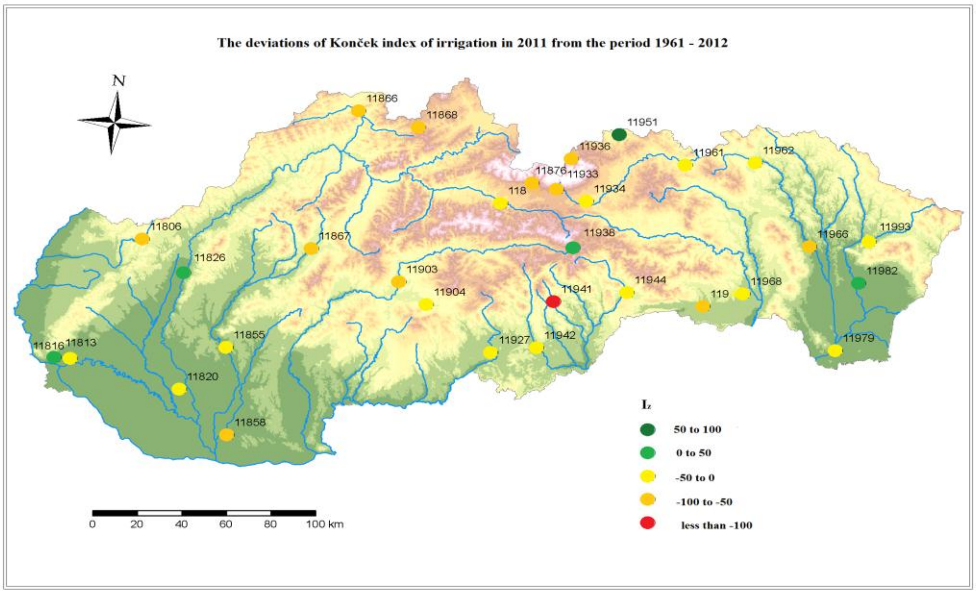
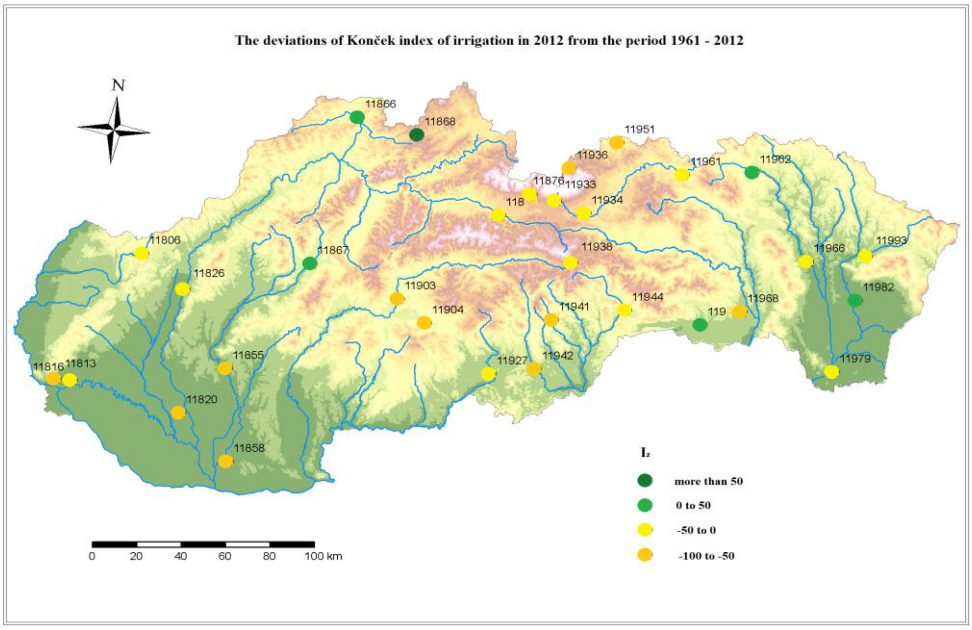


Fig. 18 The deviations of Konček index of irrigation in 2012 from the period 1961 – 2012



The evaluation of years 2011 and 2012 by all indices – conclusions

From the results obtained by the methods of SPI and PDSI indices, that at the beginning of the 2011 – 2012 period there was the surplus of precipitations from year 2010. Later, with the occurance of dry autumn months in 2011 and spring months in 2012, the deficit of precipitations was gradually increasing, except for the winter season 2011/12, which reduced this increase. The minimal values of SPI and PDSI were in August, resp. September 2012. It is in an accordance with the course of cumulative sums of K_Z, which achieved the highest value (deficit of water in soil) in September 2012 too. In January 2012 higher precipitation caused the decrease of deficit of soil water in the northwest of Slovakia. The vegetation season 2012 was very dry at the majority of stations, whereby the highest deviations from the period 1961 – 2012 mean were in the north of Slovakia. The minimal monthly PDSI values were in summer months 2012 on a few places in the south of the middle and eastern Slovakia. Later, in October 2012 more rain was contributed to the soil water. In both years the strongest impact of the drought was in the basins of Bodva, Ipeľ, Rimava and Slaná rivers. The driest month on the whole country was November 2011, following by August and September 2011 and March, May and August 2012. The wettest months were July 2011 and January and October 2012. These results are in an accordance with results presented in the chapter of air temperature and precipitation, and also of river flows and ground water.

Discussion on drought indices

In Slovakia there were previously used only national indices for the drought evaluation. Primarily Tomlain climatic indicator of irrigation and Končok index of irrigation were applied. Especially Končok index has found its use for the categorisation of the climatic regions for the Slovak territory in terms of hydrological and radiation regime of climate. In addition often was also used Seljanin hydrothermal coefficient and Lange rain factor, or Budyko radiation index. Each of these indices has its shortages and advantages as well. E.g. Končok index is based solely on the nature of the weather in the winter and during the growing season. Months March, October and November are not taking into account, but for evaluation of drought for the whole year these months are also important and can´t be omitted. In addition, Končok index of irrigation can´t be calculated for individual month.

In the year 1973 [7] began to be used NDVI also for the drought identification. NDVI is recognized worldwide, particularly in the United States. The calculation has some limitation and the interpretation of this index is not so simple. In addition, it can be calculated only for days without clouds.

Last year, for the Project Atlas of Slovakia some of Palmer indices were calculated. Actually the PDSI and Z - index plus relative rPDSI and rZ – index were carried out. Relative indices rPDSI and rZ - index are very useful for estimating in which area was actually the most intense drought because these relative indexes allow comparison of the intensity of drought for all used meteorological stations. The disadvantage of this approach is that relative indices are usable only for the Slovak territory, because all input data of precipitation and air temperature applied to their long-term regime for the so called reference Slovak station, where the mean data from our territory were used. This is the reason why the relative values of these indices are not applicable for the comparison with other countries, where the similar approach was used.

Recently the SPI index has been calculated for 94 precipitation stations in the period 1961 - 2013. In the near future we would like to include into our drought monitoring system some of other indices, such a SWSI and SPEI.

The drought is a very complex process. We can recognize and distinguish the meteorological, hydrological, agricultural and socio-economic drought. The world's most used meteorological index is the SPI index, but most of countries use also their own indices taking into account their national conditions. The SPI index is very simple one, because it uses only precipitation amount for each month. The intensity of the drought, however, depends on several factors. If we have two months, with the same amount of rainfall, the intensity of drought is higher in the month with a higher temperature of soil and evapotranspiration. In the summer months, therefore the impact of drought is higher than in the winter months. For these reasons there is more preferable to use the SPEI drought index. There is a similarity between the SPEI and Tomlain climatic indicator of irrigation. The calculation of SPEI is based on the difference of precipitation and potential evapotranspiration $R - E_0$. Similarly to the SPI index the probability of occurrence is fixed in a given month. The SPEI values are similar to the SPI and vary generally in the range -4.00 to 4.00. This index better reflects the drought than SPI, because it is a combination of humidity, temperature and radiation conditions. Therefore, there is the effort for using SPEI in Slovakia.

Palmer indices are also very suitable for evaluating of drought, because in addition to rainfall and evapotranspiration they also take into account the soil water content and soil type, which is defined by the value of available water capacity. It is very important to distinguish the soil types, because the impact of drought may be different for various soil types under the same conditions of rainfall and evaporation. The additional advantage of Palmer indices is that they can also be calculated in a weekly step. PDSI is more applicable for an evaluation of the long-standing soil condition and Z - index for the short-term state of the soil. Using these indexes we can evaluate the drought intensity from the short and long term points of view, in the monthly and weekly step and with the SPEI index seem to be the most suitable for the evaluation of drought.

WMO proposed and approved a number of other drought indices such as SWSI, the RDI (reclamation drought index), ADI (aggregate index of dryness), SDI (stream-flow drought index), EDI (effective drought index) etc. These indices, however, have only limited use. They were not applied in the real conditions of Slovakia.
In conclusion, we recommend the most suitable and most representative drought indexes: SPEI, PDSI and Z – index and SPI as a supplement to them.

Possibilities for providing operational information on status, course and forecast of drought

Drought indices SPI and PDSI are used world-wide. The SPI is suitable for the precipitation deficit monitoring in monthly step, or for last 3, 6, 9, 12 and 24 months. These indices are good tools for monitoring the drought development of the various seasons including the growing season. The values of indices can be applied only for the concrete site with its precipitation deficit compared to long-term average of precipitations.

PDSI can be summarized after each month, as well as after individual weeks. However, it is important to stress that it is a cumulative index and the individual value of PDSI for a given week represents some long-term drought condition. If the long wet season is interrupted with several weeks of dry weather the PDSI values remain still high. The same we can expect in reverse. For the assessment of each week are therefore more appropriate indices Z - index and CMI (Crop Moisture Index). The Z - index has no memory and its value actually represents the degree of drought in the area for the individual week. Basically the indexes PDSI and Z – index can describe a kind of difference to the long-term course of precipitations for the station. The CMI is more suitable for the comparison of individual stations. Weekly maps of PDSI and CMI indices are prepared regularly in the United States in the Climate Prediction Center, NOAA.

For practical use of indices in the frame of the SHMI, each of maps on monthly or weekly base would contain a legend, with explanation of the extent of drought in individual areas depending on the kind of index. For calculating the index weekly we shall use data from climatological stations that regularly send daily data of variables for calculation (INTER reports). Weekly values of Palmer indices we plan to calculate in specific weeks. The first week of the year begins 1.1. and ends at 7.1. and the second begins with 8.1. and ends 14.1., etc. With Palmer indices we can characterize periods of 2, 4 and 13 weeks. For monthly values of Palmer index is possible to use another source of data from monthly reports. In addition when using monthly precipitation totals for the SPI, about 600 rain-gauge stations can be used with delay of two months. The relative rPDSI and rZ – index are better tools for a comparison of individual stations. Each value of these indices in a particular station is linked to the long-term course of precipitations and air temperature at the reference station, which was obtained as the average of all the stations included into the calculation. We propose PDSI and rPDSI as the most appropriate indices in a weekly step for assessing the long-term condition and also Z- index and rZ – index for assessing a particular week.

The daily forecast of these indices is not possible. If we knew the forecast of rainfall and temperature from numerical models for next period of 7 – 10 days, we would be able for a particular week to calculate Palmer indices only (PDSI, Z - index and CMI). It is always important to determine the starting date of calculation, because the length of the reporting period reflects the actual value of the drought index.

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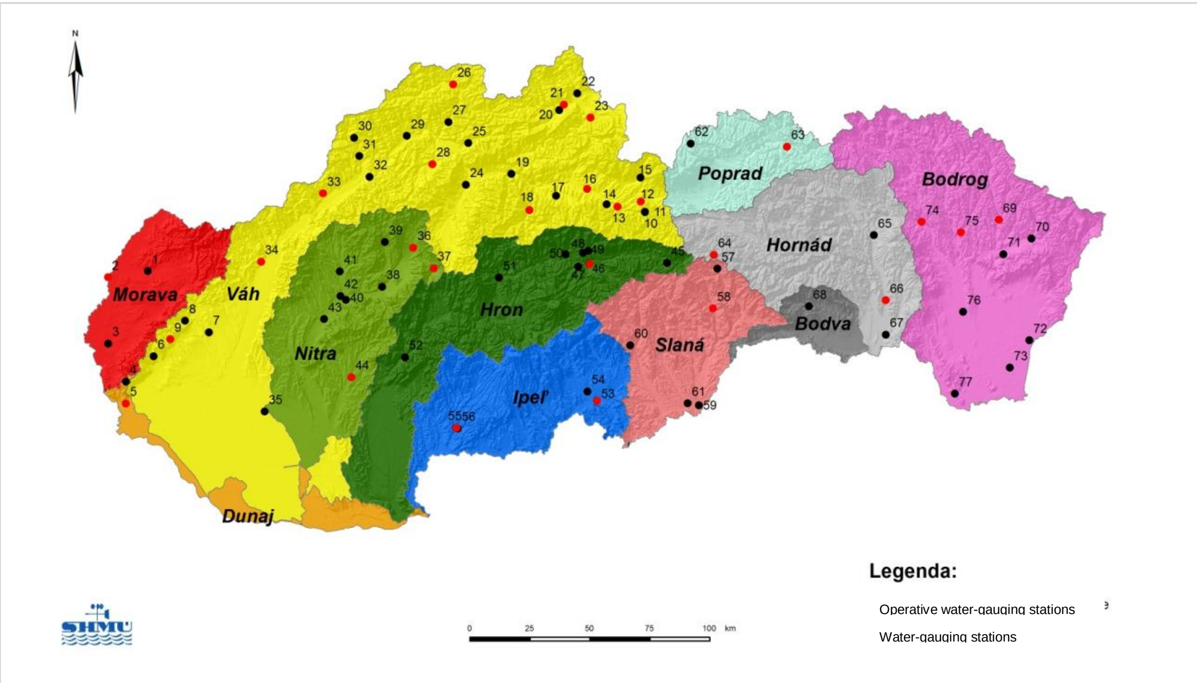
3.3 River flow assessment

Assessment of surface water hydrological situation is based on the data from the water-gauging stations of the state hydrological network. The data from 418 gauging stations have been used for the assessment of the hydrological regime and hydrological processes. 268 stations from the total number of 418 water-gauging stations are operative stations, from which transmission of data is provided in 15-minute and 1-minute steps (water level, water temperature, air temperature and precipitation total).

The hydrological data from the water-gauging stations with natural hydrological regime (without human influence: e.g. water usage, water manipulation in water reservoirs, water transfers, etc.) are considered for hydrological drought and water scarcity assessment. Another necessary condition for real-time assessment is to use the data from operative stations.

For assessment of the development of hydrological regime including the development of drought indicators, 77 gauging stations with natural hydrological regime have been selected, where the discharges have been monitored since 1961 and earlier. The hydrological forecasting is performed in 26 of 77 selected gauging stations (Fig. 1 - red points = operative stations; colours of main river basins are matching with Table 4).

Fig. 1 Selected gauging stations with natural hydrological regime in the main river basins in Slovakia



- **Drought** is a natural phenomenon. It is the part of the natural hydrological regime of water resources. It represents causal and rarely occurring depression of water resources capacity. It represents significant deviation from an average status of natural variability of the river. The hydrological characteristics from unaffected stations and the hydrological balance are used to assess the drought.
- **Water scarcity** represents the status when the available amount of water in water resources is insufficient to ensure human water demands. Water scarcity can therefore occur also in the period without occurrence of drought. This status happens in case when water usage requirements exceed the natural capacity of water resources. To assess and to control the water scarcity the water-resource balance tool (Water Scarcity Management Plan) are used.

3.3.1 Assessment of hydrological drought in 2011 and 2012

Hydrological drought analyses of chosen period are based on the assessment of discharge characteristics of low flow. The most frequently used are the following:

- ***Minimum discharge*** – the lowest unaffected mean daily discharge of selected period (month, season, year, more years).
- ***M-day discharge (Q_{Md})-*** is the mean daily discharge, whis is reached or exceeded during M days in selected period. The period is usually chosen as 1 year. If different period is used, this issue has to be declared, e.g. M-day discharge of vegetation season. The symbol "M", in case of more-year periods represents the average time in year (in number of days), during which the mean daily discharge is equal or higher than particular discharge. 330-, 355- and 364-day discharges are the discharges with high probability of exceedance. These hydrological characteristics are the most widely used hydrological low flow characteristics for water planning and environmental assessment in Slovakia.

Analyses of hydrological situation in 2011

Hydrological year 2011
Unlike the year 2010 which has been considered to be the year of floods and the wettest year since 1931, the year 2011 belongs among the drier years. The assessed values of water bearing coefficient (% ratio of the mean yearly discharge/long-term discharge Q_a) in particular hydrological stations have varied in range from 55 % to 150 % Q_a.
The lowest values in 2011 were evaluated in the upper part of river basins of Vah (60 % to 67 % Q_a) and Nitra (56 % Q_a).
Low precipitation totals during the year 2011 influenced also the occurrence and values of minimum discharges. Monitored values of minimum discharges were lower than Q_{355d} in most part of water-gauging stations. In quite a number of stations with long-term observation period the significant minimum discharges were monitored, e.g. in Bratislava (Danube) where the mean daily discharge lower than Q_{364d} was recorded. This value represents the 33th lowest value of minimum mean daily discharges since 1901. In Vah River basin the minimum discharge values varied from Q_{270d} to Q_{364d}. In upper part of the Nitra river basin the minimum discharges lower than Q_{364d} were recorded. In lower part of the Nitra river basin the monitored minimum discharges were close to Q_{330d}. In the Hron and Ipel river basins the minimum discharges with values from Q_{355d} to Q_{364d} were monitored, in few cases the minimal discharges fell even below these values. In the Slana, Hornad and Bodrog river basins the minimum discharges from Q_{330d} to Q_{364d} were observed and in the Poprad river basins the values from Q_{330d} to Q_{355d} were monitored.

Hydrological balance in calendar year 2011
Precipitation totals of the year 2011 in particular river basins are executed in Table 1.
The precipitation total in particular river basins and its distribution during the year has manifested in the values and distribution of runoff as follows: The higher values of annual runoff than the long-term value have been assessed only in the Danube and Poprad river basins (103% and 117% of normal). In other river basins these values have been assessed in range 40 % to 93 % of long-term runoff only (Tab. 1, Fig. 2).

Table 1 Mean annual precipitation total and mean annual runoff in 2011 in particular river basins of Slovakia

River basin	*Morava	*Dunaj	Váh	Nitra	Hron	*Ipeľ	Slaná	Bodva	Hornád	*Bodrog	*Poprad Dunajec	SR
Catchment area [km^2]	2282	1138	14268	4501	5465	3649	3217	858	4414	7272	1950	49014
Mean yearly precipitation total [mm]	616	429	703	576	668	508	622	598	656	647	851	649
% of long-term mean	90	68	83	83	85	74	79	82	97	92	101	85
Precipitation character of the period	N	VD	D	D	D	VD	VD	D	N	N	N	D
Yearly runoff [mm]	102	37	258	115	116	107	176	136	194	195	404	191
% of long-term mean	77	103	81	80	40	79	93	83	92	66	117	73

D - dry, VD - very dry, ED – extremely dry, N - normal, W - wet, VW - very wet, EW - extremely wet

* Rivers and values only from the Slovak parts of river basins

Fig. 2 Annual precipitation totals in 2011 in particular river basins of Slovakia

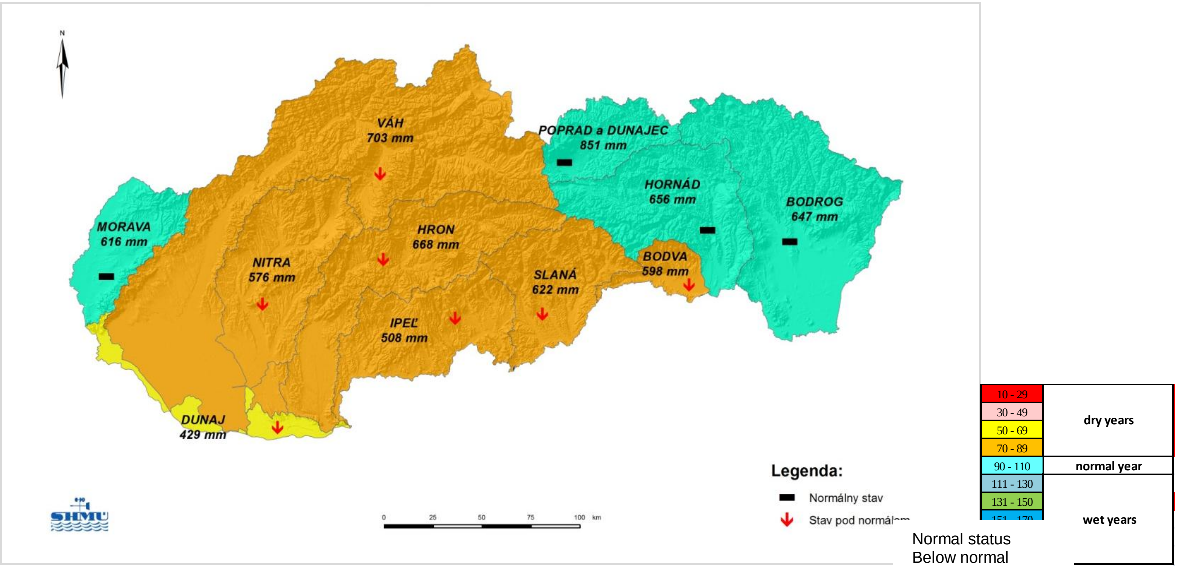
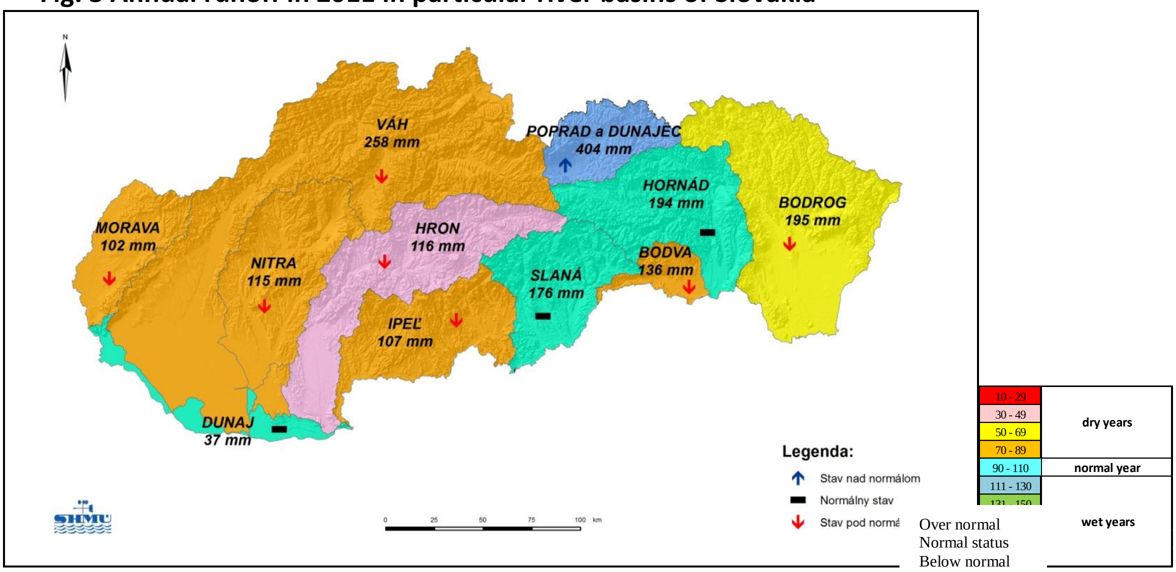


Fig. 3 Annual runoff in 2011 in particular river basins of Slovakia



Analyses of hydrological situation in 2012

Hydrological year 2012

According to the surface waters the year 2012 we can consider to be extremely dry (Table 4). The assessed values of water bearing coefficient in particular hydrological stations were assessed in range from 20 % to 106 % Q_a. The lowest values were evaluated in the Ipeľ River basin in the stations Holiša (19% Q_a) and Lučenec – Krivánsky potok (23% Q_a). Other very low values were assessed in the Slaná River basin, in the station Rimavská Seč –Blh (22% Q_a) and in the station Lehota nad Rimavicou – Rimavica (23% Q_a).
The low flow in the year 2012 was more significant. The minimum discharges lower than Q_{364d} were in 2011 recorded in 15% stations while in 2012 such values were monitored in 31 % of stations. While in 2011 the minimum discharges lower than Q_{355d} were monitored in 45, 5 % stations, in 2012 such values were reorded in 73,3% of stations.

Hydrological balance in calendar year 2012

According to the annual precipitation total the Nitra, Hron, Ipeľ, Bodva, Hornád, Bodrog and Poprad river basins were assessed as normal (92 to 104 % of normal) and the Morava, Váh and Slaná river basins were assessed as dry (84 to 89 % of normal). The Danube river sub-basin (Slovak part) was assessed as very dry; the annual precipitation total in this basin represented the lowest value in Slovakia (78% of normal or 490 mm).

The period from December 2011 to February 2012 was rich in snow, but the precipitation scarcity and the abnormally high air temperatures in March and in April caused the beginning of the dry hydrological situation. During the months June and July, according to the missing precipitation, the runoff was minimal. The situation with low precipitation and high air temperatures continued in August and September as well.
The specific distribution of rainfall during the year has caused that the annual runoff of particular river basins has not exceeded the long-term values. The values of annual runoff have varied in range from 26% to 89% of long-term values. In spite of the fact, that precipitation total of the year in Slovakia was close to the long-term value, according to the runoff from Slovak territory the year 2012 was assessed as a dry one (155 mm, 59 % of long-term runoff).

Table 2 Annual precipitation totals and average annual runoff in 2012 in particular river basins of Slovakia

River basin	*Morava	*Dunaj	Váh	Nitra	Hron	*Ipeľ	Slaná	Bodva	Hornád	*Bodrog	*Poprad Dunajec	SR
Catchment area [km^2]	2282	1138	14268	4501	5465	3649	3217	858	4414	7272	1950	49014
Mean yearly precipitation total [mm]	570	490	755	640	771	630	704	697	704	727	804	711
% of long-term mean	84	78	89	92	98	92	89	95	104	103	96	93
Precipitation character of the period	**D**	**VD**	**D**	**N**	**N**	**N**	**D**	**N**	**N**	**N**	**N**	**N**
Yearly runoff [mm]	86	13	246	85	159	36	79	50	109	148	307	155
% of long-term mean	65	36	78	59	55	26	42	30	52	50	89	59

D - dry, VD - very dry, ED – extremely dry, N - normal, W - wet, VW - very wet, EW - extremely wet

* Rivers and values only from the Slovak parts of river basins

Fig. 4 Average precipitation totals in 2012 in particular river basins of Slovakia

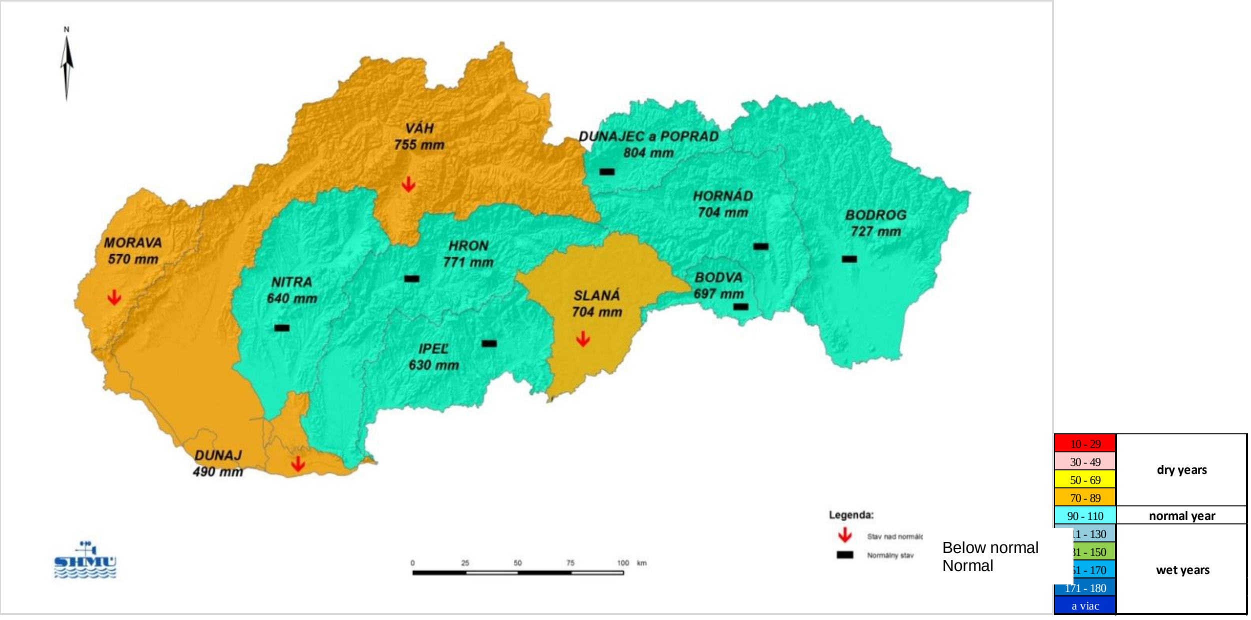
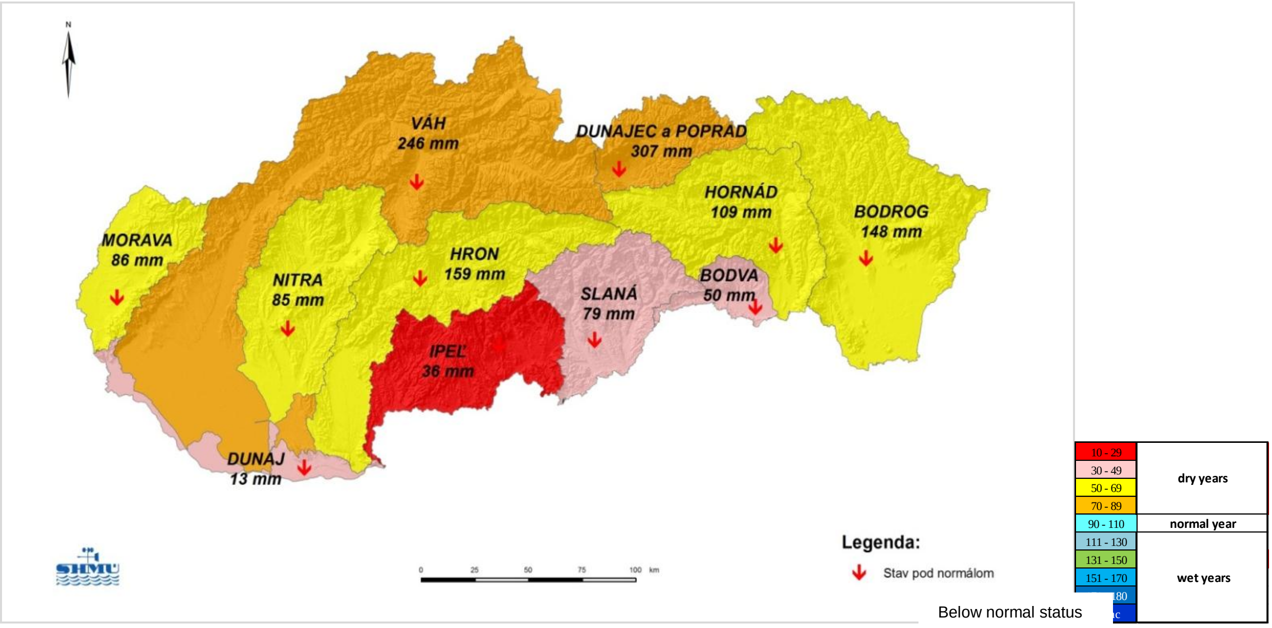


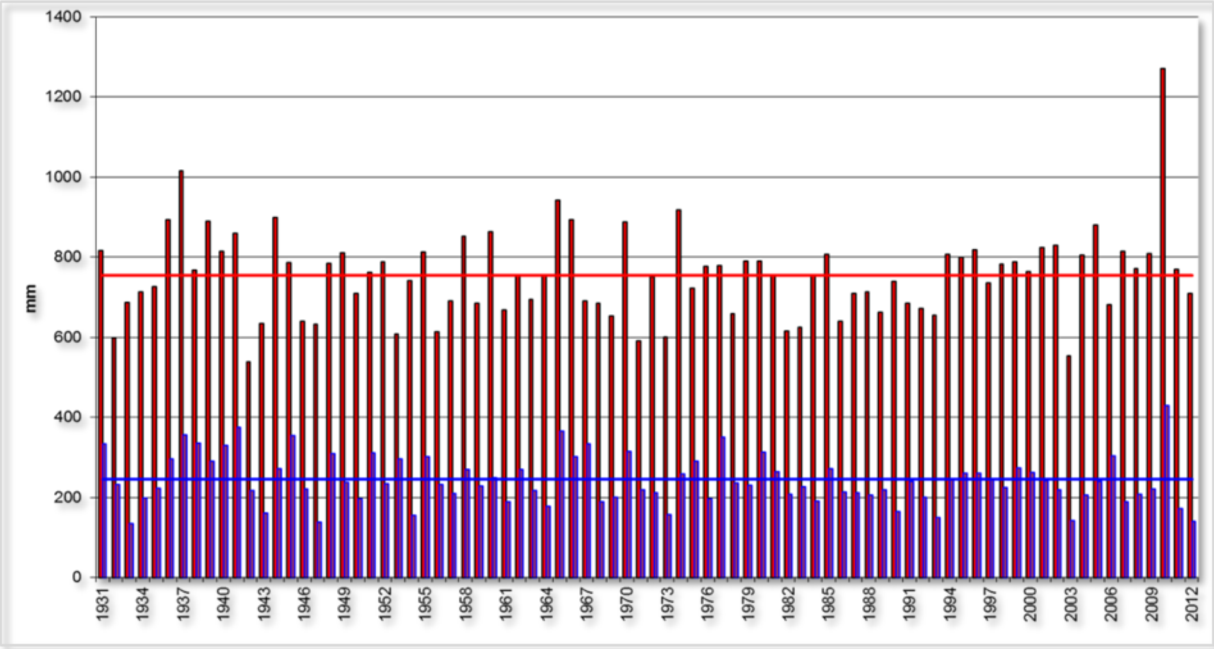
Fig. 5 Annual runoff in 2011 in particular river basins of Slovakia



Hydrological year 2012 in point of view of long-term assessment

Hydrological year 2012 is one of the driest years since 1931 (Fig. 6). According to the results of the long-term assessment of the annual runoffs, the runoff of the year 2012 was evaluated as the fourth lowest.

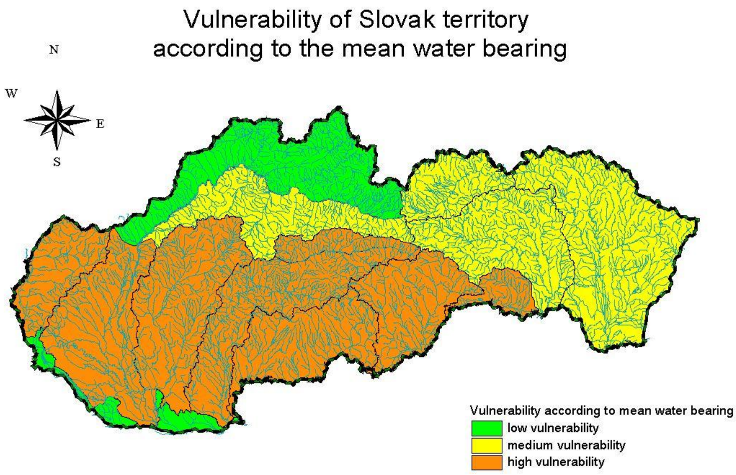
Fig. 6 Annual runoff and annual precipitation total in Slovakia in particular years of the period 1931 - 2012



Map of vulnerability

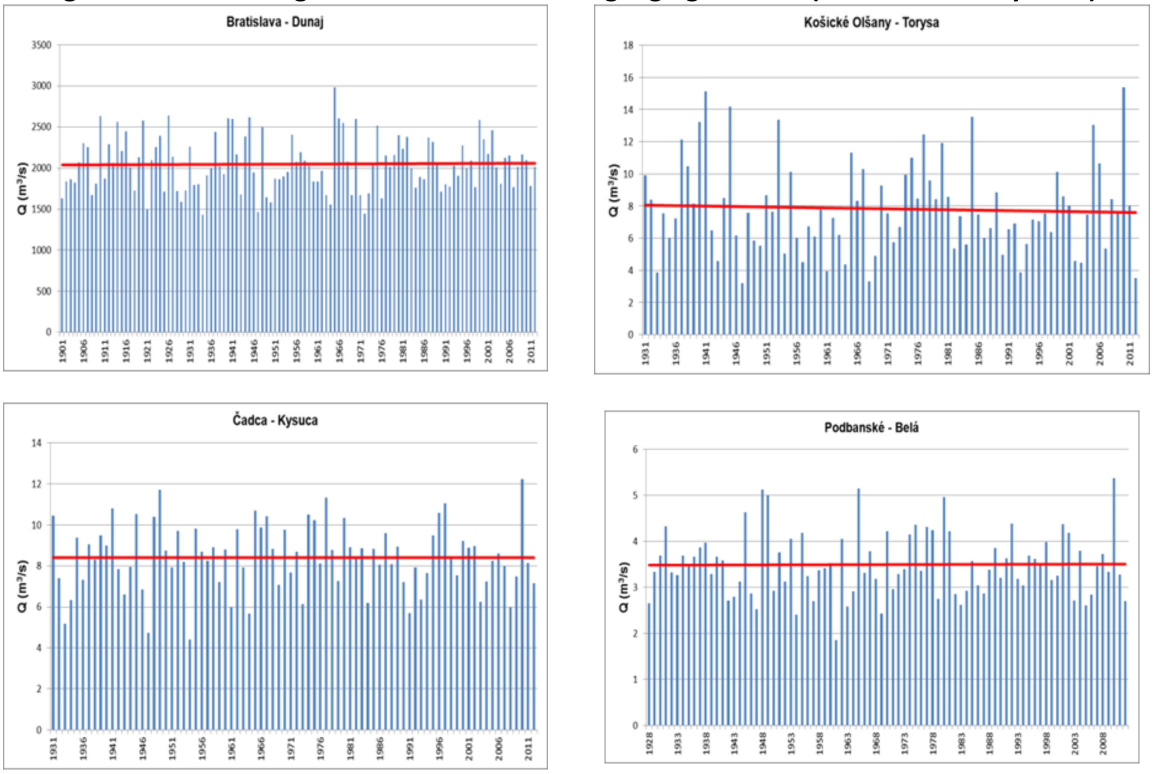
According to the results of the assessment of the regime of the particular annual runoffs during the long-term period, their development and trends, the territory of Slovakia has been divided into 3 zones: with low vulnerability, medium vulnerability and high vulnerability (Fig. 7).

Fig. 7 Vulnerability of the territory according to the development of the annual runoff



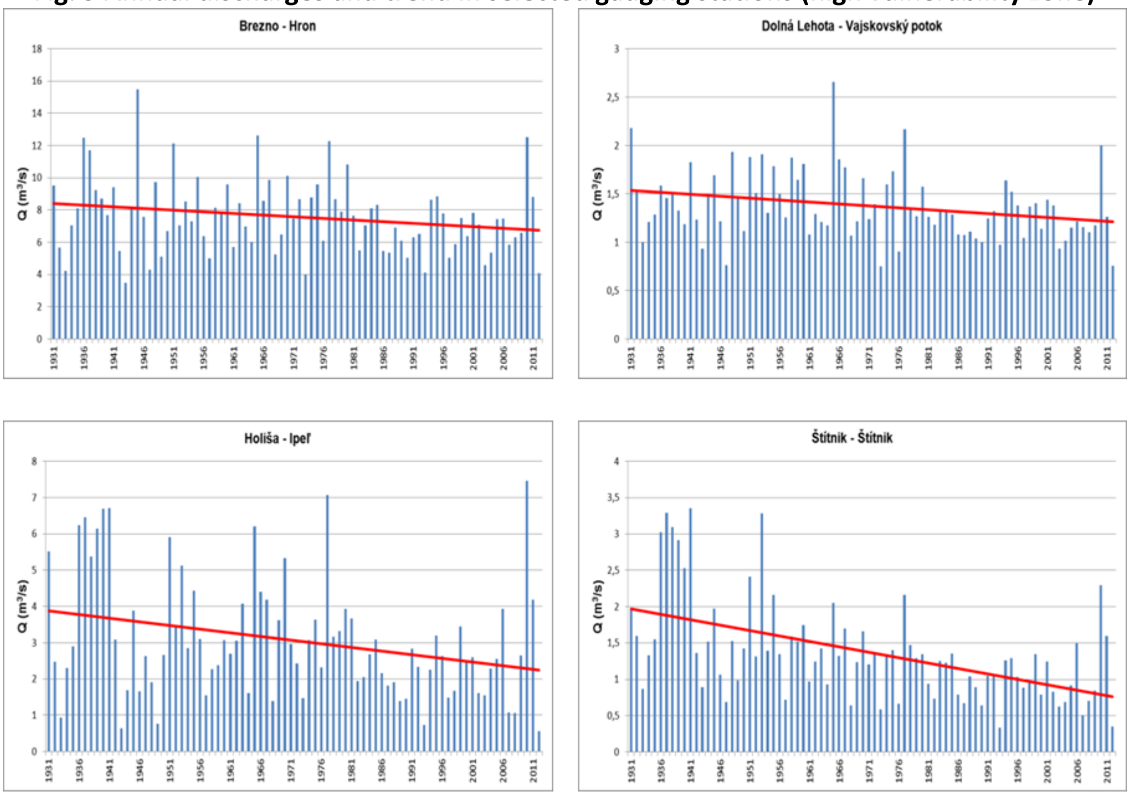
For illustration the graphical visualization of the development of the annual discharges in particular years of observed period in 4 stations which have been classified into the low vulnerability zone are presented below (Fig. 8).

Fig. 8 Annual discharges and trend in selected gauging stations (low vulnerability zone)



The graphical visualization of the development of the annual discharges in particular years of observed period in 4 stations which have been classified into the high vulnerability zone are presented below (Fig. 9).

Fig. 9 Annual discharges and trend in selected gauging stations (high vulnerability zone)



Water bearing of the years 2011 and 2012

The comparison of relative values of the annual water bearing of the years 2011 and 2012 is showing the following results: in 2011 annul discharges did not achieve the long-term values in 85% stations; in 2012 such case was assessed in 97% of stations. That means that in 2012 the annul discharges only in 3% of stations have exceeded the long-term values. It is necessary to note, that about one half of these 3% were the stations on the Danube River and in the lower part of the Váh River. The relative values of annual water bearing in 2011, lower than 60% have been assessed only in 13% of the stations, however, in 2012 it was even in 53% of the stations.

Analyses of the hydrological year 2012 in the particular river basins

Year 1931 is assumed as the beginning of the systematic continuous evaluation of the discharges on the rivers in the Slovakia. The evaluation of discharges in Slovakia has been provided many years before this year, however in some stations only (e.g. Bratislava-Danube since 1901). The systematic evaluation of discharges has started in the year 1931 in 81 gauging stations. That is why we have assessed the water bearing of the years 2011 and 2012 in context of the period 1931 -2012. In Tab. 3 the selected gauging stations are listed, which are being considered as the key stations for the historical ranking assessment in the particular river basins.

Table 3. The key gauging stations

Stream	Station	Hydrol. number	River log (km)	Catchment area (km^2)	Discharge evaluation since
Myjava	Šaštín - Stráže	4-13-03-073	15,18	644,89	*1931
Morava	Moravský Svätý Ján	4-17-02-001	67,15	24,129,30	1922
Dunaj	Bratislava	4-20-01-006	1868,75	131 331,10	1901
Váh	Šaľa	4-21-10-057	58,5	11 217,61	*1921
Nitra	Nitrianska Streda	4-21-12-017	91,1	2093,71	1931
Hron	Brehy	4-23-04-110	93,9	3821,38	1931
Ipeľ	Holiša	4-24-01-058	157,2	685,67	1931
Krivánsky potok	Lučenec	4-24--01-078	5,4	204,2	1931
Krupinica	Plášťovce	4-24-03-058	11,8	302,79	1931
Litava	Plášťovce	4-24-03-071	0,9	214,27	1931
Slaná	Lenartovce	4-31-02-098	3,6	1829,65	1931
Rimavica	Lehota nad Rimavicou	4-31-03-046	2,9	148,95	1931
Torysa	Košické Olšany	4-32-04-151	13,0	1298,3	1931
Ondava	Horovce	4-30-10-001	29,2	2885,8	1931
Poprad	Chmeľnica	3-01-03-088	60,1	1262,41	1931
* - observation period interrupted					

The stations from Danube river sub-basin (Slovak part) (except Danube – Bratislava) and the Bodva river basin are not involved in the table. Danube river basin is represented with the gauging station Danube-Bratislava, but we have to note, that the values of discharges in this station are not included into evaluation of runoff from Slovak territory (the discharge in Danube is formed mainly by runoff from the territories outside Slovakia); however the values are used for water resource availability assessment of Slovakia. The systematic evaluation of discharges in the Bodva river basin began in 1941.

According to the assessment of the discharge time series from the selected key stations it was assumed that the driest year in whole territory of Slovakia since 1931 was the year 1933, the second was the year 1993 and the third one was the year 1947. Right after these years follows the hydrological year 2012. (Tab. 4, Fig.10).

Table 4 Long-term discharge and average annual discharges in dry years in selected stations.

No.	Stream	Station	Catchment	1961-2000	Q_{2012}	$Q_{r2012}/Q_{(61-00)}$	Q_{2011}	$Q_{r2011}/Q_{(61-00)}$	Q_{2003}	$Q_{r2003}/Q_{(61-00)}$	Q_{1993}	$Q_{r1993}/Q_{(61-00)}$	Q_{1947}	$Q_{r1947}/Q_{(61-00)}$	Q_{1933}	$Q_{r1933}/Q_{(61-00)}$
1	Myjava	Šaštín - Stráže	Morava	2,71	1,621	60	4,462	165	1,901	70	1,128	42	1,568	58	0,965	36
2	Morava	Moravský Ján		106,37	66,9	63	111,2	105	90,863	85	54,245	51	106,953	101	44,796	42
3	Močiarka	Láb		0,201	0,073	36	0,171	85	0,123	61	0,091	45				
4	Vydrica	Spariská	Dunaj	0,06	0,026	43	0,104	173	0,051	85	0,031	52				
5	Dunaj	Bratislava		2061	2018	98	1782	86	2007	97	2030	98	1463	71	1800	87
6	Blatina	Pezinok	Váh	0,225	0,124	55	0,29	129	0,123	55	0,108	48				
7	Trnávka	Bohdanovce		0,411	0,141	34	0,455	111	0,261	64	0,205	50				
8	Parná	Horné Orešany		0,373	0,113	30	0,68	182	0,150	40	0,223	60				
9	Gidra	Píla		0,297	0,148	50	0,441	148	0,224	75	0,215	72				
10	Ipoltica	Čierny Váh		1,49	1,563	105	0,898	60	0,906	61	0,899	60				
11	Čierny Váh	Čierny Váh		3,547	1,764	50	3,811	107	2,137	60	2,146	61	2,303	65	2,633	74
12	Biely Váh	Východná		1,491	1,15	77	1,658	111	1,441	97	1,149	77	0,930	62	1,112	75
13	Boca	Kráľova Lehota		1,892	1,076	57	1,855	98	1,168	62	1,052	56	1,384	73	1,772	94
14	Váh	Liptovský Hrádok		8,738	5,668	65	8,806	101	6,413	73	5,845	67				
15	Belá	Podbanské		3,481	2,703	78	3,272	94	2,709	78	3,187	92	2,528	73	3,266	94
16	Váh	Liptovský Mikuláš		20,134	13,76	68	20,892	104	15,525	77	15,143	75	13,107	65	16,293	81
17	Ľupčianka	Part.Ľupča		1,704	0,895	53	1,544	91	1,334	78	1,483	87				
18	Revúca	Podsuchá		4,711	2,82	60	4,283	91	3,081	65	4,123	88	2,722	58	2,762	59
19	Ľubochnianka	Ľubochňa		2,323	1,852	80	2,488	107	2,067	89	1,927	83	1,335	57	1,760	76
20	Biela Orava	Lokca		6,751	5,94	88	5,769	85	5,191	77	5,499	81				
21	Veselianka	Oravská Jasenica		1,574	1,199	76	1,309	83	1,177	75	1,221	78				
22	Polhoranka	Zubrohlava		3,295	2,711	82	2,673	81	2,713	82	2,495	76				
23	Oravica	Trstená		2,687	1,628	61	2,522	94	2,104	78	1,745	65				
24	Turiec	Martin		9,828	7,553	77	10,512	107	7,953	81	6,233	63	5,943	60	7,026	71
25	Varínka	Stráža		3,139	2,445	78	2,532	81	2,335	74	2,191	70	1,094	35		
26	Kysuca	Čadca		8,552	7,162	84	8,142	95	6,252	73	6,351	74	4,731	55	5,190	61
27	Kysuca	K.N.Mesto		16,603	10,009	60	14,497	87	11,466	69	12,546	76	9,463	57	10,609	64
28	Rajčianka	Poluvsie		3,465	1,893	55	2,856	82	2,061	59	2,242	65	1,729	50	1,582	46
29	Petrovička	Bytča		0,72	0,764	106	0,79	110	0,607	84	0,492	68				
30	Petrinovec	Vydrná		0,109	0,084	77	0,115	106	0,122	112	0,054	50				
31	Biela voda	Dohňany		1,99	1,32	66	1,342	67	1,434	72	1,186	60				
32	Pružinka	Visolaje		1,248	0,615	49	1,155	93	0,842	67	0,568	46				
33	Vlára	Horné Sŕnie		3,242	2,269	70	3,082	95	2,240	69	2,087	64				
34	Jablonka	Čachtice		0,903	0,418	46	1,001	111	0,715	79	0,408	45				
35	Váh	Šaľa		141,962	103,095	73	135,222	95	113,361	80	98,399	69	87,966	62	90,379	64
36	Nitra	Nedožery	Nitra	2,125	1,135	53	1,636	77	1,483	70	1,373	65	1,416	67		
37	Handlovka	Handlová		0,578	0,348	60	0,323	56	0,403	70	0,302	52	0,373	65	0,158	27
38	Nitra	Chalmová		6,075	3,522	58	6,271	103	4,313	71	3,841	63	3,302	54	2,325	38
39	Nitrica	Liešťany		1,908	1,013	53	1,563	82	1,182	62	1,201	63				
40	Nitra	Chynorany		9,75	5,398	55	9,278	95	6,881	71	6,374	65	5,546	57		
41	Bebrava	Biskupice		1,964	1,127	57	1,96	100	1,148	58	0,946	48	1,640	84	0,758	39
42	Bebrava	Nadlice		3,266	2,022	62	4,044	124	2,368	73	1,765	54				
43	Nitra	Nitrianska Streda		14,624	8,994	62	14,93	102	10,108	69	8,880	61	8,638	59	5,233	36
44	Žitava	Vieska nad Ž.		1,6	0,656	41	1,56	98	0,822	51	0,781	49	1,349	84	0,903	56
45	Hron	Zlatno	Hron	1,337	0,759	57	1,668	125	0,810	61	0,763	57	0,720	54	0,903	68
46	Hron	Brezno		7,416	4,082	55	8,811	119	4,558	61	4,133	56	4,309	58	4,210	57
47	Čierny Hron	Hronec		2,898	1,137	39	2,856	99	1,697	59	1,279	44	1,912	66	1,251	43
48	Bystrianka	Bystrá		0,916	0,577	63	0,852	93	0,545	59	0,569	62	0,632	69	0,635	69
49	Štiavnička	Mýto		1,017	0,692	68	1,075	106	0,650	64	0,621	61	0,552	54	1,089	107
50	Vajskovský potok	Dolná Lehota		1,342	0,76	57	1,263	94	0,932	69	0,972	72	0,764	57	0,996	74
51	Hron	Banská Bystrica		25,526	13,234	52	26,049	102	18,239	71	14,738	58	16,179	63	14,897	58
52	Hron	Brehy		45,898	23,14	50	50,195	109	30,749	67	25,077	55	28,016	61	20,268	44
53	Ipeľ	Holiša	Ipeľ	2,877	0,56	19	4,211	146	1,552	54	0,730	25	2,630	91	0,930	32
54	Krivánsky potok	Lučenec		1,332	0,305	23	1,623	122	0,673	51	0,425	32	0,584	44	0,317	24
55	Krupinica	Plášťovce		1,589	0,46	29	1,757	111	0,904	57	0,581	37	1,339	84	0,440	28
56	Litava	Plášťovce		0,952	0,267	28	1,338	141	0,504	53	0,267	28	0,848	89	0,295	31
57	Dobšinský potok	Dobšiná	Slaná	0,442	0,189	43	0,492	111	0,271	61	0,198	45	0,310	70	0,522	118
58	Štítnik	Štítnik		1,138	0,351	31	1,604	141	0,622	55	0,333	29	0,686	60	0,865	76
59	Slaná	Lenartovce		12,693	4,678	37	17,413	137	7,370	58	4,747	37	6,905	54		
60	Rimavica	Lehota nad Rim.		1,437	0,327	23	1,667	116	0,732	51	0,468	33	0,920	64	0,631	44

10 - 29	dry years
30 - 49	
50 - 69	
70 - 89	
90 - 110	normal year
111 - 130	wet years
131 - 150	
151 - 170	
171 - 180	
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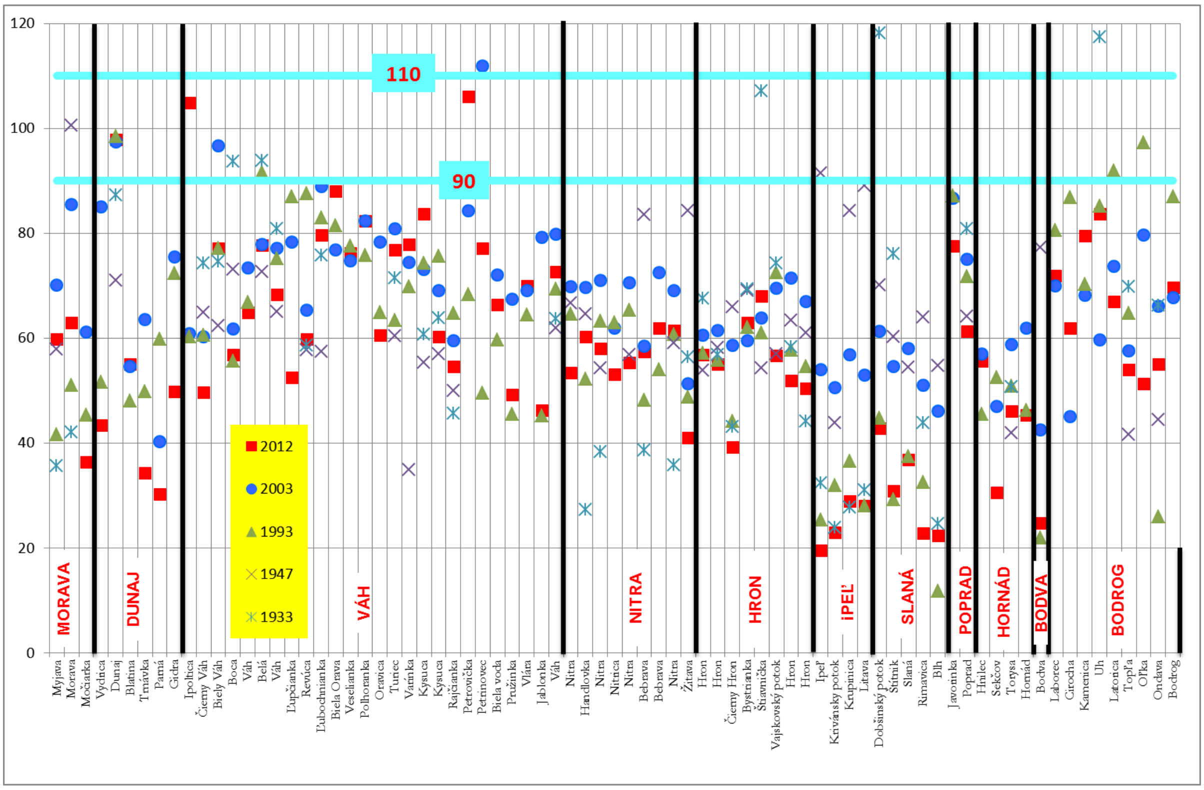
Fig. 10 Water bearing coefficient in dry hydrological years 1933, 1947, 1993, 2003 and 2012 in selected stations.



Minimum discharges

According to data in Table 5, no minimum discharge occurred in hydrological year 2012, which would fall below the absolute minimum value recorded since 1931. The absolute minimum discharge has been recorded in 2012 in some water-gauging stations with shorter period of discharge evaluation and on smaller streams. (Note: Zero discharge has been recorded in some water-gauging stations in the river basins of South and Southeast Slovakia). The absolute minimum discharges for the whole period of observation are listed in the table, too.

It is obvious from the results that in principle, there exists no year in which the occurrence of minimum mean daily discharges is significantly prevailing. The minimum mean daily discharge occurred in the years 1947, 1961 and 2003 in six water-gauging stations, in the years 1973, 1992 and 1993 it was in five water-gauging stations.

The fact that the minimum mean daily discharges for the whole period of observation in 77 selected water-gauging stations were occurring even in 30 different years (Tab. 5) is suggesting, that the exceptionally dry year (drought affecting the whole territory) in Slovakia has not occurred yet, and Slovakia is still “waiting” for such a year. Similarly to assessment of the driest years, there is obvious the fact, that for the assessment of the hydrological drought and elaboration of the case studies, as a part of the drought and water scarcity management it is necessary to focus on the flow depressions (deficit volumes) and its analysis, as well.

Tab. 5 Minimum discharges

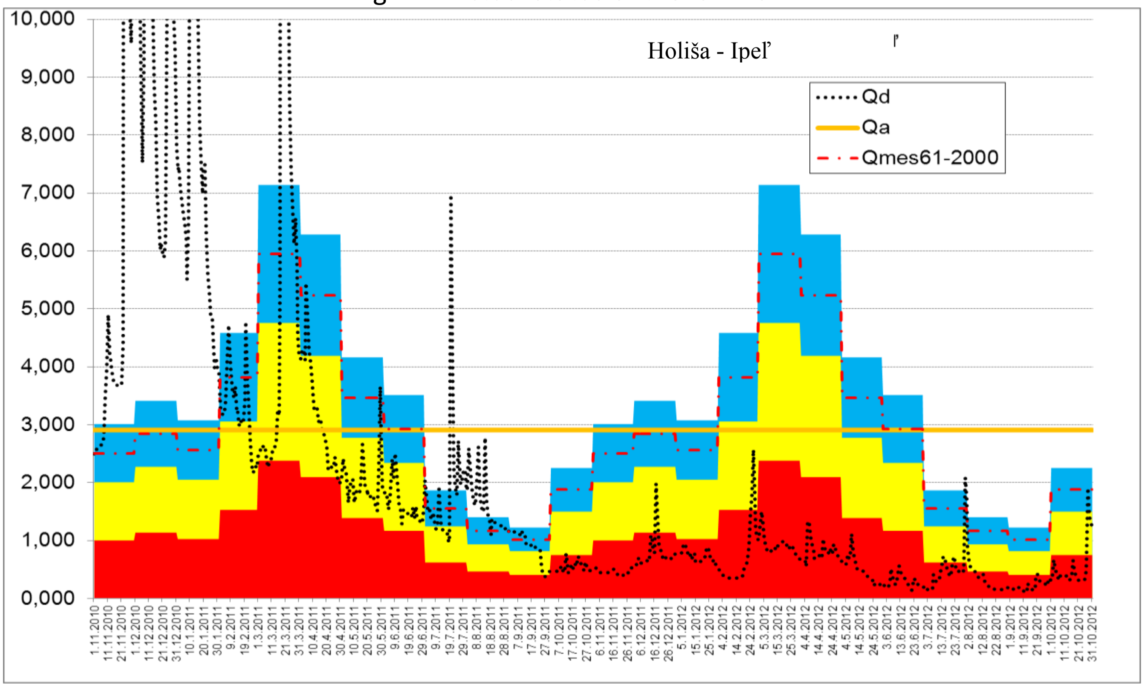
No.	Stream	Station	River basin	Period	Qmin2011	Qmin2012	QAbsMin	Year (AbsMin)
1	Myjava	Šaštín - Stráže	Morava	1969-2012	0,425	0,320	0,190	1973
2	Morava	Moravský Ján		1922-2012	29,709	21,278	7,700	1934
3	Močiarka	Láb		1961-2012	0,07	0,035	0,003	1973
4	Vydrica	Spariská	Dunaj	1961-2012	0,007	0,004	0,000	1992
5	Dunaj	Bratislava		1901-2012	1039,5	815,538	580,000	1909
6	Blatina	Pezinok	Váh	1961-2012	0,106	0,006	0,000	1978
7	Trnávka	Bohdanovce		1961-2012	0,042	0,040	0,012	1971
8	Parná	Horné Orešany		1961-2012	0,06	0,040	0,025	2006
9	Gidra	Pila		1961-2012	0,087	0,068	0,020	1962
10	Ipoltica	Čierny Váh		1961-2012	0,563	0,322	0,096	1987
11	Čierny Váh	Čierny Váh		1931-2012	1,231	0,646	0,492	1987
12	Biely Váh	Východná		1923-2012	0,962	0,613	0,209	1996
13	Boca	Kráľova Lehota		1931-2012	0,6	0,372	0,206	1981
14	Váh	Liptovský Hrádok		1951-2012	3,292	2,253	1,922	1996
15	Belá	Podbanské		1928-2012	0,847	0,807	0,400	1929
16	Váh	Liptovský Mikuláš		1921-2012	7,747	4,887	4,200	1996
17	Ľupčianka	Part. Ľupča		1961-2012	0,785	0,508	0,190	1968
18	Revúca	Podsuchá		1931-2012	1,674	1,067	0,500	1973
19	Ľubochnianka	Ľubochňa		1931-2012	1,345	1,120	0,320	1962
20	Biela Orava	Lokca		1951-2012	0,543	0,368	0,260	1962
21	Veselianka	Oravská Jasenica		1951-2012	0,168	0,121	0,103	2003
22	Polhoranka	Zubrohlava		1951-2012	0,502	0,269	0,100	1954
23	Oravica	Trstená		1961-2012	0,771	0,537	0,200	1973
24	Turiec	Martin		1931-2012	4,641	3,203	2,121	1984
25	Varínka	Stráža		1941-2012	0,534	0,462	0,180	1965
26	Kysuca	Čadca		1931-2012	0,866	0,642	0,320	1992
27	Kysuca	K.N.Mesto		1931-2012	2,693	1,748	0,840	1944
28	Rajčianka	Poluvsie		1931-2012	0,636	0,364	0,298	1992
29	Petrovička	Bytča		1961-2012	0,153	0,038	0,010	1963
30	Petrinovec	Vydrná		1961-2012	0,012	0,011	0,001	2003
31	Biela voda	Dohňany		1961-2012	0,168	0,063	0,026	2003
32	Pružinka	Visolaje		1961-2012	0,463	0,350	0,150	1992
33	Mára	Horné Sŕnie		1961-2012	0,359	0,095	0,075	2003
34	Jablonka	Čachtice		1961-2012	0,083	0,063	0,030	1963
35	Váh	Šaľa		1963-2012	7,439	33,143	6,502	1988
36	Nitra	Nedožery	Nitra	1941-2012	0,385	0,218	0,138	1992
37	Handlovka	Handlová		1931-2012	0,131	0,085	0,042	1993
38	Nitra	Chalmová		1931-2012	2,042	1,151	0,510	1947
39	Nitrica	Liešťany		1949-2012	0,154	0,126	0,080	1949
40	Nitra	Chynorany		1941-2012	2,781	1,792	1,000	1947
41	Bebrava	Biskupice		1931-2012	0,423	0,254	0,149	2003
42	Bebrava	Nadlice		1941-2012	1,046	0,776	0,219	1993
43	Nitra	Nitrianska Streda		1931-2012	5,483	2,287	2,000	1933
44	Žitava	Vieska nad Ž.		1931-2012	0,467	0,094	0,030	1962
45	Hron	Zlatno	Hron	1931-2012	0,488	0,284	0,160	1963
46	Hron	Brezno		1931-2012	2,342	1,583	1,200	1943
47	Čierny Hron	Hronec		1931-2012	0,682	0,501	0,373	1983
48	Bystrianka	Bystrá		1931-2012	0,256	0,142	0,096	1983
49	Štiavnička	Mýto		1931-2012	0,302	0,215	0,170	1973
50	Vajskovský potok	Dolná Lehota		1931-2012	0,342	0,246	0,245	1985
51	Hron	Banská Bystrica		1931-2012	8,357	5,864	4,800	1954
52	Hron	Brehy		1931-2012	12,995	9,304	7,700	1947
53	Ipeľ	Holiša	Ipeľ	1931-2012	0,379	0,098	0,010	1947
54	Krivánsky potok	Lučenec		1931-2012	0,208	0,068	0,040	1968
55	Krupinica	Plášťovce		1931-2012	0,151	0,072	0,017	1973
56	Litava	Plášťovce		1931-2012	0,075	0,038	0,010	1961
57	Dobšinský potok	Dobšiná	Slaná	1931-2012	0,17	0,073	0,052	1993
58	Štítnik	Štítnik		1931-2012	0,352	0,091	0,062	1993
59	Slaná	Lenartovce		1931-2012	3,307	2,147	0,800	1947
60	Rimavica	Lehota nad Rim.		1931-2012	0,237	0,109	0,030	1964
61	Blh	Rimavská Seč		1931-2012	0,158	0,102	0,001	1993
62	Javorinka	Ždiar Podspády	Poprad	1961-2012	0,33	0,340	0,100	2003
63	Poprad	Chmeľnica		1931-2012	4,797	3,062	2,240	1987
64	Hnilec	Stratená	Hornád	1954-2012	0,4	0,202	0,080	1968
65	Sekčov	Prešov		1961-2012	0,349	0,125	0,080	1971
66	Torysa	Košické Olšany		1931-2012	1,856	0,891	0,540	1968
67	Hornád	Ždaňa		1958-2012	9,124	6,819	3,940	1961
68	Bodva	Nižný Medzev	Bodva	1941-2012	0,122	0,026	0,014	2000
69	Laborec	Koškovce	Bodrog	1961-2012	0,56	0,273	0,160	1961
70	Cirocha	Snina		1957-2012	0,577	0,584	0,050	1963
71	Kamenica	Kamenica		1961-2012	0,212	0,225	0,009	1984
72	Uh	Lekárovce		1951-2012	3,593	1,847	1,310	1961
73	Latorica	Veľké Kapušany		1951-2012	5,578	4,338	2,600	1954
74	Topľa	Hanušovce		1931-2012	1,283	1,044	0,710	1947
75	Olka	Jasenovce		1961-2012	0,042	0,043	0,025	1970
76	Ondava	Horovce		1931-2012	6,167	6,103	1,490	1961
77	Bodrog	Streda nad Bod.		1951-2012	24,374	20,453	8,390	1961

Methodology of the assessment of hydrological drought in real time:

When making the real-time assessment, it is necessary to focus on evaluation of the actual hydrological situation as well, including the actual flow depression (deficit volume) under certain threshold value. Therefore it is necessary to know the initial status, in addition to the precipitation also the air temperature, evaporation and the actual water supply in the snow cover, which will help to evaluate comprehensively the origin and the course of the hydrological drought.

Practically, this means to operatively evaluate the operational discharge in comparison with particular monthly averages for the reference period 1961-2000 (Fig. 11), and on the basis of additional information also the possible future development of the hydrological drought, respectively a possible impact on the availability of water resources.

Fig. 11 Actual status of the low flow



Legend:

$Q_{mes61-2000}$ – mean long-term monthly discharges for the period 1961-2000 (m^3/s),
Q_d – mean daily discharges (m^3/s), in real-time assessment – operative discharge values,
Q_a – mean long-term discharge for the period 1961 - 2000 (m^3/s).

The course of the mean daily discharge in 2011-2012 (in the hydrological year), mean long-term monthly discharges for the period 1961-2000 and mean long-term discharge for the period 1961-2000 (m3/s) are shown in the Fig. 11.

The variability of hydrological regime (monthly discharges) during the year is greater than the variability of annual discharges. Therefore, for the operational evaluation of the occurrence of the hydrological drought as a part of the hydrological regime of selected period, the evaluation of the operational discharge according to the mean long-term discharge is not sufficient. For this reason the mean long-term monthly discharges have been chosen as the benchmark line and the scaling range for the evaluation of drought has been increased, at 40%. (Note: this value is still the first estimation based on historical measurements in the same month of reference period and requires even more analysis.) This way, 3 reference quantiles are proposed:

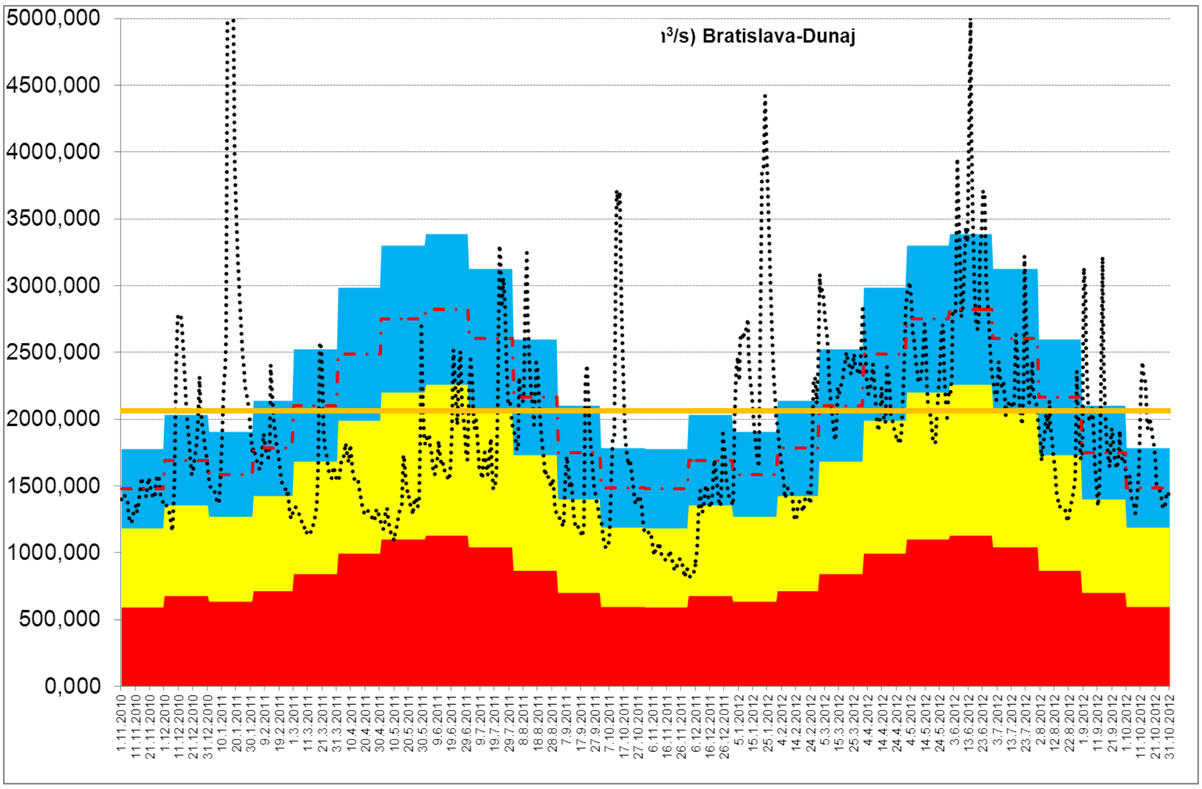
1. quantile (120 to 80 % of $Q_{mes61\text{-}2000}$ - normal status of water bearing)
2. quantile (80 to 40 % of $Q_{mes61\text{-}2000}$ – subnormal status of water bearing)
3. quantile (less than 40 % of $Q_{mes61\text{-}2000}$- critical value of water bearing status)

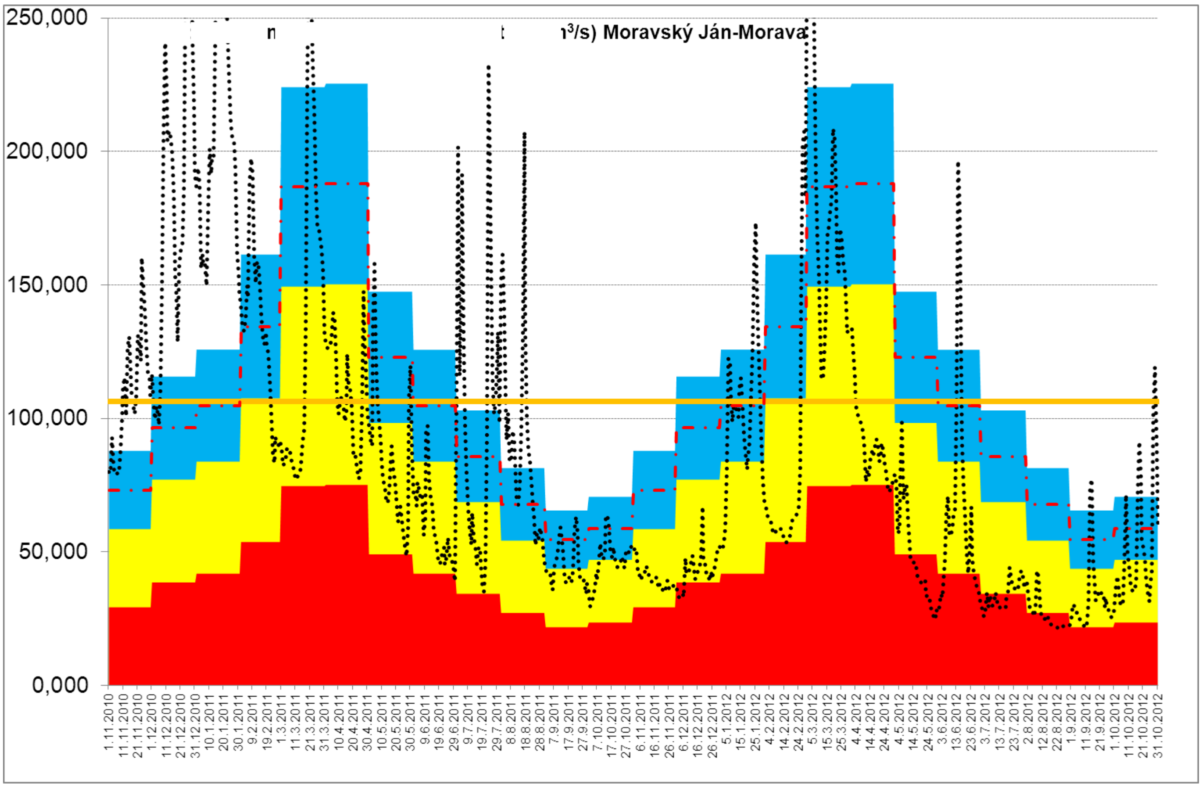
When assessing the current hydrological situation we can follow the operational discharge also by comparison with the reference value Qa. The reference value of Qa (orange line) is used to compare the state of the hydrological situation in the stream with regard to the water bearing throughout the whole reference period.

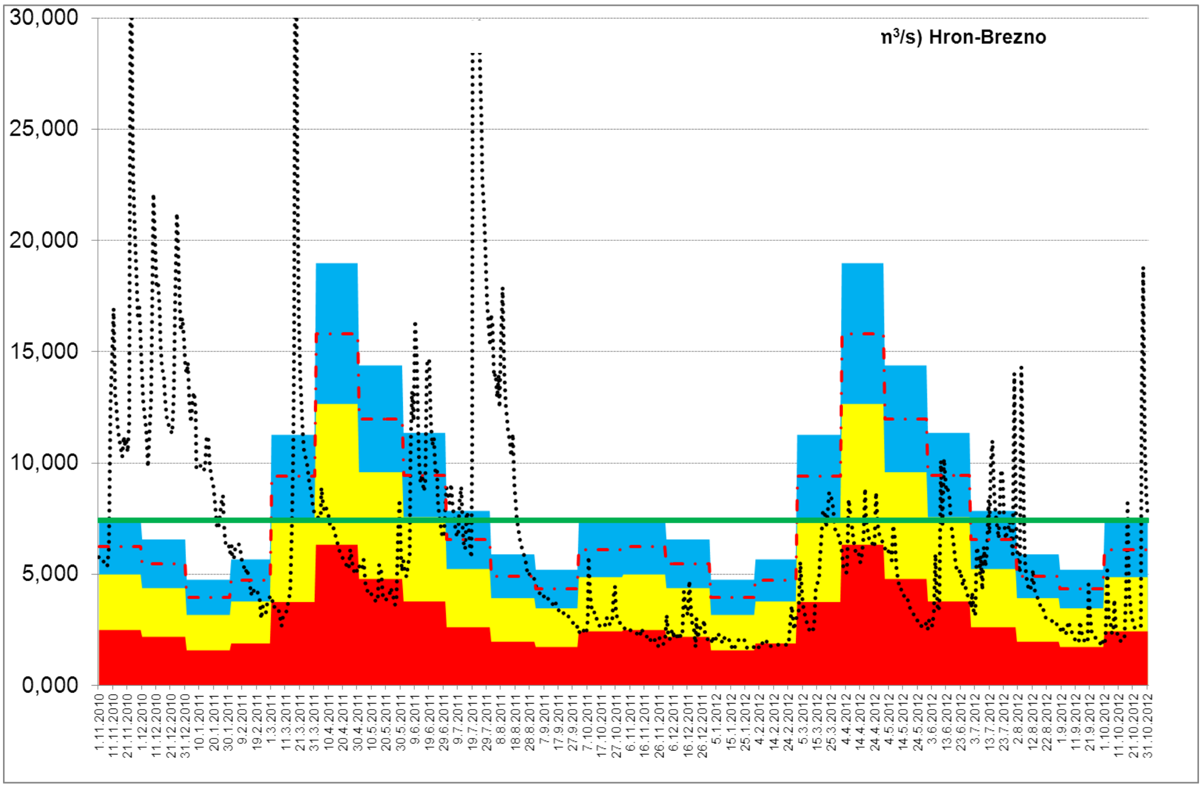
For the evaluation itself the following should be taken into account:

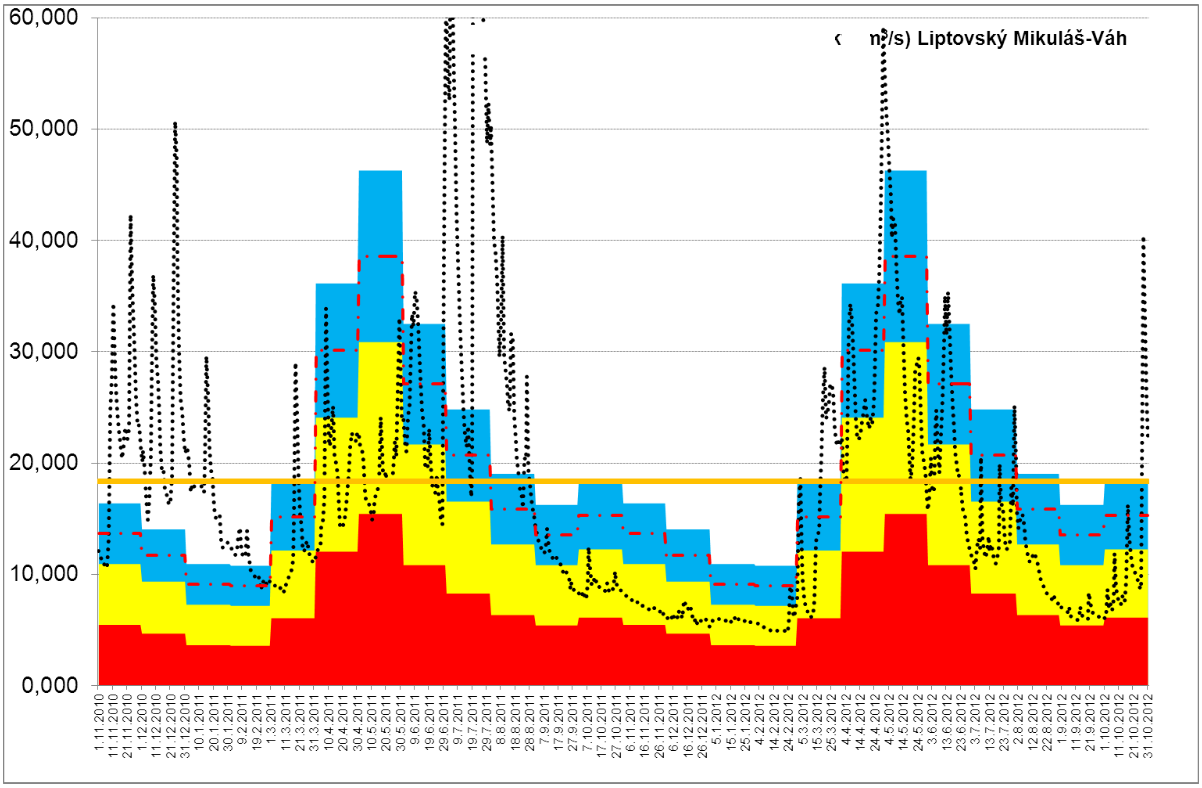
- During the months that are typically aqueous (e. g. spring months), where Q_a is lower than the value of the particular long-term monthly discharges ($Q_{mes61\text{-}2000}$), the evaluation of actual discharge to the Q_a irrelevant, it is therefore necessary to monitor the operational discharge with respect to the proposed 3 quantiles of long-term monthly discharges. During this period, the climatic factors play also an important role, such as actual water supply in snow cover, actual and forecasted precipitation total and air temperature.
- During the other months of the year, which are usually less aqueous, i.e. where the long-term monthly discharge ($Q_{mes61\text{-}2000}$) is lower than Q_a, the assessment with respect to Q_a is reasonable. It can represent the first indication after the actual value falls below Q_a that it is necessary to follow the development of hydrological situation, including the development of climatic indicators.

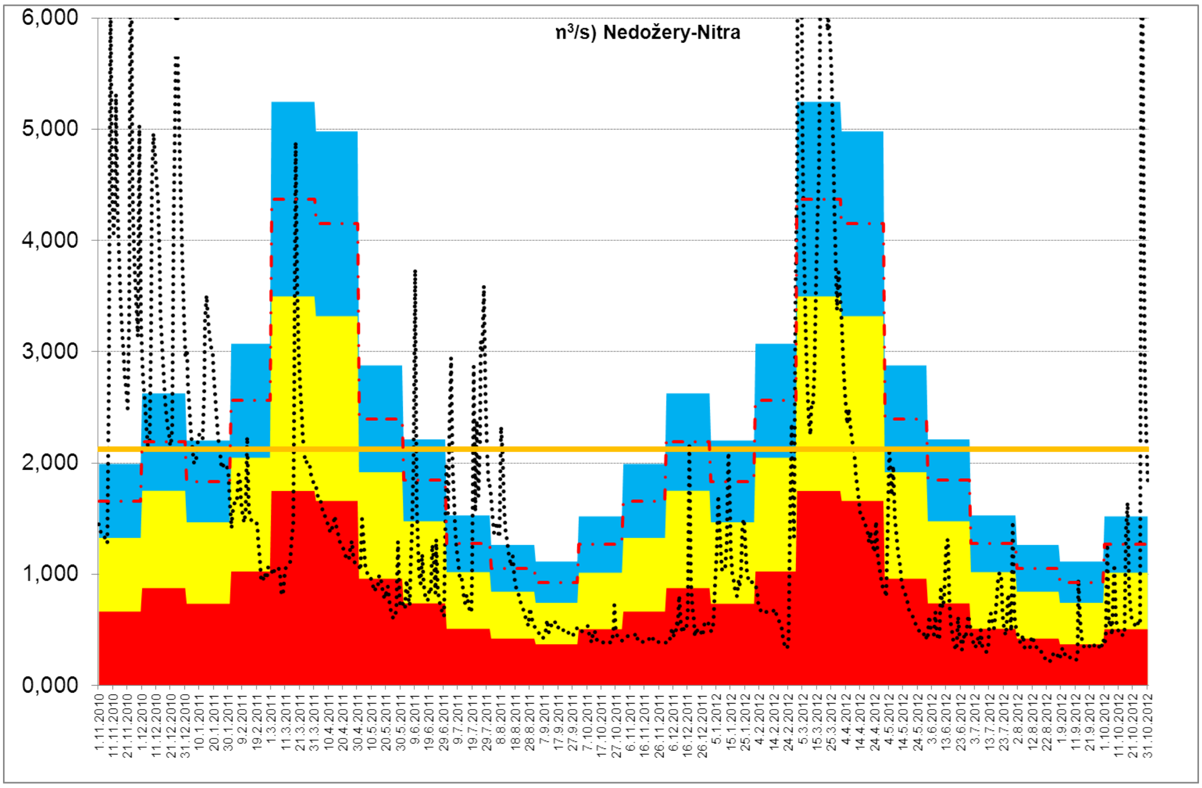
We present this graphic evaluation of the hydrological years 2011 and 2012 as an example, applied in each sub-basin in the selected gauging station with online data transfer (Fig. 12).

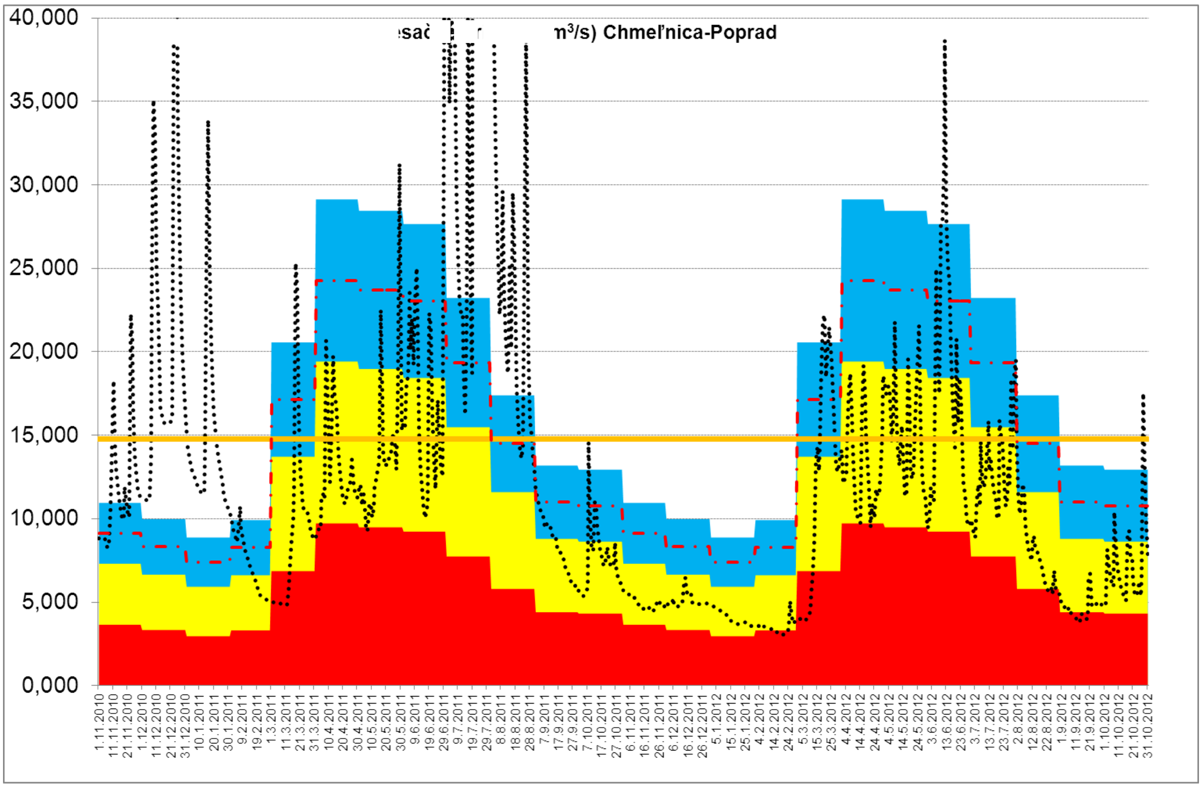


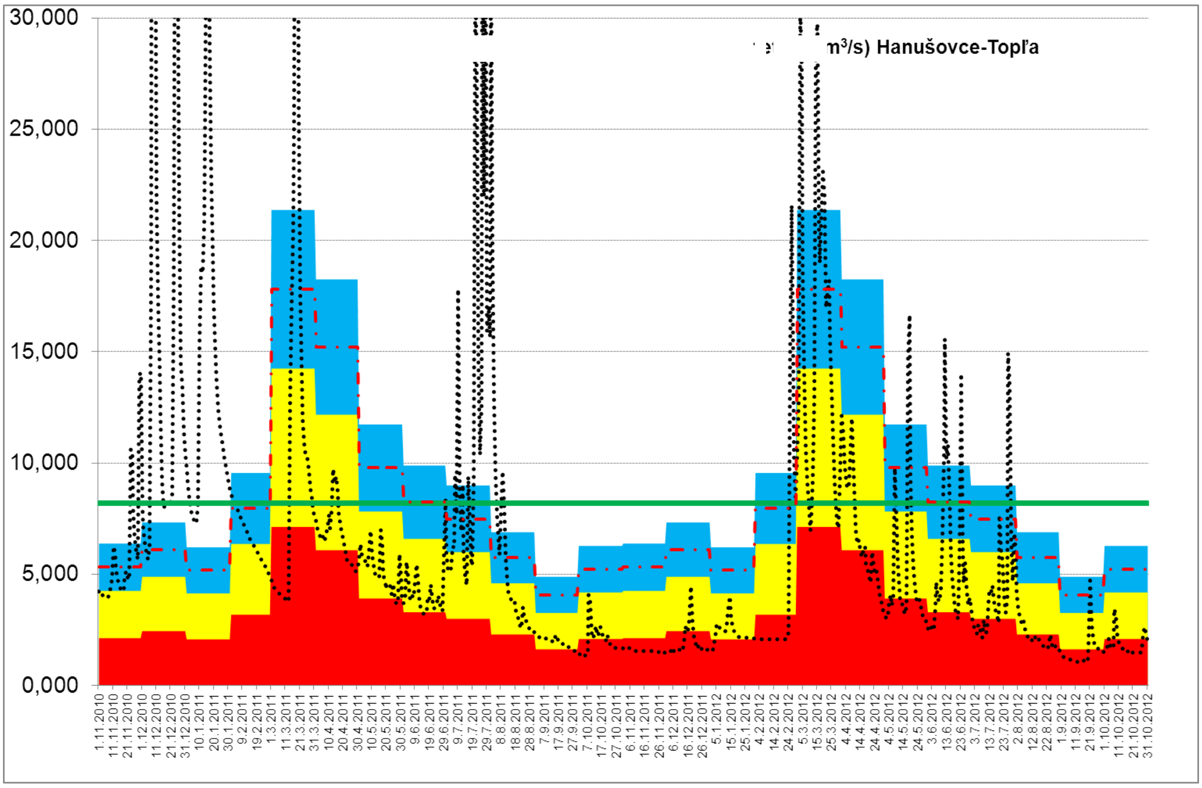

ı³/s) Moravský Ján-Morava

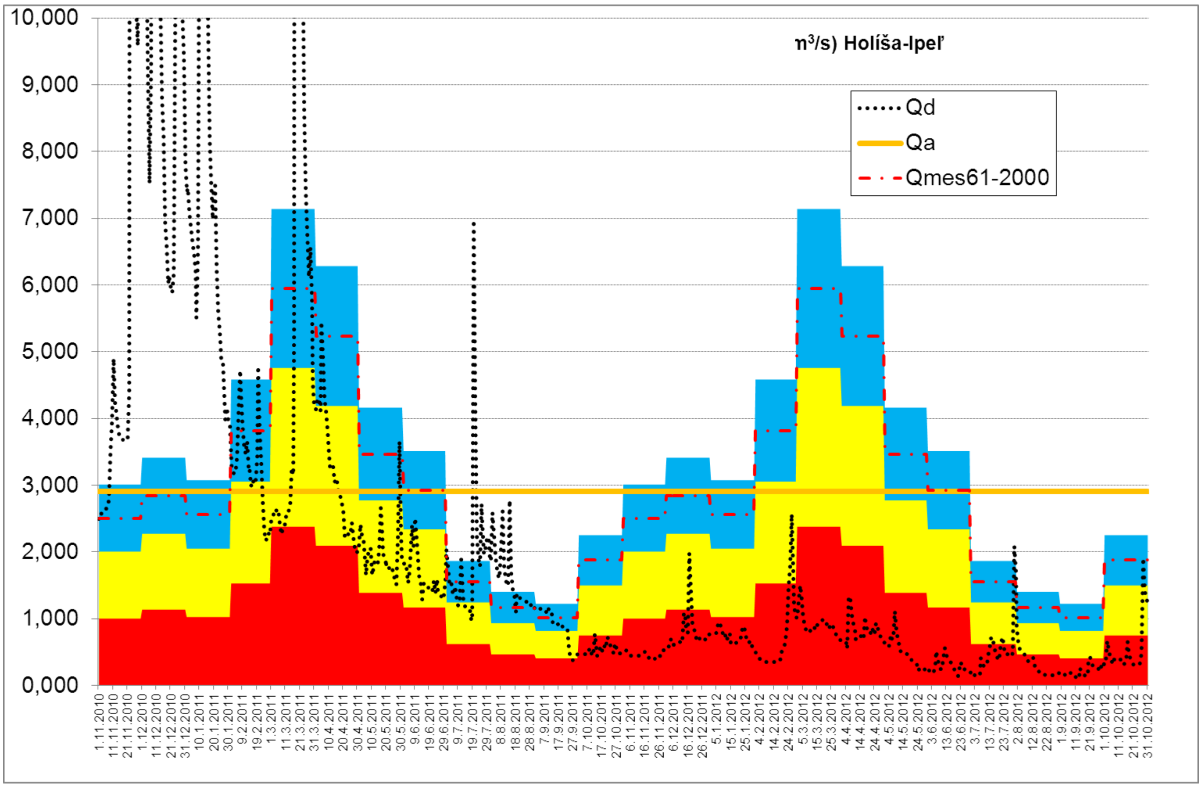

ı³/s) Hron-Brezno

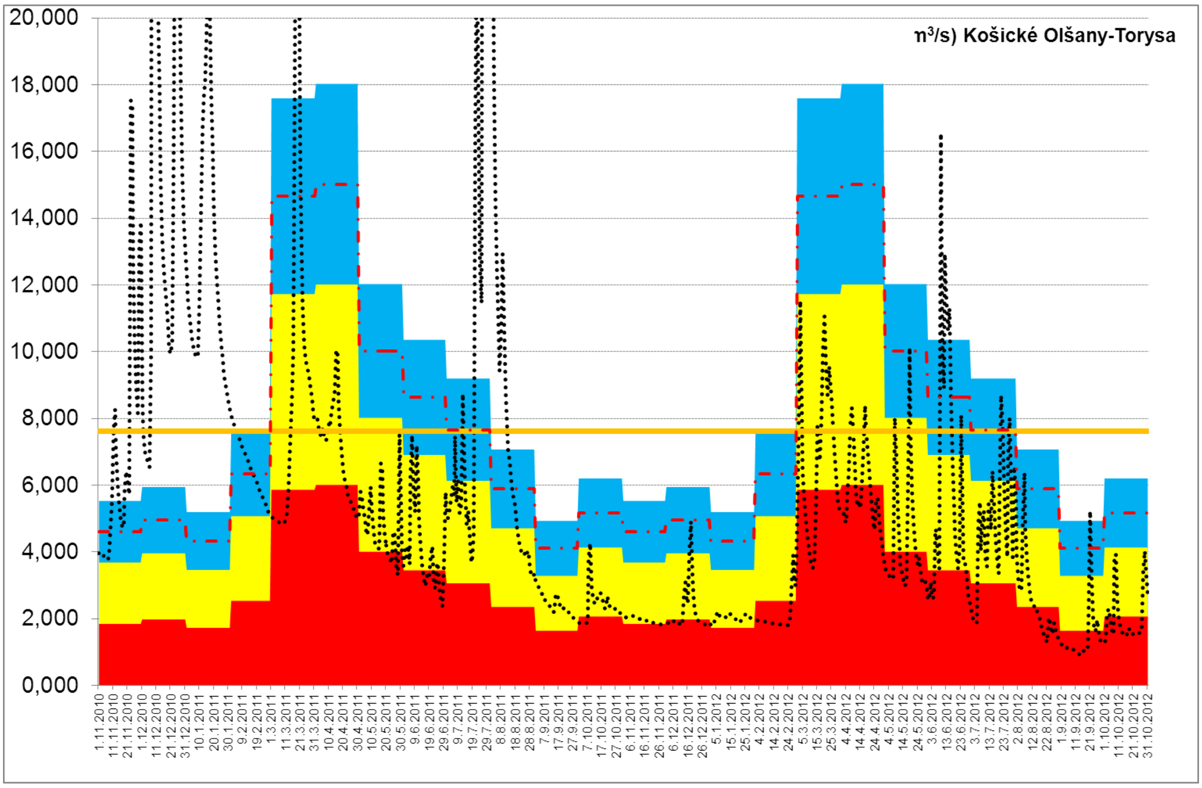

n³/s) Liptovský Mikuláš-Váh
60,000
50,000
40,000
30,000
20,000
10,000
0,000


n³/s) Nedožery-Nitra
6,000
5,000
4,000
3,000
2,000
1,000
0,000


m³/s) Chmeľnica-Poprad
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0,000


m³/s) Hanušovce-Topľa
30,000
25,000
20,000
15,000
10,000
5,000
0,000


m³/s) Holíša-Ipeľ
Qd
Qa
Qmes61-2000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0,000


m³/s) Košické Olšany-Torysa
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0,000

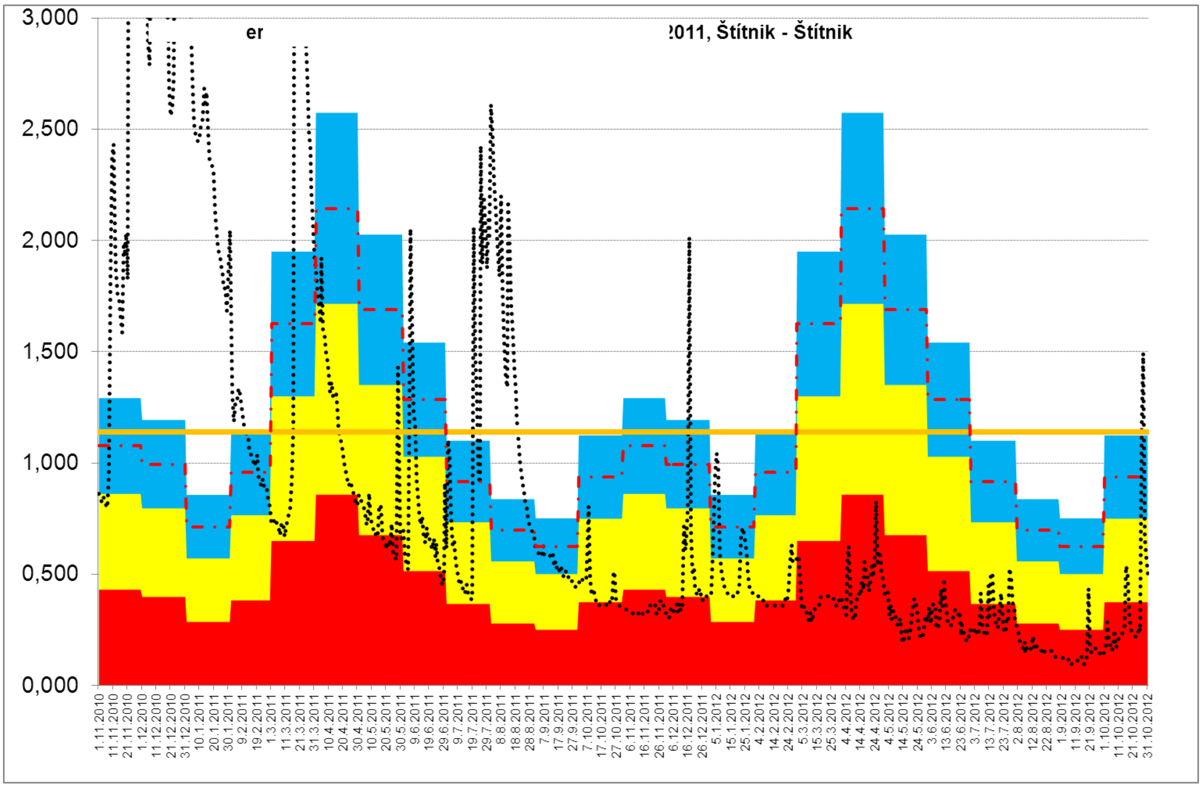


Fig. 12 Graphic assessment of discharges in hydrological years 2011 and 2012.

3.3.2 Conclusions

The assessment of precipitation and runoff in 2011 and 2012, with emphasis on the evaluation of minimum discharges has shown the exceptionality of this period in so far observed time series on most part of Slovakia's territory. Although the mean precipitation totals were close to normal, their distribution during the year was atypical. Low precipitation total in winter and autumn period and relatively high totals in summer months occurred in both years. There were more than average air temperatures, more than average values of sunshine and relatively windy weather at the end of winter and in spring 2012, causing sublimation of snow from snow cover. These factors led to low amounts of surface runoff during the spring, which was also reflected in the hydrological flow regime during the year, and it affected the annual runoff values.

When assessing the hydrological situation in real time, it is necessary to focus on the evaluation of the current hydrological situation, discharges, including the assessment of the current flow depression (deficit volume) below a certain reference value. To do this, it is necessary to know the initial state, in addition to precipitation and evaporation also the air temperature and the water supply in the snow cover during the relevant period, which will help to comprehensively evaluate the occurrence and the development of the drought. The assessment of the years 2011 and 2012 and their place in historical observations have shown that it is necessary to evaluate the occurrence of drought in smaller time units and the individual sub-basins. It has turned out that in river basins, which were identified as the most vulnerable according to the long-term development of the mean annual discharges and minimum annual discharges, the relative water bearing in the hydrological 2012 was the lowest as well.

For actual assessment of hydrological situation in terms of occurrence of the hydrological drought and for prediction of its possible development, we need to have sufficient amount of operational data of the monitoring of quantity of surface water available. At the same time the historical data are necessary. This means, in our practice, not only to maintain operational the status of state hydrological network and to systematically and continuously monitor the hydrological regime of surface waters in it, but also to direct it to the operational monitoring of drought as well. It is necessary to supplement the current state of hydrological network by more stations in profiles with unaffected hydrological regime with online data transfer, to reduce the impacts of drought. This is a necessary requirement for the possibility of obtaining the actual data continuously as well as information on the capacity and regime of state own water resources and their development, and subsequently to identify and assess the impacts of artificial interventions into the natural regime of water resources and their impact on the available potential, and, as final result, to know the boundaries, beyond which the conditions of renewability of water resources and the environment are worsening.

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3.4 Groundwater assessment

Spatial assessment of groundwater in Slovakia until year 2012 was based on simple statistical processing and reporting of data from about 1,500 individual monitoring stations within the state hydrological network of groundwater measured last year (annual average, minimum and maximum). This approach appeared to be inadequate at present. Particularly dry period 2012 led us to the idea of creating more detailed, visually and spatially appropriate tool to assess month to month changes in groundwater regime in Slovakia. We incorporate the procedures applied in France (Sandre) with easy utilization in Slovakia. Analytical assessment is based on a statistical appraisal of individual *monthly averages* (evaluated in each considered object) to the *long-term monthly average* of at least 12 years reference period. For each month and monitoring point was created five reference quantiles based on the calculated probability from exceedance curve (from the dataset of measurements in the same month of reference period 1981-2010).

DRY				WET
much lower than the normal	lower than the normal	normal level, normal yield	higher than the normal	much higher than the normal
10%	40%	60%	90%	

Monthly averages in every (single) monitoring object in the reporting month were classified towards the calculated reference quantiles for each month/object and transposed on the map outputs afterwards.

An important aspect of the applicability of this method (and for representative outputs) was the proper selection of pertinent objects from the state groundwater monitoring network. Monitoring network was designed to meet a number of other national required criteria in the past (for assessment of groundwater quantitative status, for assessment of water balance etc.). State groundwater monitoring network consists from 1134 wells and 361 springs. For assessing the drought in groundwater the monitoring objects have to be selected that reflect the natural groundwater regime completely. We selected 102 objects from the monitoring network of groundwater (78 wells and 24 springs) that relatively homogeneous cover the whole territory of Slovakia and fully comply with criterion for month to month evaluation of groundwater levels and springs yields from drought point of view. The reference period was uniform for each monitoring object and was represented by continuous set of measured data from 1981 to 2010. Based on the statistical processing of monthly data from individual objects (for the years 2011 and 2012) compared to the reference period we were estimated the relevant quantiles for each monitoring point/month and presented in maps in accordance with the following legend later:

- much higher than the normal
- higher than the normal
- normal level, normal yield
- lower than the normal
- much lower than the normal

a) Point monthly evaluation of groundwater in Slovakia

Shape of the five quantiles of the reference period 1981 - 2010 processed for individual monitoring point and subsequent plotting of measurements from the same observation point in a particular evaluated year (dot line). Point monthly assessment has been processed for each selected monitoring object separately.

Fig. 1 represents point monthly evaluation of monitoring point No. 1079, hydrological year in 2012. It is evident that groundwater level in this monitoring point (dotted) was an average (till March 2012, even slightly above average). Slight decrease of groundwater level below average levels was documented during period April 2012 - July 2012. On the other hand, fig. 2 shows the evaluation of the monitoring object No. 10, hydrological year 2012 with groundwater level significantly below an average level during almost all months of hydrological year 2012. Fig. 1 and fig. 2 show the spatial inhomogeneity of the effects of drought on groundwater regime in Slovakia in the same evaluated year 2012 also.

Fig. 1 Groundwater monitoring point No. 1079, hydrological year 2012

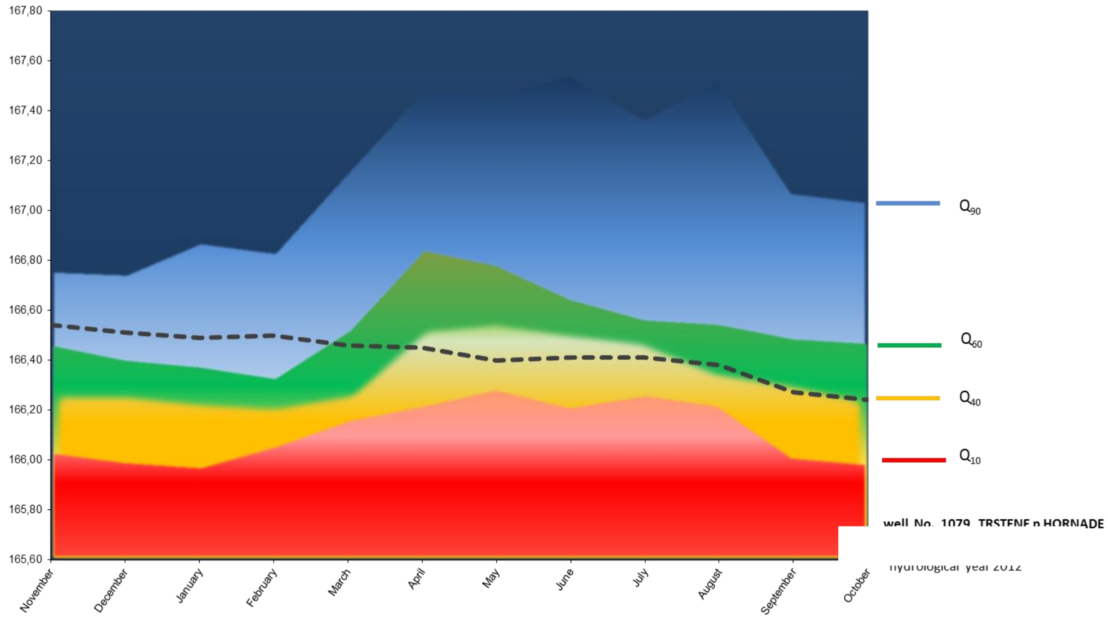
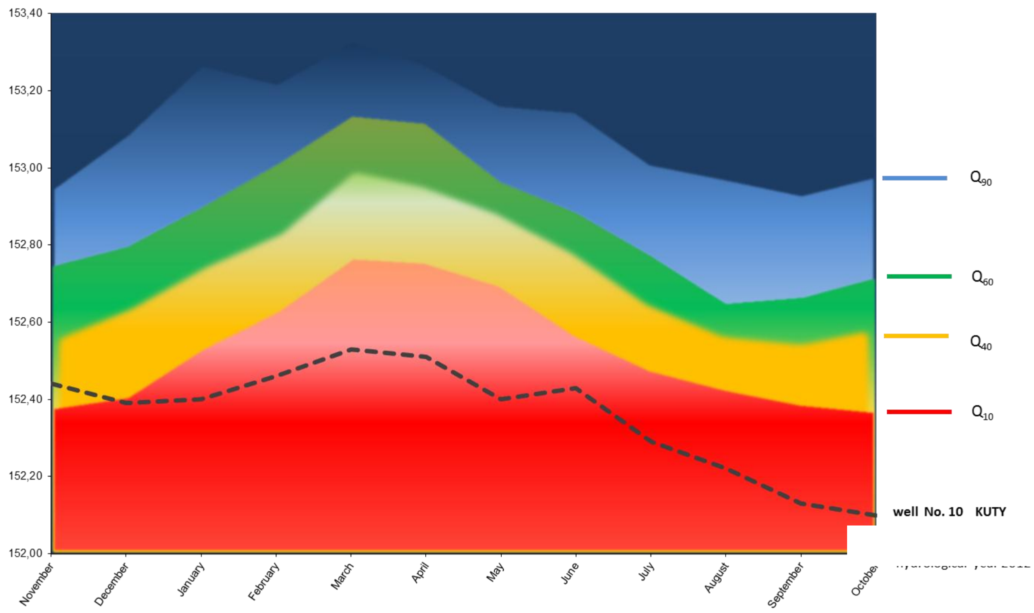


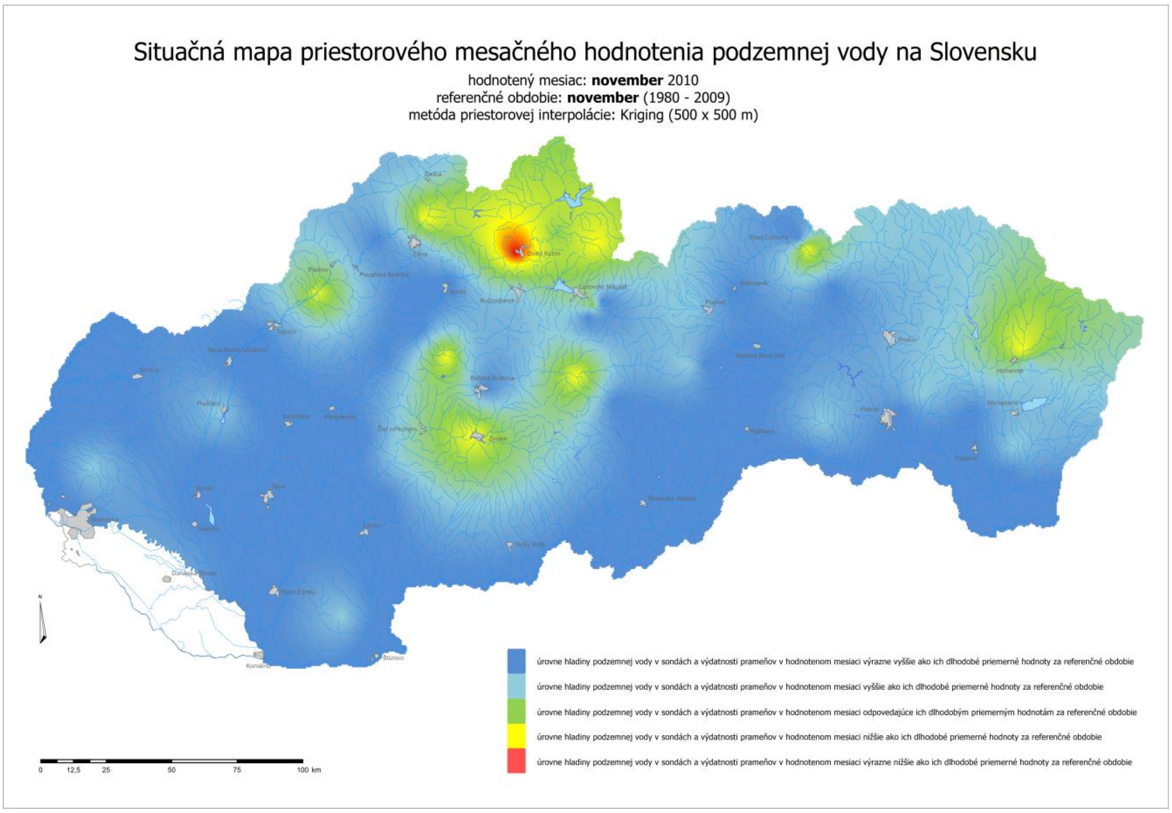
Fig. 2 Groundwater monitoring point No. 10, hydrological year 2012



b) Spatial monthly evaluation of groundwater in Slovakia

Fig. 3 to fig. 28 represents the assessment of groundwater in the particular monitoring stations transposed to whole area of Slovakia using gridding spatial interpolation method Krigging (500 x 500 m). These maps were elaborated for the period November 2010 - December 2012 separately for each month.

Fig. 3 Monthly evaluation of groundwater in Slovakia (wells and springs), evaluated month: **November 2010**, ref. period: November (1980 - 2009) gridding method: Krigging (500x500 m)



Fig, 4 Monthly evaluation of groundwater in Slovakia (wells and springs), evaluated month: **December 2010**, ref. period: December (1980 - 2009), gridding method: Krigging (500 x 500 m)

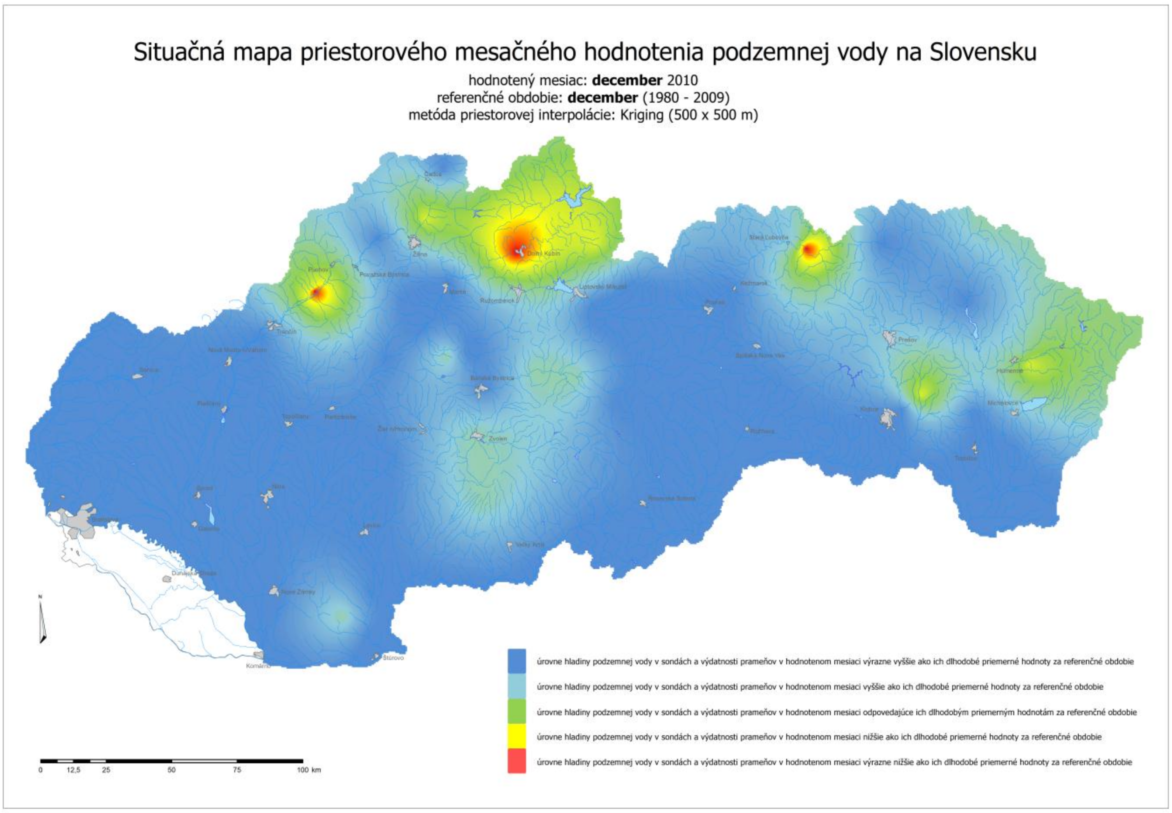


Fig. 5 Monthly evaluation of groundwater in Slovakia (wells and springs), evaluated month: **January 2011**, ref. period: January (1981 - 2010), gridding method: Krigging (500 x 500 m)

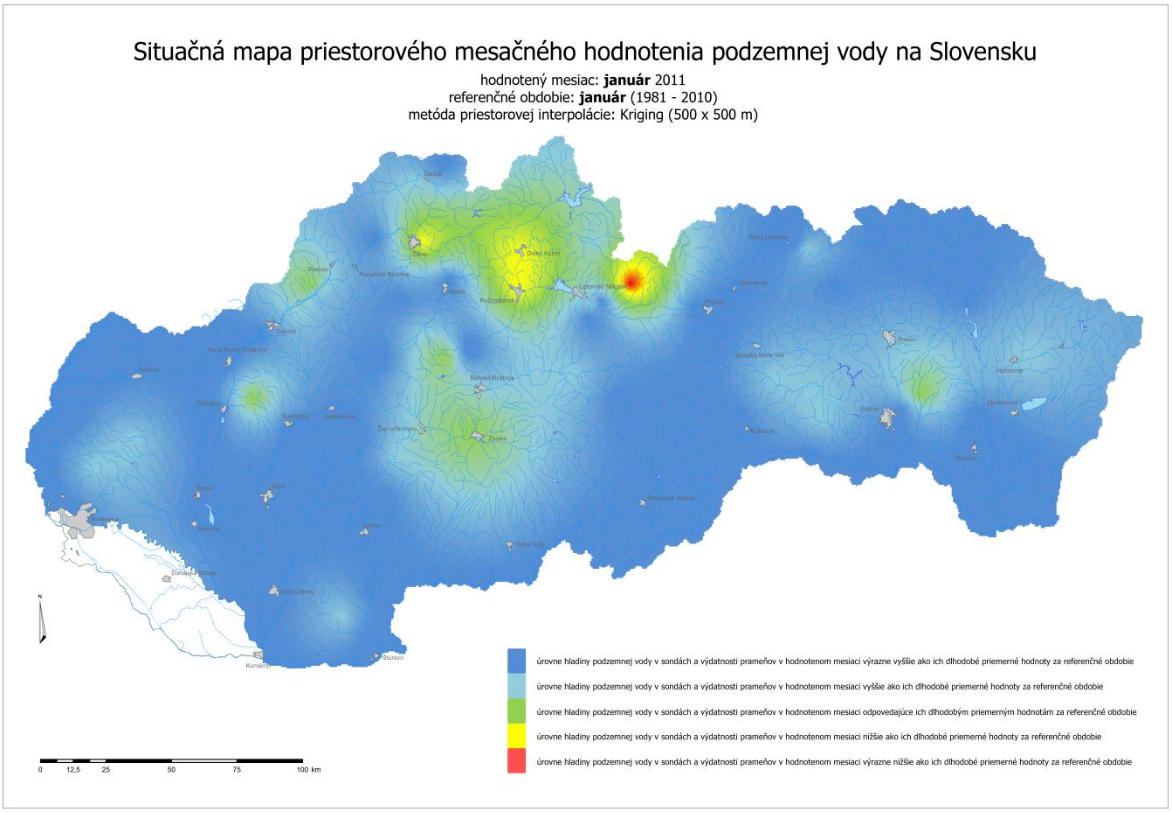


Fig. 6 Monthly evaluation of groundwater in Slovakia (wells and springs), evaluated month: **February 2011**, ref. period: February (1981 - 2010), gridding method: Krigging (500 x 500 m)

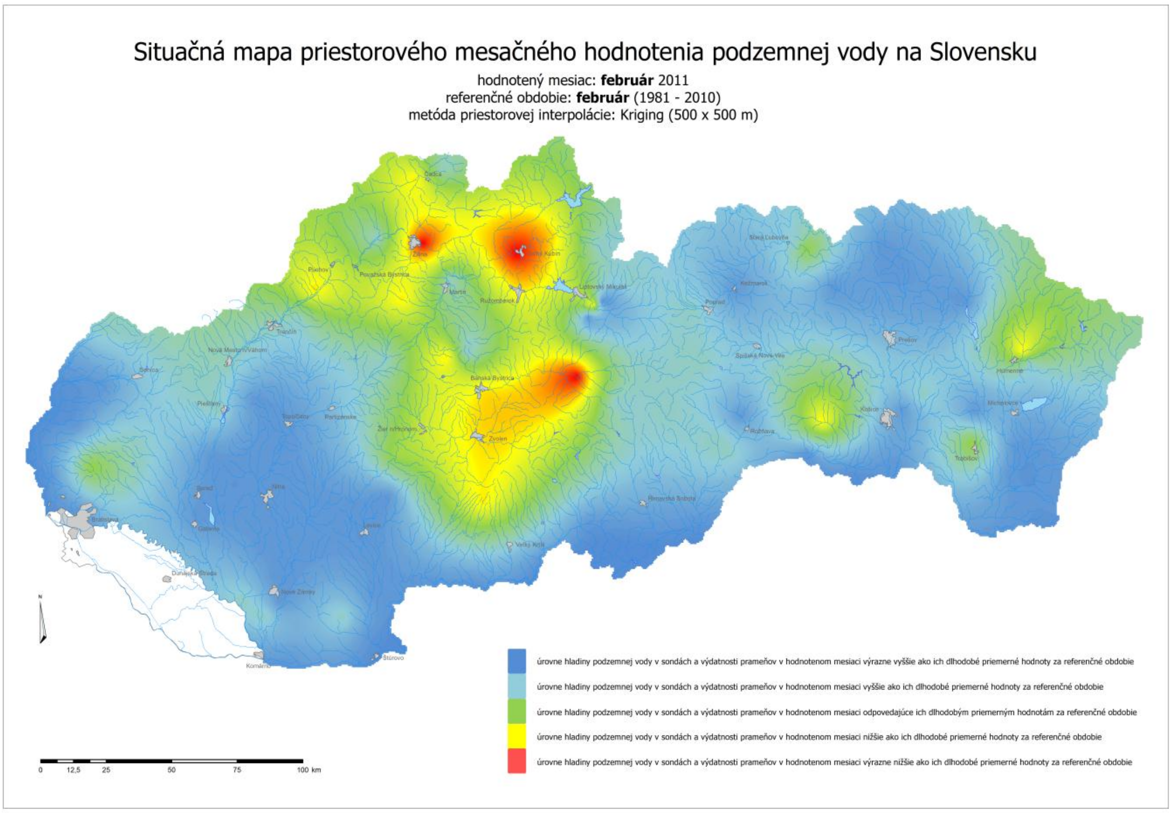


Fig. 7 Monthly evaluation of groundwater in Slovakia (wells and springs), evaluated month: **March 2011**, ref. period: March (1981 - 2010), gridding method: Krigging (500 x 500 m)

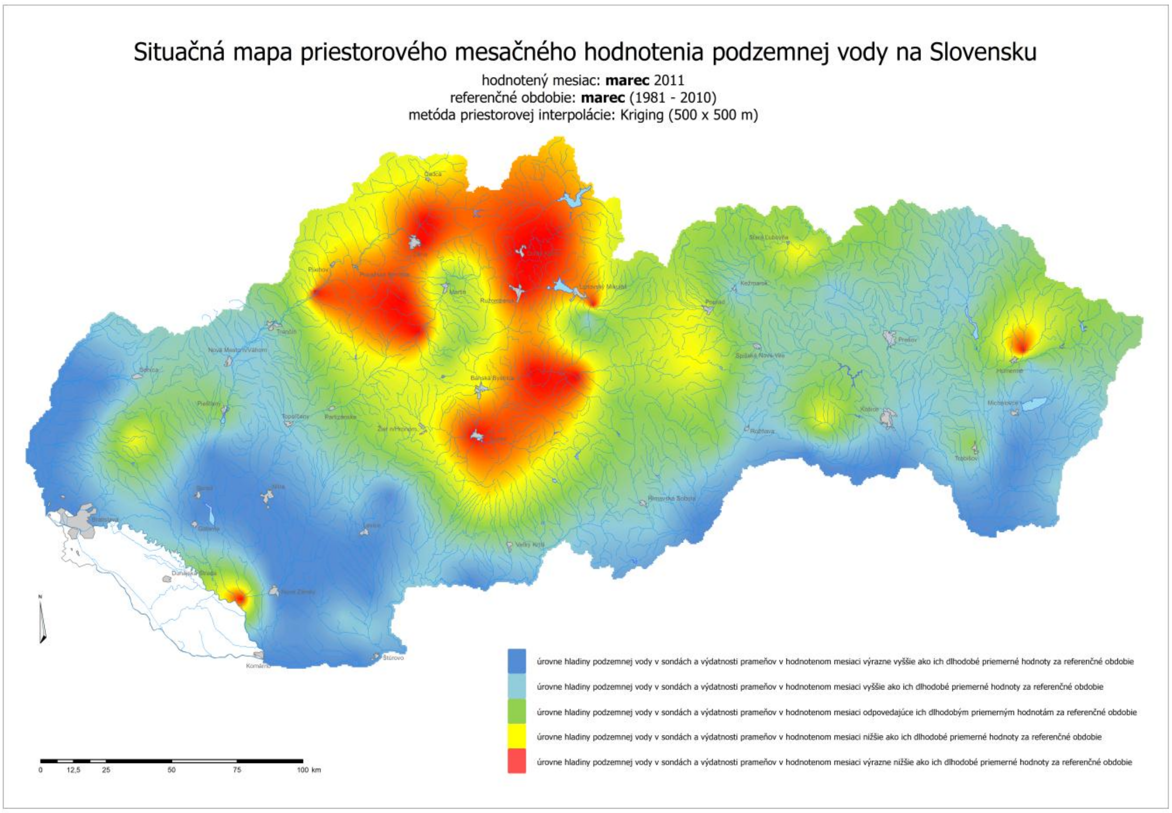


Fig. 8 Monthly evaluation of groundwater in Slovakia (wells and springs), evaluated month: **April 2011**, ref. period: April (1981 - 2010), gridding method: Krigging (500 x 500 m)

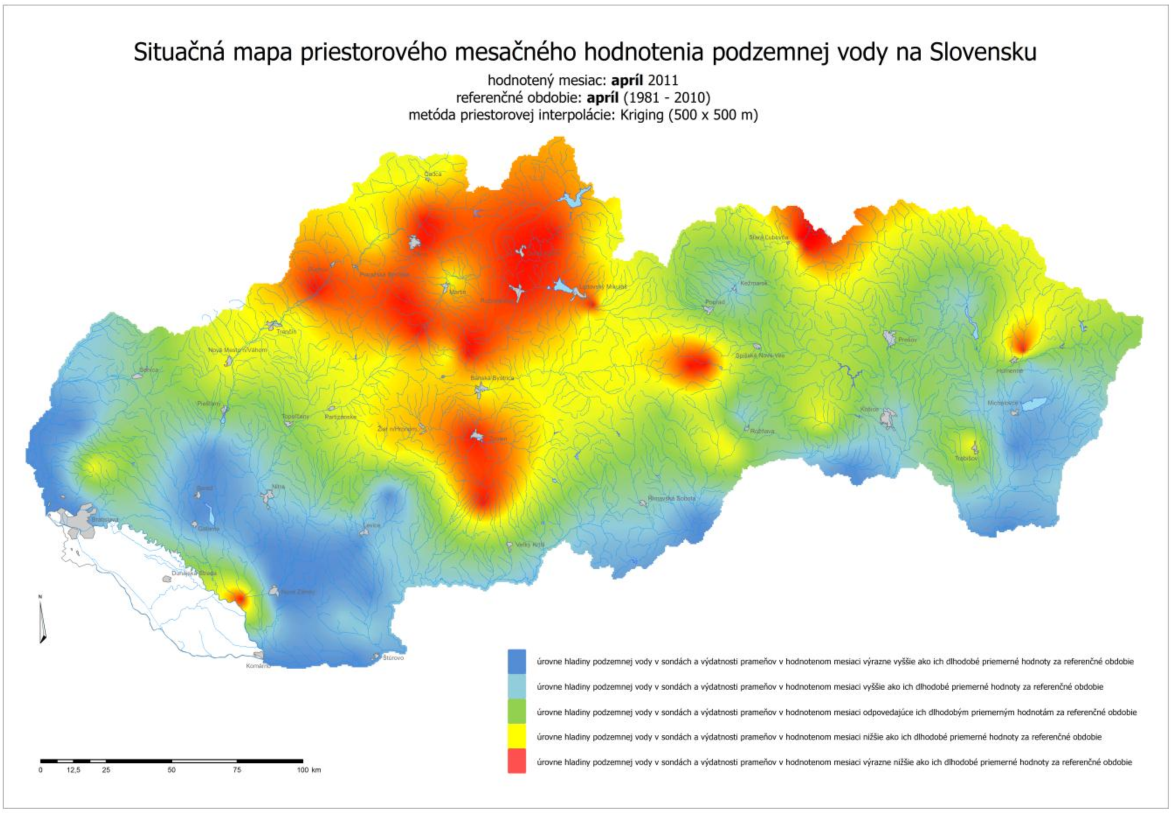


Fig. 9 Monthly evaluation of groundwater in Slovakia (wells and springs), evaluated month: **May 2011**, ref. period: May (1981 - 2010), gridding method: Krigging (500 x 500 m)

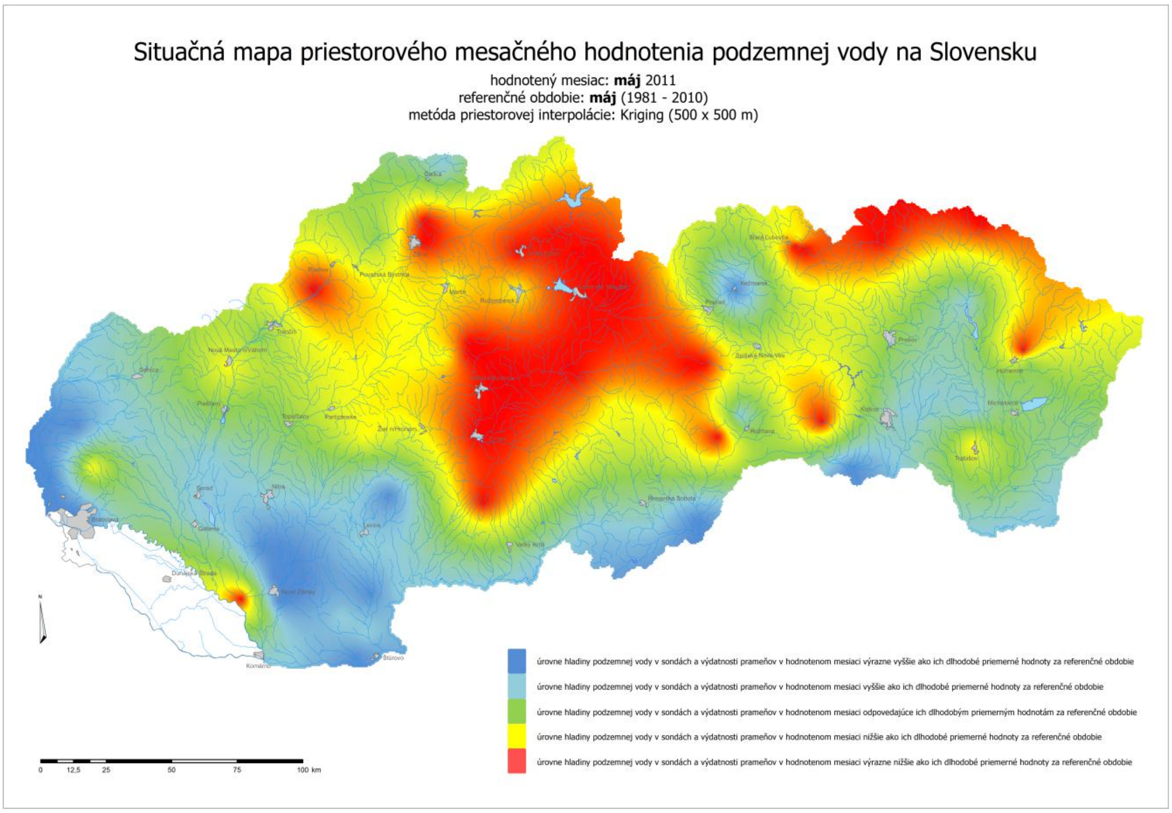


Fig. 10 Monthly evaluation of groundwater in Slovakia (wells and springs), evaluated month: **June 2011**, ref. period: June (1981 - 2010), gridding method: Krigging (500 x 500 m)

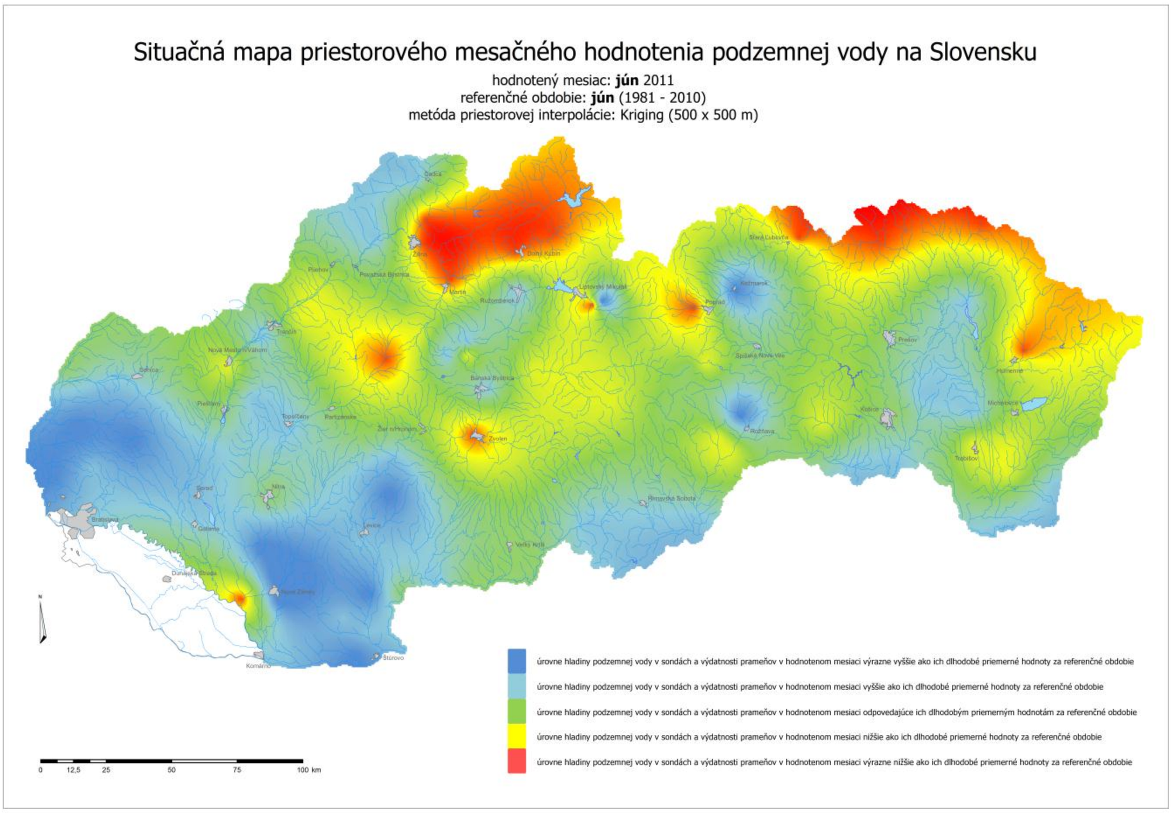


Fig.11 Monthly evaluation of groundwater in Slovakia (wells and springs), evaluated month: **July 2011**, ref. period: July (1981 - 2010), gridding method: Krigging (500 x 500 m)

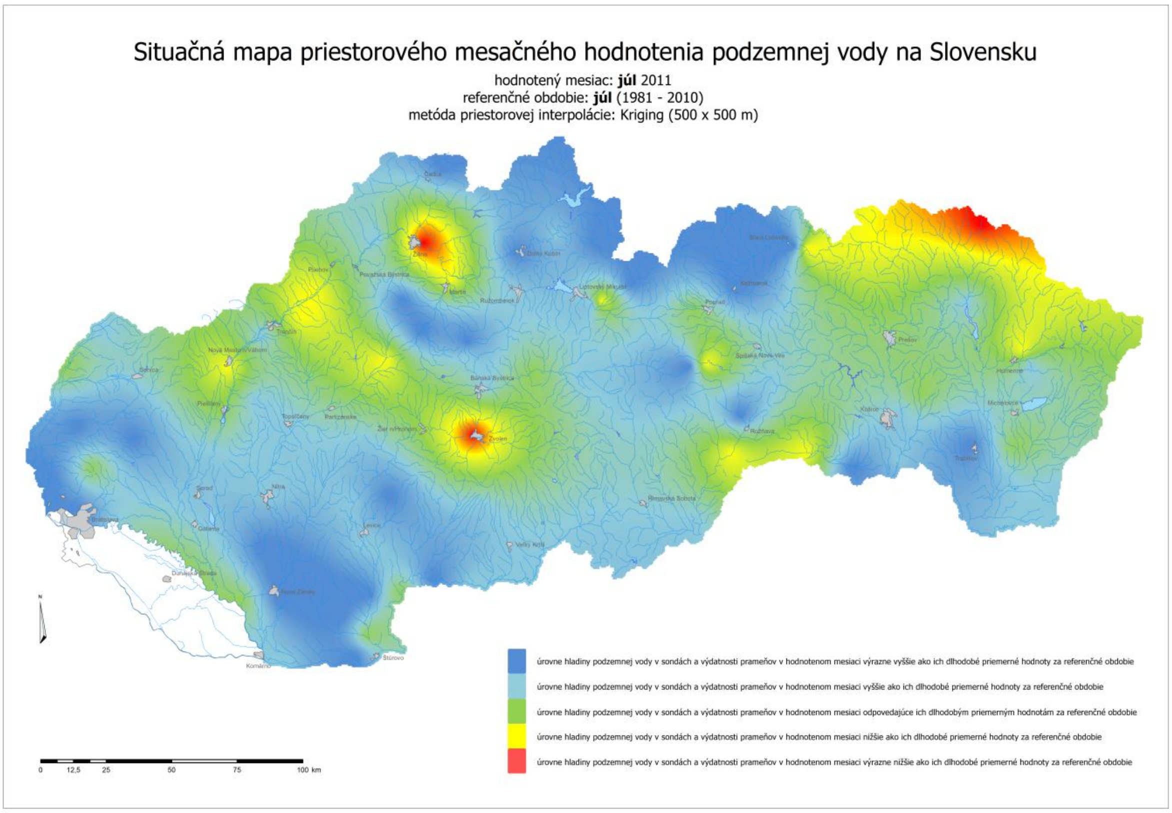


Fig. 12 Monthly evaluation of groundwater in Slovakia (wells and springs), evaluated month: **August 2011**, ref. period: August (1981 - 2010), gridding method: Krigging (500 x 500 m)

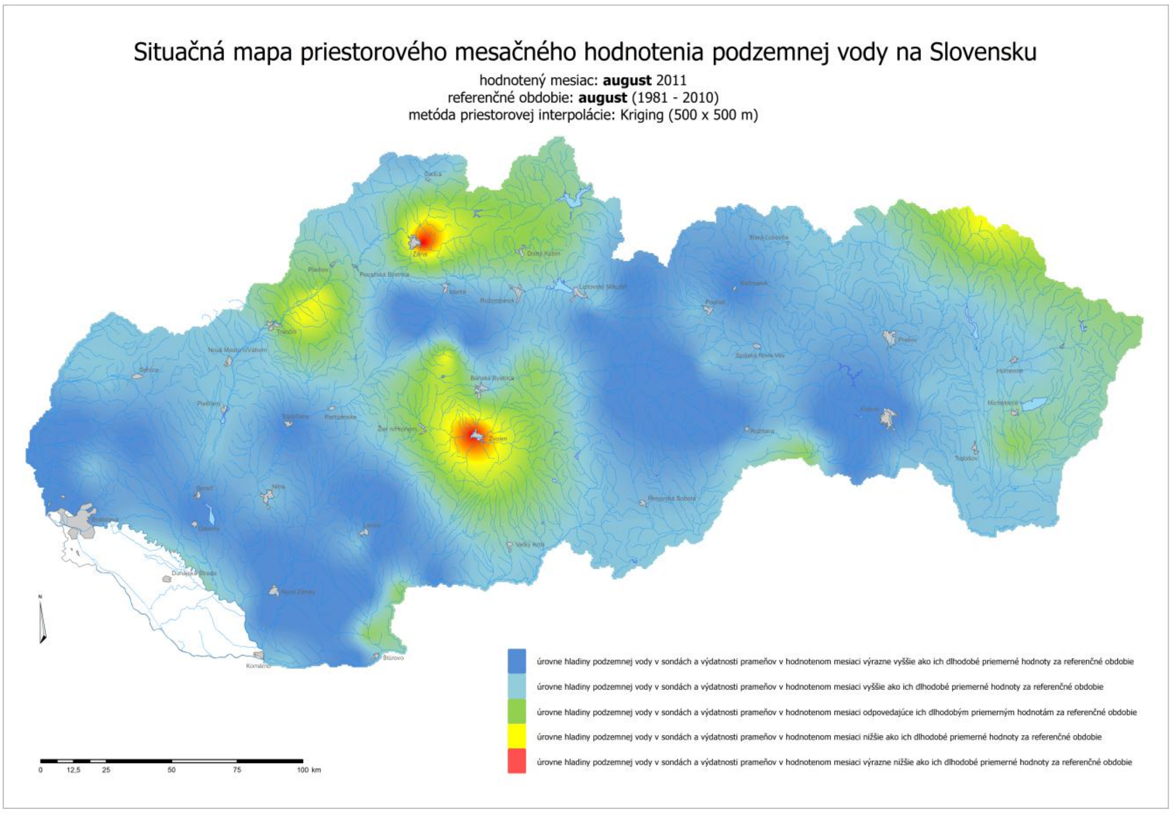


Fig. 13 Monthly evaluation of groundwater in Slovakia (wells and springs), evaluated month: **September 2011**, ref. period: September (1981 - 2010), gridding method: Krigging (500 x 500 m)

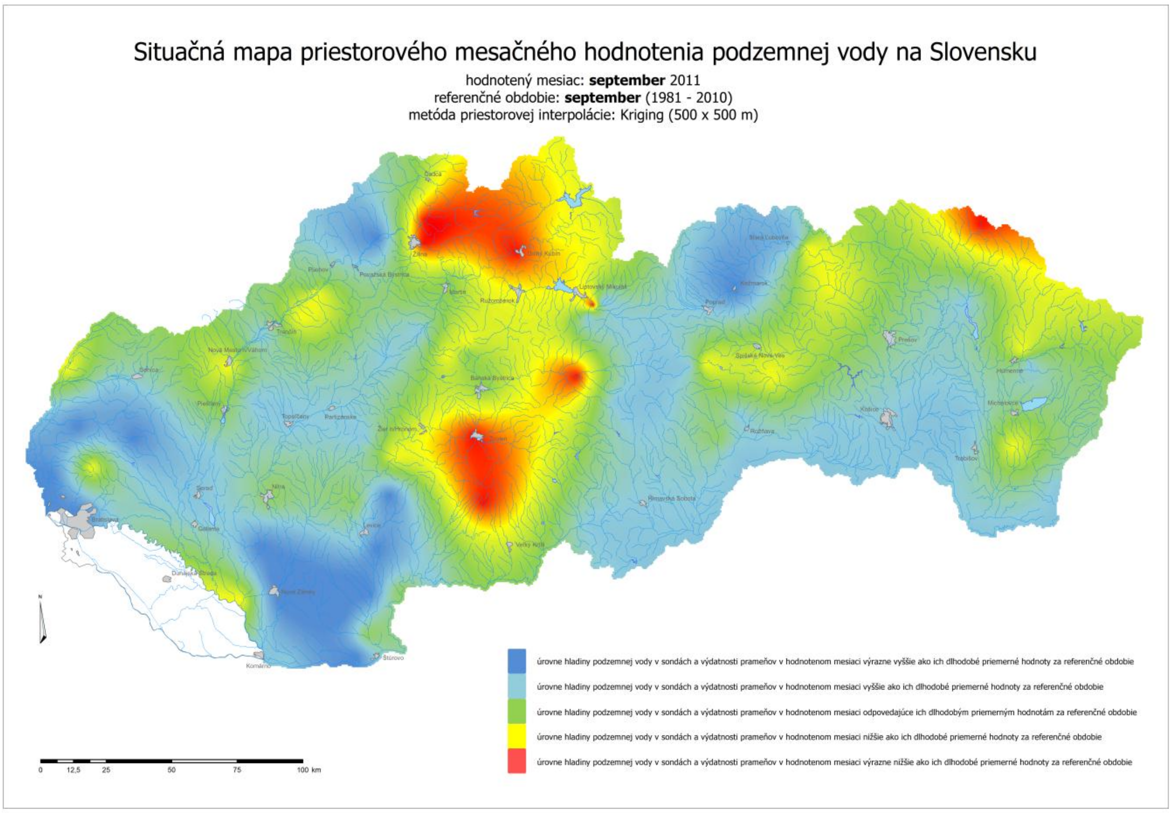


Fig. 14 Monthly evaluation of groundwater in Slovakia (wells and springs), evaluated month: **October 2011**, ref. period: October (1981 - 2010), gridding method: Krigging (500 x 500 m)

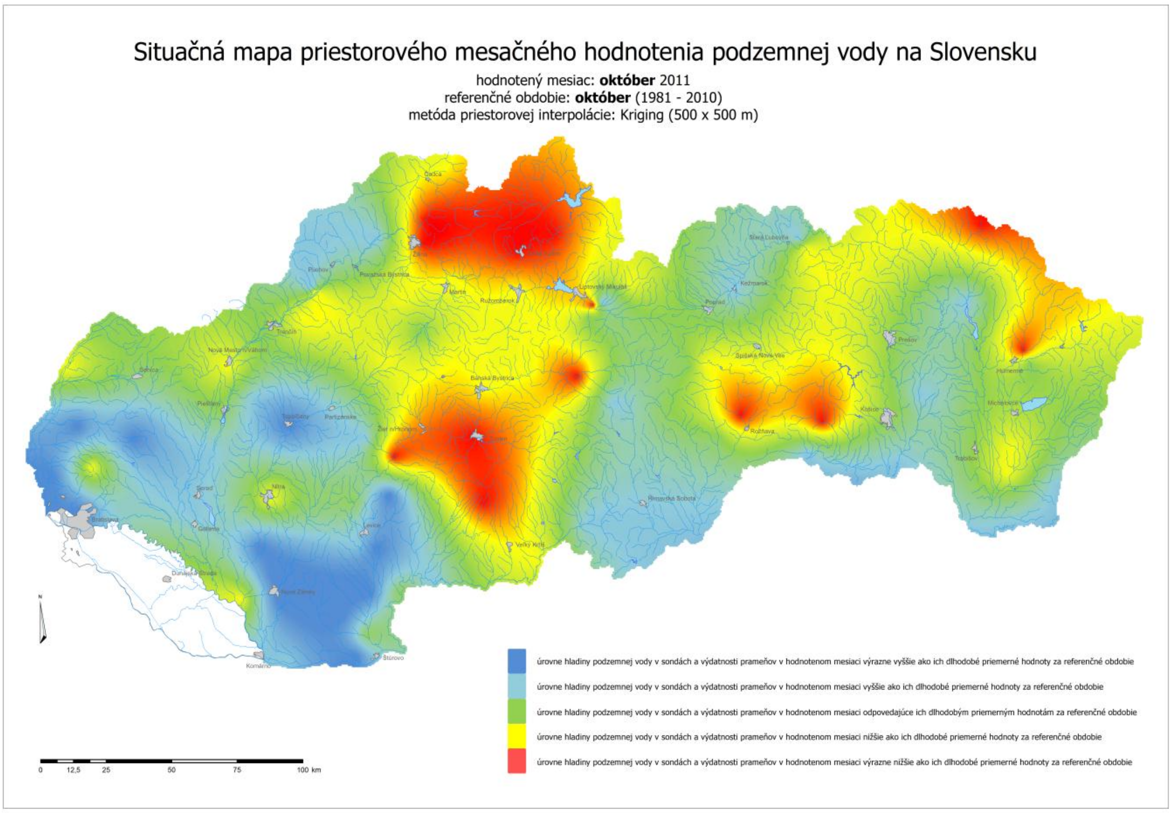


Fig. 15 Monthly evaluation of groundwater in Slovakia (wells and springs), evaluated month: **November 2011**, ref. period: November (1981 - 2010), gridding method: Krigging (500 x 500 m)

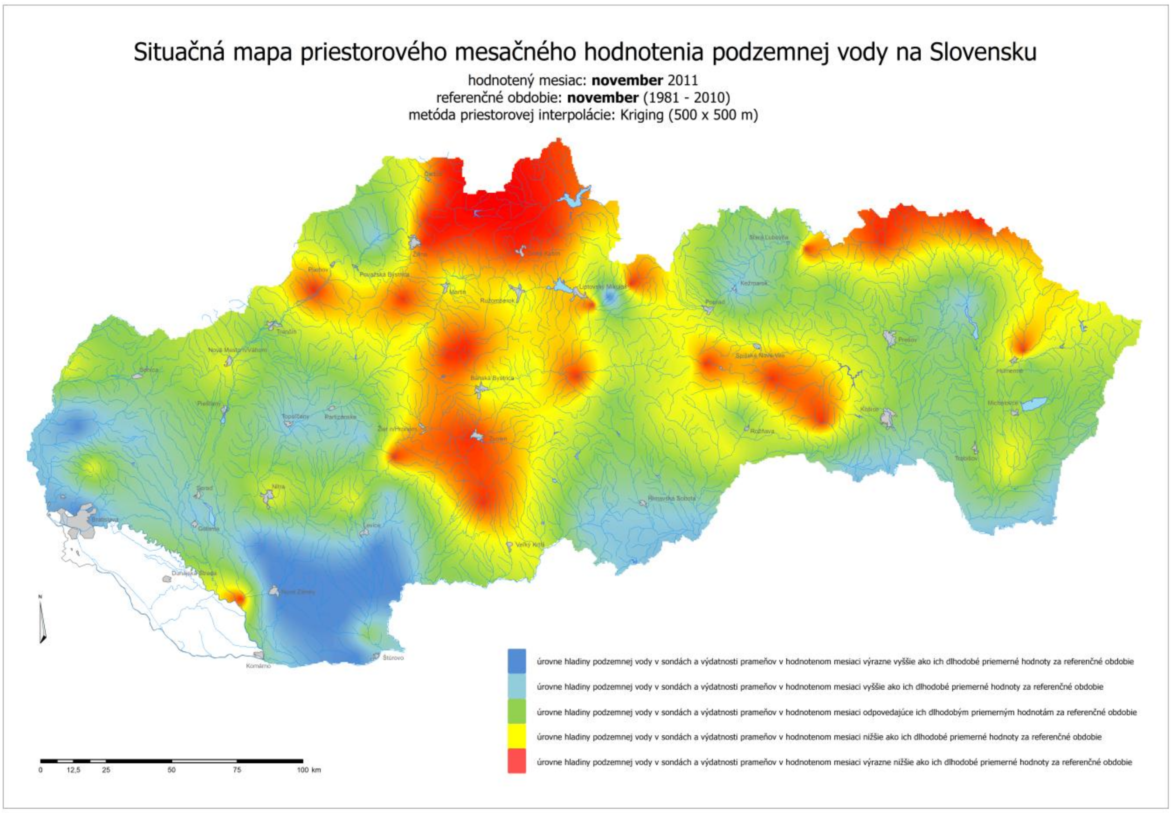


Fig. 16 Monthly evaluation of groundwater in Slovakia (wells and springs), evaluated month: **December 2011**, ref. period: December (1981 - 2010), gridding method: Krigging (500 x 500 m)

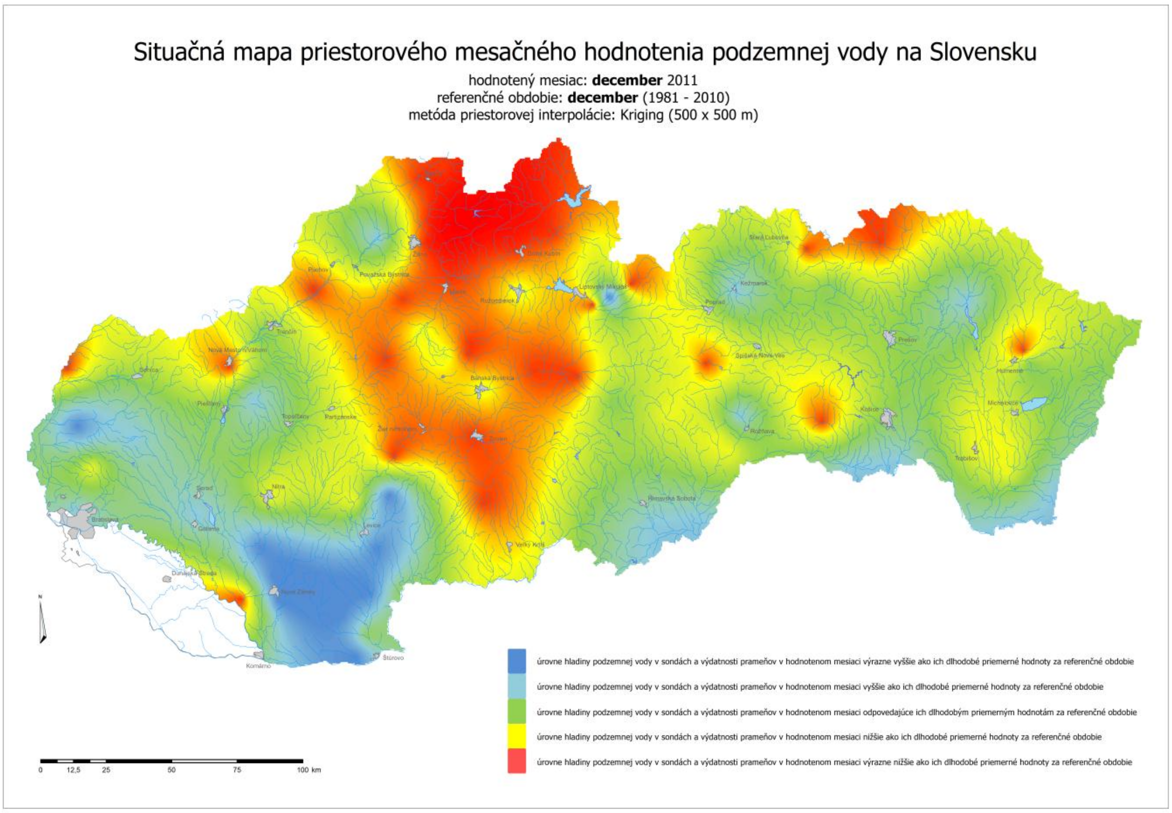


Fig. 17 Monthly evaluation of groundwater in Slovakia (wells and springs), evaluated month: **January 2012**, ref. period: January (1981 - 2010), gridding method: Krigging (500 x 500 m)

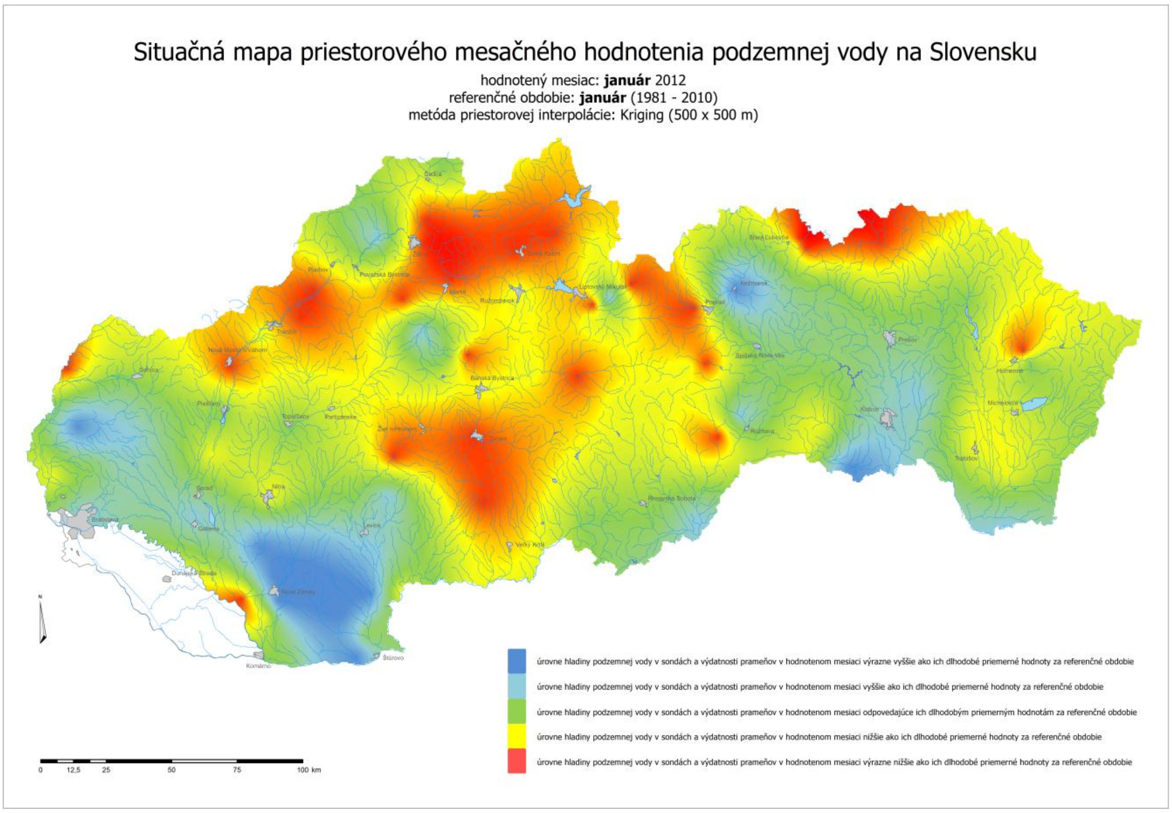


Fig. 18 Monthly evaluation of groundwater in Slovakia (wells and springs), evaluated month: **February 2012**, ref. period: February (1981 - 2010), gridding method: Krigging (500 x 500 m)

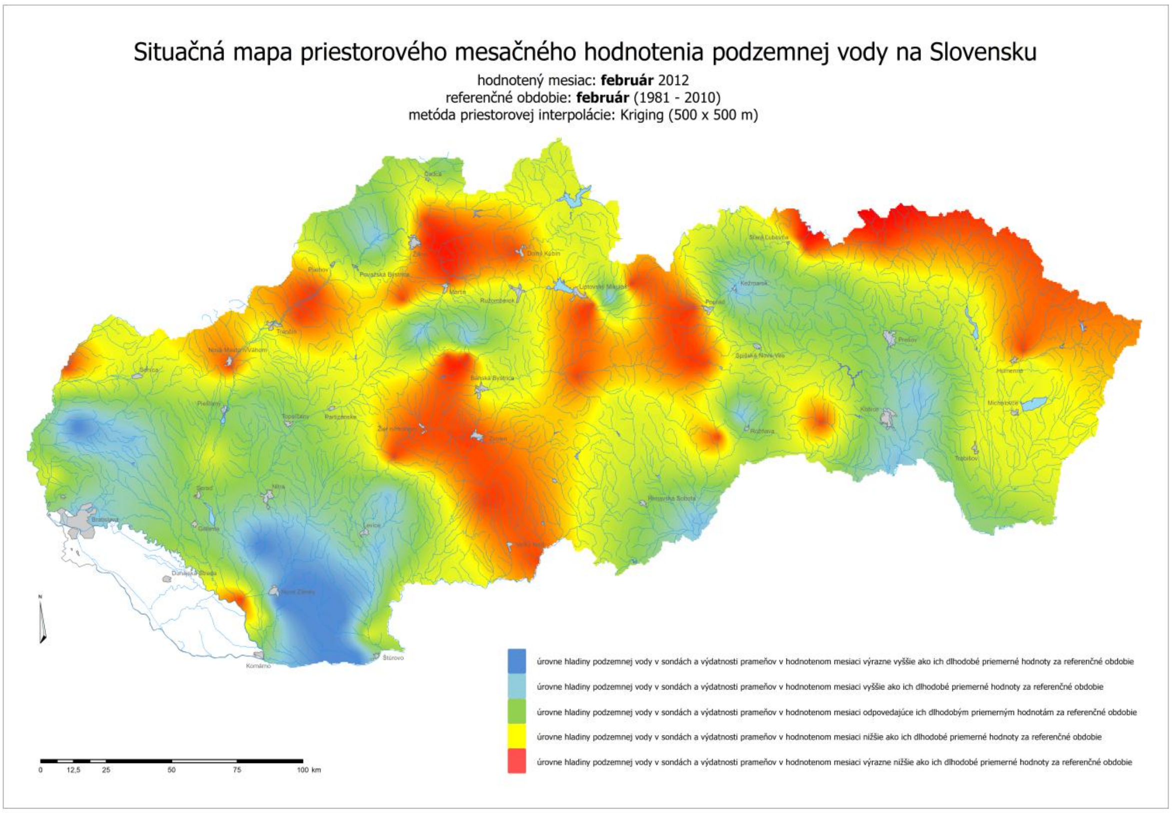


Fig. 19 Monthly evaluation of groundwater in Slovakia (wells and springs), evaluated month: **March 2012**, ref. period: March (1981 - 2010), gridding method: Krigging (500 x 500 m)

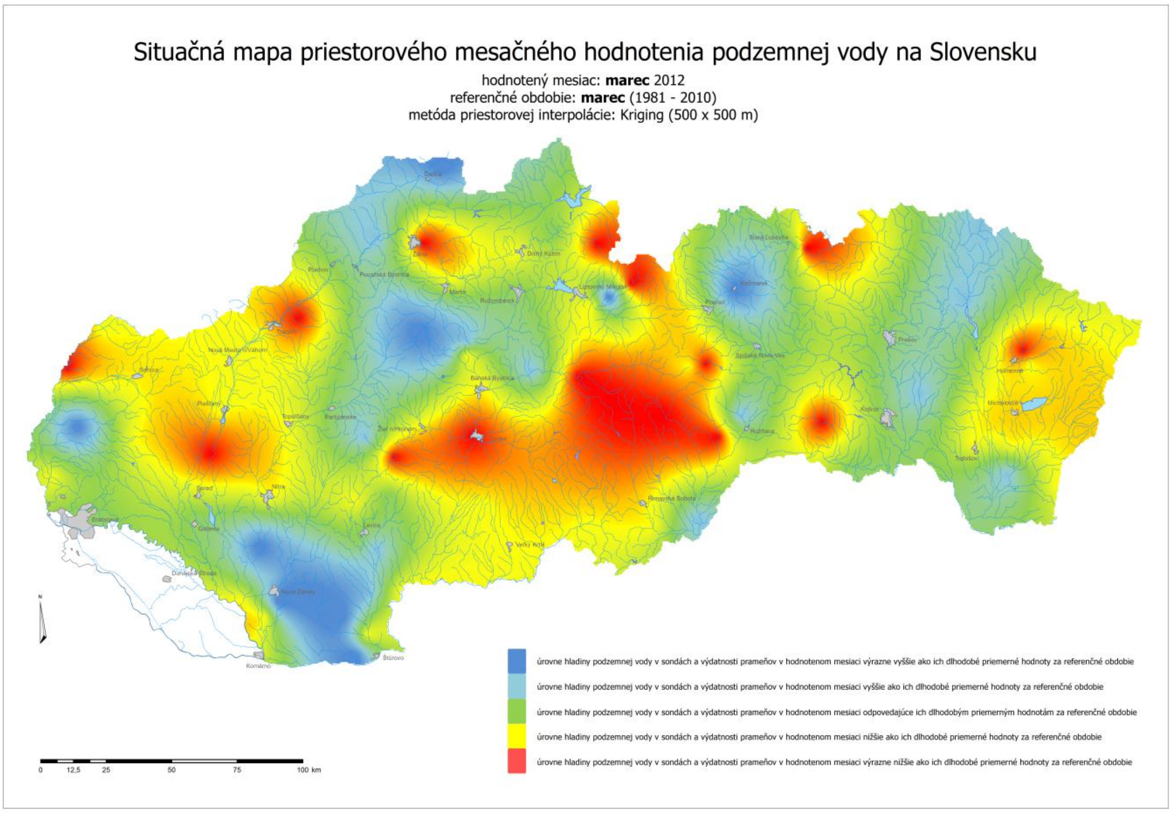


Fig. 20 Monthly evaluation of groundwater in Slovakia (wells and springs), evaluated month: **April 2012**, ref. period: April (1981 - 2010), gridding method: Krigging (500 x 500 m)

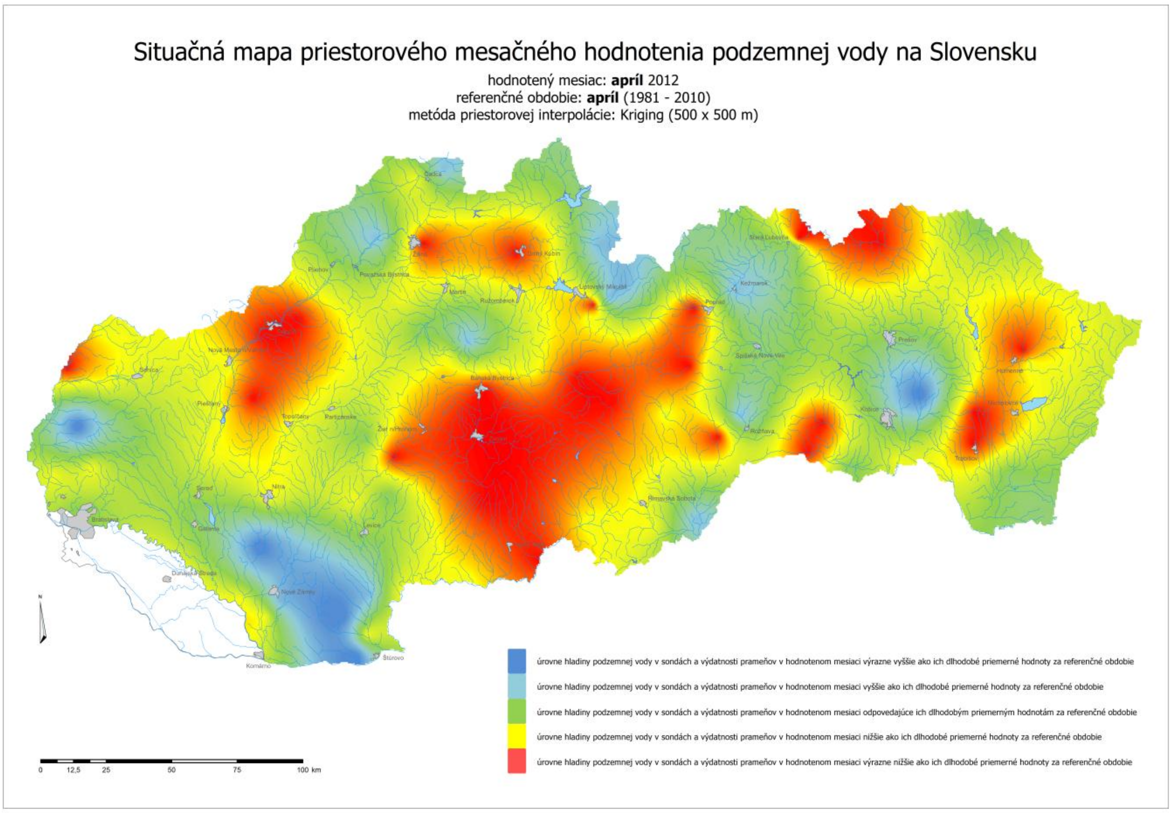


Fig. 21 Monthly evaluation of groundwater in Slovakia (wells and springs), evaluated month: **May 2012**, ref. period: May (1981 - 2010), gridding method: Krigging (500 x 500 m)

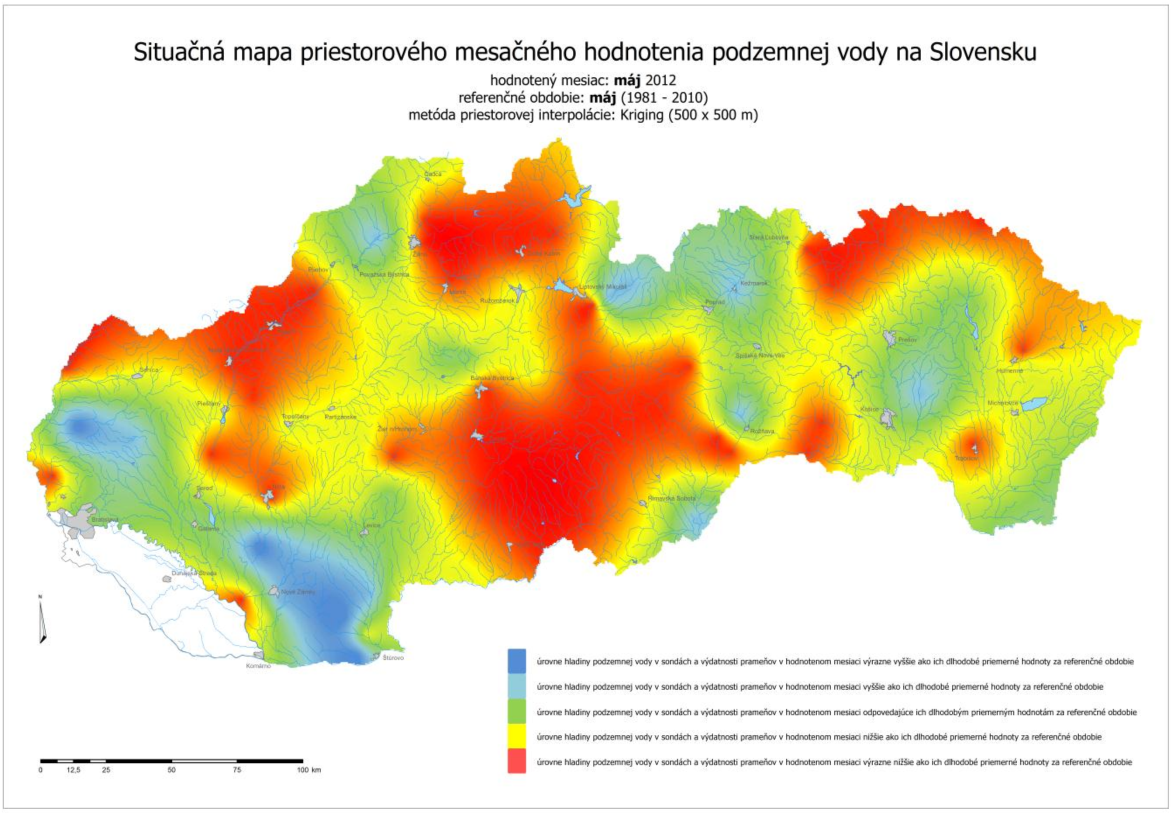


Fig. 22 Monthly evaluation of groundwater in Slovakia (wells and springs), evaluated month: **June 2012**, ref. period: June (1981 - 2010), gridding method: Krigging (500 x 500 m)

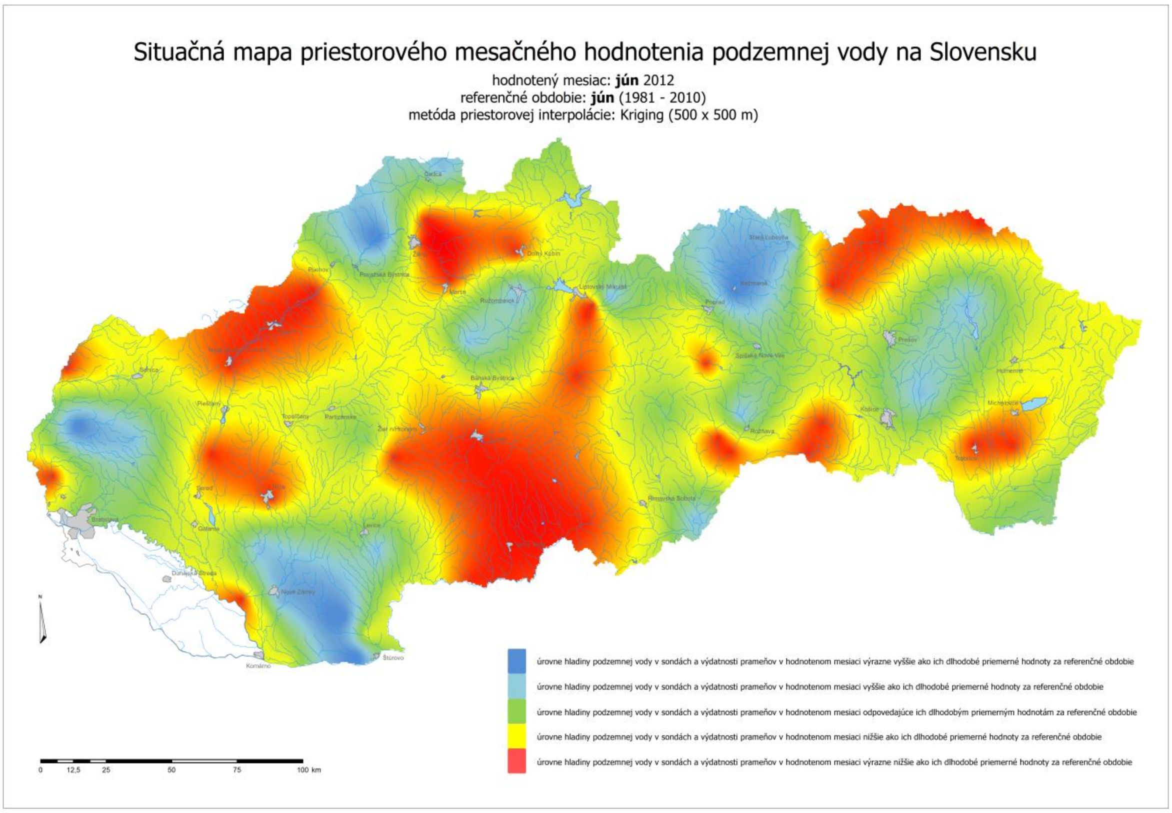


Fig. 23 Monthly evaluation of groundwater in Slovakia (wells and springs), evaluated month: **July 2012**, ref. period: July (1981 - 2010), gridding method: Krigging (500 x 500 m)

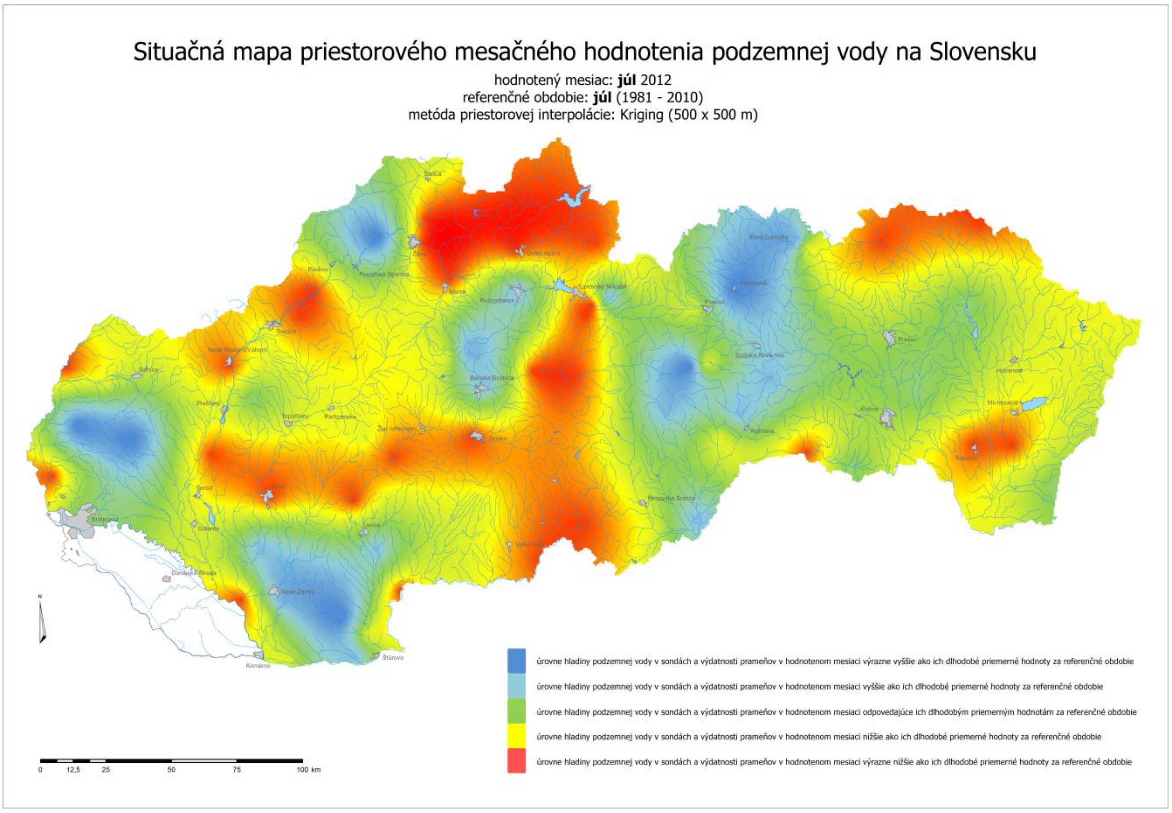


Fig. 24 Monthly evaluation of groundwater in Slovakia (wells and springs), evaluated month: **August 2012**, ref. period: August (1981 - 2010), gridding method: Krigging (500 x 500 m)

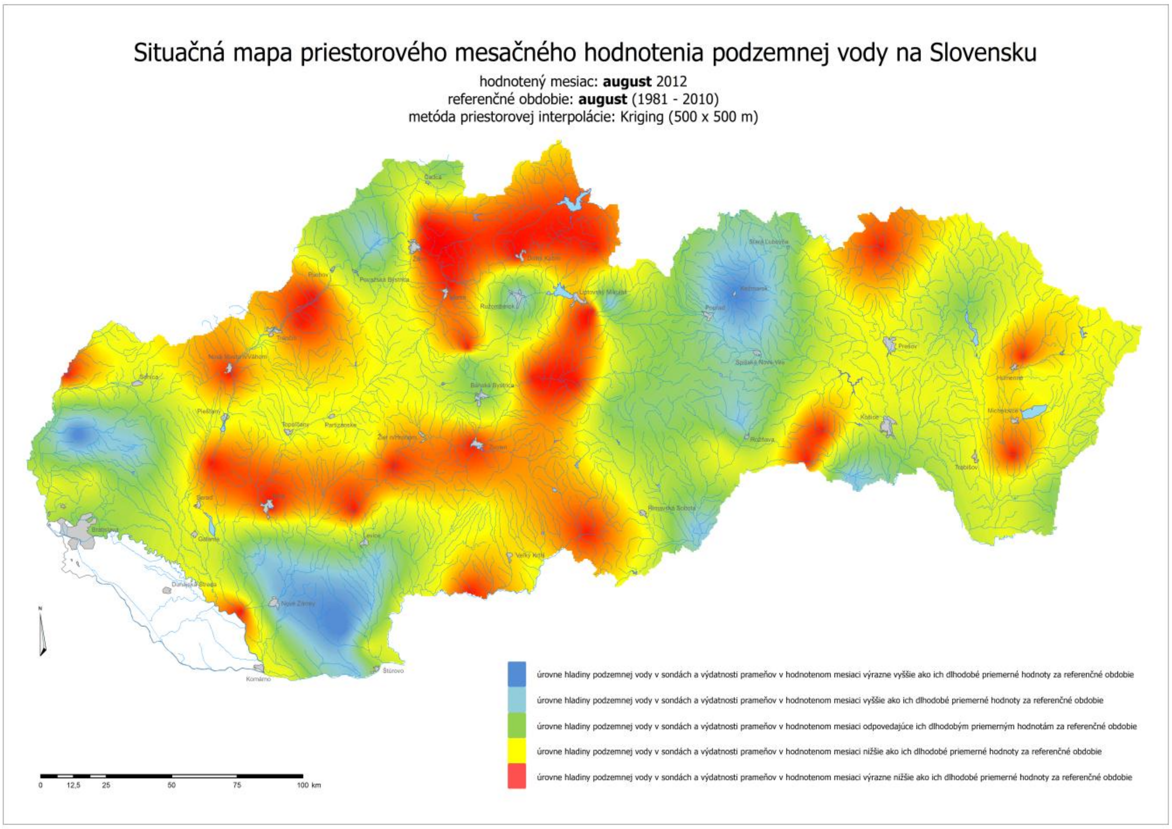


Fig. 25 Monthly evaluation of groundwater in Slovakia (wells and springs), evaluated month: **September 2012**, ref. period: September (1981 - 2010), gridding method: Krigging (500 x 500 m)

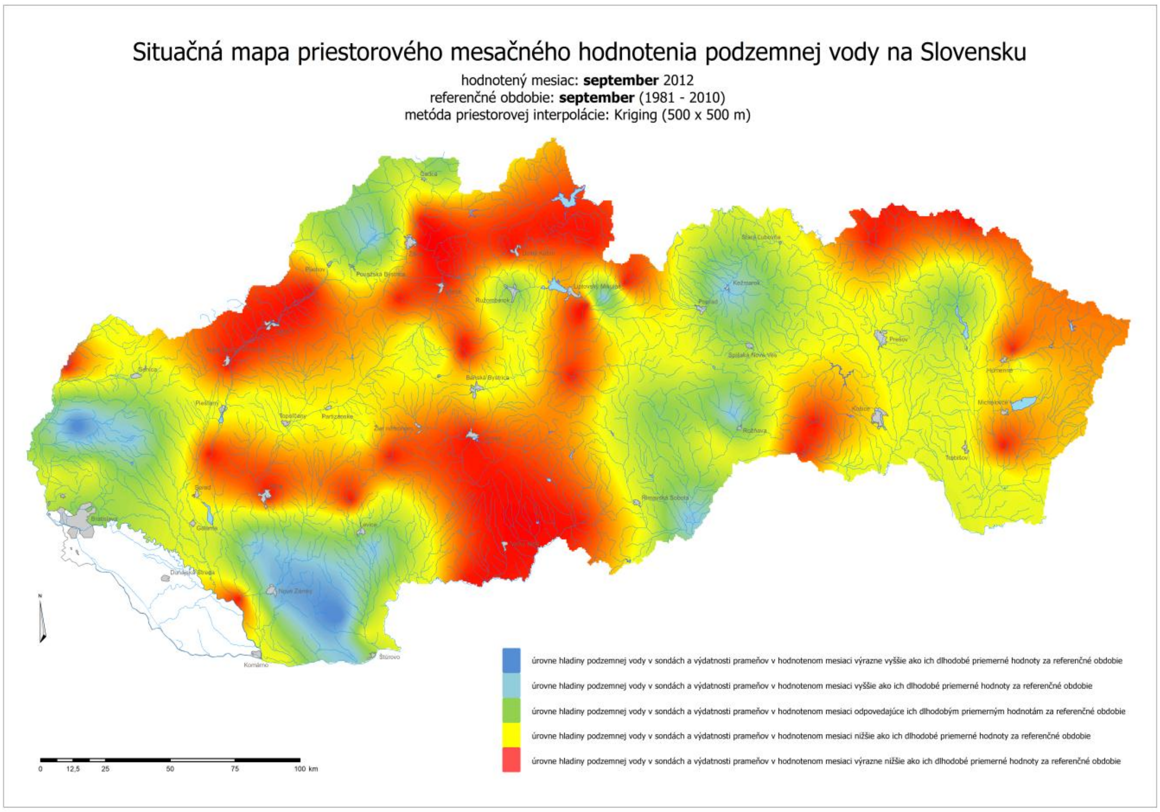


Fig. 26 Monthly evaluation of groundwater in Slovakia (wells and springs), evaluated month: **October 2012**, ref. period: October (1981 - 2010), gridding method: Krigging (500 x 500 m)

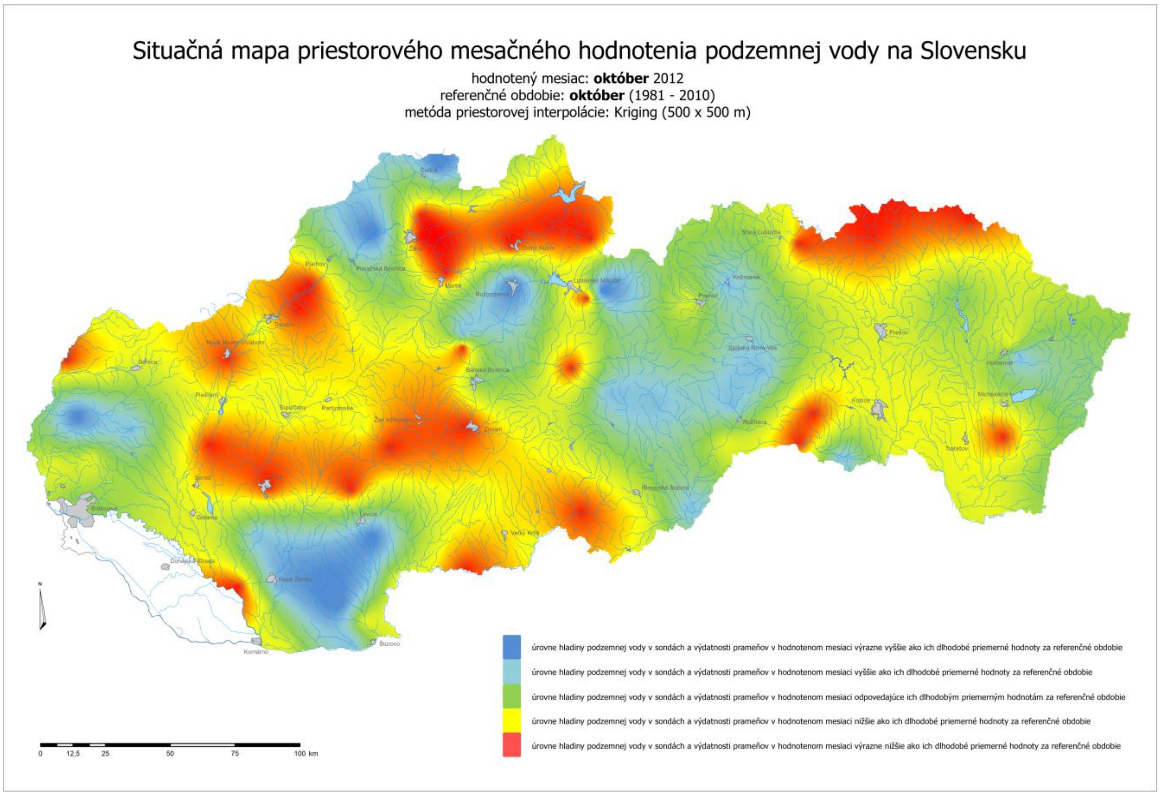


Fig. 27 Monthly evaluation of groundwater in Slovakia (wells and springs), evaluated month: **November 2012**, ref. period: November (1981 - 2010), gridding method: Krigging (500 x 500 m)

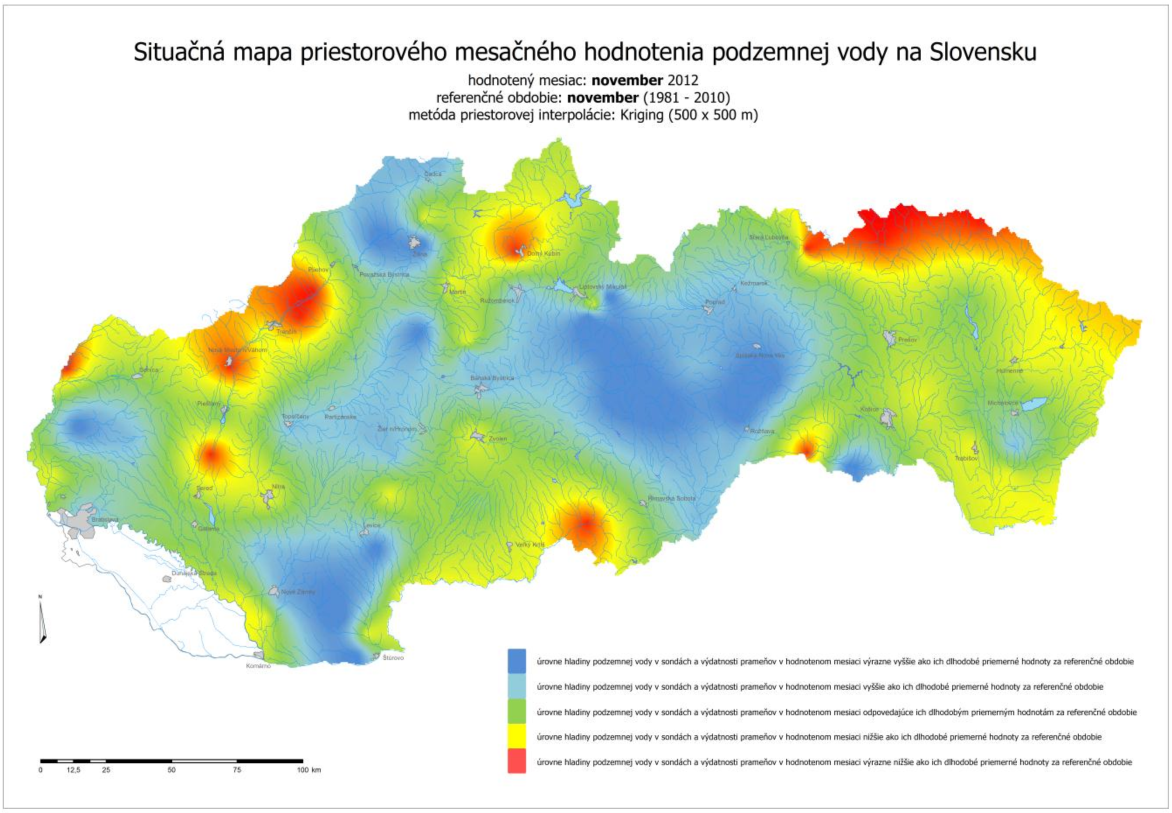
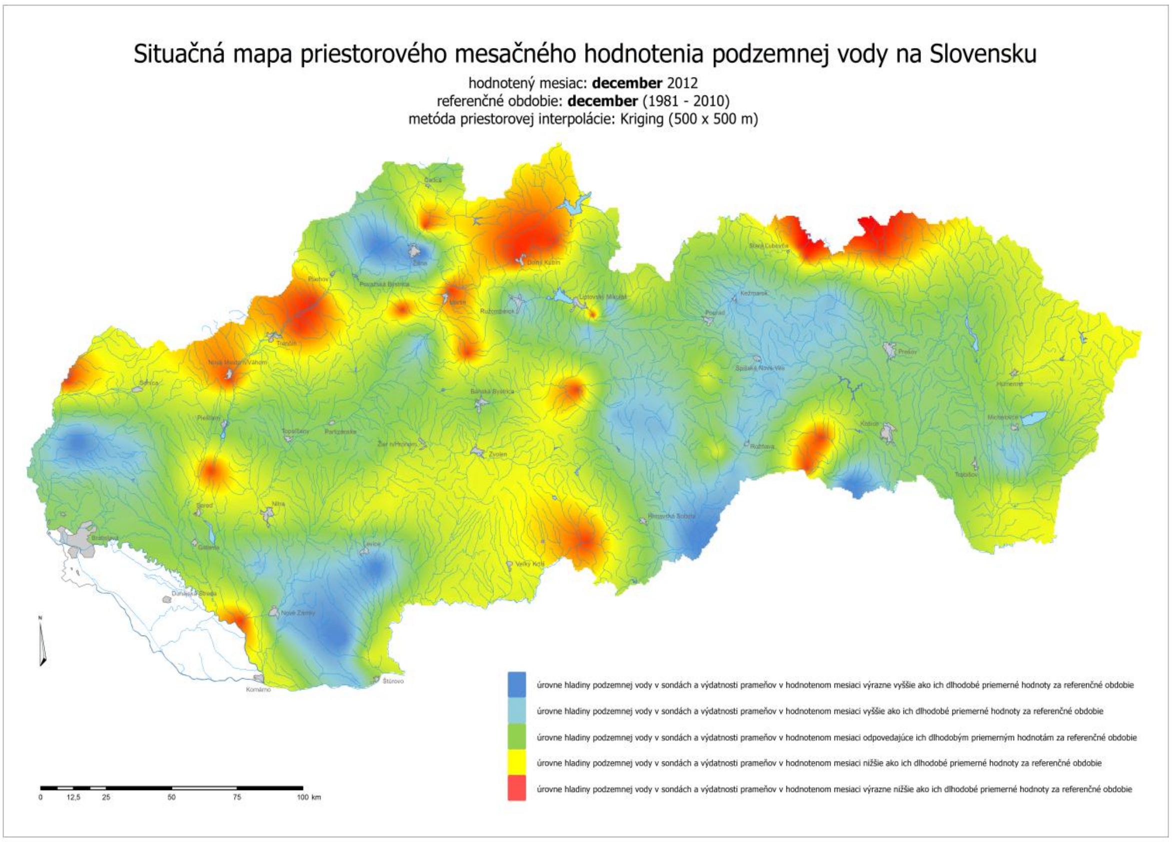


Fig. 28 Monthly evaluation of groundwater in Slovakia (wells and springs), evaluated month: **December 2012**, ref. period: December (1981 - 2010), gridding method: Krigging (500 x 500 m)



Maps of the monthly assessment of groundwater show a significantly above average status of groundwater sources in July 2011 (Fig. 11) and August 2011 (Fig. 12) almost in the whole territory of Slovakia and significantly below average status (dry period) in May 2012 (Fig. 21) and September 2012 (Fig. 25).

Fig. 29 presents evaluation of the draught impact on groundwater in Slovakia for the entire period of the hydrological year 2011 compared to the reference period of 1981 - 2010. Hydrological year 2011 was, in terms of groundwater, in an average or slightly above an average. Only areas Kysuce, Orava and middle river basin Hron had groundwater levels and springs yield values significantly lower in hydrological year 2011 compared with the long-term averages values of wells and springs in reference period 1981 - 2010.

Fig. 29 Yearly evaluation of groundwater in Slovakia (wells and springs), evaluated period: **hydrological year 2011**, reference period: hydrological years 1981-2010 gridding method: Krigging (500 x 500 m)

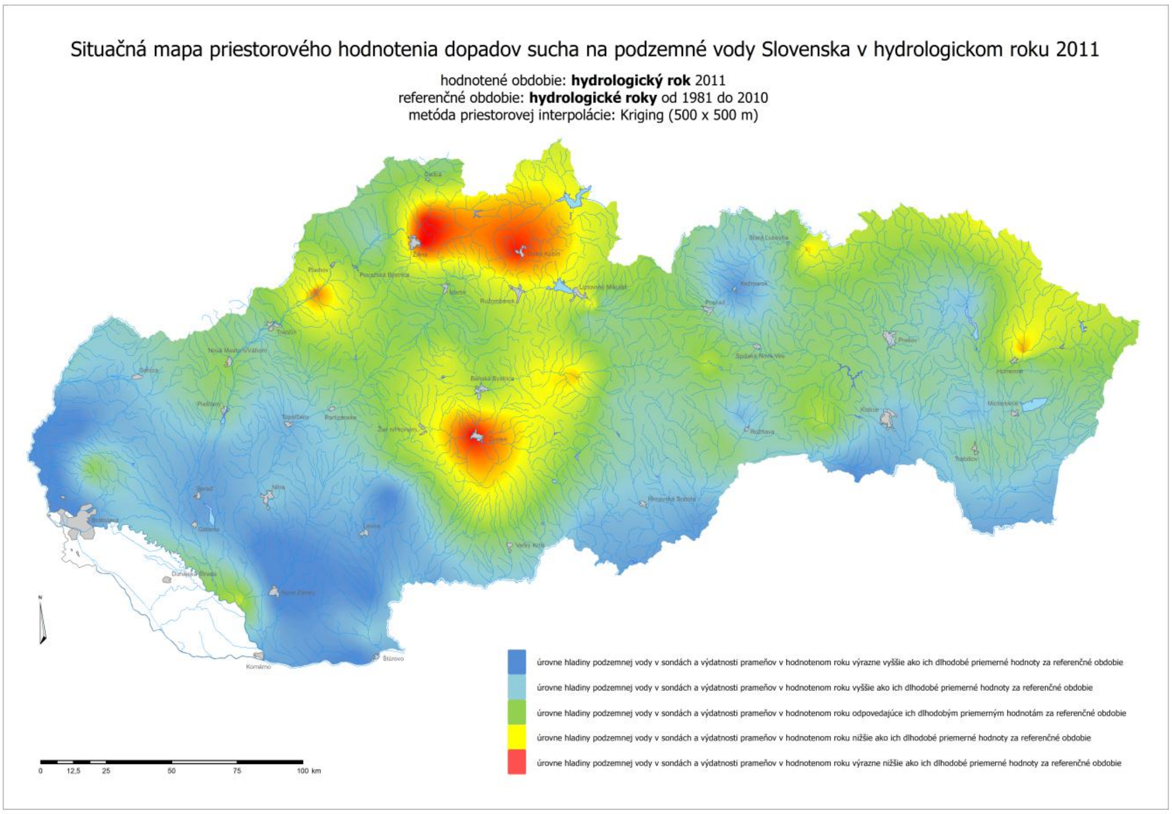
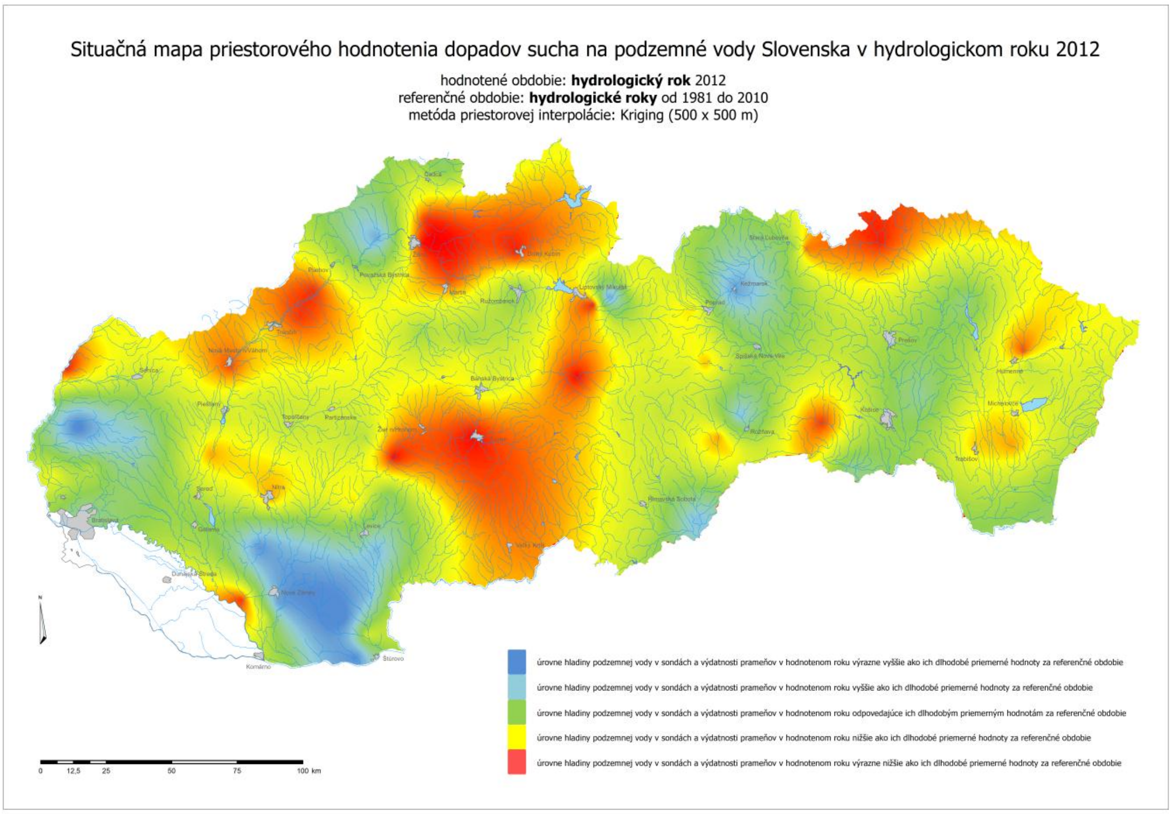


Fig. 30 presents evaluation of the draught impact on groundwater in Slovakia for the entire period of the hydrological year 2012 compared to the reference period of 1981 - 2010. It confirms the assumptions of significant negative effect of drought on groundwater almost on the whole territory of Slovakia. Compared to the hydrological year 2011 is clearly visible the reaction of groundwater (groundwater level and yield of spring) on precipitation below average and the temperature above average year 2011 – values are lower and significantly lower than their long-term averages. It identifies the major negative impacts of drought on groundwater in the northwestern part of Slovakia, in the extensive area in the northern part of Slovakia, in the northeastern part, as well as in the central and southern part of Slovakia.

Fig. 30 Yearly evaluation of groundwater in Slovakia (wells and springs), evaluated period: **hydrological year 2012**, reference period: hydrological years 1981-2010 gridding method: Krigging (500 x 500 m)



c) Month to month evaluation of changes the groundwater level and springs yield

It is represented by evaluating changes (decrease ↓/steady state →/increase ↑) of groundwater level respectively springs yield between the evaluated month and the previous month. Maps indicate the presence of spatial inhomogeneity of groundwater recharge in Slovakia. Fig. 31 represents the results of the evaluation of groundwater in February 2012 compared with the state of groundwater in the previous month (January 2012). Relatively steady is state of groundwater with existence of upward and downward trends. Fig. 32 is an example of the period of significant groundwater recharge almost in all regions of Slovakia (March 2012). On the other hand, fig. 33 (September 2012), is an example of months with significant negative impact of drought on groundwater sources with major declines in groundwater levels and decreases the yield of springs almost in all monitoring points in Slovak territory.

Graph 1 and graph 2 summarize information from the monthly assessment of groundwater in the period November 2010 to December 2012 and represent an alternative view of the results presented in fig. 31 to fig. 33. Summarize the monitoring objects with increasing (+1) respectively decreasing trend (-1) in each month of the year. They point to the above-average months of groundwater status (December 2010, March 2012 and November 2012) and significantly below average months of groundwater status (May 2011, 2012, September 2012).

Fig. 31 Month to month evaluation of groundwater in Slovakia (evaluated month: February 2012, compared to preceding month: January 2012)

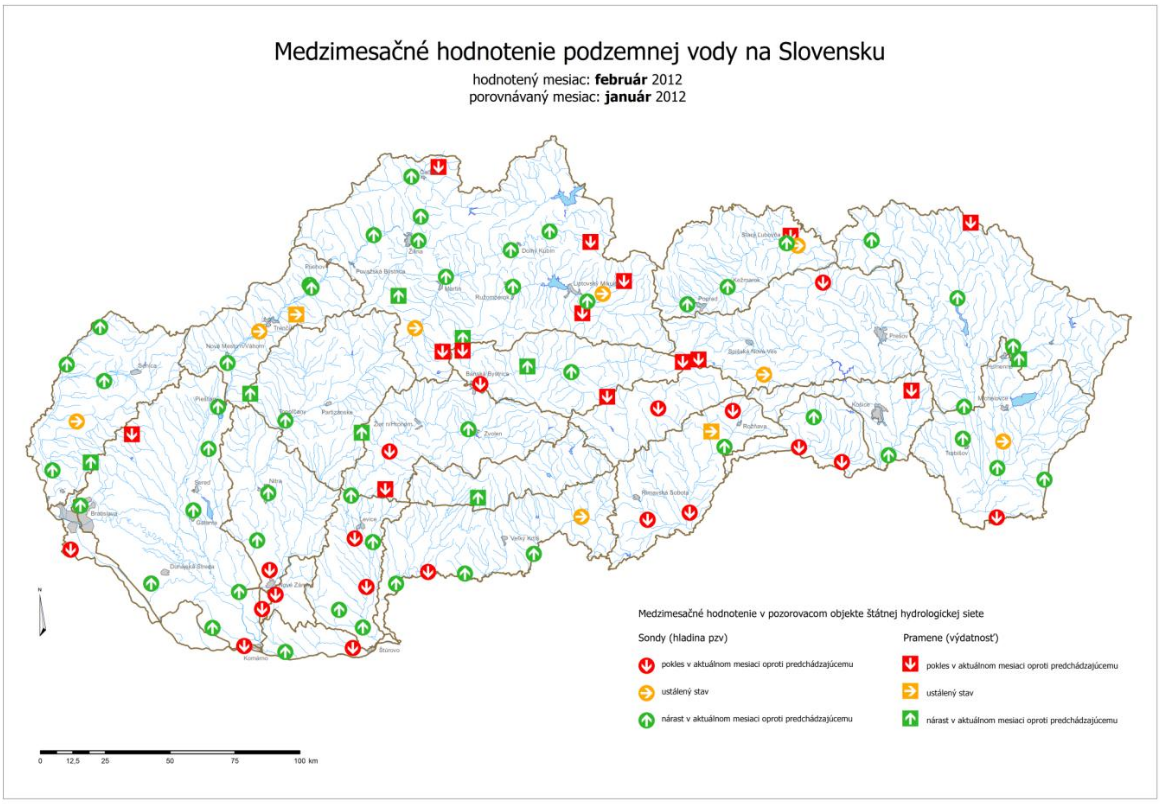


Fig. 32 Month to month evaluation of groundwater in Slovakia (evaluated month: March 2012, compared to preceding month: February 2012)

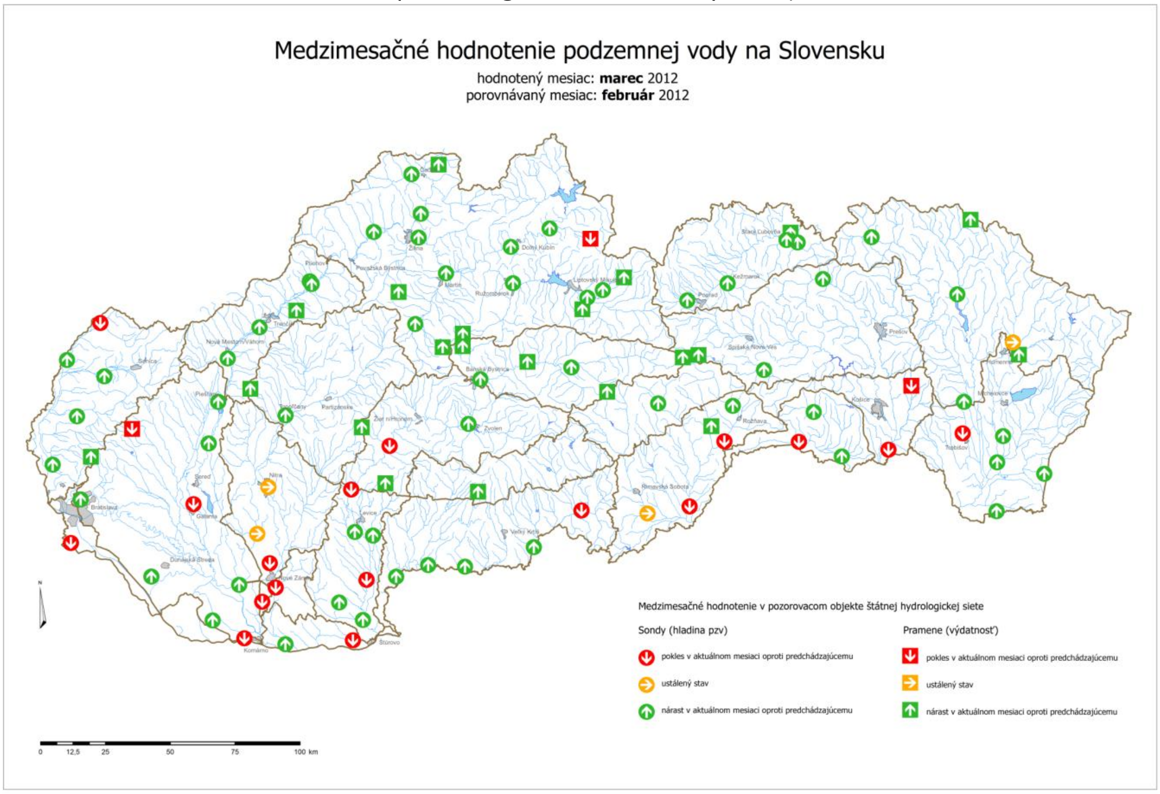
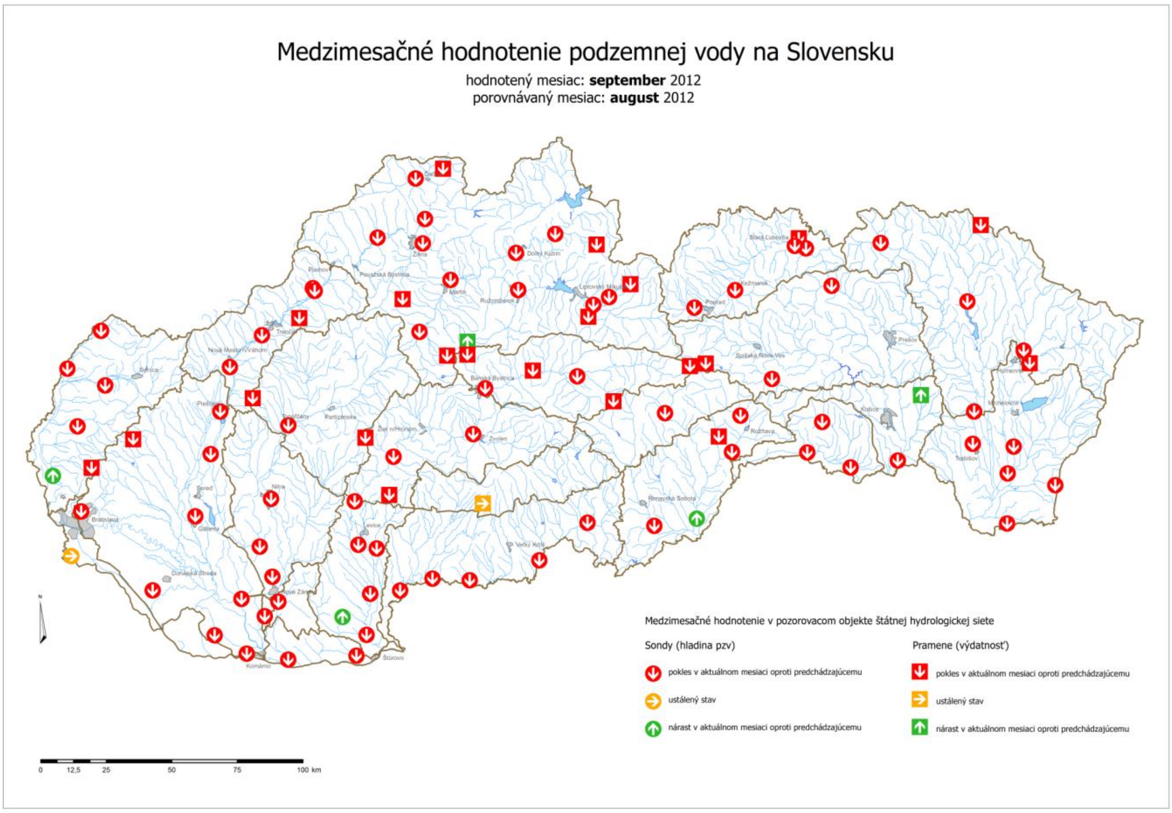
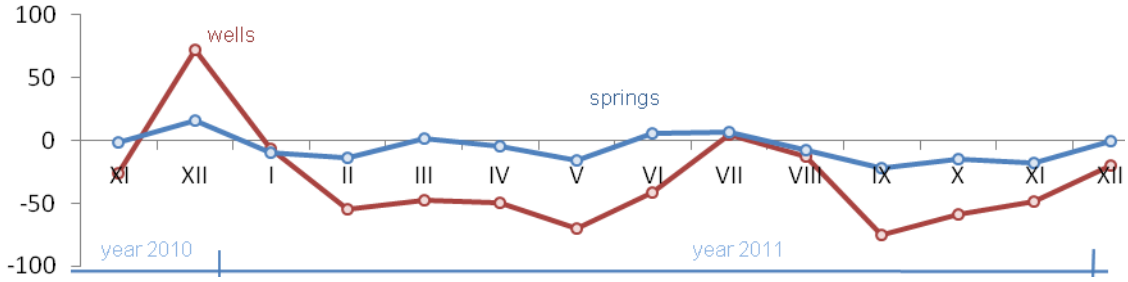


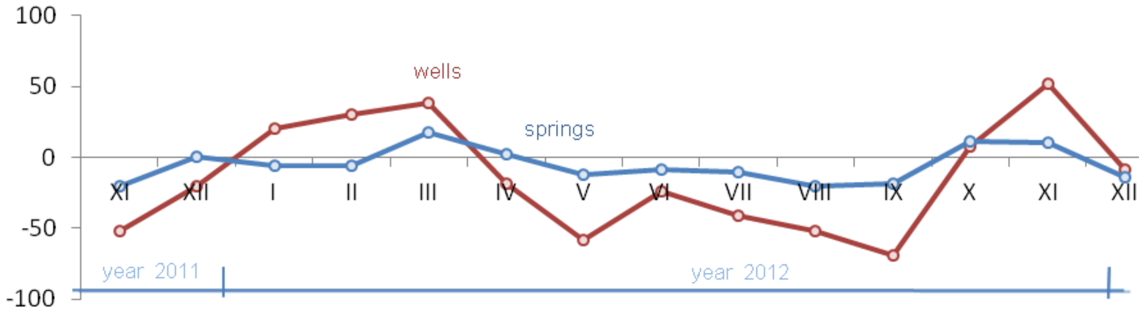
Fig. 33 Month to month evaluation of groundwater in Slovakia (evaluated month: September 2012, compared to preceding month: August 2012)



Graph 1



Graph 2

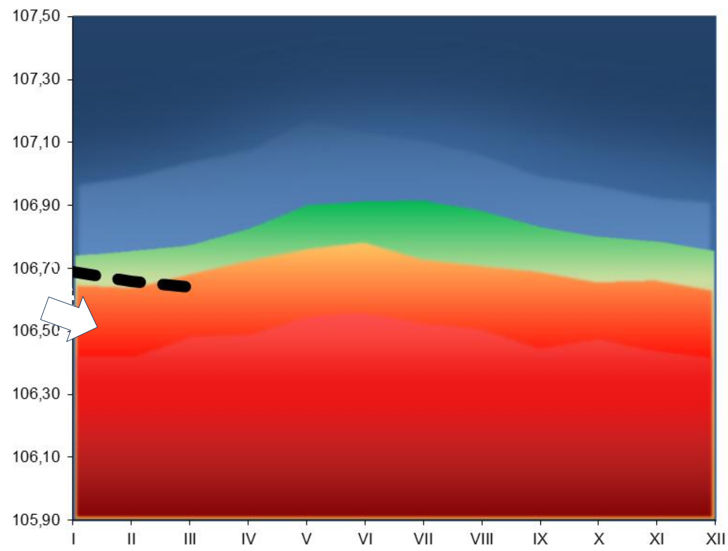


Despite considerably generalized approach, presented evaluation of groundwater for the territory of Slovakia seems to be the effective methodology and good tool for analyzing the spatial distribution of the effects of drought on groundwater sources. Clearly points to the spatially inhomogeneous of impacts of drought on groundwater wells and springs on the territory of Slovakia and (with a detailed assessment of climatic parameters and their changes over time) it can confirm response and retardation of drought indicators (based on precipitation and evapotranspiration parameters) on the sources and reserves of groundwater.

With respect to existing technological process of groundwater measurement, data collection and processing datasets from objects of the state hydrological network of groundwater in Slovak Hydrometeorological Institute and the absence of automatic stations for monitoring groundwater quantity on-line (present status is processing data with 2-3 months delay) it is not possible to evaluate drought in real-time and forecast the effects of drought on groundwater operationally yet.

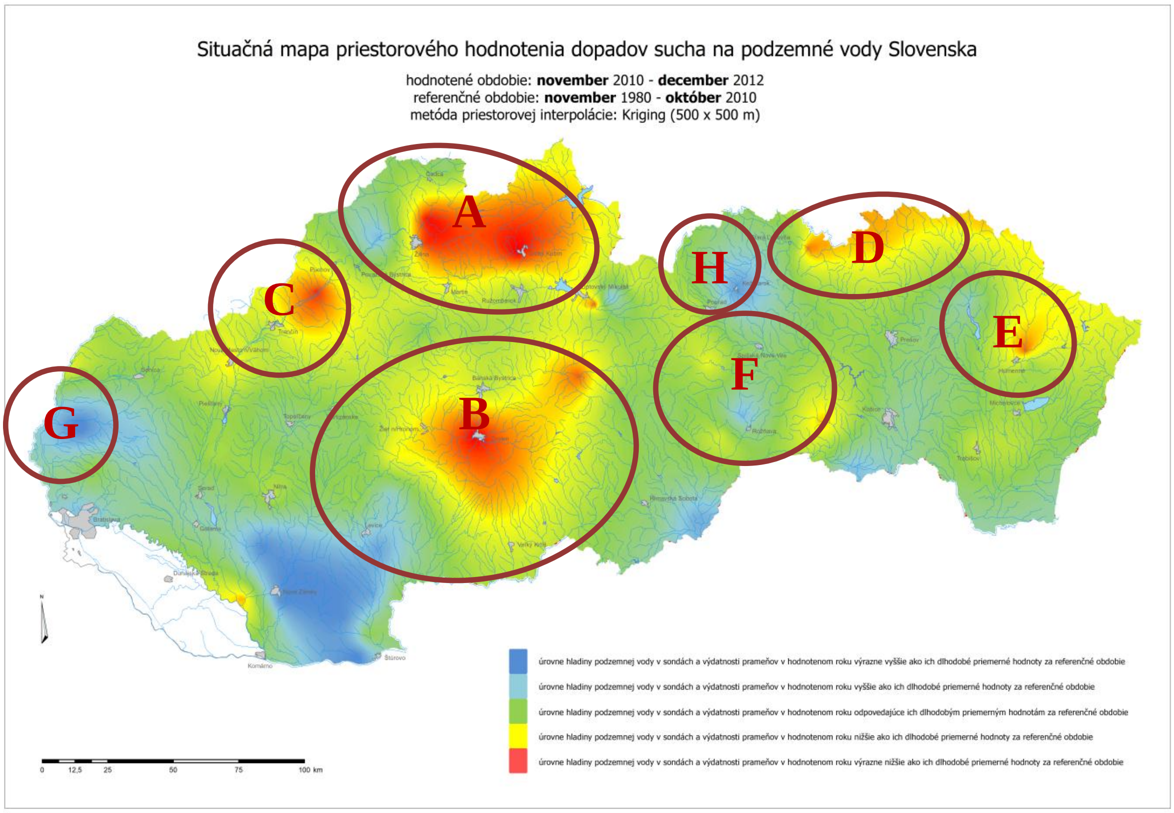
Constitution the national representative network of groundwater quantitative monitoring with on-line measurement (and with operational transfer of measured datasets into the evaluation centre) it would allow us (in the particular object and after appropriate transposition in the hydrogeological structure or relevant area as well) to analyse drought operationally. It would be possible to establish the appropriate tools for indication the responses of droughts to the groundwater quantity status also. This concept is simulated on fig. 34, in which we illustratively present our plan based on on-line measured data of well in February - March (values are in the interval “much lower than the normal”). Using the operational climate data we would be able to predict decrease/steady state/increase of groundwater level in April and predict response groundwater sources to drought for example. In the case that groundwater sources are used for drinking water purposes, this could be a warning signal/starting point to start up forecasts process and subsequently applying the measures in the water management for elimination drought in such affected area.

Fig. 34 Operational indication of drought period in groundwater



Based on processed monthly cumulative assessment of groundwater for the period November 2010 - December 2012 (Fig. 35) there were selected important areas (hydrogeological structures), that point out significant anomalies of groundwater status compared to the reference period between 1980 - 2010. On these important areas would be focused our proposed reference objects of groundwater monitoring with on-line measurement and operational data transfer in the first phase of the solution drought-groundwater interaction in the future. The reference monitoring network would measure groundwater on-line and generate operative datasets for indication of drought beginning and also it would produce the datasets for application of appropriate programme of measures. We expect that the reference monitoring network will cover about 8 regions in Slovakia (40 groundwater objects total, springs or wells) with transmission of measured groundwater regime data from the objects in real time.

Fig. 35 Spatial map of the important areas with significant impacts of drought on groundwater in Slovakia (based on monitoring data 2010 -2012)



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3.5 Calculation of the water balance in agricultural land

3.5.1 Introduction

The growing and development of plants in our conditions is largely determined by water regime. Lack of water in soil is a stress factor affecting negatively crop yields. Frequent droughts may be a limiting factor in agricultural production.

Soil water regime in lowlands depends mainly on inputs from atmospheric precipitation. In respect of natural property of climate, which is the territorial and temporal variability, we meet on the one hand with periods of heavy rainfall, on the other hand with periods of drought. In our latitude the draught is natural demonstration of atmospheric circulation. It occurs with different frequencies. Draught starts slowly and its effects are amplified with increasing length of the dry season.

The drought differs in severity, duration and extent of the affected area. The term drought expresses a negative deviation from the normal water balance in a given area (BRÁZDIL et al, 2009). Quantitative definition of the degree of abnormality of the drought through various climatic indices is difficult due to the interaction of meteorological, hydropedological, agronomical and the other factors. Given the complexity of the problem and its several aspects there are no uniform criteria for quantification of drought. According to the meteorological dictionary (Sobíšek et al, 1993) we distinguish meteorological drought, agronomic drought, hydrological drought and physiological drought.

In European context the territory of Slovakia is not considered as an area prone to droughts. The meteorological observations, however, confirm that in recent decades also in our territory drought occurres more frequently in local or full-area scale. The impact of drought on the country's vulnerability in terms of climate change and increasing demands for water will grow in the future. In Europe is expected the increasing incidence of barren years due to drought and heat waves, which will also have economic consequences (EEA, 2012). The risk of disfavourable dry years in Central Europe as a result of climate change will increase, which will result in an increased risk of soil erosion and lower productivity (Trnka et al, 2013). In hot and dry Podunajská lowland production potential will be increasingly limited by decreasing of water availability for crops and by heat (Eitzinger et al, 2012).

Spatial definition of drought and the likelihood of its occurrence is a prerequisite for the formulation of follow-up measures and activities related to building the necessary capacities and mitigation of their consequences.

3.5.2 Materials and method

The crop growth is limited by sufficiency of soil water for evapotranspiration and therefore methods that include soil moisture are considered as the most suitable for evaluation of drought. The dynamics of soil water is a result of flow of water in the system comprising atmosphere - vegetation - soil - groundwater and is one of the most dynamic soil properties.

Soil water below wilting point is not available for plants. Available for plants is considered to be the soil water in the interval between field capacity FC [mm] and wilting point WP [mm]. Amount of soil water available for the plants is called available water capacity AWC [mm]. In agronomic practise soil water storage is usually expressed as available soil water content ASWC [mm]:

$$ASWC = SWC - WP$$

Soil water content SWC as well as FC and WP are calculated as weighted averages of horizons. Actual *SWC* can be calculated from the water balance:

$SWC_i = SWC_{i-1} + P_i + CR_i - ET_i - RO_i$

Where *P* is the precipitation, *ET* is the evapotranspiration, *CR* is capillary rise, *RO* is the runoff and subscript *i* is the number of the day.

To evaluate anomalies in time series standardised indices are suitable. Standardised indices express relative relation of variable deviation from the average to standard deviation of time series. In general, standardised indices are used to compare large data sets, e.g. SPI (McKee *et al*. 1993). Standardisation allows achieve index distribution close to the normal (Gaussian) distribution (Takáč 2012). The advantage of standardized indices is that they allow to evaluate anomalies for different periods of time (year, half-year, month, etc.). Standardization of the soil water allows comparisons not only the intensity of droughts at different times, but also in different regions with different soil and climatic conditions. Proposed standardised available soil water index $ASWI_i$ is calculated from available soil water content $ASWC_i$ in daily steps according to the equation:

$$ASWI_i = \frac{ASWC_i - ASWC_{AVE}}{ASWC_{SD}}$$

Where $ASWC_{AVE}$ is long term average of *ASWC* and $ASWC_{SD}$ is standard deviation of *ASWC*. Similarly in case of climatic indices for $\mathrm{ASWC_{AVE}}$ and $\mathrm{ASWC_{SD}}$ calculation it is required 30 year duration of the time series. Normal climate period 1961–1990 was chosen as reference period to enable historical comparison of drought severity as well as climate change impacts.

In accordance with assessment established in climatology (Lapin *et al*. 1988) boundaries of 25 % exceeding probability for moderate drought, 10 % exceeding probability for severe drought and 2 % exceeding probability for extreme drought have been set. Averages of *ASWI* from considered set of meteorological stations were –0.72 for moderate drought, –1.15 for severe drought and –1.81 for extreme drought, respectively. Medians of *ASWI* were –0.72, –1.16 and –1.80 for individual drought degrees, respectively (Takáč, 2012).

Drought is related to the long term mean conditions and it is defined as long term occurrence of *SWC* below average value. Basic assumptions for drought are 1) the SWC is below 50 % of AWC and 2) SWC is below long term average SWC at the same time. Drought duration was defined as consecutive days of negative *ASWI*. Exceeding probability intervals of *ASWI* were used for drought severity classification (Table 1). The beginning of a drought period of given degree is determined by the day when *ASWI* falls below threshold value and a drought continues until the threshold is exceeded again. In order to classify the drought in a particular degree the duration must be continuously at least 15 days. In the case that the relevant condition lasts more than 15 days, shorter wetter periods are not considered as the end of drought period when they lasted less than 10 % of previous drought period. These days are included in the drought period. Cumulative sum of *ASWI* was used to the drought quantification throughout its duration:

$$ASWI_{CUM} = \sum_{i=1}^{N} ASWI_i$$

Where *i* is the serial number of the day and N is the number of the days in the period with negative *ASWI*. Based on the probability of occurrence in the reference period 1961-1990 the rounded values of $ASWI_{CUM}$ were chosen for dry period classification (Table 2).

Table 1. Degrees of drought severity based on the available soil water index *ASWI* (TAKÁČ, 2013)

Drought degree	Extreme drought	Severe drought	Moderate drought	Normal drought
Probability interval [%]	≤ 2%	2.1% to 10%	10.1% to 25%	25.1% to 50%
ASWI interval [–]	≤ –1.8	–1.8 to –1.151	–1.15 to –0.721	-0.72 to 0

Table 2. Degrees of drought severity based on the cumulative available soil water index $ASWI_{CUM}$ (TAKÁČ, 2013)

Drought degree	Extreme drought	Very severe drought	Severe drought	Normal drought
Probability interval [%]	≤ 2%	2% to 10%	10.1% to 25%	25.1% to 50%
$ASWI_{CUM}$ interval [–]	≤ –300	–299 to –200	–199 to –100	-99 to 0

Daily data of mean, maximum and minimum air temperature, air humidity, global radiation, wind speed and precipitation for the period 1961 to 2012 were used in calculation. Daily totals of reference and actual evapotranspiration were calculated according to the Penman-Monteith method (Allen et al., 1998).

1k (soil) and 10k (climate) spatial resolution data served the input for the soil moisture balance routine running on daily step. Daily climate data (1961 – 2012) on minimum, maximum and average air temperature (°C), sunshine duration (hour), vapour pressure (hPa), average wind speed ($m.s^{-1}$) and rainfall (mm) from totally 71 climate stations distributed regularly across agricultural land of Slovakia was provided by Slovak Hydrometeorological Institute. Data was interpolated to 10k grid locations by algorithm developed by JRC (Crop Growth Monitoring System – CGMS) and further modified for national needs by Novakova (2007); and potential evapotranspiration was calculated for each cell afterwards using Penman-Moneith equation implemented within the CGMS system. Land evaluation maps in 1:5000 scales (Linkeš et al 1996) provided information on agricultural soil texture class distribution. Spatially dominant topsoil texture class from the map was then assigned to each relevant 1k cell location and taken as representative value for the whole 120 cm deep soil profile. National soil profile database (AISOP, Linkeš et al. 1988) counting 17,740 soil profile records provided data on soil analytical properties. Soil texture class representative sand, silt and clay content was calculated as an average from the AISOP data and all other necessary hydro-physical parameters (soil bulk density, soil water content at field water capacity and wilting point) were then estimated by HYPRES (Wosten et al. 1998, 1999) pedo-transfer functions. Available water capacity (AWC) for the soil profile was calculated as follows: AWC = (FC-WP)*h, where AWC is available water capacity (mm), FC is water content at field water capacity (cm^3/cm^3), WP water content at field wilting point (cm^3/cm^3), and h is soil depth (mm) which is 120 cm in our case. Representative soil profile values used for pre-defined soil texture classes are listed in Tab. 3.

Tab. 3 Soil texture class specific average sand, silt, and clay content, estimated soil hydro-physical properties, and available soil water capacity in 120 cm soil profile.

texture class*	%			g/cm^3	vlhkosť %		mm
	clay	silt	sand	BD	FC	WP	AWC
1	7,7	22,3	70,0	1,6	21,69	4,19	210
2	20,9	53,3	25,8	1,4	34,18	11,95	266
3	31,4	52,4	16,2	1,35	37,87	16,81	252
4	44,3	46,4	9,4	1,3	41,91	21,54	244
5	13,0	41,3	45,7	1,45	29,28	7,60	260

*) 1 – sand and loamy-sand, 2 – loam, 3 – clay-loam, 4 – clay, 5 – sandy-loam

The 120 cm soil profile value of AWC was then modified for each 1k grid cell based on information on dominant soil depth and stone content coming from Land evaluation maps (Linkeš et al 1996). If soil depth was less than 60 cm or stone content in top 60 cm of soil was more than 50% the AWC value was decreased of 25%. If soil depth was less than 60 cm and stone content in top 60 cm was more than 50%, the AWC value was decreased of 50%. Un-modified AWC value was left in all other cases. Groundwater influence was assumed for all locations (1k grid cells) with dominant Gleysols, Histosols or Gleyic Fluvisols having also heavy texture. Groundwater influence as estimated based on soil information well corresponds with spatial distribution of the lowest parts of the big alluvial areas of the Danube lowlands. Spatial intersection of climate and soil grid data yielded totally 3.865 simulation units (SimU) which represent spatial units homogenous as for its climate and soil (AWC, groundwater influence). Each SimU is a spatial zone consisting of 1 – 100 1k grid cells located within the borders of only one particular 10k climate cell.

Seven strategically important crops were selected for evaluation of crop yields, treated separately in two groups as: i) winter and spring crops (winter wheat, spring barley, winter rapeseed) and ii) summer crops (corn maize, sunflower, sugar beet, and potato). Long-term average yields of all crops (1997 – 2010) were calculated from NUTS3 level statistical data provided by the Statistical Office of the Slovak Republic. Crop specific long-term averages were then compared to statistical yields for 2011 and 2012 years using relative deviation as the statistical measure of observed differences:

$$RD = 100*(Y_i\text{-}Yavg/Y_{avg})$$

Where RD is relative deviation (%), Y_i is respective yield (t/ha) in 2011 or 2012 year, and Y_{avg} is long-term average yield.

3.5.3 Results and discussion

The time required for the formation of water deficit in the soil is different depending on the storage capacity of the soil and thus the time when meteorological drought (precipitation deficit) passes into agronomic drought (soil water deficit) is depending on the storage capacity of different soils.

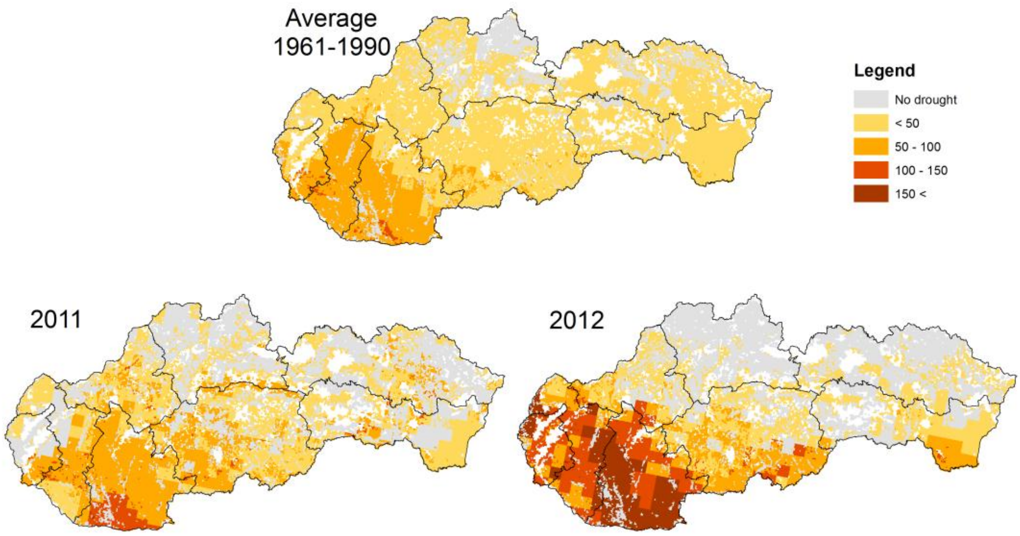
In general, the soil moisture has an annual cycle. Maximum soil water storage is at the end of the winter and minimum occurs in the summer months. For impacts of drought on crop growth, the drought duration, intensity and time of occurrence of dry spells with soil moisture in the root zone below 50% of *AWC* in terms of the crop development stage is crucial. In the case of extreme drought the impacts on yields may be severe. In agronomic and irrigation practice, soil water storage 50% of *AWC* is considered threshold when the plants begin to suffer from a lack of water to meet their water demand. In the southern regions of Slovakia SWC almost every year during the summer months falls below this threshold in the southern regions of Slovakia. This is a normal recurring phenomenon. Crop production is adapted by the structure of crops and their varieties or supplementary irrigation.

Yield variability is significantly affected by soil water dynamics in growing period as well as outside of growing period. Consequence is given to the winter water supply. It is optimal if sufficient snow cover was formed during the winter and snow melts slowly in early spring. Distribution of the precipitation during the growing season plays important role too. Drought severity is greater when the severe drought occurred in the previous year and the winter precipitation totals were insufficient.

Occurrence and duration of the period with SWC below 50 % of AWC is different in the individual regions. Such period occurs in the west Slovakian lowlands almost every year. Continuous period with SWC below 50 % of AWC lasts from 50 days to 100 days in average on Danube Lowland as well as in the southern part of Záhorská lowland. Locally, especially on light sandy soils, it is more than 100 days in average.

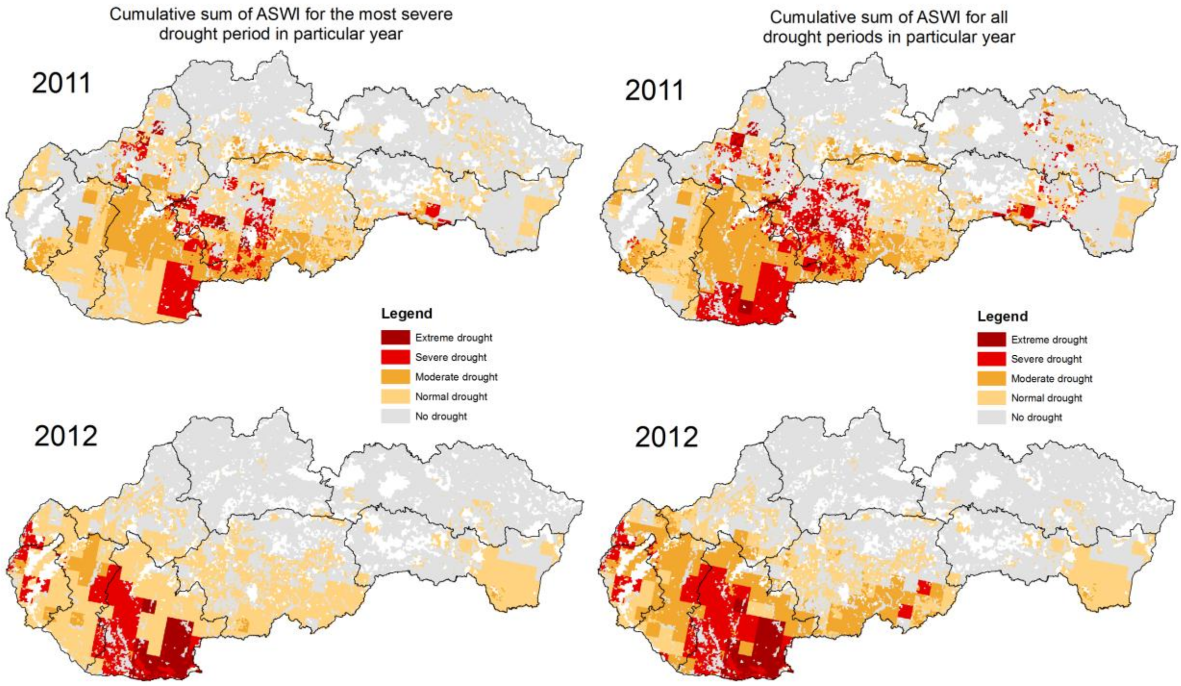
In 2011, the dry period lasted more than 100 days in the southeast of the Danube Lowland and in 2012 the whole of south-western Slovakia, while in the central and eastern part of the Danube Lowland as well as on Záhorská Lowland it was more than 150 days (Fig 1).

Fig 1 Number of days with SWC below 50 % of AWC in the period and in the years 2011 and 2012



According to the $ASWI_{CUM}$ in the year 2011 very severe drought occurred on the southeast of Danube Lowland, central part of Váh Valley and in the western part of Banská Bystrica region while locally reached the extreme severity. In the year 2012, very severe drought occurred in the eastern part of Danube Lowland and in the part of Záhorská Lowland. Extreme drought was in 2012 in the southeast of Danube Lowland.

Fig 2 $ASWI_{CUM}$ in the years 2011 and 2012 for the longest continuous period (left) and for the entire year (right)



3.5.4 Conclusions

Drought occurrence and significance evaluation was based on soil water balancing with simplified balance equation using geographical data on climate and soil covering whole agricultural land of Slovakia. Indicators for drought occurrence and significance evaluation were chosen as follows:

1) actual water storage in soil profile less than 50% of available water capacity (AWC),
2) lover actual water storage when compared to long-term average,
3) continuous drought occurrence for 15 consecutive days and more.

Spatial delimitation of drought occurrence and telling out likelihood at which it could occur is essential precondition for any subsequent formulation of the appropriate measures and other activities aimed for capacity building and mitigating drought impacts. Standardised available soil water anomaly index gives information on drought severity for the particular day. It can be employed in real-time assessment of actual drought situation development as a part of early-warning system and also for taking the decisions on drought mitigation at local level directly by individual soil users. Cumulative value of the standardised available soil water anomaly index gives an opportunity to quantify and classify even the extremely long drought event during the whole period of its impact. Introduction of the reference period can moreover help to describe the drought severity within the particular region in historical context and as such, on higher decision-making levels to support decisions on compensation payments for farmers or for to plan long-term measures for mitigation of the negative trend (e.g. building up the irrigation infrastructure, retention water reservoirs). Climate data, soil data, and GIS coupling gives an opportunity for building-up the National drought information system based on this methodology.

Drought warning system – agricultural land

Current status of water reserves in agricultural land has a significant influence on several landscape processes such as availability of water for crops and the formation of water stress for plants. Drought has a major economic impact and causes social and economic damage. Timely and correct information on the state of water in the soil profile may contribute to operational and targeting decision-making on measures against drought, on a local, regional or even national level.

Slovak Hydrometeorological Institute (SHMÚ) on its website operates an online service for medium-range weather forecast for 10 days (ECMWF model). This service allows for selected points (municipalities) in Slovakia to predict the development of several meteorological parameters (eg, minimum and maximum daily temperature, total rainfall and distribution of rainfall, cloud cover, wind direction and speed).

National Agricultural and Food Centre – Soil Science and Conservation Research Institute (NPPC-VÚPOP) in the long-term deals with the water balance modelling of agricultural land and operates a national system for predicting yields of selected agricultural crops during the current season SK-CGMS (National modification of European forecasting system CGMS). Outputs SK-CGMS represent spatially localized information on a regular square grid of 1 x 1 km. The content of this information is represented by the estimate of the time development in the biomass of agricultural crops as well as by the current state of the water balance of the soil profile in a day or 10-day step. VÚPOP runs an online mapping service Soil Portal, through which various information concerning the soil are published. Outputs of E-CGMS, however, are not currently made available for public in the form of online mapping services.

<u>Warning system - a brief description</u>
The warning system should operate as an online forecasting system of the state of water in the soil profile of agricultural soils in Slovakia. It should provide *real-time* and also historical data to model the state of soil moisture. Online forecasting system should behave as a web mapping service, which in specified spatial resolution (1 x 1 km), fixed time step (1 day) for a predetermined (future) period (10 days) publishes

information on the likely state of water reserves in the soil profile of agricultural soils in Slovakia. Forecasting system should be fully automated, i.e. the updated daily generated spatial models of soil water reserves will run without direct intervention from the system administrator. Online forecasting system should be integrated into existing web map service operated by some public institution (e.g. SHMÚ, NPPC-VÚPOP).

Ensuring the operation and administration of the warning system

Self- perceived is the development, integration and operational part of the warning system implementation.

Development and integration section presents particularly the following key tasks:

- Conceptual system level – expert resolving of the system linking of SK CGMS and forecasting ECMWF model on the level of data exchange (claims analysis of models , input-output analysis of models , design of system functionality , identification of key elements and processes, etc.)
- Development and implementation of system content elements: soil data, crop and crop phenology data, computational algorithms soil water balance and interpretation of outputs in terms of all identified system requirements,
- Establishment of functional forecast system based on weather data from the ECMWF model, computational algorithms and data (soil , crop) of SK - CGMS system using historical data - test the feasibility and functionality of created conceptual solution,
- System architecture (logic level) - design of the technical solution of the online forecast system (components, processes, data flows, distribution and publication of data, parallelization),
- Implementation and testing on-line forecast system - a functional applications and Web services establishment
- Integration of Web services into existing web application on the SHMÚ or NPPC - VÚPOP side (development and testing).

Operational section is aimed at ensuring system performance and at update the system established:

- Administration of hardware for data storage, analysis and management of inputs and outputs calculations (server),
- Administration of database system and web application, application and data management,
- Administration of Web application for data publication (conditionally, depending on the method of implementation),
- Update of the expert system - in terms of actualisation of the input data on soil, crops and their phenology, the model used for soil water balance calculation and interpretation of outputs.

Capacity requirements for the creation and operation of the warning system

Development and integration part (creation) represents a one-time requirement for the creation of a prototype of system, its full implementation and integration , including testing .

To ensure this part of the solution experts in the analysis of spatial data and spatial modelling, process modelling of soil water balance, geoinformatics (establishment of Web services and database security solutions) and computer science (management hardware and software) will be needed.

The time needed to complete prototype development, integration and testing of the system is estimated at 18 to 24 months .

Staffing requirements are estimated at 36 to 48 person-months .

Operating section presents the ongoing activities in managing and updating the system and solutions of one-time tasks associated with the operation of the system.

To ensure this part of the solution will be needed experts in the analysis of spatial data and spatial modelling, process modelling of soil water balance (system upgrade), geoinformatics (management of web services and database security solutions) and computer science (management of hardware and software). Staffing requirements are estimated at 12 to 18 person-months.

Demands on computational support of the system - hardware and software

Realization and implementation of the warning system at NPPC - VÚPOP under existing computing platforms causes the following requirements for the expansion of existing capacity:

- The database server - to store and manage data, meteorological data on a daily basis, spatial data, intermediate computations on multiple levels.
- Publishing server – distribution of attribute and spatial services (WMS, WFS, REST, SOAP)
- Backup server - data and services archiving
- Operating System (Linux Redhat 2x, 1x Windows Server)
- Oracle Database SDE + (1 + 1 license) - administration and data processing (Oracle - attribute data, SDE - spatial data)
- ArcGIS for Server (1 license + 1 maintenance on an annual basis) - spatial and attribute services publishing

The estimated one-time cost of hardware and software solutions are at 75 000 EUR.
The estimated annual cost of management and maintenance are 25 000 EUR.

3.6 Impact on the yield of field crops

Fig. 3 shows long-term average crop yields and its spatial pattern within the cropland of Slovakia (3a – winter wheat, 3b – spring barley, 3c – corn maize, 3d – potatoes). Highest average yields for all crops are observed in Danube lowland (SW part of Slovakia).
Spatial patterns of the relative deviation for above crops in 2011 and 2012 are displaed on Fig. 4 (winter wheat), Fig. 5 (spring barley), Fig. 6 (corn maize), and Fig. 7 (potatoes).

Fig. 3 Long-term (1997 – 2010) average yield (t/ha) of winter wheat (a), spring barley (b), corn maize (c), and potatoes (d)

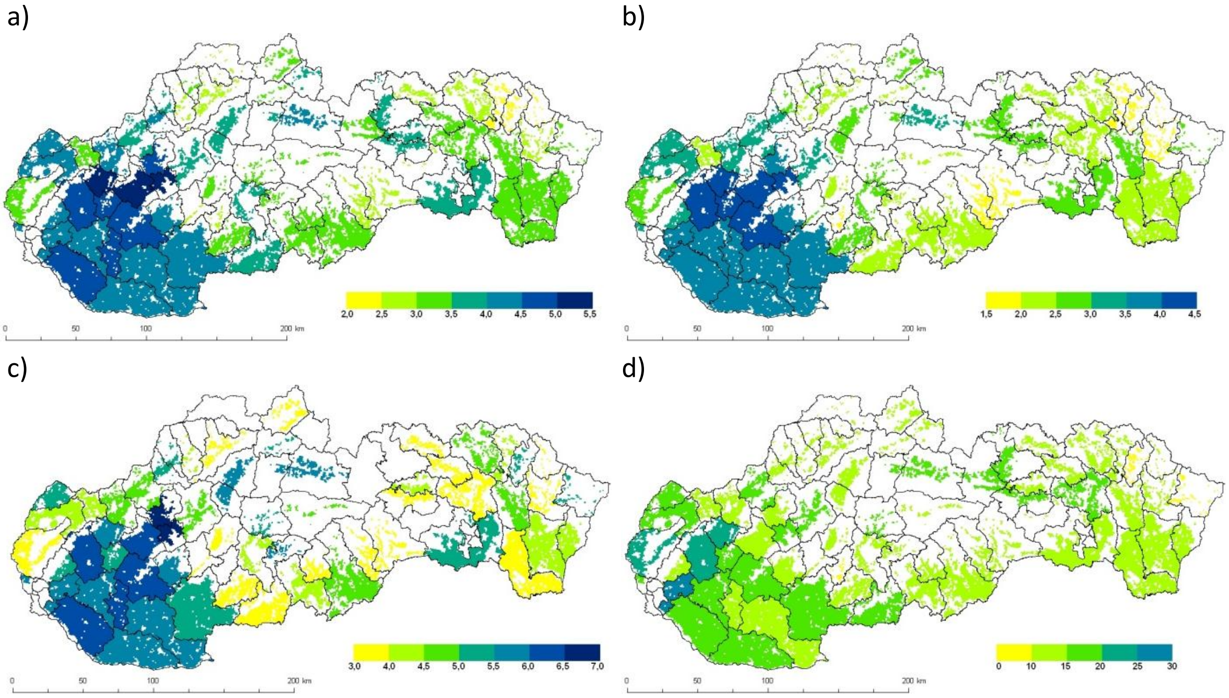


Fig. 4 Relative deviation (%) of winter wheat yield (t/ha) in 2011 (a) and 2012 (b) from long-term average yield for 1997 – 2010

a) b)

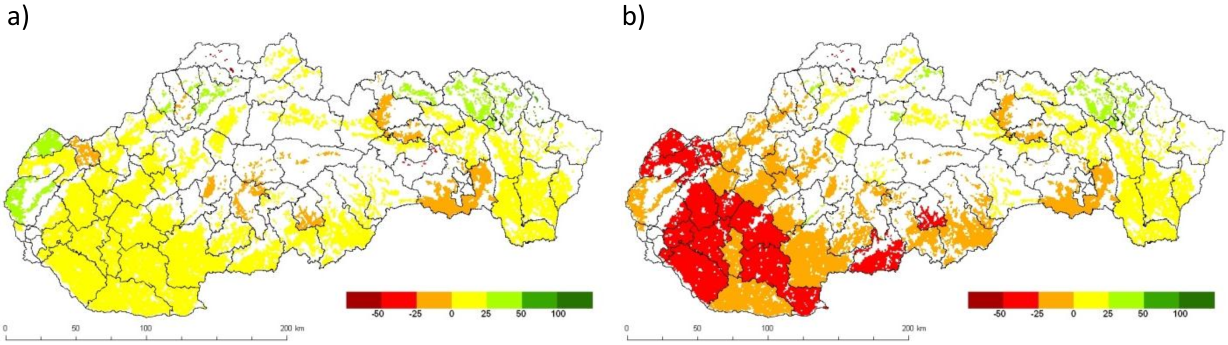


Fig. 5 Relative deviation (%) of spring barley yield (t/ha) in 2011 (a) and 2012 (b) from long-term average yield for 1997 – 2010

a) b)

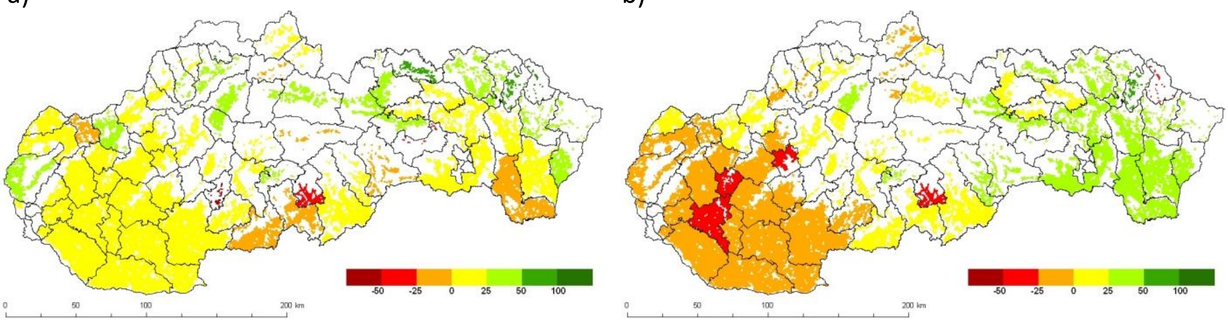


Fig. 6 Relative deviation (%) of corn maize yield (t/ha) in 2011 (a) and 2012 (b) from long-term average yield for 1997 – 2010

a) b)

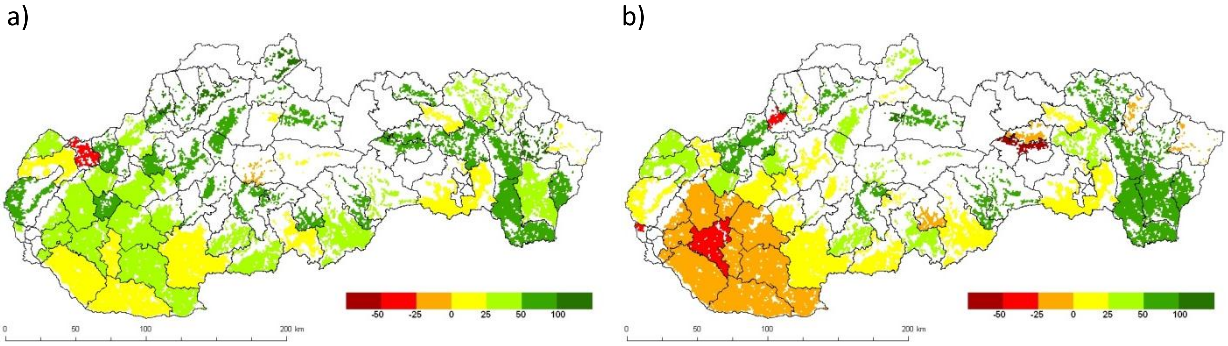
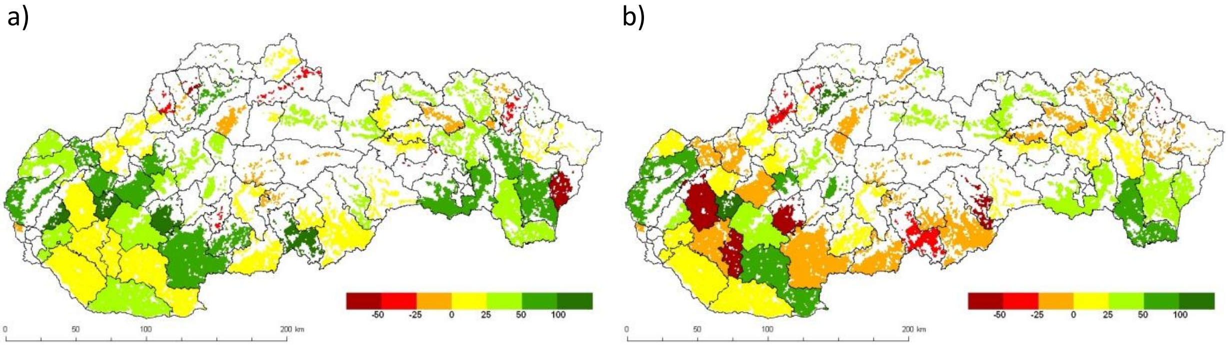


Fig. 7 Relative deviation (%) of potatoes yield (t/ha) in 2011 (a) and 2012 (b) from long-term average yield for 1997 – 2010

a) b)



Compared to long-term average yield, normal yield of winter and spring crops (winter wheat, spring barley) were observed for most regions of the Slovakia in 2011, slightly higher yields were observed mostly in northern regions of Slovakia. Different situation was recorded in 2012 where in western parts of Slovakia the yields were lower than long-term average, whereas in eastern regions yields attained were normal or higher then long-term average.

Higher yields than long-term average were observed for summer crops (corn maize, potatoes) in most regions of Slovakia in 2011, while the situation was worst in northern regions, where the attained yield was lower compared to long term average yield. In 2012 the spatial pattern of relative deviations for summer crops followed the pattern of winter and spring crops; i.e. lower yields than long term average in western regions and higher in eastern regions. Similar pattern was observed also for all other analysed summer crops.

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3.7 Conclusions

Based on the conclusions from respective chapters, it is clearly visible, that the intensity of the drought is not only influenced by the deficit of precipitation but also by the distribution of the precipitation throughout the year, air temperature distribution, snow accumulation in winter period and by other negative meteorological factors.

The same way it is possible to monitor and forecast the hydrometeorological situation during floods we can also monitor and forecast the drought. The main difference between the two is that the drought has softer time boundaries of its occurrence and end and that it can occur in each phase of the hydrological cycle with a considerable delay.

Although a solution for drought monitoring and forecasting is not operated by SHMI, it is generally possible and its development depends mainly on two factors: demand of the general public for such a solution and sufficiency of financial and personal resources.

4. EARLY WARNING SYSTEM AND DROUGHT STAGES

Early warning system is needed to deliver timely information to decision makers to reduce the impacts of drought.

Early warning system has been developed as a part of comprehensive assessment of the drought episode occurred in Slovakia during the period of 2011 – 2012. Data evaluation confirmed that operated monitoring system is sufficient for drought assessment using climatic, hydrologic and agricultural indicators: temperature, precipitation, river flow, groundwater level and soil moisture. The methodologies applied for assessment can be grouped into three groups:

- Methodologies used for processing of long-term series of meteorological measuring,
- Methodologies suitable for detailed assessment of chosen drought indicators over a period of drought duration and after ending of drought (ex post evaluation), namely annual, seasonal and closing evaluation of the drought event,
- Methodologies enabling evaluation of actual drought stage, that present basis for operation of early warning system.

All methodologies needed for comprehensive drought evaluation and production of DMP are described in capture 3.

Establishment of early warning system is a key step in process of drought management development. Currently four representative drought indicators can be included into this system:

- precipitation,
- river flow,
- groundwater level and spring-discharge,
- soil moisture.

4.1 Drought Stages – Thresholds

Four stages of drought severity have been suggested:

- ***Normal stutus*** – no or minor drought effects observed – none operational measures are required,
- ***I. drough status (pre-alert) – slight drought –*** activation of drought early warning system is needed (e.g. TV forecasting),
- ***II. drought status (alert) – moderate drought –*** activation of working group for drought assessment and operational measures are needed (e.g. get started or intensify drought impact monitoring

providing information on actual impacts on housholds, agriculture, aquatic and terrestrial ecosystems),

- ***III drought status (extreme) – extreme drought –*** operational measures are needed for mitigating of drought impacts (e. g. restriction of water abstraction).

The following thresholds have been selected for classification of drought stages:

- Normal status:
  - precipitation – actual cumulative values of precipitation lying in the interval ($^{+}$/-) 1 standard deviation from normal cumulative values for the period 1961-1990
  - river flow – 1. kvantil (120 až 80 % z $Q_{mes61\text{-}2000}$ – normal status of water balance),
  - groundwater level and spring-discharge – 1. kvantil (40-60 % of reference period 1981 – 2010)
  - Soil moisture - AI_{VV} - -0.72 till 0, KAI_{VV} - 99 till 0
- Slight drought (I. drought status):
  - precipitation – actual cumulative values of precipitation lying in the interval of minus 1 – minus 2 of standard deviation from normal cumulative values for the period 1961-1990
  - river flow – 2. kvantil (80 až 40 % from $Q_{mes61\text{-}2000}$ – subnormal status of water balance),
  - groundwater level and spring-discharge – 2. kvantil (10-40 % of reference period 1981 – 2010)
  - Soil moisture - AI_{VV} –1.15 till –0.721, KAI_{VV} –199 till –100
- Moderate drought (II. drought status):
  - precipitation – actual cumulative values of precipitation lying in the interval of minus 2 – minus 3 of standard deviation from normal cumulative values for the period 1961-1990
  - river flow – 3. kvantil (less than 40 % from $Q_{mes61\text{-}2000}$ – critical status of water balance),
  - groundwater level and spring-discharge – 3. kvantil ((<10 % of reference period 1981 – 2010)
  - Soil moisture – AI_{VV} –1.8 till –1.151, KAI_{VV} –299 till –200
- Extreme drought (III. drought status):
  - precipitation – actual cumulative values of precipitation under the border of minus 3 standard deviation from normal cumulative values for the period 1961-1990
  - river flow – values on the bottom of 3. kvantil interval of $Q_{mes61\text{-}2000}$ – emergency status of water balance
  - groundwater level and spring-discharge – values on the bottom of 3. kvantil interval of reference period 1981 – 2010),
  - Soil moisture - $AI_{VV} \leq -1.8$, $KAI_{VV} \leq -300$.

Effective early warning system requires:

- timely warning by providing information on actual drought status in real time,
- providing timely warning on drought severity to brought public namely to stakeholders potentially effected by drought in real time or near future.

Fulfilment of the first condition requires upgrading of current measurements carried out on the monitoring stations by increasing of metering frequency of the chosen indicators. A rational selection of representative monitoring stations is needed for this purpose so that the whole the Slovak territory will be covered by early warning points.

The second condition is applicable already on the present, for example by using technical means of SHMU to mediate information for public through web and/or electronic communications media (radio or TV broadcast).

Currently is not possible to include into early warning system any impact indicators enabling evaluation of actual effects on some threatened stakeholders (inhabitants, farmers, ecologists, fishers). Establishment of a comprehensive early warning system requires developing some impacts indicators such as impact on drinking water supply, environmental impacts (e.g. mortality of fish species, impact on wetlands (Natura sites), loss of biodiversity) and impacts on socio-economic uses (e.g. power production). Monitoring of impact indicators is needed especially when drought occurs and should be operational throughout the duration of the drought event.

The presented design of early warning system has not been tested yet. It is based mainly on the expert judgement using national and international experiences. After the testing phase the suggested thresholds can be calibrated and re-evaluated.

5. PROGRAM OF MEASURES

As stated above in chapter 2 implementation of effective drought management system requires adoption of wide range of measures, which can be aggregated into 5 groups (organizational, preventive, operational , follow up and restoration measures). The most important ones, which should be described in more detail in early stage of drought management and policy development, are as follows:

- organizational,
- operational,
- preventive.

5.1 Organizational measures

Organizational measures are needed primarily for:

- creation of drought management organizational structure,
- identification and involvement of relevant bodies and interested groups into the drought management system,
- establishment of drought working group,
- development of a DMP,
- activation of an early warning system,
- introduction of operational management during drought event,
- enforcement of program of measures adopted in the DMP.

It is clear that organizational measures are needed during all drought stages. But it is necessary to point out on their crucial role mainly at the beginning of the process presenting the first step inevitable for running the drought management system. Basic organizational measures should be focused on administrations arrangements needed for securing coordination of the whole process. The main responsibility is on the competent authority identified for application of drought management system. More detail description of organizational measures is presented in chapter 6 of this Report.

5.2 Operational measures

Operational measures are closely associated with the organizational measures. Drought working group should be responsible for proposition of appropriate operational measures which should be applied mainly during the alert and extreme drought stages. The main purpose of the operational measures is to react on actual drought situation by imposing the necessary measures with the aim to minimize an adverse impacts on the economy, social life and environment when drought appears (e.g. prohibition of watering, regulation of river flow, reduction of abstraction). Enforcement of these measures should be ensured by decision making authority and river basin authority (ED, municipalities, SRBE). The procedure for adoption and enforcement of appropriate operational measures should be elaborated in detail and included in the mandate of the drought working group.

5.3 Preventive measures

The preventive measures should be executed mostly during the normal status with the aim to increase resistance on drought and mitigate drought adverse impacts on the society, economy and environment.

Program of preventive measures are closely associated with an integrated water management in accordance with WFD, it means with RBMPs. Direct links between drought issues and integrated water management present groundwater quantitative status assessment and ecological status assessment of surface water bodies. These obligatory elements of RBMPs provide also initial data for assessment of drought occurrence and relevance.

The main criterion of a good quantitative status of groundwater is balance between water demands and availability of groundwater resources. In case of over abstraction when water demand exceeds the available water resources the respective water body is classified as a body in bad quantitative status. All appropriate measures have to be included in the program of measures of RBMPs in order to achieve good groundwater status (by 2015). The bodies identified in bad quantitative status usually face a water scarcity problems occurring during the normal drought status. Such groundwater bodies should be designated as a vulnerable areas inclined to drought occurrence. During hydrological drought an available water resources are declining and water demands are usually increasing (e.g. due to irrigation) what contributes to extension of areas impacted by water scarcity and drought.

Occurrence and assessment of drought severity is linked also with ecological status assessment of surface water bodies. One of the impacts of prolonged droughts is a deterioration of ecological status of surface water bodies (caused by changes of temperature and oxidation conditions) having impacts mainly on fish mortality. The temporary deterioration of ecological status caused by prolonged drought is not considered to be a breach of the requirement of WFD (Article 4.6 WFD). During the second planning cycle focused on updating of RBMPs is desirable to identify river passages impacted in the past by prolonged droughts with documented drought effects on ecological status.

Inevitable requirement for effective drought management is creation of complete database files summarising the basic quantitative data. The required data can be structured as follows:

- database containing data on water abstraction for different group of uses including seasonal alterations observed during the normal and drought status,
- water demand trends taking into account of long term forecasts of water supply and water demand with regard to climatic change (e.g. increasing water demands for irrigation),
- database containing data on available groundwater resources taking into account seasonal alterations and long term trends with regard to climatic change.

The mentioned data sets shall be processed as a part of obligatory water information system needed for production of RBMPs (Article 5 WFD). They present initial data for drought management needed for development of DMP and its program of mitigation measures.

5.3.1 Preventive measures relevant for Slovakia

Currently Slovakia is not a country suffering from a critical water scarcity. However there are many evidences documenting a considerable decrease of available groundwater resources, deterioration of water quality and increasing frequency of drought events. In order to stop and reverse an identified negative trends a comprehensive program of measures have to be developed within an integrated water management in accordance with WFD.

The suitable measures that could greatly improve quantitative water management (including drought management) can be grouped according the following goals:

a) measures for improvement of water governance,
b) measures focused on increasing of resistance against drought and mitigation of drought adverse impacts,
c) action plan for science and research drought program.

a) Measures for improvement of water governance

On the base of identification of shortcomings in the current status of implementation of WFD the following actions are suggested:

- to update and improve methodology for groundwater quantitative status assessment (mainly evaluation of available groundwater resources) and ecological status of surface water bodies with regard to drought occurrence and apply them during development of RBMPs and DMP,
- to improve metering and control of water abstraction (revision of issued authorizations and identification of illegal abstractions),
- to improve water supply management (update a register of water abstractions, update a water supply plans, evaluation of water demand trend),
- to ensure an evaluation of water scarcity indicator (index WEI+),
- to develop a water accounts at sub-catchment level in accordance with the EU guidelines developed in the CIS process,
- to ensure calculation of “eflows” (ecological flow – amount of water required for the aquatic ecosystem) for surface water bodies in accordance with guidelines developed in the CIS process,
- to identify a problematic areas facing a water scarcity and water supply problems and design a specific project with the aim to secure an access to water (based on the review of existing water infrastructure and available water resources),
- to develop water efficiency targets for river basins on the basis of water stress indicators developed in the CIS process (guidance will be available in 2014).

b) Measures focused on increasing of resistance against drought and mitigation of drought adverse impacts

The suggested measures are based on the policy options taken from strategy document of EC A Blueprint to Safeguard Europe´s Water Resources. They can be divided into two groups:

- water efficiency measures,
- measures for mitigating of drought impacts.

<u>Water efficiency measures</u>

One of the most important measures is implementation of ***pricing policies*** stimulating more efficient water use in the main water-using sectors. It is obligatory measure required in Article 9 of FWD. Improvement of metering is a pre-condition for implementation of incentive pricing policy. Article 9 also requires cost-recovery (including environmental and resource costs) for water services taking into account the polluter pays principle. The measures for fulfilment of Article 9 must be included in updated RBMPs.

Another priority measures contributing to reduction of water stress are linked with the problem of ***leakage from water distribution networks***. The situation in Slovakia is locally different and the leakage rates vary between 10 – 30 %. The problem can be tackled on a case-by-case basis. In order to achieve a sustainable economic leakage level it is recommended to develop a detailed investment plan.

<u>Measures for drought impacts mitigating</u>

Among the measures that can greatly contribute to limiting the negative effects of droughts (also floods) is ***"green infrastructure"***, particularly ***natural water retention measures***. These measures include restoring floodplains and wetlands, which can hold water in period of excessive precipitation for use in periods of scarcity. Green infrastructure can help ensure the provision of ecosystem services in line with the EU Biodiversity Strategy. These measures should be included in all planning documents – RBMP, DMP and Flood risk management plan. The program of water retention measures have to be fully coordinated and based on the principles of integrated water management when developing multi hazard risk management plans. To support an implementation of green infrastructure projects the EU guidelines development is in the CIS process (Blueprint, deadline 2014). These measures should become a priority for financing under the CAP, Cohesion and Structural Funds for the period 2014 – 2020.

In the structure of measures for improving affectivity of water holding in the farming landscape and for better water management an ***innovation activities*** and their application in the agriculture are highly perspective. Agricultural farm land covers approximately half of the Slovak territory extent. Limiting factor on this area is water having consequences on economic profit of agricultural production. On the other side agriculture is identified as one of the key sectors having impacts on water management (pollution, abstraction). From many reasons agricultural sector have an eminent interest on no deficit water balance in the land based on effective regulation of water regime. The progress can be achieved mainly through the following activities and measures:

- To apply soil water holding technologies in the land management increasing infiltration of water into soil profile and limiting water loses caused by discharge and evapotranspiration (deep root plants cultivation, organic fertilizers use, carbonized biomass use, and others – in accordance with results of demonstration project of IDMP (Act. 5.1)),
- To integrate a land consolidations with RBMPs,
- To enforce water conservation measures into financing mechanism for agricultural sector (mainly Agro environmental program of Rural Development Plan),
- To enforce a water conservation measures into the conditions of direct payments granted to farmers (through GAEC – Good Agricultural and Environmental Conditions),
- To incorporate a water conservation measures into the water protection law with the aim to change philosophy of water protection against soil taking (such provisions which are common in the soil policy of other countries are missing in the national legislation),
- To re-evaluate impacts of large area drainage system built in the past for water holding in the land and adopt a clear decision in the matter and outline of long term measures (nearly 20 % of the land area are drained),
- To elaborate Code of water management and protection in agriculture,
- To start working on development of the national strategy of *low water farming* systems in agriculture.

Another important water saving option which can be applied in the field of agricultural is development and enforcement of program of measures focused on improvement of ***irrigation efficiency*** in ways that are consistent with the WFD objectives. The intention of EC is to support this measure through requirements of minimal water consumption set for irrigation projects within the Rural Development Plan.

Complementary irrigation is considered to be an effective method for mitigation or elimination of water stress of crops. Prerequisite of the extension of irrigation systems is currently considered one of the most adaptation measures to mitigate the negative effects of a changing climate. The use of irrigation systems requires plenty of water and it is likely that the needs of field crops will be met only in part. Management of the irrigation system should be placed at a higher theoretical and technical level. Essential will be the implementation of efficient irrigation technologies.

A thorough analysis of the development and current status of the use of irrigation facilities defined measures to be taken in different directions and areas having the aim to use in more effective and efficient way the irrigation systems. In terms of forecast trends in consumption of irrigation water should be noted that the development of water uptake for irrigation purposes has declining, in recent years stabilized or non-increasing trend. This amount of irrigation water can be applied to an area where there are possibilities of irrigation water supply by facilities built in the state as well as private ownership, therefore about for 200-250 000 hectares. At present time the irrigation norm presents 20-25 mm per hectare. If we compare this irrigation amount to the soil water content which represents on irrigated land where irrigation facilities are built about 2 to 2,5 million m3 of water, we influence and regulate by irrigation only 1 % of soil water.

It is assumed that during the subsequent years until 2050 the irrigation water demand in major irrigation areas will rise from an estimated 310 million m^3 in 2010 to 585 million m^3 in 2050. At present, the consumption of water for irrigation is about 20-25 million m^3 per year. This figure does not reflect an actual need for irrigation water and even technical and organizational potential consumption of irrigation water. Currently, the lack of consensus is reflected in the outstanding management and ownership relations to the distribution systems of irrigation water, forming assets of hydromelioration devices. Potentially favourable hydrological balance of Slovakia mastered in the past (1986, 1990) without problems the annual consumption of irrigation water up to 300 million m^3.

The estimated demand of water needed for irrigation in quantities of 0,585 billion m^3 in 2050, currently is or will be in the future available potentially hidden in the sufficient accumulation capacities of water reservoirs (large and small dams have a total of 2 billion m3) and in the surface flows. Of the total volume of water in agricultural soils which is approximately 7 billion m^3 at a depth of 0.0 to 1.0 meters could increase this component also by irrigation and the other measures to about 8% of total soil water. It is a measure of the potential manipulation of soil water regime regulation.

Additional specific recommendations are related to the application of conservation and saving land farming systems under agro - environmental and irrigation measures to which belong:

- Contour tillage;
- Implementation of conservation crop rotations;
- Establishment of grassed infiltration belts;
- Greening of degraded lands;
- Reclamation of drained areas by disposal of drainage effect of the embedded system;
- Change of the drainage (accumulation) channels by limiting their functioning by creating obstacles (bales of straw or twiggery) on the valley wetland liner ecosystems;
- Renewal of permanent grassland to the original stable grasslands;
- Revitalization of old or implementation of new wetlands, small reservoirs and ponds on economically unused areas (fishponds, agriculture).

Another water saving option included in the Blueprint is ***water re-use for irrigation or industrial purposes.*** Currently this measure is used to a limited extent in the EU, as lack of joint environmental standards for water re-use constrain from its wider application. The regulatory instrument on standards for water re-use will be developed in the CIS process by 2015.

For execution of above mentioned options, measures and activities are necessary to elaborate detailed realization plans, which should linked with program of measures of RBMP and/or DMP. The following realization plans (or investment plans) could be sufficient:

- Plan (or program) for execution of natural water retention measures (green infrastructure projects),
- Realization plan for improvement of irrigation efficiency,
- Realization plan for reducing of leakage level from water distribution network,

- Realization plan for implementation of water re-use projects for irrigation or industrial purposes.

c) Action plan for science and research drought program

On the base of identification of specific research needs that could contribute to better understanding of drought, its impacts and mitigation alternatives a program of action have been suggested:

- Development of methodology for drought risk analysis, understanding of linkages between drought indicators and impacts, identification of drought hazard risk areas, archiving impacts of drought,
- Modelling of climatic, hydrologic, agricultural processes in their interconnection,
- Development of national methodology for eflows calculation,
- Evaluation of climatic change with regard to drought occurrence and its severity, methodology for distinction of impacts caused by climatic change from effects of human activities,
- Upgrading of wastewater treatment technology in connection with re-use of water for irrigation and industrial purposes.

6. DROUGHT MANAGEMENT ORGANIZATIONAL STRUCTURE

According to general guidelines for production of DMP (Report 2007) establishment of organizational structure for drought management is one of the key components of DMP. Drought is considered to be an all-society problem having significant social, environmental and economic impacts on various areas of society mainly on water supply (households), economic sector (agriculture, energy, tourism) and aquatic and terrestrial ecosystems. The organizational structure should reflect the multidisciplinary nature of drought and its impacts and it should include all appropriate government ministries, drought key experts and representative of public interest groups. The process for creating an effective organizational structure for drought management is connected with the critical need to coordinate all necessary activities (establishment of monitoring, early warning system, DMP development) of many key actors.

In order to establish a drought management organizational structure the following series of steps is recommended:

- Determination of competent authority for drought management,
- Identification of the main key players (decision makers on national and local level of touched sectors, professional institutions, stakeholders), that should be involved into the process of drought management,
- Establishment of working group for drought management consisting of representatives of identified key bodies and interested groups,
- Approval of mandate of the working group for drought management, specification of responsibility for individual persons (bodies, groups),
- Creation of coordination scheme of linkages among different management levels, sectors, institutions and interested groups,
- Creation of communication strategy among involved bodies, interested groups and brought public.

6.1 Determination of competent authority for drought management

Drought policy of EU countries has been developed jointly within the Common strategy for implementation of WFD, as in accordance with this Directive drought issue can/or should be integrated into the process of water management. According to Article 3 of WFD Member States had to establish a competent authority for WFD implementation by December 2003. It means that the body once identified as a competent authority for WFD is/or should be automatically responsible also for drought management. In Slovakia Ministry of Environment of the Slovak Republic (MoE) is a competent authority for water management and also for drought management. Determination of different authority responsible for drought management does not mean breaking of WFD, but can be risky for effective coordination of water policy with drought policy.

6.2 Establishment of working group for drought management

Working group for drought management should be established as a permanent commission consisted of officially nominated members representing ministries, decision making authorities, professionals providing expert services and interested groups (effected stakeholders). The organizational structure should have three levels:

- ***governing level*** – key resorts (ministries) responsible for drought issues within their sectorial competencies (Ministry of the Environment SK, Ministry of Agriculture and Rural Development SK, Ministry of Economy SK) and local decision making authorities (Environment departments, Slovak Environmental Inspectorate),
- ***professional level*** – professional institutions providing expert services (e.g. monitoring of drought indicators) for key ministries (SHMU, VUPOP, SVP, SOP),
- ***effected stakeholders*** - interested groups affected by drought, which could provide an actual information on drought impacts on water supply (municipalities represented by Association of municipalities, Water companies), agriculture (association of farmers, SPPK), energy production (chosen companies of power generation industry), fishery (e.g. Slovak Fishery Union).

Schematic diagram of drought management organizational structure designed for Slovak conditions is presented in Fig. 1.

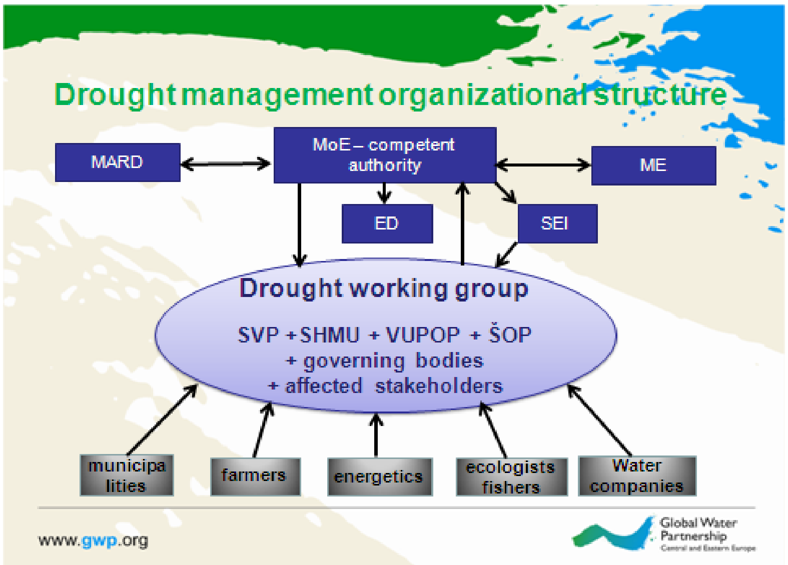

Fig. 1 Drought management organizational structure

Presented diagram illustrates that three key sectors (ministries) are responsible for drought issues. In order to establish inter-sectorial drought working group a Government decision and approval of drought policy is needed. This task is under responsibility of the competent authority (MoE).

6.3 Mandate of Drought Working Group (DWG)

The mandate of DWG should contain specification of the tasks which should be executed during the normal status and operating system for the period of drought duration.

The main tasks during normal status:

- To produce and update DMP as a part of planning process for RBMP development,
- To enforce preventive and mitigating measures adopted in DMP,
- To monitor and evaluate the affectivity of realized preventive measures.

The main tasks during the drought occurrence:

- To activate early warning system,
- To adopt and enforce an operational measures for mitigating od drought impacts (e.g. regulation measures),
- After ending of drought event to evaluate drought impacts and adopt the follow-up and restoration measures.

The DWG mandate should include specifications of duties assigned for all involved bodies, partners or groups:

- MoE – Ministry of the Environment of the Slovak Republic – competent authority responsible for drought management. The main tasks: coordination of the bodies involved into drought management, establishment and governing of the DWG, approval of DWG mandate, enforcement of program of preventive and mitigating measures adopted in DMP and operative measures during the duration of drought.
- MARD SK (Ministry of Agriculture and Rural Development), ME SK (Ministry of Economy) – key sectors responsible for elaboration and enforcement of DMP in accordance in their competencies,
- ED (Environmental departments) – decision-making authorities justified to issue regulations during the drought period (e.g. limitation of water abstraction) and decisions for enforcement of preventive measures during normal status adopted in DMP,
- SIZP (Slovak Environmental Inspectorate) – inspection body of MoE responsible for investigation of disasters caused by drought (e.g. fish mortality),
- SHMU (Slovak Hydrometeorological Institute) – professional institution of MoE responsible for monitoring of meteorological and hydrological drought indicators, operation of early warning system, drought evaluation,
- VÚPOP – professional institution of MARD responsible for continuous observation and evaluation of agricultural drought indicators and elaboration of program of measures for mitigating of agricultural drought impacts on agricultural output,
- SVP (Slovak River Basin Enterprise) – state enterprise - river basin administration responsible for observation and evaluation of surface water status, insurance of water quantity for surface water uses (e. g. water abstraction),
- SOP (State Nature Protection) – professional institution of MoE responsible for nature protection,
- Effected stakeholders – associations representing interest of drought effected groups – households, farmers, fishers, energy production and other. They should provide actual information on drought impact throughout duration of drought event.

A special part of DWG mandate should be focused on elaboration of communication strategy establishing interconnections among individual drought groups associated in DWG. The main stress should be laid on the development of forecasting system through early warnings for public (radio or TV forecast) and communication with competent authority, decision-making authorities and municipalities.

The drought management organizational structure has been developed as an initiative design from “bottom” in accordance with EC general guidelines (Report 2007). The draft respects competencies of all bodies involved into DWG. The study showed that expert core group (SHI, NPPC VUPOP) is currently capable to provide necessary services connected with drought management. Involvement of other key partners (governing groups, stakeholder groups) depends on the decision of the competent authority (MoE).

6.3.1 Gaps and uncertainties

One of the objectives of the Slovak case study was identification of the main gaps, uncertainties and shortcomings of the current drought management system in Slovakia. The main weaknesses are summarised in the following points:

- Officially drought is not considered to be a relevant issue of Slovakia, and therefore is not included in the scope of key problems and priority areas of the national water policy. Nevertheless, in terms of Convention UNCCE Slovak Republic is declared as an affected and also developed country.
- No state body has been officially charged with the production of Drought management plan within the second planning cycle of preparation of River basin management plans.
- One of the main week points of drought management is absence of drought impact indicators that are to be monitored during the drought episode so that to reflect direct adverse impacts of drought on water supply, agriculture, industry, energy production, recreation, tourism, fishery, aquatic and terrestrial ecosystems and other water use sectors. It is imperative to establish a network of observers to gather impact information from all of the key sectors affected by drought and to create an archive of this information. This information is of pronounced importance in identifying the correlations between thresholds of various drought indicators and drought stages and emergence of specific impacts. This information is also critically important to policy makers to identify effected stakeholders with the aim to establish targeted measures to minimize socio-economic and environmental impacts. This gap in drought management system requires execution of a research project focused on drought risk assessment (identification of impacted groups, identification of vulnerable areas, creation of central database of drought impact data, establishment of drought impact monitoring).
- Current monitoring program of representative drought indicators (temperature, precipitation, river flows, groundwater levels, soil moisture) enables to provide a comprehensive temporal and spatial drought assessment ex post (regular annual evaluation) or assessment with time delay of several months (e.g. 2 months for groundwater). Only some indicators (e.g. precipitation) can be evaluated continually. Currently, an operated monitoring system is not sufficient for running of reliable drought early warning system and has to be upgraded.
- Submitted design for establishment of drought management (its key components) has not been tested in a complex range. During the first phase is necessary to test the defined thresholds set for individual representative indicators and different drought stages and subsequently initiate revision of the tentative early warning system. The substantial corrections can be done after establishment of drought impact indicators and monitoring of impacts on water supply, economic activities, and aquatic and terrestrial ecosystems. The interconnection of monitoring of meteorological, hydrological, agricultural drought indicators with monitoring of drought impact indicators is considered to be a crucial step in the drought management process.

7. CONCLUSIONS AND RECOMMENDATIONS

The Slovak case study resulted in the following findings:

- It was documented that frequency and relevance of drought occurrence during the last 20 years is increasing and therefore drought should be considered as a relevant water management issue of Slovakia. The last drought episode occurred during the years 2011 – 2012 confirmed that substantial part of Slovakia was affected by drought. The production of the Drought management plan is therefore a well-founded requirement. In accordance with WFD (article 13.5) DMP shall be produced as an additional plan within an actualization of RBMPs during the second planning cycle (deadline December 2015). DMP will be the main instrument through which a national drought policy is executed.

- Slovakia has established a competent authority for integrated water management in accordance with WFD requirements (Ministry of the Environment of Slovak Republic - MoE) In line with Article 3 of this Directive MoE is responsible also for coordination drought issues and activities needed for development of DMP including establishment of the multi-sectorial drought management working group. This working group can be created from representatives of existing governmental bodies (MoE, Ministry of Agriculture, and Ministry of Economy), professional institutions dealing with drought issues that already exist and representative of stakeholders impacted by drought. There is no need to set up new institutions for implementation of risk based national drought policy. The start of the process for development of drought policy depends on the decision of MoE having all competencies for running all necessary actions.
- Rather high volume program of basic drought indicators needed for drought assessment (temperature, precipitation, river flow, groundwater level) is being monitored by hydro met services (SHMU). Data are regularly assessed at the end of hydrological year. Density of monitoring network is sufficient for reliable temporal and space drought assessment of preceeding year (ex post assessment).
- Activation of drought early warning system requires continuous assessment of actual drought stages of the representative indicators on daily basis. To do this a further extension of monitoring system by observation stations with on-line data collection is inevitable.
- Monitoring of drought indicators reflecting the impacts of drought on public, economy and water and terrestrial ecosystems is missing. Absence of central database of this information is considered to be one of the main shortcomings for establishment of effective drought management system.
- Securing of a reliable water supply data (with regard to users), data on availability of water resources during normal and drought period, trends of water consumptions and water availability, as well as data on quantitative groundwater status assessment, ecological surface water status assessment and information relating to condition of terrestrial ecosystems (e.g. wetlands) is further fundamental prerequisite for functioning of drought management system. The databases of this information present basic data for production of RBMP and are obtained during the planning cycle according to WFD.
- Effective measures for drought prevention and mitigation of negative drought effects (e.g. green infrastructure, measures for reduction of leakage from water distribution networks, improvement of irrigation efficiency, water re-use for irrigation or industrial purposes) are applied in minor extent and very often as uncoordinated actions. While implementing their efficiency is not evaluated.

The following steps below provide an outline of action program needed for establishment of functioning drought management system in Slovakia:

- To initiate development of a drought national strategy document at MoE based on the principle of drought risk based management. Key elements of drought planning process (organizational structure, early warning system, program of measures) are to be elaborated in detail utilising also Slovak case study results. The stress should be laid on creating of inter-governmental drought working group specifying competencies and duties of effected sectors. The strategy document shall be submitted to the Government for approval.
- To establish drought management working group consisting of representatives of affected sectors, professional institutions and impacted stakeholders. Subsequently to elaborate and approve a mandate of established working group.
- To activate drought early warning system (public warnings through TV forecasting) based on suggested drought indicators system and defined drought stages (pre-alert, alert, extreme).
- To create or extent a drought impact monitoring system composed of indicators signalling occurrence of socio-economic drought (e.g. impact on water supply, industry, agriculture, energy production, tourism) and impacts on water and terrestrial ecosystems (wetlands, ecological status of surface water bodies).

- To upgrade monitoring network (meteorological, hydrological) and increase a number of observation stations with on-line metering of chosen indicators (precipitation, temperature, river flow, and groundwater level and spring-discharge) needed for running of drought early warning system.
- To produce a Drought management plan as a part of RBMPs within the second planning cycle in accordance with WFD.
- To update and complete database containing mainly quantitative data (abstraction, available water resources, current status and future trends) needed for groundwater quantitative status assessment and ecological status assessment of surface water bodies. Databases primarily created for production of RBMPs present an initial data also for development of DMP. In order to enhance and complete existing databases the calculations of “eflows” (i.e. ecological flow – amount of water required for preservation of aquatic ecosystem) in river basins are needed. Additional actions focused on improvement of quantitative water management are associated with the development of “water accounts” (water balance in river basin and sub-catchment level). The EU guidelines for identification of both parameters are under preparation within CIS process.
- The program of prevention and mitigation measures applied when drought impacts appear shall be elaborated in DMP. Some measures suggested for the “normal status” should be included in the RBMPs (measures associated with bad quantitative status of groundwater and water scarcity issues). The production of both planning documents (DMP and RBMP) has to be coordinated and interconnected.
- In order to achieve systematic and effective progress a certain groups of measures for drought impacts mitigation should be elaborated in the form of investment plans (e.g. plans for green infrastructure projects, plans for water re-use for irrigation or industrial purposes, plans for improvement of irrigation efficiency, plans for reducing of leakage from water distribution networks). Also catalogue of measures could be an appropriate source of information for selection of cost-effective measures.
- Within the framework of scientific and research works to secure a comprehensive drought risk assessment of Slovak territory based on historical data on drought occurrence with the aim to identify the most vulnerable areas responsive to droughts.
- To initiate within the framework of scientific and research program an assessment of climatic change impacts on water balance (precipitation, recharge, water regime), water bodies and water users (households, agriculture, industry). The main objective is to distinguish effects of climatic change from changes of environment caused by man-made activities (e.g. afforestation).

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