

Hydrological Hazard Assessment by Index Methods in Eastern Slovakia

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Hydrological Hazard Assessment by Index Methods in Eastern Slovakia

- ▣ Thesis of the research:
- ▣ i) Mathematical and statistical evaluation of hydroclimatological data.
- ▣ ii) Comparative study of meteorological and hydrological drought evaluation using drought indexes.
- ▣ iii) Modeling of hydrological extremes and determination of their basic characteristics.
- ▣ iv) Research on regression relationships in river basins.
- ▣ v) Interpretation of time series evaluation results and spatial analysis using geographical information technology tools.
- ▣ vi) Development of recommendations in the field of drought mitigation by taking into account the requirements of meteorology, climatology and hydrology as a basis for the preparation of drought management plans in Slovakia.

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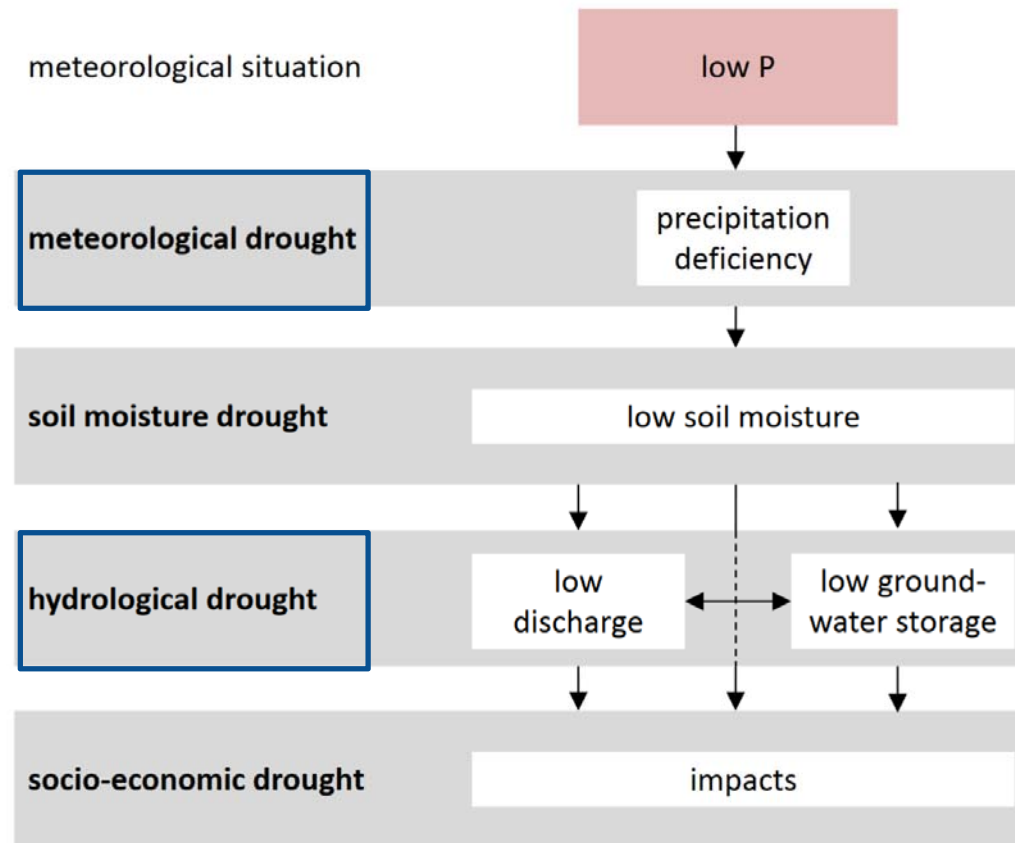


Figure 1.1: Scheme representing different categories of drought and their development (derived from Stahl [2001]; Peters [2003]). P = precipitation. (Loon, 2013)

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- ▣ Factors affecting drought in the temperate climate zone:
- ▣ **Morphological** conditions in the catchment area (catchment area, average altitude, average river basin slope).

Geological and hydrogeological conditions in the catchment (composition and condition of the soil, type and composition of the vegetation, impact of the relief, occurrence of natural and artificial reservoirs, availability of groundwater reserves).

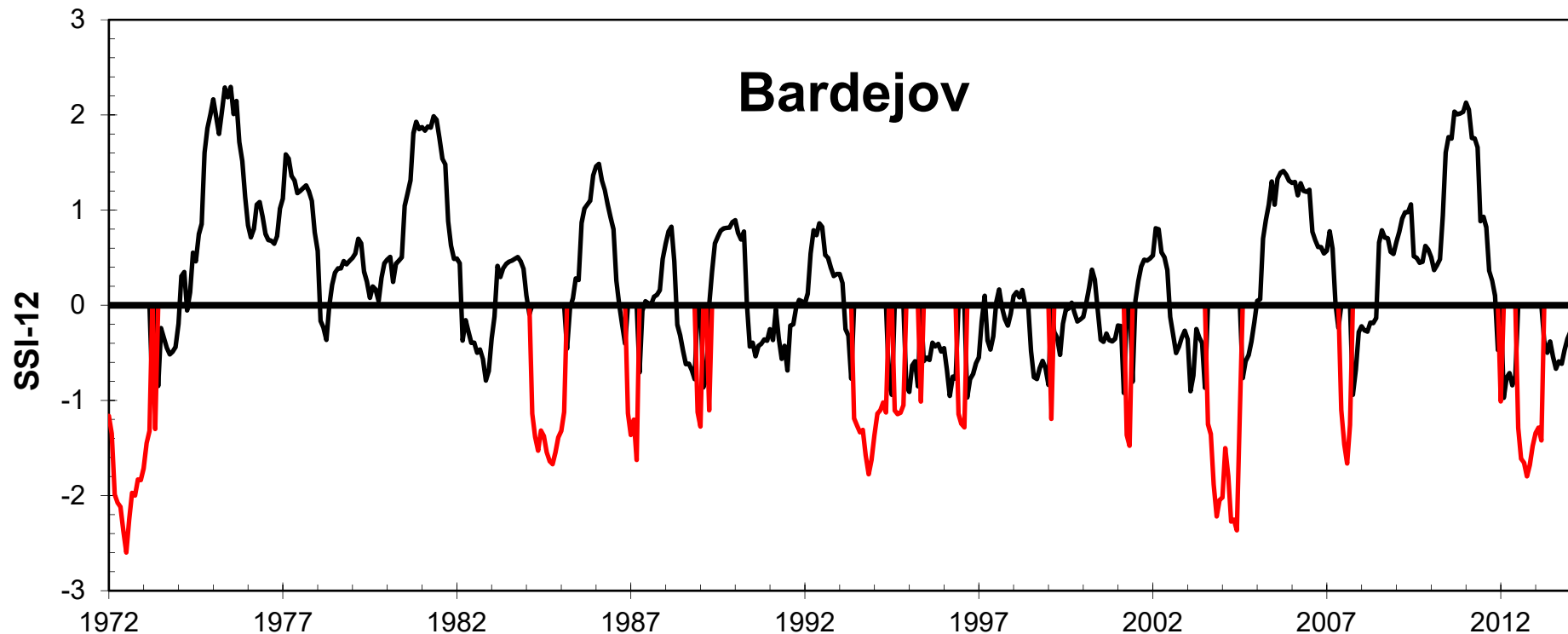
Climatic factors (precipitation, temperature, evaporation, snow cover, wind flow).

Anthropogenic impacts (surface treatment and soil structure by agro-technical measures, deforestation, urbanization, excess water abstraction and others).

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□ Drought indices:

- 1) SPI - Standardized Precipitation Index (McKee et al., 1993)
- 2) SSI - Standardized Streamflow Index (Nalbantis, 2008)



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Basic Drought Characteristics (Mishra et al., 2010):



Drought **Duration** (Dd) - is the period in which the drought parameter is constantly below the critical level



Drought **Severity** (Sd) - represents the cumulative drought parameter deficit below the critical level.



Drought **Intensity** (Id) - represents the proportion of severity and duration of drought.



Time between two droughts (Td) - defined as the time that elapses between the start of a drought event and the start of the next drought event.

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Raingauge station / River station	Water stream	HG index (transmissivity of the basin)	Forestry (%)	Altitude (m)	Slope (‰)
Bardejov / Bardejov	Topľa	163	55	596	13,2
Červený Kláštor / Červený Kláštor	Dunajec	142	50	960	16,6
Kamenica nad Cirochou / Humenné	Laborec	130	57	420	11,2
Vysoká nad Uhom / Ižkovce	Laborec	172	44	328	8
Štós / Medzev	Bodva	114	70	632	16,4
Tisinec / Svidník	Ondava	116	43	424	8,6
Skalnaté Pleso / Ždiar	Biela voda	239	44	1518	27

SHMI BO Košice - average daily flow and precipitation - 1970-2014
- physico-geographical characteristics

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▣ I. Statistical data processing

- ▣ Preparation of statistical files - grouping into 1, 3, 12, 24 time intervals.

Identification of basic statistical parameters.

Statistical File Testing - Pettit test (Pettit, 1979) with a confidence level $\alpha = 5\%$.

II. Calculation of SPI and SSI indices by nonparametric method

III. Calculation of SPI and SSI indexes by parametric method

IV. Spatial distribution of drought presented by using GIS

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Statistical data processing

Preparation of statistical files - grouping into 1, 3, 12, 24 time intervals.

Identification of basic statistical parameters.

River station	Statistics	Discharges in time scale d:			
		1	3	12	24
Svidník	Minimum	0,1015	0,1518	0,5983	0,8840
	25% Percentil	0,4901	0,7199	1,275	1,407
	Median	1,105	1,392	1,626	1,711
	75% Percentil	2,131	2,374	2,005	1,971
	Maximum	11,48	7,020	3,442	2,792
	Average	1,687	1,687	1,681	1,687
	Variance	1,751	1,209	0,5187	0,3479
	Skewness	2,114	1,059	0,5018	-0,05521
	Sharpness	5,384	0,9828	-0,02569	-0,5202

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Statistical File Testing - Pettit test (Pettit, 1970) with a confidence level

	Prietoky	1M	3M	12M	24 M	Zrazky	1M	3M	12M	24 M
2	Bardejov									
3	change point	139	117	120	132		28	391	324	333
4	Pettit stat.	9381	10809	18540	24538		3035	4869	16143	22564
5	p value	Discharges							2,33E-05	4,61E-10
6										
7	Bardejov	1M	3M	12M	24 M				285	297
8	change point	139	117	120	132				34128	44982
9	Pettit stat.	9381	10809	18540	24538				1,79E-22	9,97E-39
10	p value									
11									392	393
12	p value	0,0431	0,0122	6,23E-07	8,00E-12				10328	17098
13	p value	0,1130351643	0,0127560848566149	6,25E-08	1,42E-15		1,301337413235	1,13719854373278	0,019135326	5,85E-06
14	Izkovce									
15	change point	89	93	132	132		315	306	298	308
16	Pettit stat.	7305	7897	17368	22370		6497	8604	15022	22260
17	p value	0,0885858192	0,0523685751804016	4,46E-08	4,04E-13		0,317676282697	0,0793744333820326	0,000106986	8,34E-10
18	Medzev									
19	change point	174	178	177	180		388	390	392	396
20	Pettit stat.	17316	17490	26583	35818		7895	11712	27422	35298
21	p value	4,2174615429	3,23897616219154e-06	8,40E-14	1,04E-24		0,132165247326	0,0050630697732303	1,17E-14	5,19E-24
22	Svidnik									
23	change point	111	115	32	130		376	389	320	392
24	Pettit stat.	5314	6795	10420	12354		3817	6342	19934	27213
25	p value	0,5840896705	0,267302870344647	0,017607691	0,002581914		1,059821543241	0,346462241203138	6,01E-08	1,92E-14
26	Zdiar									
27	change point	128	282	283	214		232	294	283	295
28	Pettit stat.	3709	3724	12369	15796		6640	11017	38800	52479
29	p value	1,0980421756	1,09271887667935	0,002540515	3,78E-05		0,292700506426	0,0100795501445127	6,36E-29	1,47E-52

II. Calculation of SPI-1 a SSI-1 by nonparametric method

Let $x_1, x_2, \dots, x_N$ be a sequence of N observations of the precipitation variable X_d , where $x_{(1)} \leq x_{(2)} \leq \dots \leq x_{(N)}$ is relative statistics. For i -th statistical order $x_{(i)}$, the cumulative frequency is determined by the relationship:

$$\diamond F_N(x_{(i)}) = i/(N+1)$$

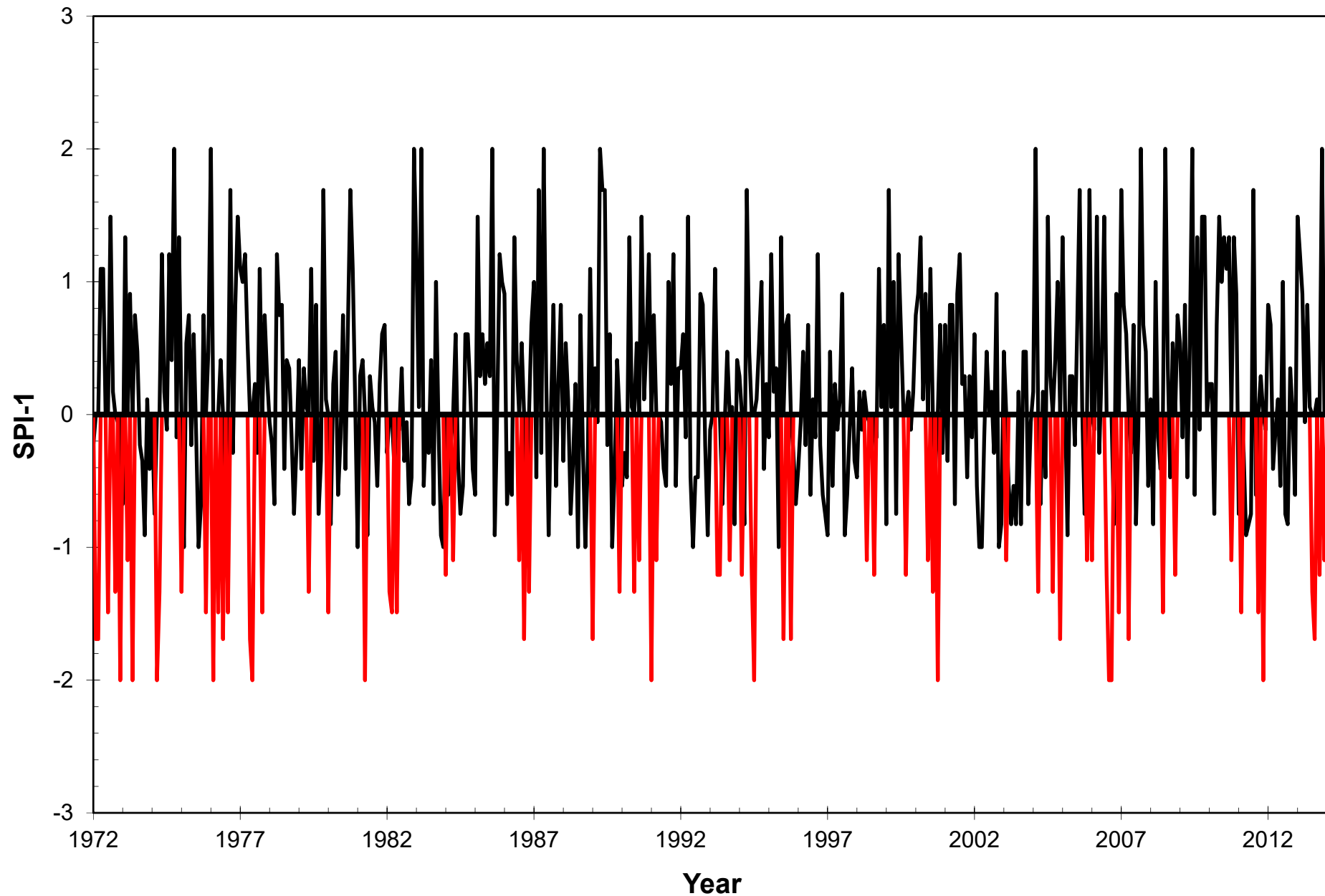
i – serial number, $i = 1, 2, \dots, N$;
 N - number of observations.

Then the standardized precipitation index Z_d is defined as the inversion of the cumulative standard normal distribution (Φ^{-1}) $F(x)$ (McKee et al. 1993):

$$\diamond Z_d = \text{SPI} = \Phi^{-1}(F(x))$$

Identification of basic drought characteristics.

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	Bardejov	Červený Kláštor	Humenné	Ižkovce	Medzev	Svidník	Ždiar
Parameters of meteorological drought identified by SPI-1							
Duration	72	72	72	72	72	72	72
Severity	-105,7	-104.1	-105,8	104,7	-103,3	-104,6	-103,1
Intensity	-1,49	-1,50	-1,46	-0,74	-1,43	-1,44	-1,48
Time	61	65	64	61	61	64	63
Parameters of hydrological drought identified by SSI-1							
Duration		72	72	72	72	72	72
Severity		-102.8	-105,8	102,1	-103,0	-102,6	-104,6
Intensity		-1,35	-0,97	-1,35	-1,38	-1,41	-1,42
Time		41	55	41	34	45	47

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III. Calculation of SP 1, 3, 12, 24 – monthly p

➤ Selection of the m
from 11 function
of its parameters
(Kottegoda and R

➤ Calculation of the
❖ $F(x) = P_0 + (1 - P_0) * \dots$
where:

P_0 – probability of occu
 N_0 – number of zeros in
 N – number of observa

➤ We get Z values by
❖ $\Phi^{-1}(F(X)) = Z \approx N(0, \dots)$

➤ Identification of ba

Počet	Názov funkcie	Kumulativna funkcia pravdepodobnosti $F(x)$	Parametre
1	Gamma 3P	$F(x) = \frac{\Gamma_{(x-\gamma)/\beta}(\alpha)}{\Gamma(\alpha)}$	α, β, γ
2	Weibull 3P	$F(x) = 1 - \exp\left(-\left(\frac{x-\gamma}{\beta}\right)^\alpha\right)$	α, β, γ
3	Gen. Extreme Value		
4	Normal		
5	Gen. Gamma 3P		
6	Lognormal 3P		
7	Burr 3P		
8	Inv. Gaussian		
9	Pearson 5		
10	Pearson 6		
11	Log-Logistic 3P		

	A	B	C	D	E	F	G
1	1972	26,9	0,417847	-0,20194	9,2	0,073932	-1,44712
2	1973	22	0,287437	-0,58089	56,2	0,914218	1,367193
3	1974	28,6	0,460885	-0,03862	16,2	0,203132	-0,83049
4	1975	12,9	0,056854	-1,58174	13,7	0,151856	-1,02851
5	1976	77,5	0,978938	2,03228	1,8	0,003367	-2,70976
6	1977	53,2	0,868918	1,12129	54,1	0,898076	1,270664
7	1978	28,4	0,455901	-0,19377	27,6	0,467394	-0,08182
8	1979	39,5	0,69279	0,80377	19,9	0,285894	-0,56542
9	1980	11,3	0,026858	-1,32913	14,8	0,17384	-0,9391
10	1981	16,8	0,148436	-1,04317	33,1	0,590206	0,228075
11	1982	26	0,394496	-0,28762	11,5	0,111107	-1,22066
12	1983	54,7	0,881604	1,18334	30,1	0,524669	0,061875
13	1984	16,4	0,138257	-1,08819	17,4	0,229237	-0,74136
14	1985	22,8	0,309133	-0,48821	58,3	0,92823	1,462737
15	1986	50,5	0,843195	1,08198	16,4	0,207423	-0,81539
16	1987	51	0,848252	1,02867	17,8	0,238116	-0,71238
17	1988	24,4	0,35219	-0,37942	40,4	0,729197	0,610387
18	1989	10,9	0,020453	-2,04448	33,2	0,592318	0,233511
19	1990	22,9	0,311839	-0,49394	27,2	0,458064	-0,10531
20	1991	9,8	0,005999	-2,51223	44	0,785215	0,789927
21	1992	38,6	0,676833	0,49598	40,8	0,735847	0,630593
22	1993	27,4	0,430658	-0,1747	30	0,522418	0,056224
23	1994	36,9	0,645088	0,37209	11,8	0,116386	-1,19325
24	1995	27,1	0,422986	-0,19428	54,3	0,89971	1,279902
25	1996	23,3	0,322648	-0,48931	29,3	0,506562	0,016449
26	1997	18,4	0,190224	-0,87737	33,8	0,604879	0,265996
27	1998	23,1	0,317247	-0,47541	31,9	0,56448	0,162338
28	1999	19,6	0,222351	-0,78428	67,3	0,968738	1,862563
29	2000	49,8	0,835881	0,97767	53,9	0,896421	1,261417
30	2001	41,8	0,730931	0,81963	23,1	0,361112	-0,35549
31	2002	40,8	0,71481	0,98749	17,5	0,231449	-0,73408
32	2003	39,7	0,696256	0,51388	12,6	0,130906	-1,12212
33	2004	31,9	0,539677	0,05892	74,2	0,984623	2,160251
34	2005	64,5	0,941348	1,38819	30,7	0,53809	0,095623
35	2006	16,7	0,145879	-1,05427	28,1	0,479001	-0,05266
36	2007	71,8	0,966591	1,8329	44,1	0,786648	0,794844
37	2008	30,2	0,49993	-0,03018	14,8	0,17384	-0,9391
38	2009	40,5	0,709836	0,95291	27,7	0,469721	-0,07597
39	2010	35,8	0,623428	0,3146	33	0,588089	0,222632
40	2011	20,5	0,246695	-0,85463	9,6	0,079955	-1,40537
41	2012	49,9	0,836943	0,98197	42,2	0,758284	0,700793
42	2013	65,4	0,945183	1,38284	54,3	0,89971	1,279902
43	2014	30,2	0,49993	-0,03018	33,6	0,600713	0,255192
44							
45		Weibul		Burr			
46	alfa	1,4657			485,27		
47	beta	27,269			1,916		
48	gamma	8,9671			685,87		

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	Bardejov	Červený Kláštor	Kamenica nad Cirochou	Somotor	Štós	Tisinec	Skalnaté Pleso
Parameters of drought identified by SPI-1							
Duration	84	92	92	82	77	86	97
Severity	-129,9	-134,3	-135,4	-123,2	-114,6	-125,0	-161,1
Intensity	-1,52	-1,47	-1,47	-1,54	-1,49	-1,44	-1,68
Max. duration	3	3	3	3	4	2	2
	2006	2008	1976	2003	2006	1972	2005
	VII	IV	VI	IV	IX	XI	IX
Time	70	80	79	67	65	75	79
Average drought return time	7,43	6,55	6,57	7,59	7,71	6,9	6,6
Parameters of drought identified by SPI-3							
Duration	79	93	82	93	90	88	81
Severity	-123,8	-133,1	-123,2	-132,4	-131,6	-130,2	-122,6
Max. duration	5	7	6	8	6	4	9
	1983	1972	2003	1992	2001	1972	2014
	XII	VIII	III	II	XII	XI	IV
Time	37	45	43	47	41	49	38

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	Bardejov	Červený Kláštor	Kamenica nad Cirochou	Somotor	Štós	Tisinec	Skalnaté Pleso
Parameters of drought identified by SPI-12							
Duration	78	82	81	80	80	82	77
Severity	-117,4	-121,4	-124,2	-122,2	-127,2	116,9	119,7
Intensity	-1,39	-1,25	-1,36	-1,36	-1,41	-1,35	-1,41
Max. duration	9	24	12	12	21	10	10
	2003	1972	1986	1992	1992	1986	1979
	V	I	XI	VII	VII	XI	X
Time	28	22	29	20	14	26	20
Average drought return time	19,42	24,23	18,14	26,78	36,8	20,36	26,78
Parameters of drought identified by SPI-24							
Duration	74	74	78	89	87	78	82
Severity	-114,1	-115,8	-121,3	-134,1	-131,7	-119,2	-122,5
Max. duration	20	26	13	25	32	11	13
	1983	1972	1986	1992/	1992	1994	1987
	X	VI	VIII	VII	VIII	VII	VII
Time	18	13	22	14	10	24	19

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	Bardejov	Červený Kláštor	Humenné	Ižkovce	Medzev	Svidník	Ždiar
Parameters of drought identified by SSI-1							
Duration	85	74	80	64	80	89	87
Severity	-126,5	-117,5	-119,2	-101,17	-124,7	-128,8	-127,8
Intensity	-1,37	-1,50	-1,44	-1,45	-1,44	-1,41	-1,46
Max. duration	6	5	5	5	6	5	7
	2003	1986	1986	2007	2002	1986	1986
	VIII	VII	IX	IV	I	IX	IX
Time	50	45	57	39	36	55	51
Average drought return time	10,38	11,02	9,14	12,23	14,4	9,4	10,1
Parameters of drought identified by SSI-3							
Duration	77	79	83	69	88	80	83
Severity	-120,3	-116,2	-124,1	-105,0	-127,4	-122,1	-122,9
Max. duration	8	7	10	6	14	6	8
	2003	1986	1983	1986	1989	1983	1986
	VII	VII	VIII	X	IX	XII	IX
Time	31	35	34	29	21	37	36

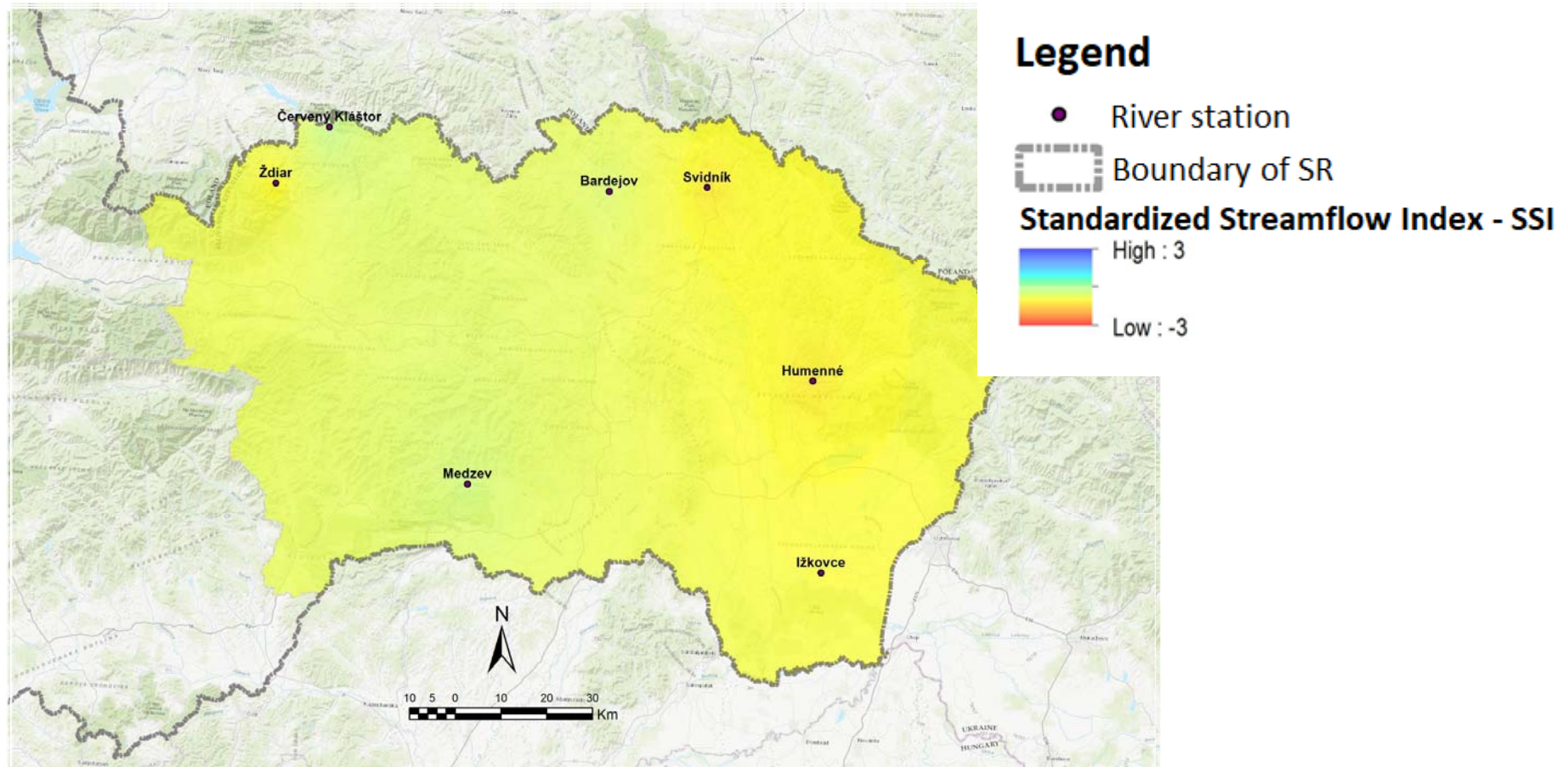
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	Bardejov	Červený Kláštor	Humenné	Ižkovce	Medzev	Svidník	Ždiar
Parameters of drought identified by SSI-12							
Duration	85	86	86	78	84	84	84
Severity	-127,6	-122,2	-127,3	-116,6	-130,1	-125,9	-119,9
Intensity	-1,32	-1,26	-1,39	-1,32	-1,42	-1,31	-1,30
Max. duration	15	13	12	13	25	13	17
	1972	1993	1986	2003	2002	1984	1986
	I	V	XII	II	IV	II	VIII
Time	17	22	15	11	9	18	20
Average drought return time	31,6	23,6	33,67	36,1	60	29,82	26
Parameters of drought identified by SSI-24							
Duration	85	85	70	91	83	94	94
Severity	-131,3	-124,9	-108,6	-127,6	-122,9	-132,9	-136,6
Max. duration	21	37	12	17	31	23	22
	1994	1993	2003	2003	1989	1972	2012
	III	VIII	VII	VI	IV	VII	VII
Time	8	9	14	14	8	10	9

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IV. Spatial distribution of drought presented by using GIS

The basis for the spatial analysis of drought risk was used values :



Spatial identification of long-term hydrological drought in 2011

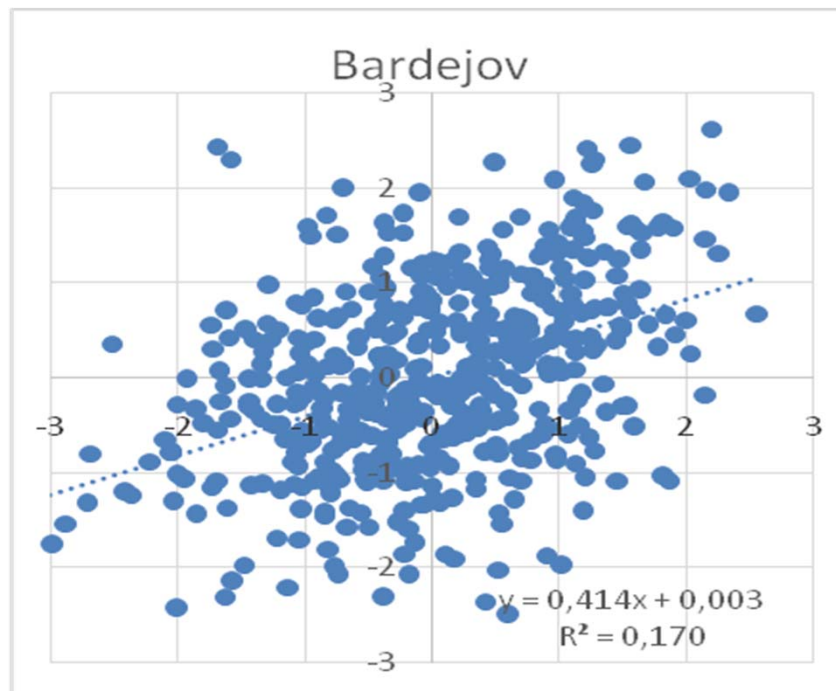
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Regression relations between meteorological and hydrological drought

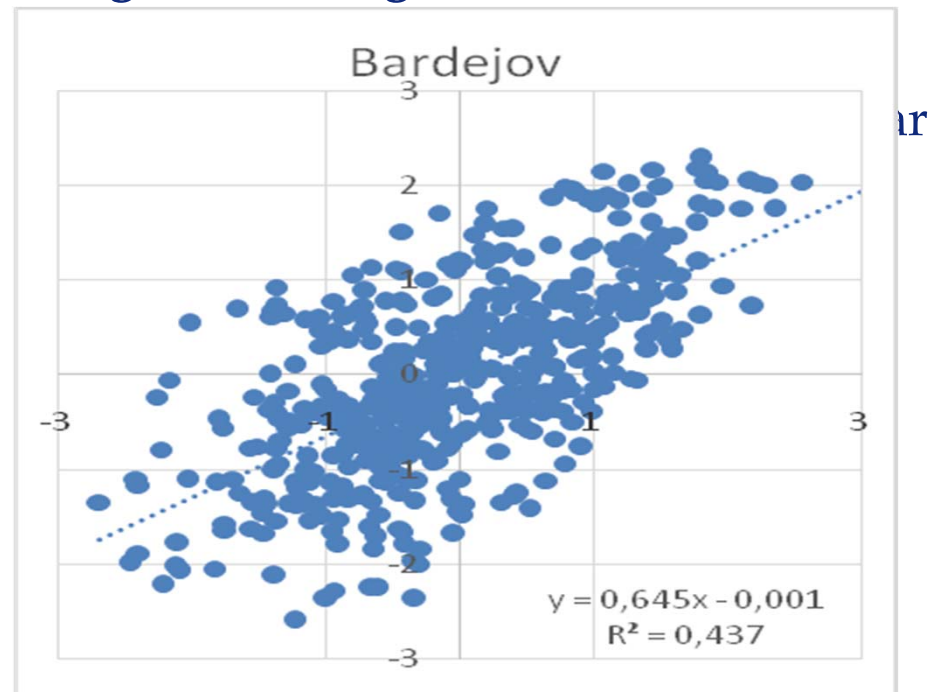
Climatic factors in the river basin are able to significantly influence the course of hydrological drought (Szolgay et al., 1994).

Using the **linear regression coefficient R** was identified the rate of dependance between precipitation deficits (SPI-1, SPI-12) and flow deficits (SSI-1, SPI-12) v stations.

Short-term drought



Long-term drought



Hydrological Hazard Assessment by Index Methods in Eastern Slovakia

Benefits of the research:

- i) Statistical evaluation of hydroclimatological data.
- ii) Comparative study of meteorological and hydrological drought evaluation using drought indexes.
- iii) Identification, analysis and evaluation of interrelationships between meteorological and hydrological drought.
- iv) Research on regression relationships in river basin.
- v) Modeling of hydrological extremes and determination of their basic characteristics.
- vi) Identification of drought return time.
- vii) Development of **recommendations** in the field of drought mitigation by taking into account the requirements of meteorology, climatology and hydrology as a basis for the preparation of drought management plans in Slovakia.

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Recommendations to mitigate drought impacts:

- 1) Developing a multidimensional drought analysis using the **Copula** method
- the obtained **basic characteristics of hydrological drought** obtained can be used to develop a multidimensional drought risk analysis, which defines

Category	Description	Criteria	Probability
0	No drought	$0.0 \leq \text{SSI}$	50.0 %
1	Slight drought	$-1.0 \leq \text{SSI} < 0.0$	34.1 %
2	Moderate drought	$-1.5 \leq \text{SSI} < -1.0$	9.2 %
3	Serious drought	$-2.0 \leq \text{SSI} < -1.5$	4.4 %
4	Extreme drought	$\text{SSI} < -2.0$	2.3 %

SSI can also be used for identifying drought severity in the river basin:

- from water management point of view (SSI is less than -1)
- from ecological point of view (SSI is less than -2) then drought is identified and the minimum residual flow is no longer sufficient to meet the requirements for the development of aquatic fauna and flora.

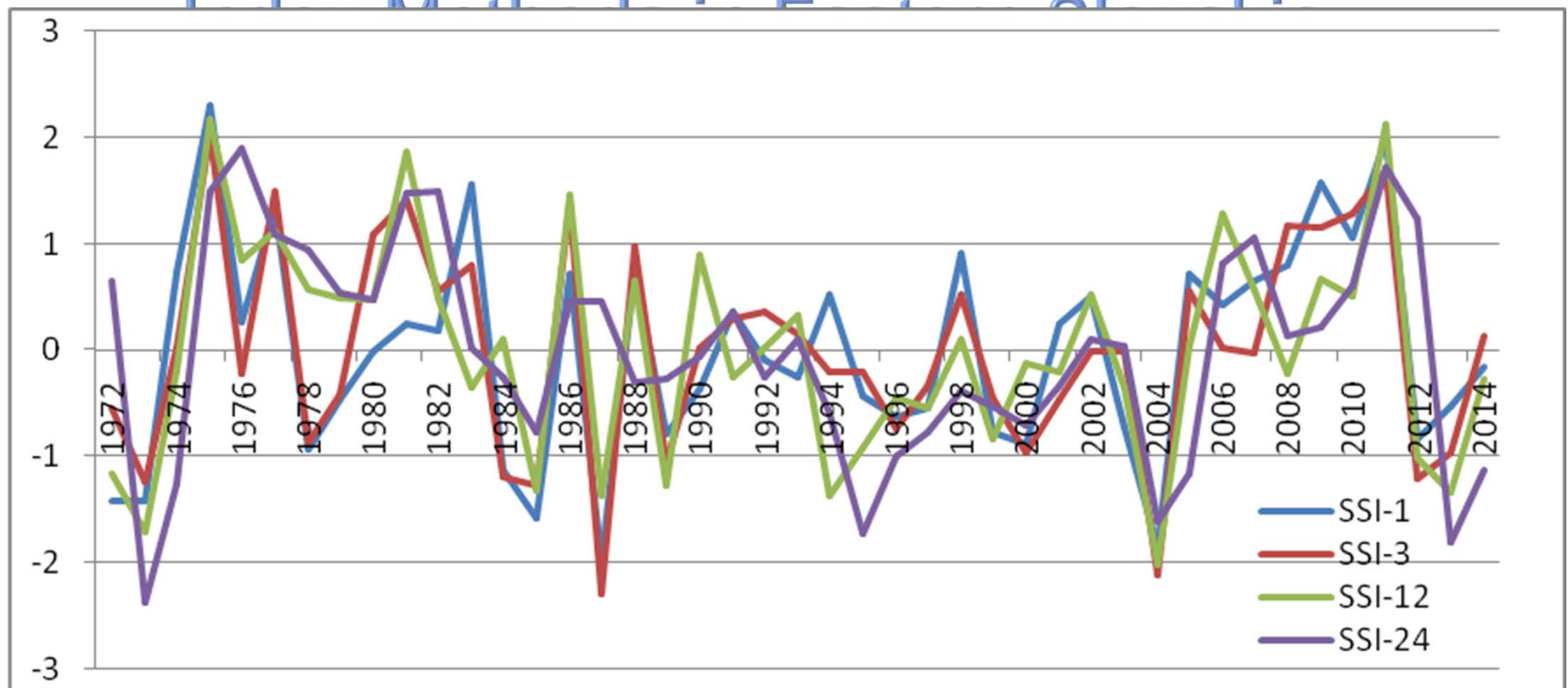
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Recommendations to mitigate drought impacts:

Complex drought vulnerability assessment - To define the drought's overall vulnerability of countryside, it is important **to know water requirements** to meet the needs of industry and human activity, as well as requirements to ensure natural ecological functions in the stream, knowledge of the natural accumulation capacity in the river basin and its impact on minimizing drought impacts (ie to wetlands, marshes, artificial lakes, planting of trees and others).



Hydrological Hazard Assessment by



- Determining the order of significant risk impacts.

Frequency of hydrological drought development in the period 1972-2014 in Bardejov river station.

The calculation of SPI and SSI at different time intervals (1, 3, 6, 12, 24 months) allows to characterize **short and long term extreme deficits** according to water resource management needs.

Thank to audience you for your kind attention

Thank you to organizers for invitation

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