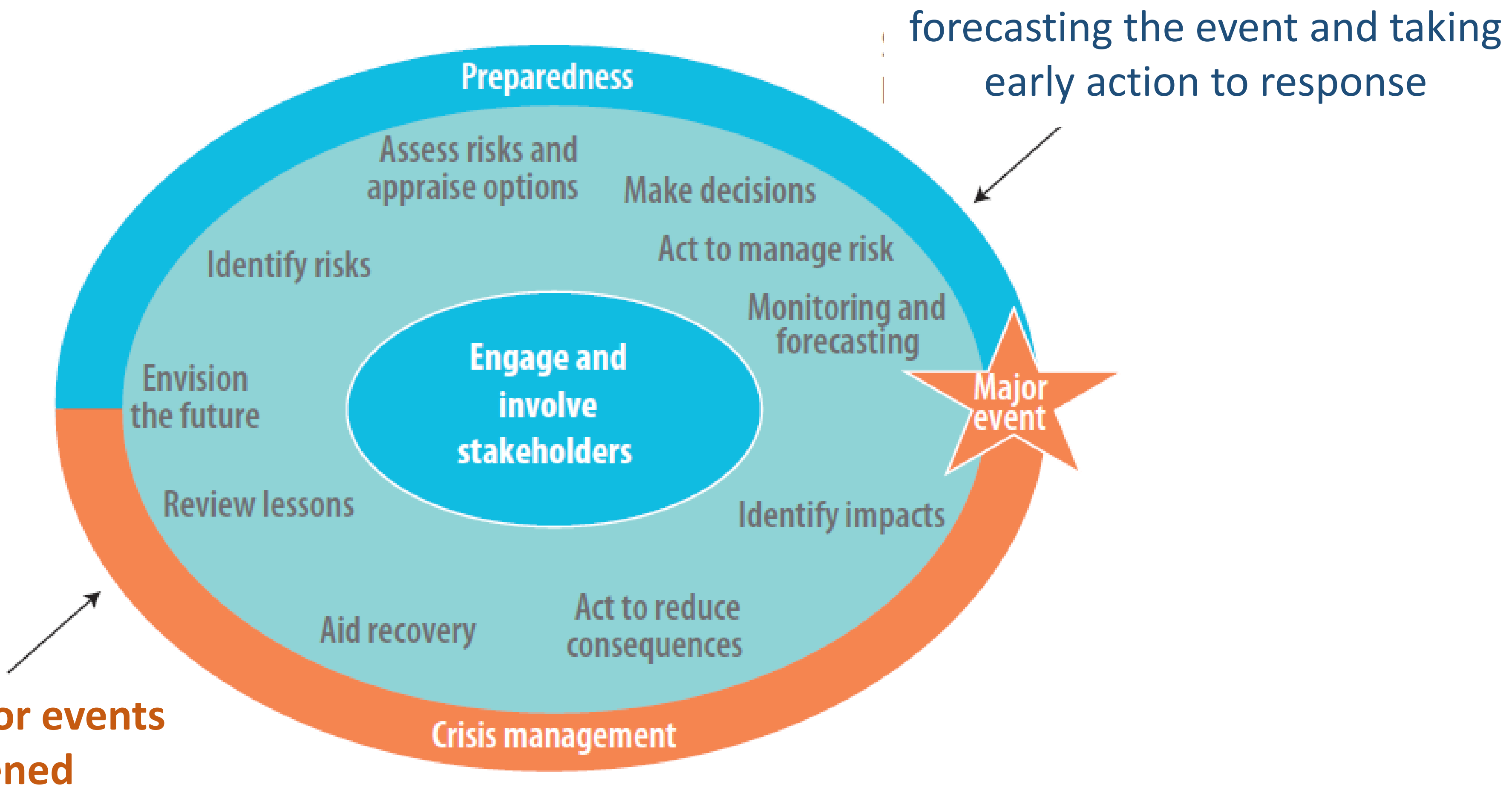
DROUGHT HAZARD ASSESSMENTS AS BASE FOR DROUGHT RISK REDUCTION

Wiwiana SZALIŃSKA, Tamara TOKARCZYK

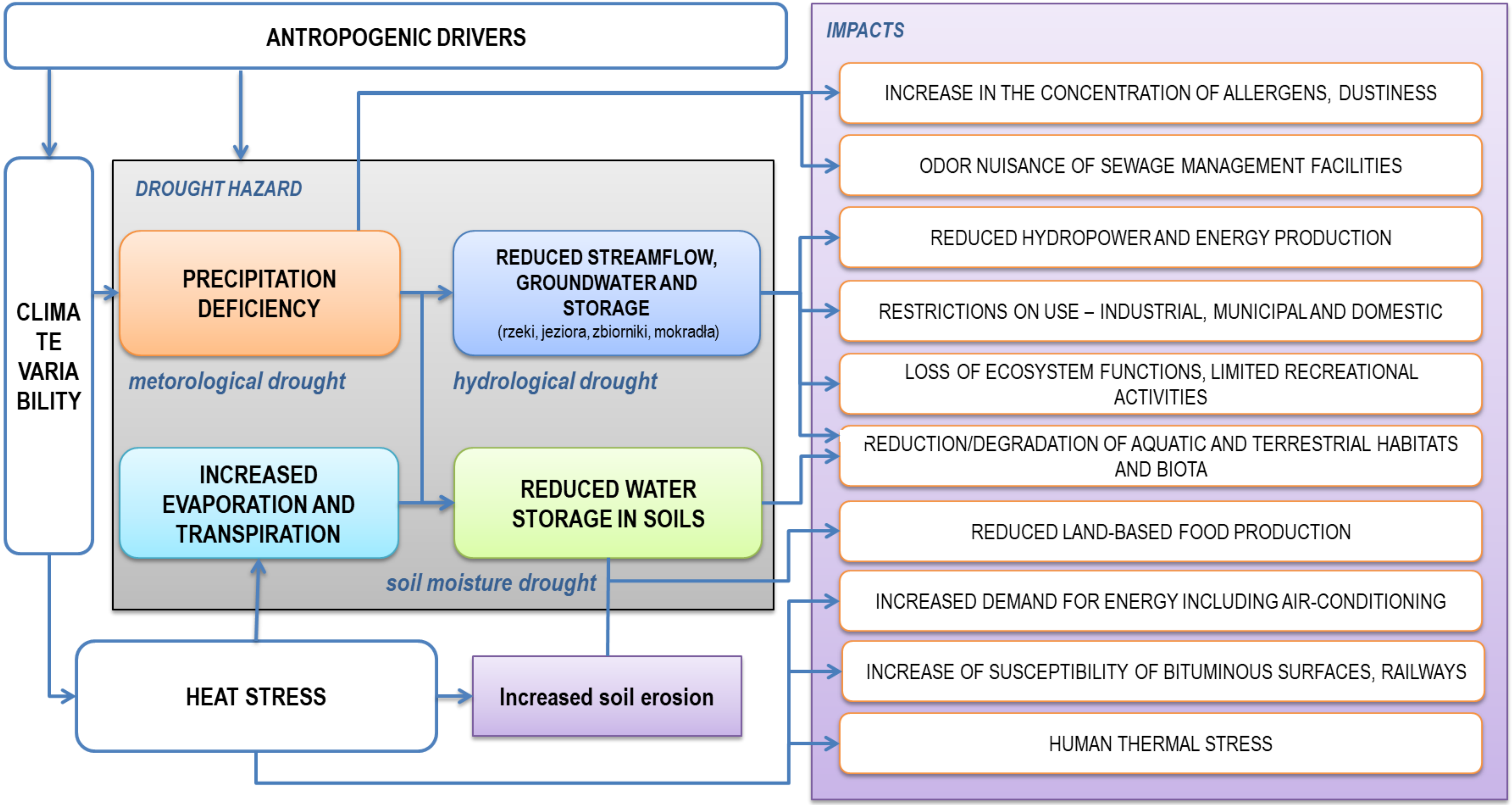
METEO
IMGW-PIB
meteo.imgw.pl

Approach to disaster risk reduction (DRR) has progressively evolved, shifting from 'crisis management' to a 'preparedness' approach



Sayers, et al.. (2016) *Drought risk management: A strategic approach.*

DROUGHT RISKS

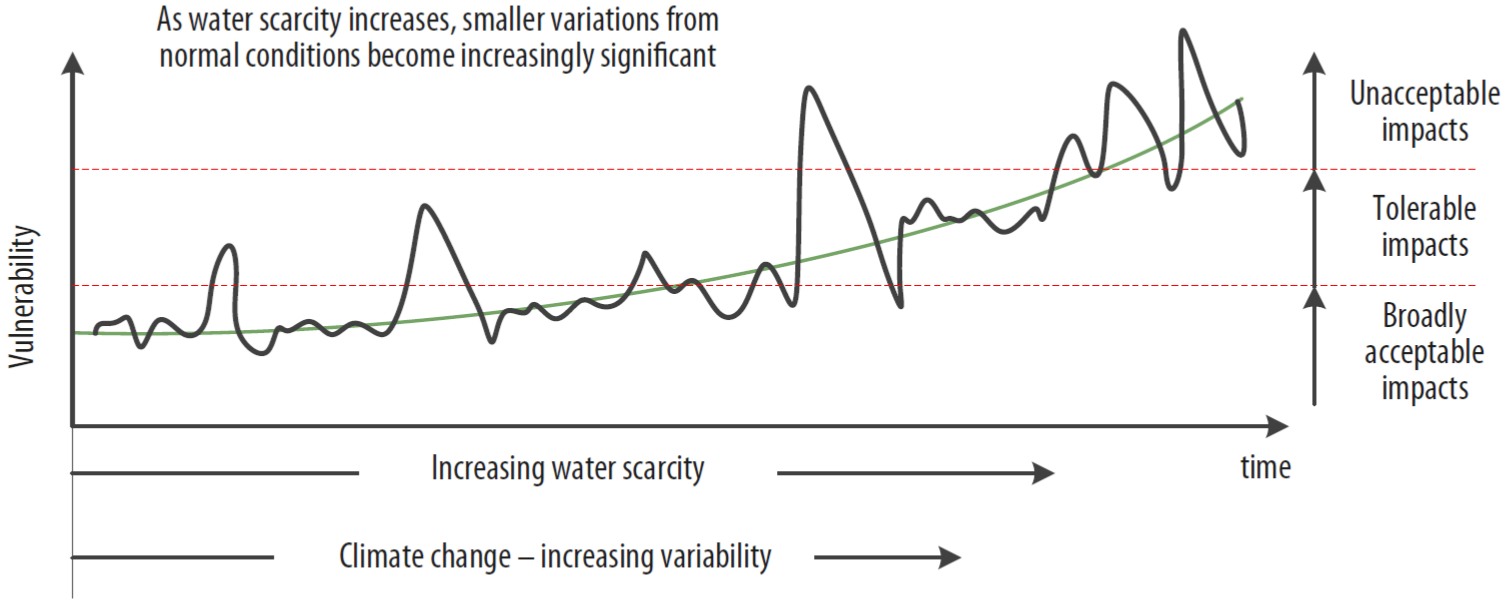


(Based on GIWP, 2016)

Drought Risk = f(**Chance of hazard occuring** (a given severity of drought) , **Associated consequences** (reflecting exposure and vulerability))

Drought risk is defined here as: an emergent property of the human and natural system, reflecting the interaction between climate (meteorological drought), the hydrological response of the basin (blue-water drought and green-water drought) and the vulnerability of the people, ecosystems and economies exposed to it. Drought risk reflects two components: the chance that a drought hazard will occur and the magnitude of the associated impacts.'

Drought as a risk
complex, multidimensional phenomenon, causing negative effects observed in the environment (natural systems), society and economy (social systems).



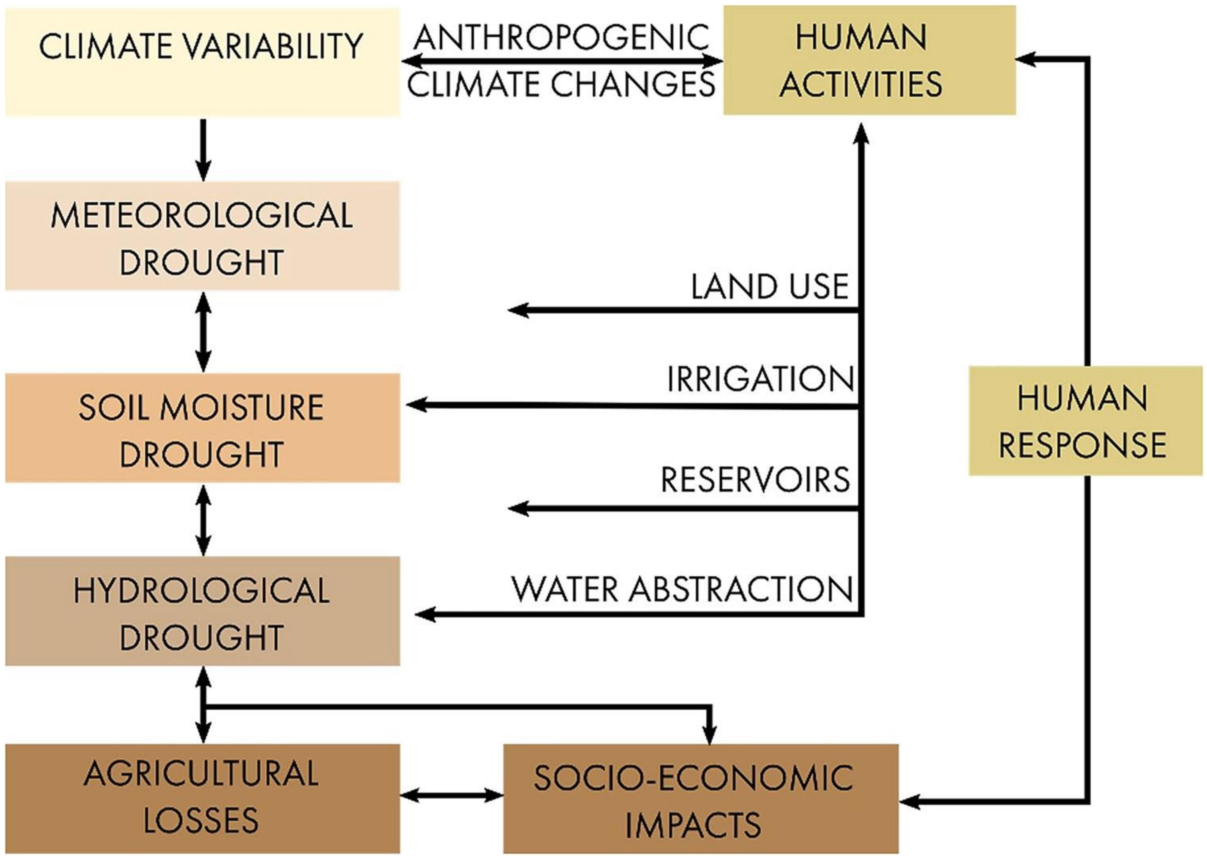
DROUGHT AS A HAZARD

METEO IMGW-PIB
meteo.imgw.pl

PROBABILITY OF HAZARD OCCURING = f(**Meteorological conditions triggering a drought (T, H, W,...)** , **Hydrological response including propagation of water deficyt through a hydrological cycle**)

DROUGHT HAZARD - the possibility of identifying, within a specified time horizon, meteorological conditions triggering a drought and shaping propagation of water deficyt through a hydrological cycle.

Evaluation of drought hazard requires assessment of probability of occurence of drought of given intensity, duration and spatial extend. The probability should be expressed in reference to the time scale of frequency evaluation i.e. once per 1 year, 10 years, 100 years.



DROUGHT HAZARD ASSESSMENT

SYSTEM COMPONENTS

DATA ACQUISITION– meteorological stations, rain gauges, water gauges, satelite images, …	operational input database
DATA PROCESSING – quality assessment, reference values, spatial inteprolation, temporal agregation	observed process dynamics
DROUGHT INDICATORS – standardized and dimensionless measures for drought assessment	process models
EARLY WARNING AND PREDICTION characteristic of spatio-temporal evolution of drought	supporting decisions

DATA SOURCES

METEO IMGW-PIB
meteo.imgw.pl

DATA CATHEGORY	SPECIFICATION	SOURCE	RESOLUTION
METEOROLOGICAL DATA	precipitation, wind speed and direction, temparature, solar radiation, humidity	meteorological stations meteorological radar	station location 1km
HYDROLOGICAL DATA	discharge, runoff	water gauge stations	river cross sections daily
WEATHER FORECAST	precipitation, wind speed and direction, temparature, cloud cover, humidity	numerical weather prediction COSMO, GFS	2.8, 7 km 0.25, 0.5 deg
BIOSPHERIC INFORMATION	Vegetation indicies	Sentinel-2 MSI NOAA Landsat 8	10 m 4 km 30 m
HYDROSPHERIC INFORMATION	Soil moisture Actual evapotranspiration	HSAF Metop ASCAT Land SAF	25 km 5-6 km
PHYSIOGRAPHIC INFORMATION	Digital terrain model Digital land cover model	SRTM-C CORINE	
SOCIO-ECONOMICAL INFORMATION	Irrigation, retention objects sowing / crops / harvest	statistical office	province agricultural parcel

DROUGHT INDICATORS

METEO
IMGW-PIB
meteo.imgw.pl

+

- Relate current hydrometeorological conditions to climatic and hydrological background,
- Detect individual phases of drought development, especially meteorological and hydrological phases,
- Represent normalized and dimensionless assessment of drought intensity,
- Reflect temporal and spatial variability of drought for regions and periods with diverse climatic and hydrological conditions.

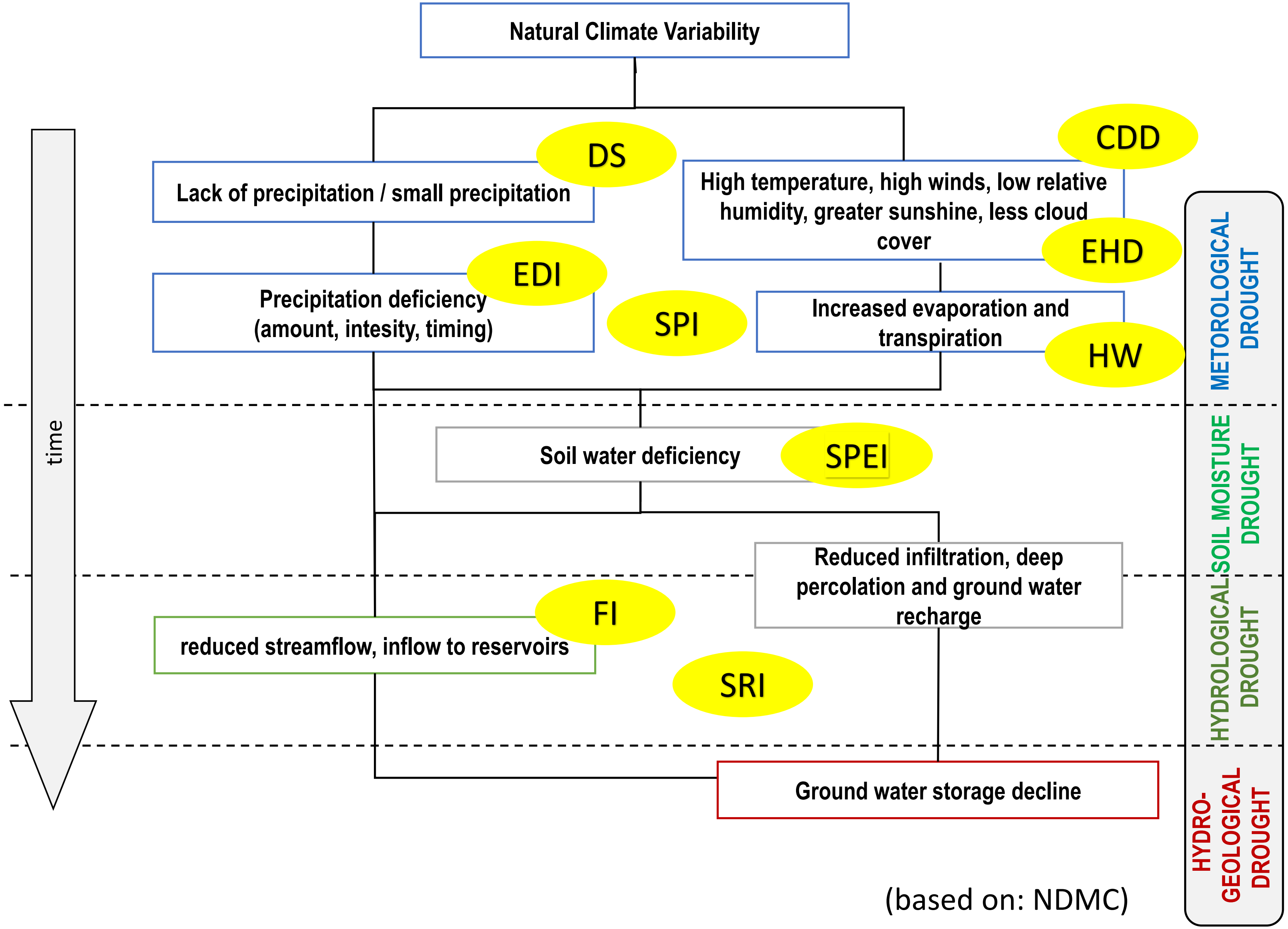
→

- Monitoring and forecasting the level of drought hazard,
- Identification of threshold levels triggering negative impacts,
- Information that is easy to interpret in decision support process

−

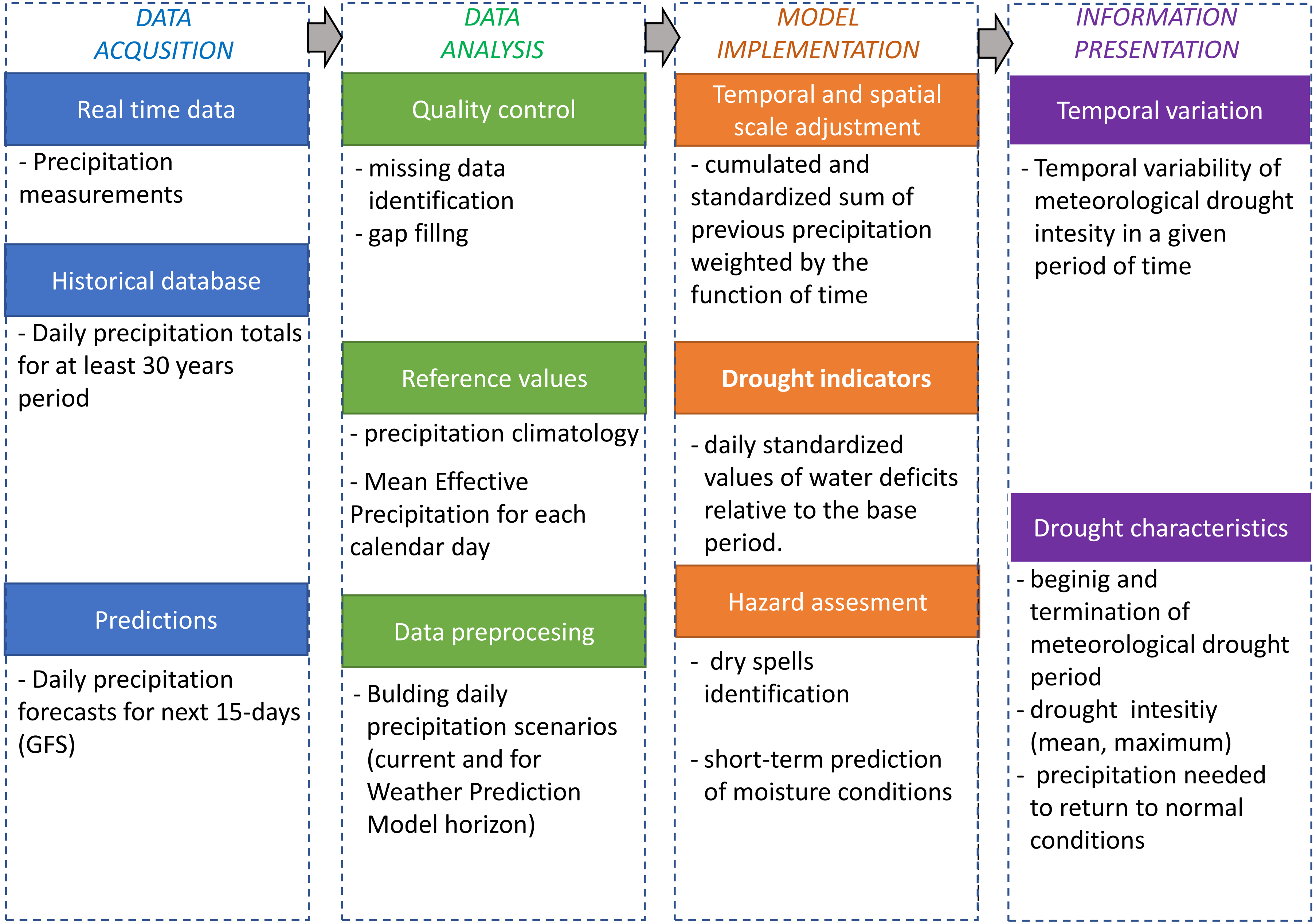
- Spatial representation - the data comes from a location distant from the area where drought impacts occur.
- Temporal resolution - the temporal resolution of the indicator does not allow capturing the dynamics of the phenomenon.
- Adequacy - the indicator values does not reflect the impacts of the occurrence of the hazard.
- Reference - the reference period is too short to assess the probability of the phenomenon occurring.

DROUGHT HAZARD ASSESSMENT



(based on: NDMC)

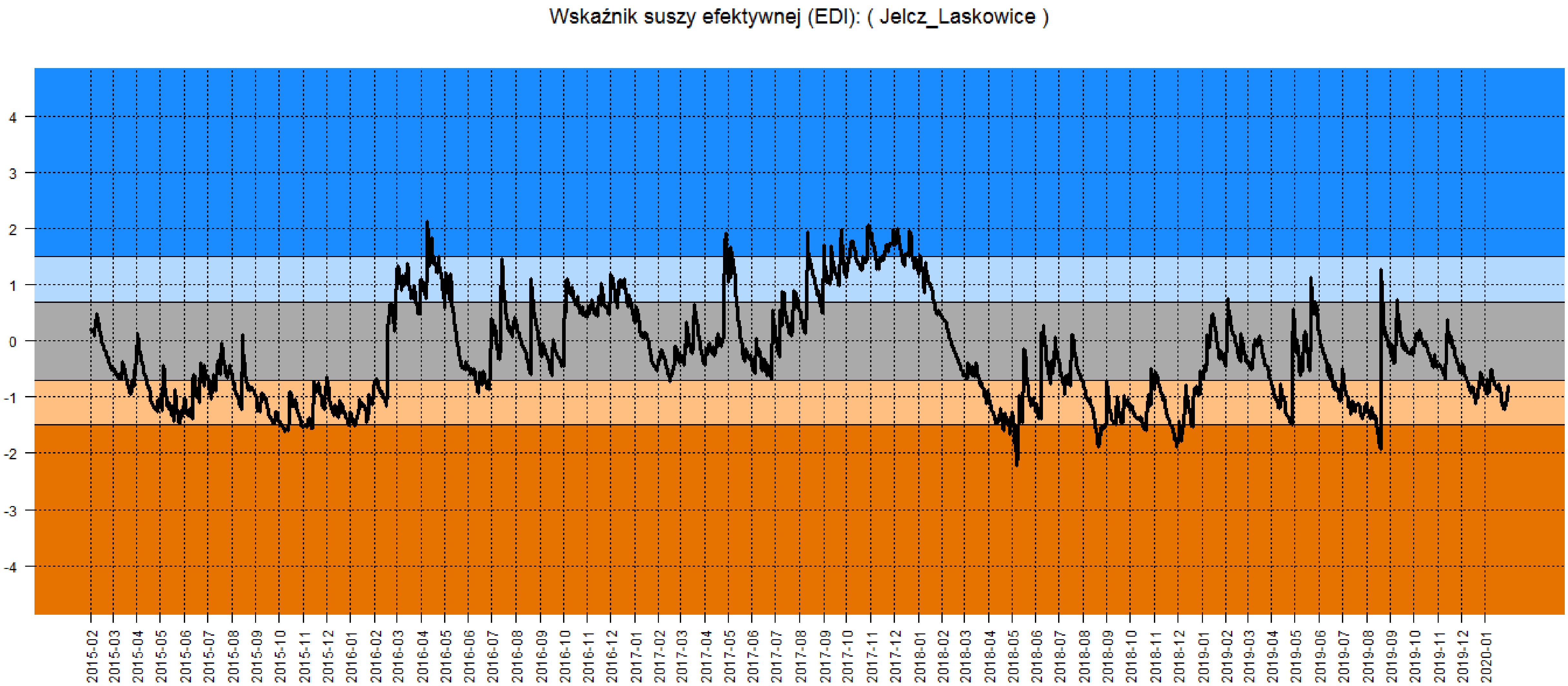
Effective Drought Index EDI Byun et al. (1999)

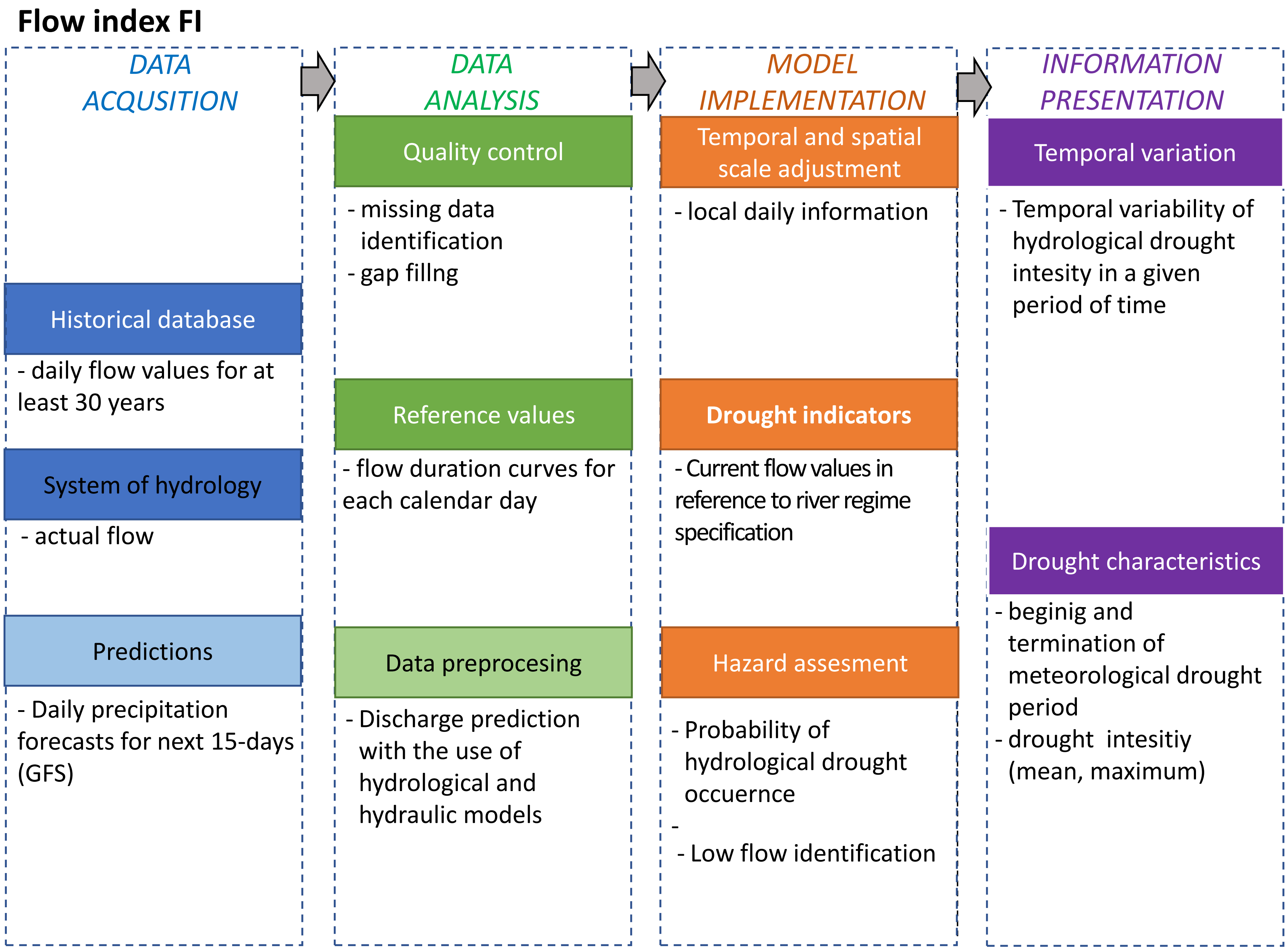


METEOROLOGICAL DROUGHT HAZARD DURATION

METEO IMGW-PIB meteo.imgw.pl

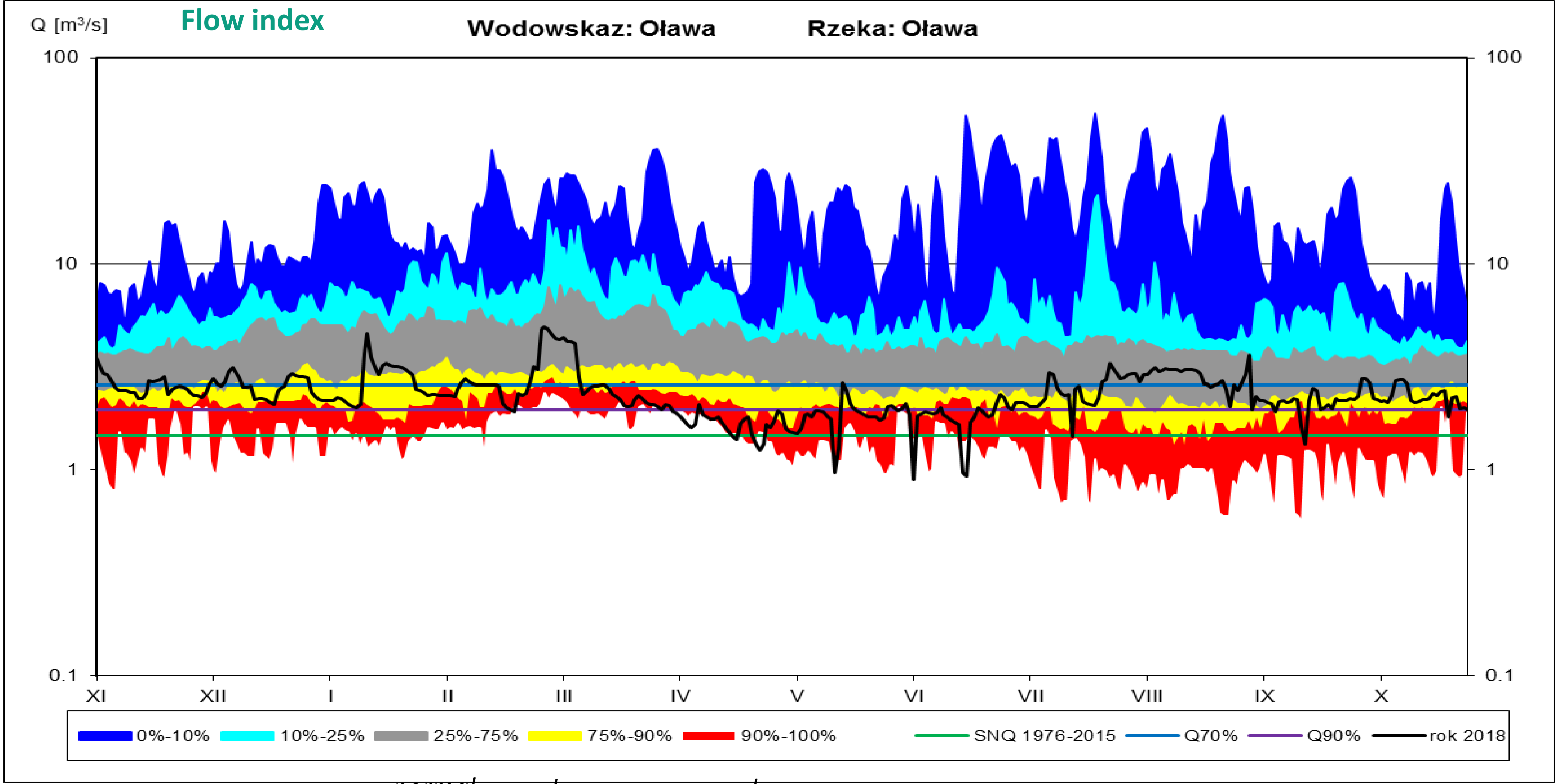
Effective Drought Index Byun et al. (1999)




Flow index FI
DATA ACQUSITION
Historical database
- daily flow values for at least 30 years
System of hydrology
- actual flow
Predictions
- Daily precipitation forecasts for next 15-days (GFS)
DATA ANALYSIS
Quality control
- missing data identification
- gap fillng
Reference values
- flow duration curves for each calendar day
Data preprocesing
- Discharge prediction with the use of hydrological and hydraulic models
MODEL IMPLEMENTATION
Temporal and spatial scale adjustment
- local daily information
Drought indicators
- Current flow values in reference to river regime specification
Hazard assesment
- Probability of hydrological drought occuernce
-
- Low flow identification
INFORMATION PRESENTATION
Temporal variation
- Temporal variability of hydrological drought intesity in a given period of time
Drought characteristics
- beginig and termination of meteorological drought period
- drought intesitiy (mean, maximum)

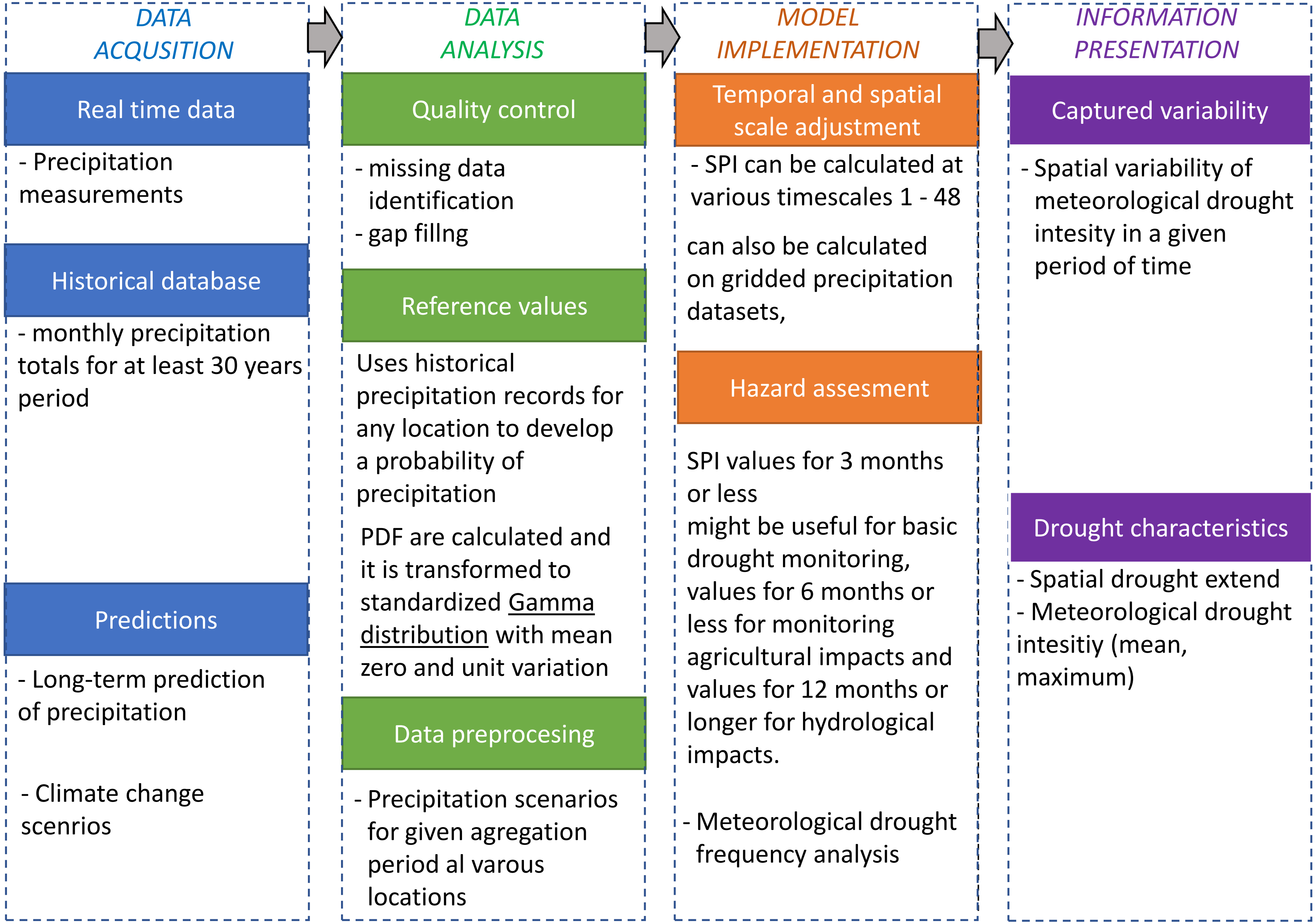
HYDROLOGICAL DROUGHT HAZARD DURATION

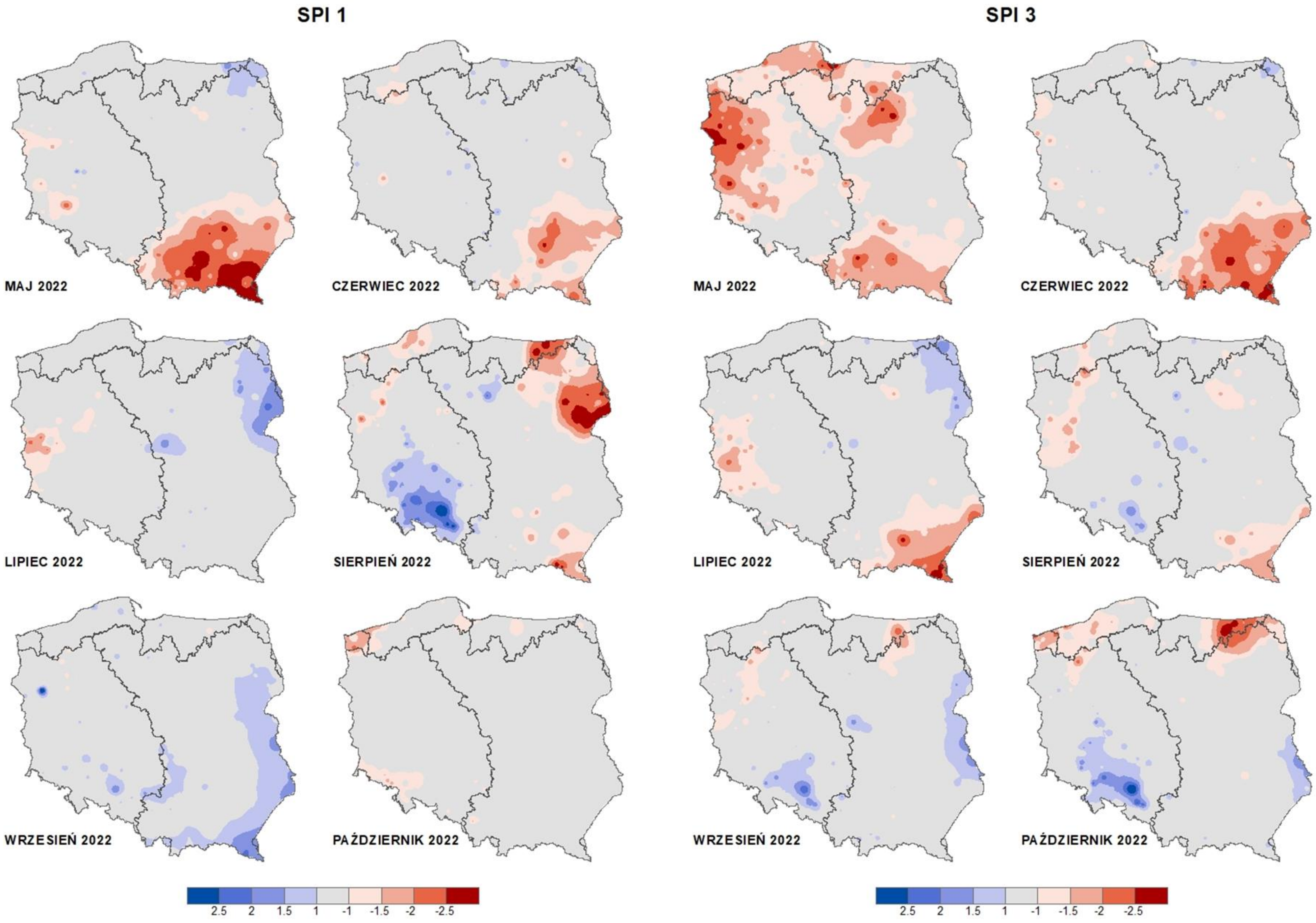
METEO
IMGW-PIB
meteo.imgw.pl



very wet *wet* *normal* *dry* *very dry*

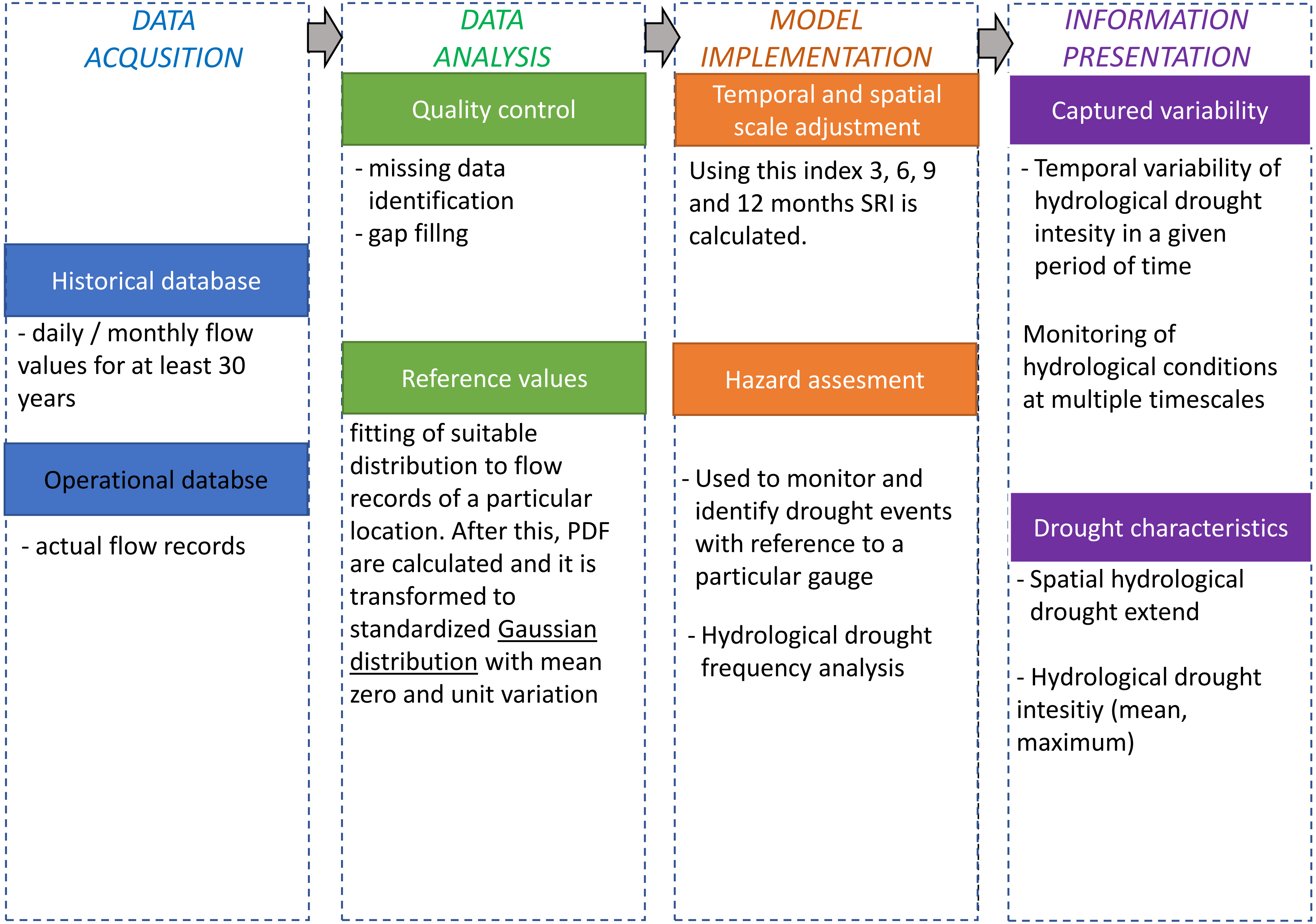
Standardized precipitation index (SPI) McKee et al. (1993)

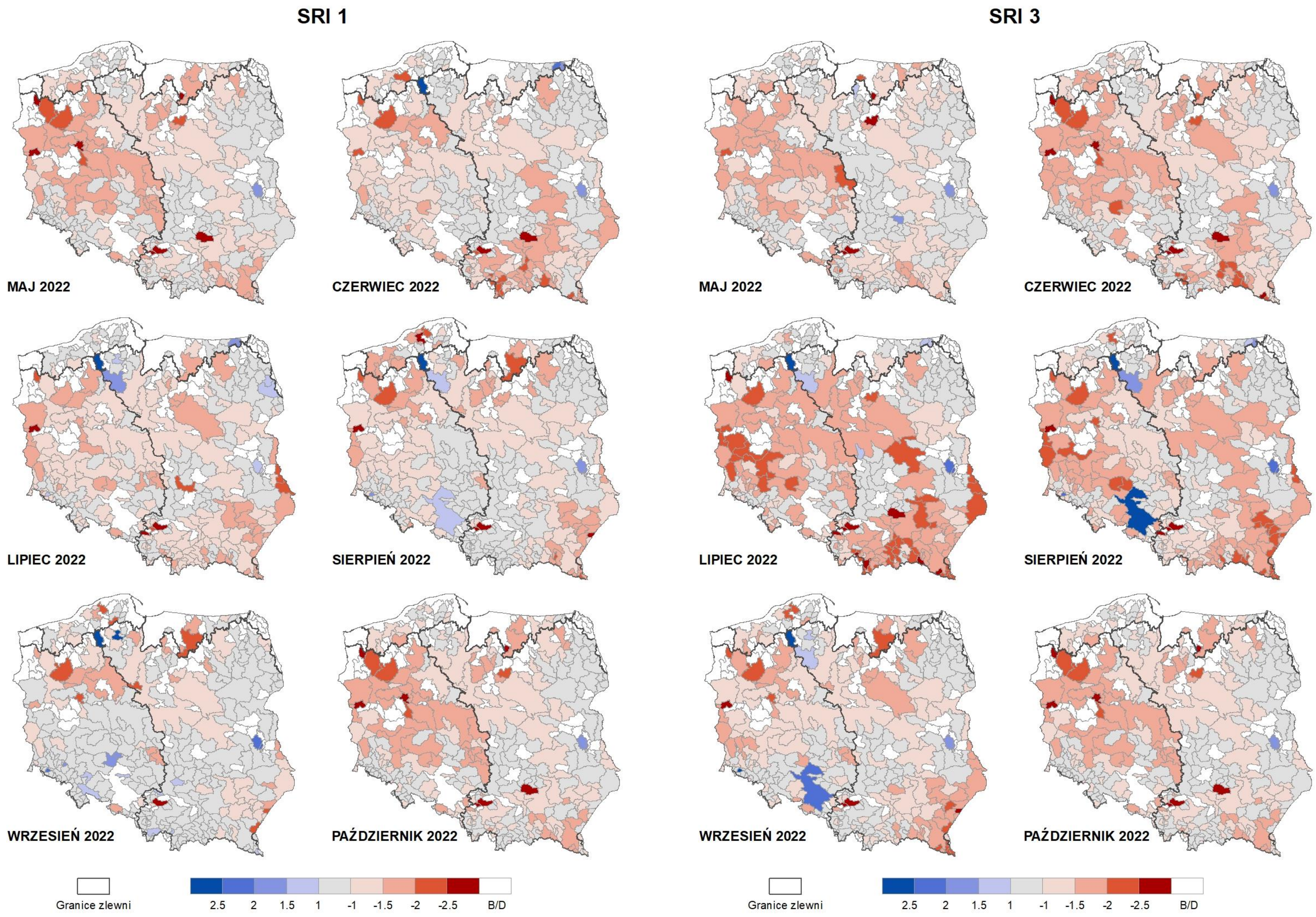




DROUGHT EVENT:
SPI3 <-1
For at least 2 months

Standarized Runoff Index SRI (Shukla and Wood 2008)

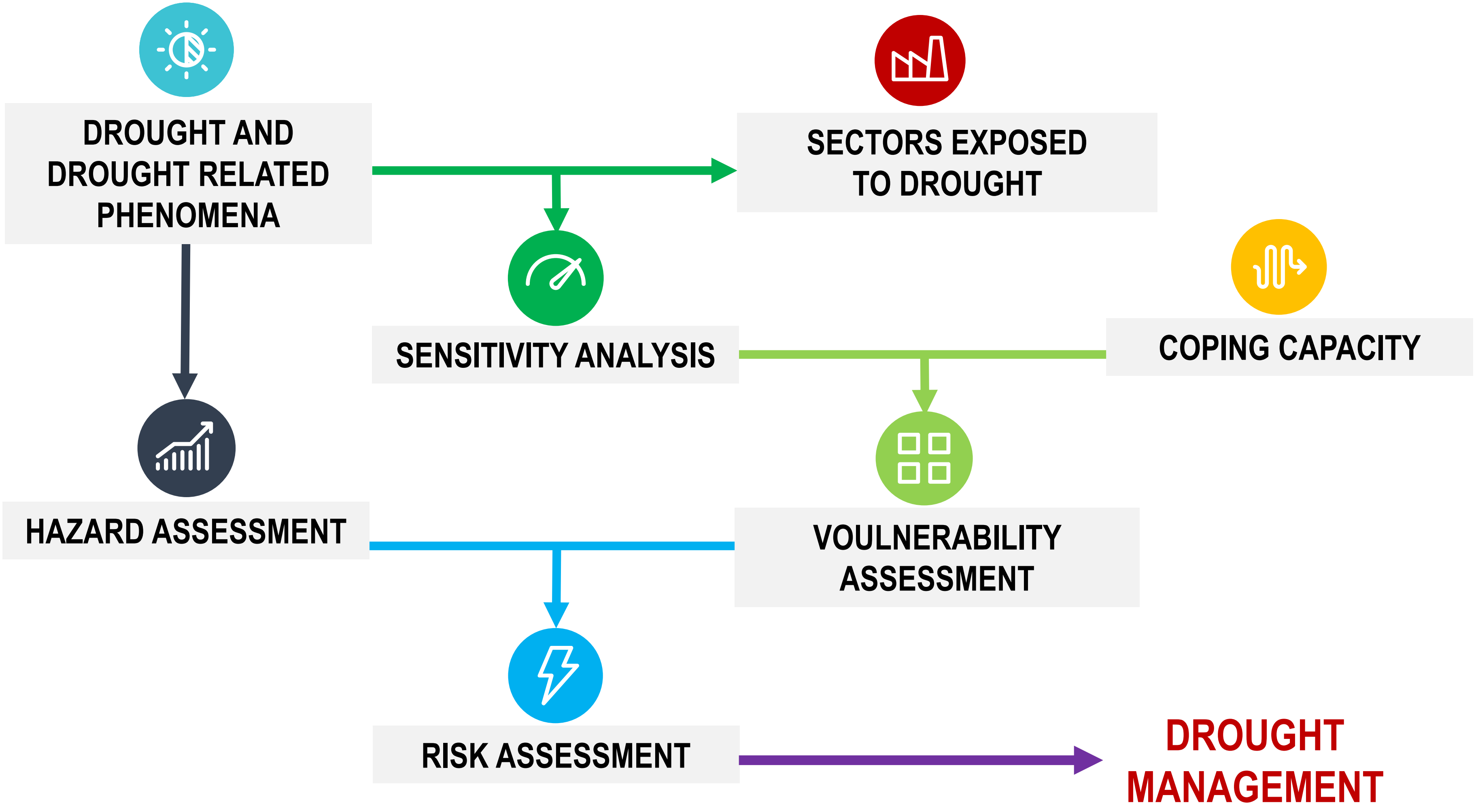




DROUGHT EVENT:
SRI3 <-1
For at least 2 months

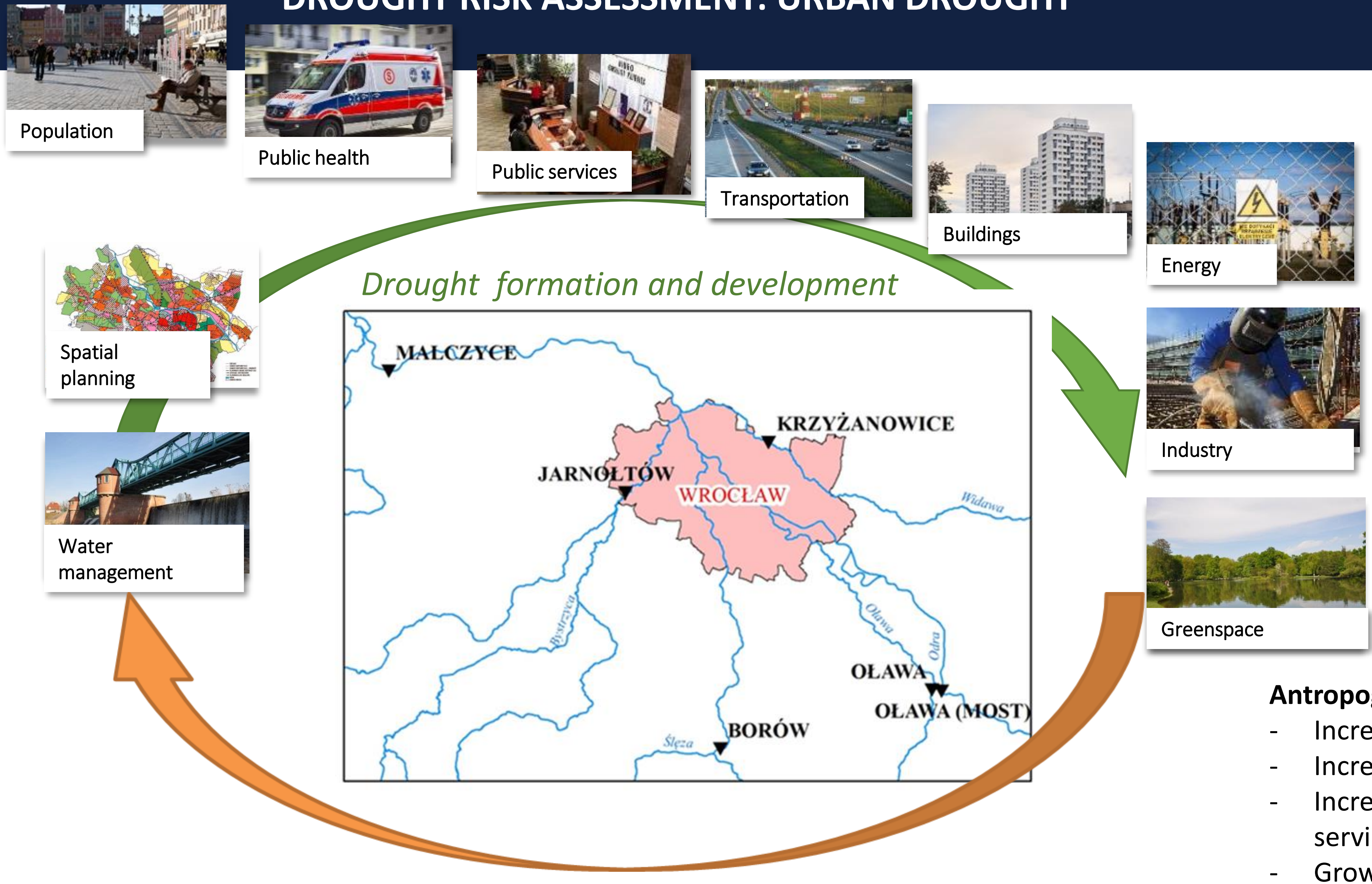
DROUGHT RISK ASSESSMENT: URBAN DROUGHT

METEO
IMGW-PIB
meteo.imgw.pl



DROUGHT RISK ASSESSMENT: URBAN DROUGHT

METEO IMGW-PIB
meteo.imgw.pl



CITY INFORMATION:
Area: 293 km^2
Population: 673 000
Climate zone: temperate with oceanic and continental influences
Water supply: surface water secured by two retention and flood prevention reservoirs the Nysa and the Otmuchów reservoirs (storege capacity - 92 days)

Antropogenic drought triggers:

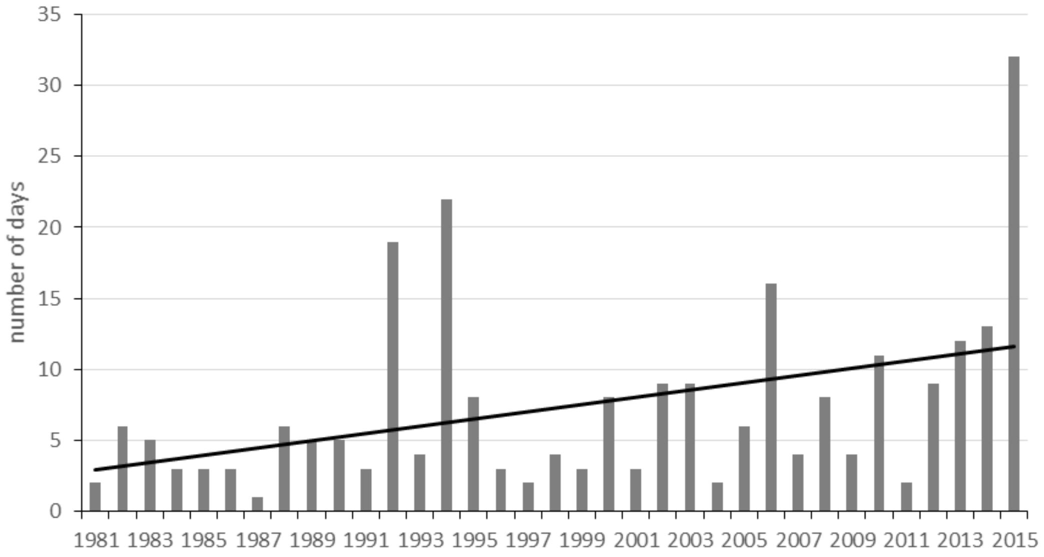
- Increased city population
- Increased demend for energy
- Increased demand for products and services with greater water footprints
- Growth of impervious area
- Poor rainwater management
- Climate change

Szalińska, W.; Otop, I.; Tokarczyk, T. Local Urban Risk Assessment of Dry and Hot Hazards for Planning Mitigation Measures. Climate Risk Management 2021, 34, 100371, doi:10.1016/j.crm.2021.100371

DROUGHT HAZARD ASSESMENT

METEO IMGW-PIB
meteo.imgw.pl

Annual number of extreme hot days



EHD - days with the daily maximum temperature higher than 98th percentile of long term observations;

	P [%]
	< 5
	5 – 10
	10 – 20
	20 – 30
	30 – 40
	40 – 60
	60 – 70
	70 – 80
	80 – 90
	90 – 95
	> 95

number of days T > 30°

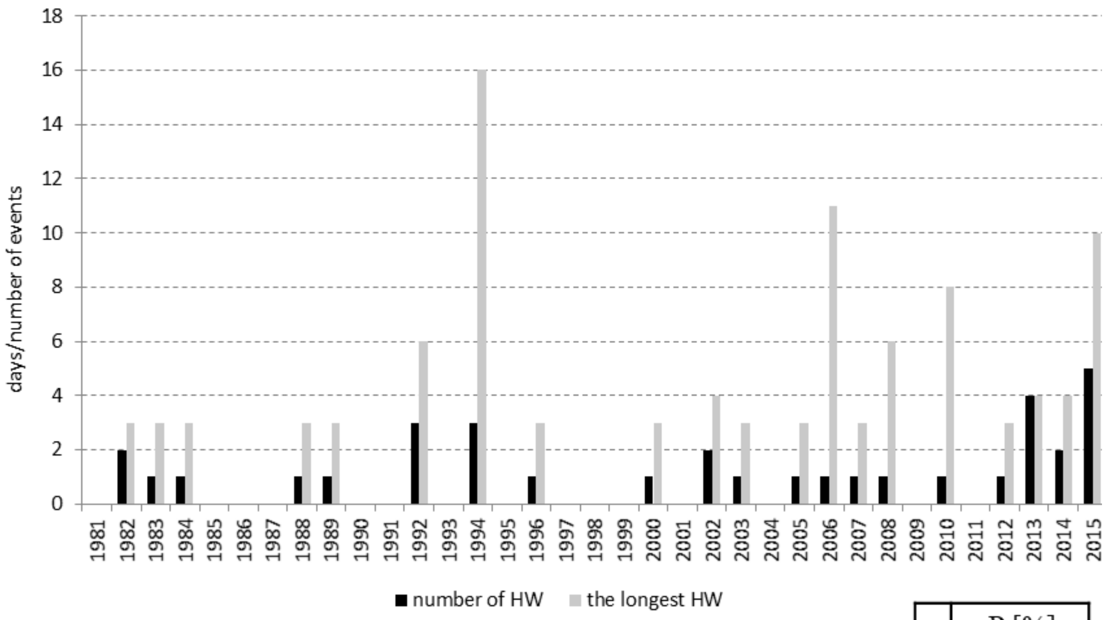
Par.	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	I-XII
1977	0	0	0	0	0	0	0	0	0	0	0	0	0
1978	0	0	0	0	0	0	0	0	0	0	0	0	0
1979	0	0	0	0	1	3	0	1	0	0	0	0	5
1980	0	0	0	0	0	0	0	0	0	0	0	0	0
1981	0	0	0	0	0	2	0	0	0	0	0	0	2
1982	0	0	0	0	0	3	2	4	0	0	0	0	9
1983	0	0	0	0	0	0	7	1	2	0	0	0	10
1984	0	0	0	0	0	0	4	2	0	0	0	0	6
1985	0	0	0	0	0	0	2	3	0	0	0	0	5
1986	0	0	0	0	0	1	2	1	0	0	0	0	4
1987	0	0	0	0	0	1	1	0	0	0	0	0	2
1988	0	0	0	0	0	0	4	2	0	0	0	0	6
1989	0	0	0	0	0	0	1	5	0	0	0	0	6
1990	0	0	0	0	0	0	1	5	0	0	0	0	6
1991	0	0	0	0	0	1	2	2	0	0	0	0	5
1992	0	0	0	0	0	2	5	15	0	0	0	0	22
1993	0	0	0	0	0	1	0	4	0	0	0	0	5
1994	0	0	0	0	0	4	14	6	0	0	0	0	24
1995	0	0	0	0	0	0	5	5	0	0	0	0	10
1996	0	0	0	0	0	4	0	0	0	0	0	0	4
1997	0	0	0	0	0	2	0	1	0	0	0	0	3
1998	0	0	0	0	0	2	3	0	0	0	0	0	5
1999	0	0	0	0	0	0	3	1	0	0	0	0	4
2000	0	0	0	0	0	5	0	4	0	0	0	0	9
2001	0	0	0	0	0	0	2	5	0	0	0	0	7
2002	0	0	0	0	0	3	8	0	0	0	0	0	11
2003	0	0	0	0	1	1	3	9	1	0	0	0	15
2004	0	0	0	0	0	0	2	3	0	0	0	0	5
2005	0	0	0	0	2	1	3	0	0	0	0	0	6
2006	0	0	0	0	0	3	17	0	0	0	0	0	20
2007	0	0	0	0	1	1	3	3	0	0	0	0	8
2008	0	0	0	0	0	1	9	4	1	0	0	0	15
2009	0	0	0	0	0	0	2	4	0	0	0	0	6
2010	0	0	0	0	0	2	11	0	0	0	0	0	13
2011	0	0	0	0	0	1	1	2	0	0	0	0	4
2012	0	0	0	1	0	3	5	5	1	0	0	0	15
2013	0	0	0	0	0	3	4	7	0	0	0	0	14
2014	0	0	0	0	0	4	8	3	0	0	0	0	15
2015	0	0	0	0	0	2	12	15	3	0	0	0	32
2016	0	0	0	0	0	4	4	4	4	0	0	0	16
2017	0	0	0	0	2	2	4	5	0	0	0	0	13
2018	0	0	0	0	3	5	5	12	2	0	0	0	27
2019	0	0	0	0	0	---	---	---	---	---	---	---	---

DROUGHT HAZARD ASSESMENT

METEO
IMGW-PIB
meteo.imgw.pl

monthly mean air temperature
increased by 0.49°C/10 years

Annual number of heat waves and duration of the longest



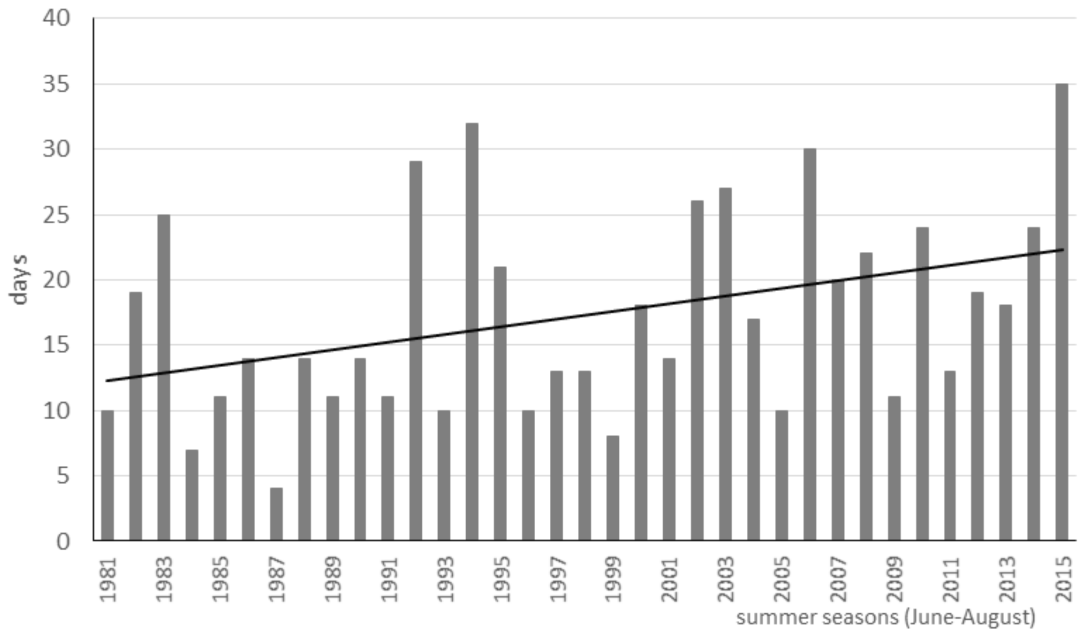
HW - periods of at least three consecutive days with daily maximum air temperature higher than 30°C

	P [%]
	< 5
	5 – 10
	10 – 20
	20 – 30
	30 – 40
	40 – 60
	60 – 70
	70 – 80
	80 – 90
	90 – 95
	> 95

Rok	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	I-XII
1975	9.9	9.7	19.8	22.4	27.1	29.1	28.5	29.7	31.8	23.0	11.4	8.1	31.8
1976	8.9	14.7	17.2	23.3	25.7	31.7	34.3	26.3	25.9	22.6	17.2	10.2	34.3
1977	8.6	12.2	19.4	24.5	27.3	29.7	27.9	28.0	28.0	23.4	18.6	11.5	29.7
1978	7.6	13.3	21.6	20.4	26.0	27.7	29.3	28.6	23.9	22.3	13.7	11.1	29.3
1979	4.2	4.4	15.7	19.0	30.6	32.1	26.0	30.4	28.2	23.8	13.9	14.0	32.1
1980	8.1	10.8	16.9	19.3	23.3	28.6	25.2	29.7	26.3	22.3	16.6	10.8	29.7
1981	7.7	9.7	19.4	21.4	26.0	31.7	28.4	29.9	27.2	21.9	15.1	7.8	31.7
1982	10.1	7.8	19.3	21.2	27.3	31.3	30.8	31.0	29.6	22.5	18.9	13.1	31.3
1983	14.9	10.9	15.8	24.2	29.2	29.2	35.9	33.8	30.3	25.2	18.4	12.9	35.9
1984	9.7	7.6	17.4	22.4	23.7	26.7	34.4	31.0	29.6	22.7	16.2	8.8	34.4
1985	6.0	7.5	15.7	23.6	29.0	28.4	32.1	32.4	25.1	26.0	16.0	15.3	32.4
1986	9.8	2.1	19.8	26.2	27.8	30.1	31.4	31.5	24.0	21.8	13.9	13.3	31.5
1987	7.2	8.9	13.4	23.3	24.0	30.2	31.4	29.6	26.2	21.4	12.5	12.0	31.4
1988	12.2	12.9	13.9	23.8	27.4	28.5	36.2	31.4	26.0	22.4	9.5	9.9	36.2
1989	9.4	14.9	20.3	22.7	25.3	28.0	31.3	34.6	28.8	24.9	14.1	14.0	34.6
1990	11.8	19.7	22.0	21.6	26.6	29.4	33.1	34.3	23.8	24.8	13.0	9.6	34.3
1991	14.9	13.5	17.9	19.7	23.1	30.0	32.6	33.6	27.4	22.8	13.6	10.6	33.6
1992	10.8	15.4	17.0	24.6	26.8	30.7	33.3	37.3	25.2	23.7	13.6	13.6	37.3
1993	15.3	7.5	18.1	26.1	28.8	30.4	29.5	33.1	26.2	22.3	10.8	11.7	33.1
1994	11.7	14.4	21.8	24.7	25.0	33.4	37.1	37.4	24.4	19.2	16.3	13.4	37.4
1995	12.0	15.8	16.9	26.1	29.7	27.3	35.0	31.6	24.7	24.9	11.2	9.7	35.0
1996	7.7	6.3	8.7	26.1	25.9	31.7	26.6	29.4	21.8	21.6	17.5	6.7	31.7
1997	5.8	15.8	18.9	19.2	29.5	33.0	26.1	30.0	26.4	22.4	17.9	11.6	33.0
1998	12.2	15.5	19.1	24.0	29.5	34.0	35.4	29.3	25.9	21.1	11.1	11.5	35.4
1999	14.0	13.4	20.5	19.0	29.8	26.8	32.1	30.1	27.5	22.1	18.5	11.6	32.1
2000	10.7	14.7	16.4	27.1	29.4	34.5	28.5	32.7	26.2	25.2	15.1	14.3	34.5
2001	11.5	13.5	17.0	26.1	26.8	28.0	31.0	31.2	21.7	26.2	17.7	6.2	31.2
2002	15.0	15.8	18.4	19.8	29.3	33.3	34.3	29.4	27.4	18.5	18.4	7.2	34.3
2003	9.0	8.3	18.4	25.0	30.5	31.8	33.4	36.3	30.4	18.0	16.9	10.9	36.3
2004	6.7	16.2	20.1	22.1	23.6	27.4	30.4	32.6	27.9	26.6	17.9	10.6	32.6
2005	13.2	8.2	16.9	21.2	32.4	31.0	35.1	27.9	29.6	21.1	16.3	6.8	35.1
2006	3.1	7.3	16.9	22.9	25.2	32.2	34.9	28.9	27.9	21.1	18.3	13.4	34.9
2007	15.1	12.7	17.6	25.7	30.0	30.5	34.5	32.2	24.8	21.0	13.6	12.3	34.5
2008	13.6	18.0	17.2	20.1	27.9	31.1	32.0	32.0	31.4	21.6	18.3	11.6	32.0
2009	5.8	12.6	14.6	25.6	28.6	28.2	32.6	33.1	27.6	24.3	16.2	12.8	33.1
2010	1.9	10.9	21.8	26.2	21.7	31.4	34.1	29.7	24.3	17.4	19.7	5.0	34.1
2011	10.2	11.2	18.7	24.1	29.0	30.0	30.8	30.9	29.6	25.6	18.1	11.3	30.9
2012	12.4	10.0	21.9	30.0	29.9	31.5	33.8	35.9	30.0	22.8	13.0	11.2	35.9
2013	11.1	8.0	14.1	26.4	26.4	33.7	35.7	34.2	26.0	22.9	17.0	12.6	35.7
2014	13.3	14.0	22.5	22.5	29.6	33.1	33.8	31.1	27.8	23.9	18.1	13.8	33.8
2015	15.3	10.6	18.8	25.5	27.3	31.9	34.5	37.9	35.3	23.7	17.3	16.0	37.9
2016	13.5	14.5	17.2	24.5	28.2	35.1	34.1	31.6	30.9	22.7	15.5	13.9	35.1
2017	6.6	16.1	22.2	23.4	31.2	32.0	32.1	35.4	25.4	26.0	15.1	13.6	35.4
2018	11.9	8.5	16.6	27.2	30.6	33.0	33.2	33.9	31.1	---	---	---	---

DROUGHT HAZARD ASSESMENT

Number of cooling days observed in summer seasons (June-August)



CDD – accumulated deviation of the air temperature over the days with the air temperature exceeding 27°C

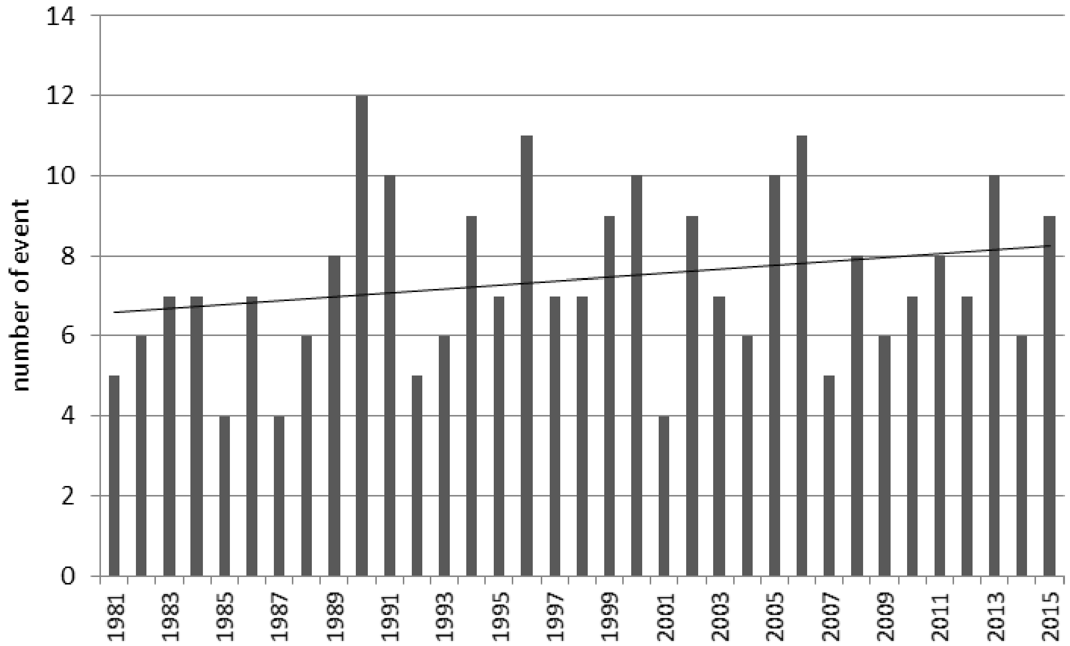
	P [%]
	< 5
	5 – 10
	10 – 20
	20 – 30
	30 – 40
	40 – 60
	60 – 70
	70 – 80
	80 – 90
	90 – 95
	> 95

Rok	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	I-XII
1975	0.0	0.0	0.0	0.0	3.2	18.6	40.3	32.6	14.8	0.0	0.0	0.0	109.5
1976	0.0	0.0	0.0	0.0	0.0	19.4	48.0	0.1	0.0	0.0	0.0	0.0	67.5
1977	0.0	0.0	0.0	0.0	6.0	31.7	7.0	11.0	6.4	0.0	0.0	0.0	62.1
1978	0.0	0.0	0.0	0.0	1.2	8.5	15.4	11.9	0.7	0.0	0.0	0.0	37.7
1979	0.0	0.0	0.0	0.0	24.0	50.7	4.0	20.4	4.1	0.0	0.0	0.0	103.2
1980	0.0	0.0	0.0	0.0	0.0	9.7	9.4	18.8	0.5	0.0	0.0	0.0	38.4
1981	0.0	0.0	0.0	0.0	1.0	40.2	29.4	36.3	3.8	0.0	0.0	0.0	110.7
1982	0.0	0.0	0.0	0.0	1.9	24.4	56.5	48.9	9.3	0.0	0.0	0.0	141.0
1983	0.0	0.0	0.0	0.0	8.3	20.4	84.4	47.8	11.1	0.0	0.0	0.0	172.0
1984	0.0	0.0	0.0	0.0	0.0	7.8	24.9	23.2	5.8	0.0	0.0	0.0	61.7
1985	0.0	0.0	0.0	0.0	13.4	5.9	29.8	33.7	1.8	0.0	0.0	0.0	84.6
1986	0.0	0.0	0.0	0.0	2.6	27.6	41.7	28.2	1.1	0.0	0.0	0.0	101.2
1987	0.0	0.0	0.0	0.0	0.0	15.6	30.9	9.4	4.7	0.0	0.0	0.0	60.6
1988	0.0	0.0	0.0	0.0	6.0	12.6	41.8	35.7	0.7	0.0	0.0	0.0	96.8
1989	0.0	0.0	0.0	0.0	1.0	13.4	42.3	57.9	9.3	0.0	0.0	0.0	123.9
1990	0.0	0.0	0.0	0.0	1.4	17.7	25.0	49.9	0.0	0.0	0.0	0.0	94.0
1991	0.0	0.0	0.0	0.0	0.0	7.9	62.4	43.4	1.7	0.0	0.0	0.0	115.4
1992	0.0	0.0	0.0	0.0	0.3	47.2	70.7	118.4	0.0	0.0	0.0	0.0	236.6
1993	0.0	0.0	0.0	0.0	8.6	15.5	23.9	31.9	4.1	0.0	0.0	0.0	84.0
1994	0.0	0.0	0.0	0.0	0.6	33.8	138.3	59.5	1.1	0.0	0.0	0.0	233.3
1995	0.0	0.0	0.0	0.5	9.2	8.2	95.5	51.6	0.8	0.0	0.0	0.0	165.8
1996	0.0	0.0	0.0	0.3	2.5	33.8	15.1	23.5	0.0	0.0	0.0	0.0	75.2
1997	0.0	0.0	0.0	0.0	14.0	33.5	15.0	56.4	8.0	0.7	0.0	0.0	127.6
1998	0.0	0.0	0.0	0.0	15.3	32.6	41.7	37.5	6.0	0.0	0.0	0.0	133.1
1999	0.0	0.0	0.0	0.0	6.3	11.3	68.2	33.4	12.5	0.0	0.0	0.0	131.7
2000	0.0	0.0	0.0	5.3	12.3	56.7	7.9	50.6	1.7	0.0	0.0	0.0	134.5
2001	0.0	0.0	0.0	0.0	4.8	7.1	48.2	58.6	0.0	4.1	0.0	0.0	122.8
2002	0.0	0.0	0.0	0.0	9.1	44.9	72.8	84.2	5.9	0.0	0.0	0.0	216.9
2003	0.0	0.0	0.0	0.0	9.8	58.8	58.7	81.5	6.1	0.0	0.0	0.0	214.9
2004	0.0	0.0	0.0	0.0	0.0	11.9	42.5	62.1	1.2	0.7	0.0	0.0	118.4
2005	0.0	0.0	0.0	0.0	20.5	26.8	67.1	24.8	13.6	0.0	0.0	0.0	152.8
2006	0.0	0.0	0.0	0.0	0.0	61.0	161.0	20.3	6.3	0.0	0.0	0.0	248.6
2007	0.0	0.0	0.0	0.0	26.9	56.3	64.9	49.7	0.0	0.0	0.0	0.0	197.8
2008	0.0	0.0	0.0	0.0	5.9	45.8	65.5	47.8	12.2	0.0	0.0	0.0	177.2
2009	0.0	0.0	0.0	0.0	3.9	8.4	58.7	51.1	3.2	0.0	0.0	0.0	125.3
2010	0.0	0.0	0.0	0.1	0.0	35.5	105.4	51.9	0.0	0.0	0.0	0.0	192.9
2011	0.0	0.0	0.0	0.0	10.8	43.8	35.7	56.0	9.9	1.3	0.0	0.0	157.5
2012	0.0	0.0	0.0	8.2	25.3	33.7	76.9	65.3	4.9	0.0	0.0	0.0	214.3
2013	0.0	0.0	0.0	1.0	6.4	40.8	86.6	59.6	0.0	0.0	0.0	0.0	194.4
2014	0.0	0.0	0.0	0.0	14.4	34.6	127.1	41.8	9.0	0.0	0.0	0.0	226.9
2015	0.0	0.0	0.0	0.0	1.6	25.6	103.5	163.0	18.8	0.0	0.0	0.0	312.5
2016	0.0	0.0	0.0	0.0	16.3	51.6	80.6	45.5	43.3	0.0	0.0	0.0	237.3
2017	0.0	0.0	0.0	0.0	15.1	50.4	67.0	79.3	0.7	0.0	0.0	0.0	212.5
2018	0.0	0.0	0.0	3.4	34.7	71.7	97.2	130.3	30.3	---	---	---	---

DROUGHT HAZARD ASSESMENT

METEO IMGW-PIB
meteo.imgw.pl

Number of 10-day and longer dry periods



DS - series of consecutive days without precipitation or with daily totals ≤ 1mm

	P [%]
	< 5
	5 – 10
	10 – 20
	20 – 30
	30 – 40
	40 – 60
	60 – 70
	70 – 80
	80 – 90
	90 – 95
	> 95

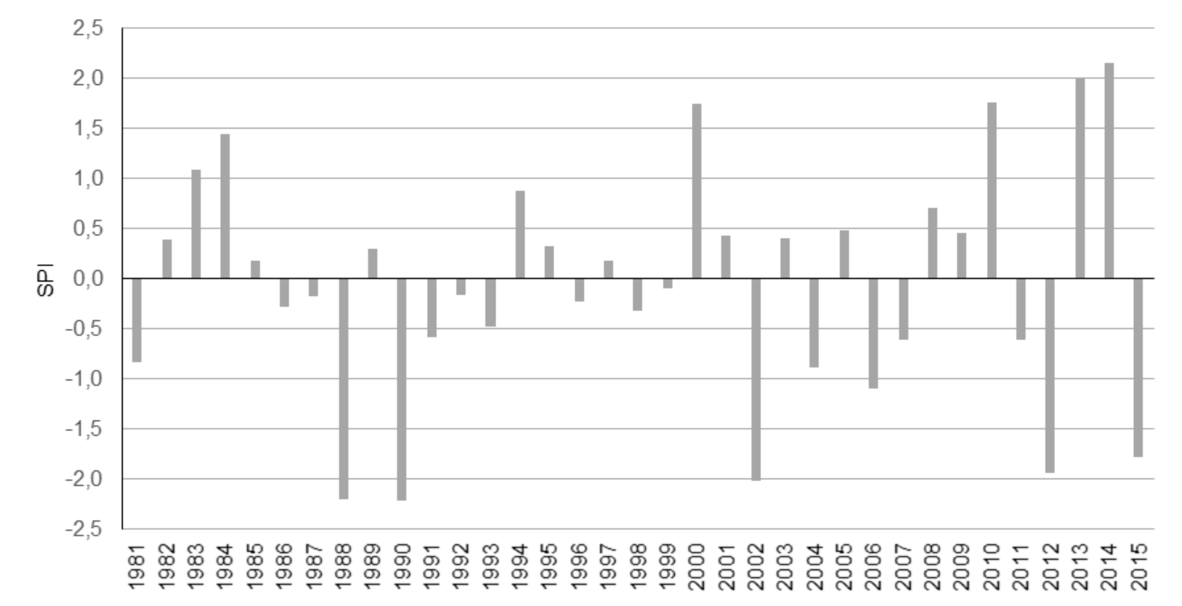
number of days with precipation > 1mm

1977	9	9	10	9	8	9	15	10	10	6	11	10	116
1978	5	0	10	6	12	7	8	11	12	6	4	13	94
1979	6	4	11	8	6	10	10	7	10	4	15	11	102
1980	7	8	3	10	6	10	15	9	8	8	5	5	94
1981	8	7	9	7	5	8	13	9	8	13	12	11	110
1982	7	2	7	6	10	9	6	4	3	5	6	7	72
1983	12	7	10	11	11	7	4	6	4	5	7	6	90
1984	3	7	2	10	17	13	10	6	15	6	4	6	99
1985	6	11	10	9	8	15	6	12	6	4	11	11	109
1986	11	3	6	3	11	6	11	14	8	8	5	13	99
1987	13	11	6	7	9	14	8	11	9	6	8	7	109
1988	7	9	13	2	2	13	10	6	9	4	10	12	97
1989	5	7	5	11	6	11	7	5	8	5	10	5	85
1990	4	5	3	9	5	12	5	10	12	5	9	6	85
1991	4	4	5	9	11	12	6	8	6	4	9	9	87
1992	5	8	11	6	5	6	9	9	3	7	10	8	87
1993	8	7	9	4	7	13	14	7	10	7	9	12	107
1994	10	4	15	8	10	6	2	10	6	8	3	12	94
1995	9	5	7	7	9	12	6	9	11	2	8	7	92
1996	2	5	6	7	11	4	12	14	14	7	3	5	90
1997	1	6	4	11	12	4	15	4	6	9	6	10	88
1998	12	4	11	7	7	11	12	8	8	14	5	4	103
1999	6	6	8	6	8	9	7	3	8	5	6	7	79
2000	6	11	14	2	12	8	13	4	6	3	7	6	92
2001	5	6	13	8	6	11	16	9	17	6	10	9	116
2002	7	10	5	4	3	7	7	8	8	15	11	4	89
2003	10	1	3	6	12	4	9	4	7	9	7	6	78
2004	11	8	5	2	8	10	8	12	5	5	12	4	90
2005	9	9	2	4	11	7	11	8	5	2	6	16	90
2006	7	8	9	7	6	6	4	17	3	8	9	7	91
2007	18	11	7	1	9	9	17	7	10	7	10	6	112
2008	13	4	8	12	7	6	9	9	5	6	7	6	92
2009	9	11	12	1	11	19	13	7	4	13	6	11	117
2010	8	3	9	9	15	6	11	15	10	1	14	11	112
2011	10	3	4	5	8	6	12	8	4	7	0	8	75
2012	15	9	3	5	7	10	13	10	5	7	5	3	92
2013	14	9	7	7	11	11	4	9	13	2	6	4	97
2014	6	0	7	10	12	7	9	7	10	7	4	7	86
2015	11	2	7	3	5	10	10	2	8	5	11	6	80
2016	10	12	10	12	4	9	9	3	4	14	9	6	102
2017	5	7	10	13	5	10	12	6	10	16	10	6	110
2018	3	1	5	8	5	5	8	4	6	4	3	12	64
2019	13	5	11	4	11	---	---	---	---	---	---	---	---
Par.	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	I-XII

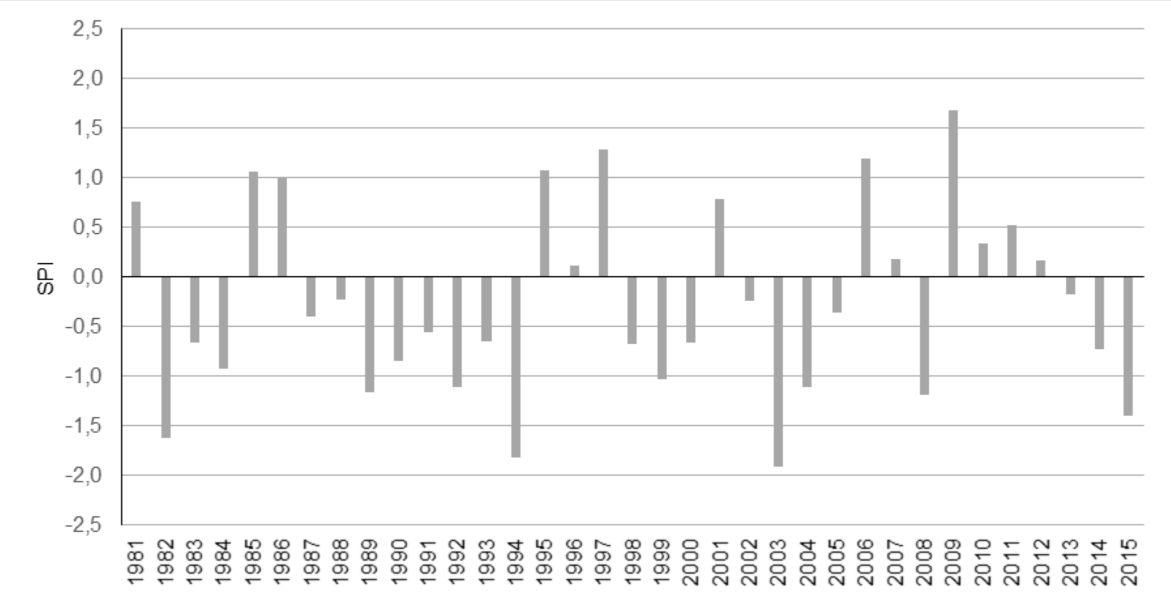
DROUGHT HAZARD ASSESMENT

METEO
IMGW-PIB
meteo.imgw.pl

SPI3 (3-month)
obtained at the end of May



Meteorological drought



SPI3 (3-month)
obtained at the end of August

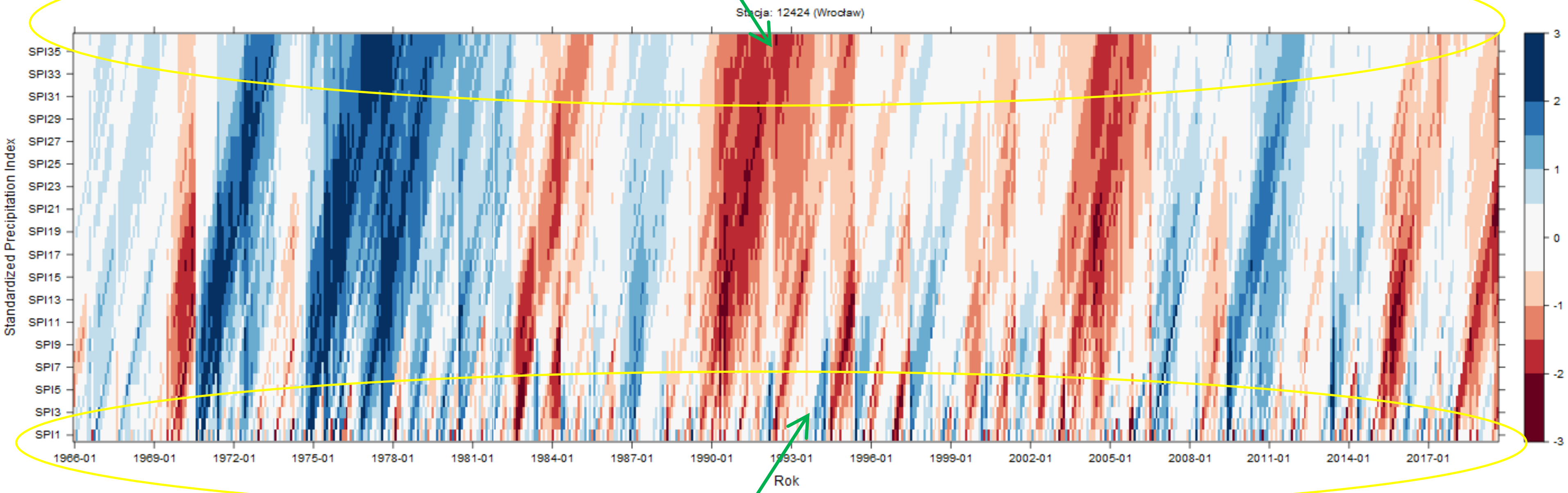
TRENDS IN DROUGHT HAZARD

METEO IMGW-PIB meteo.imgw.pl

Standardised Precipitation Index SPI

long-term variation of meteorological conditions

WROCŁAW



short-term variation of meteorological conditions

The Hovmoller-type diagram

Low Flows

Water gauge	River	Low flow periods characteristics			
		$D_i<D_{50\%}$ & $T_i<T_{30}$	$D_i<D_{80\%}$ & $T_i<T_{90}$	$D_i<D_{90\%}$ & $T_i<T_{120}$	$D_i<D_{95\%}$ & $T_i<T_{180}$
Jarnołtów	Bystrzyca	95	18	8	5
Krzyżanowice	Widawa	57	17	9	6
Oława	Oława	101	25	8	4
Borów	Ślęza	33	21	4	6
Malczyce	Odra	76	25	3	7
Oława (Most)	Odra	69	22	5	4

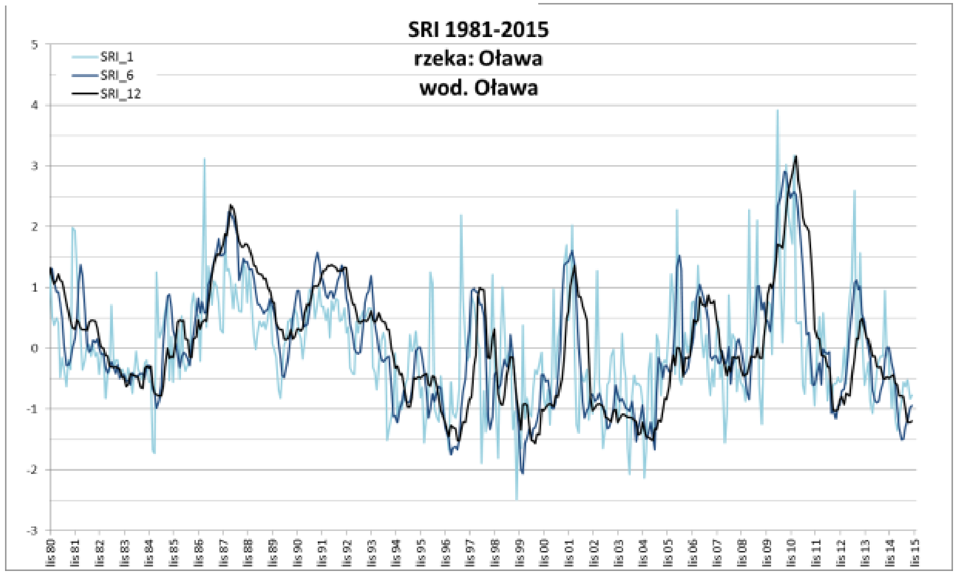
Di – deficit volume; Ti - duration

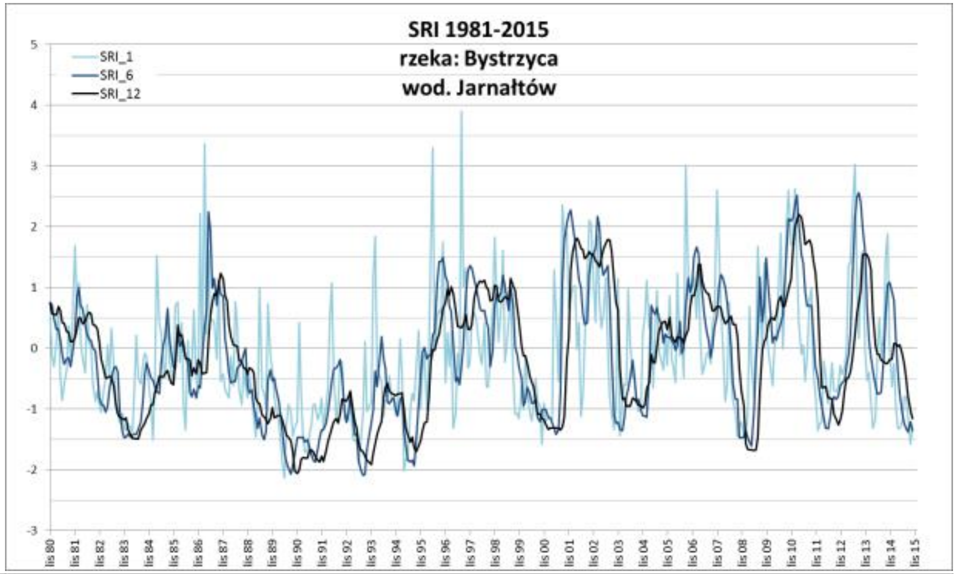
DROUGHT HAZARD ASSESMENT

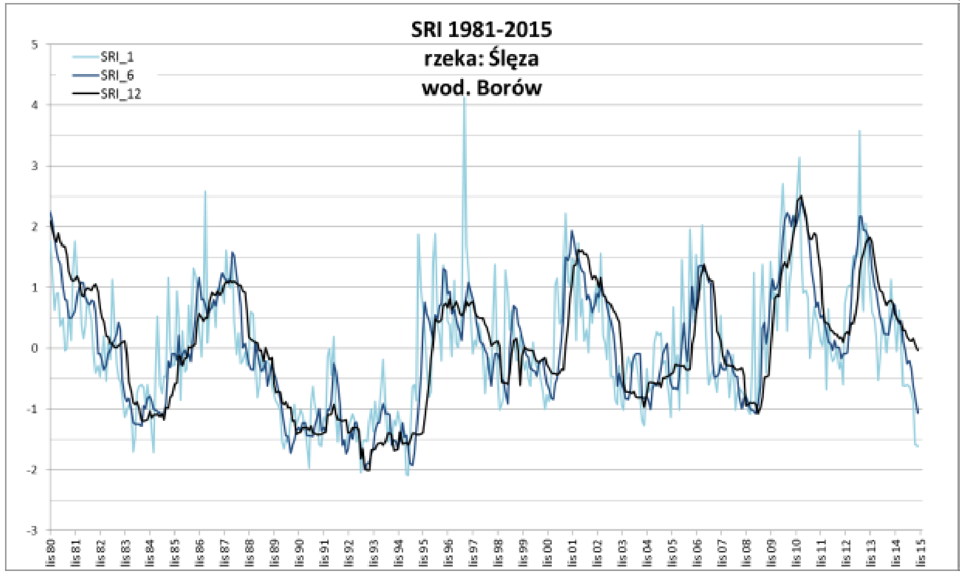
METEO IMGW-PIB
meteo.imgw.pl

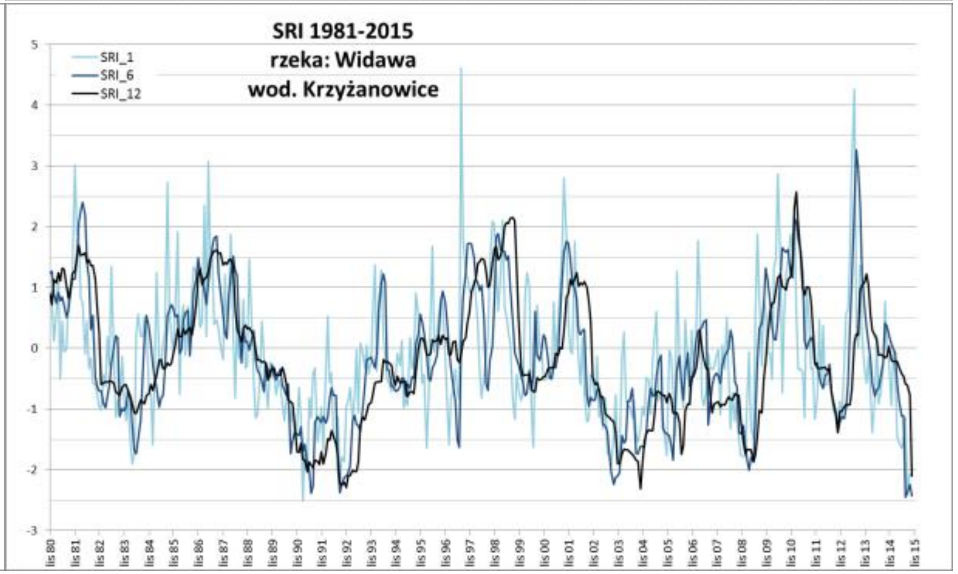
Hydrological drought

SRI1, SRI6, SRI12 for selected water gauge stations







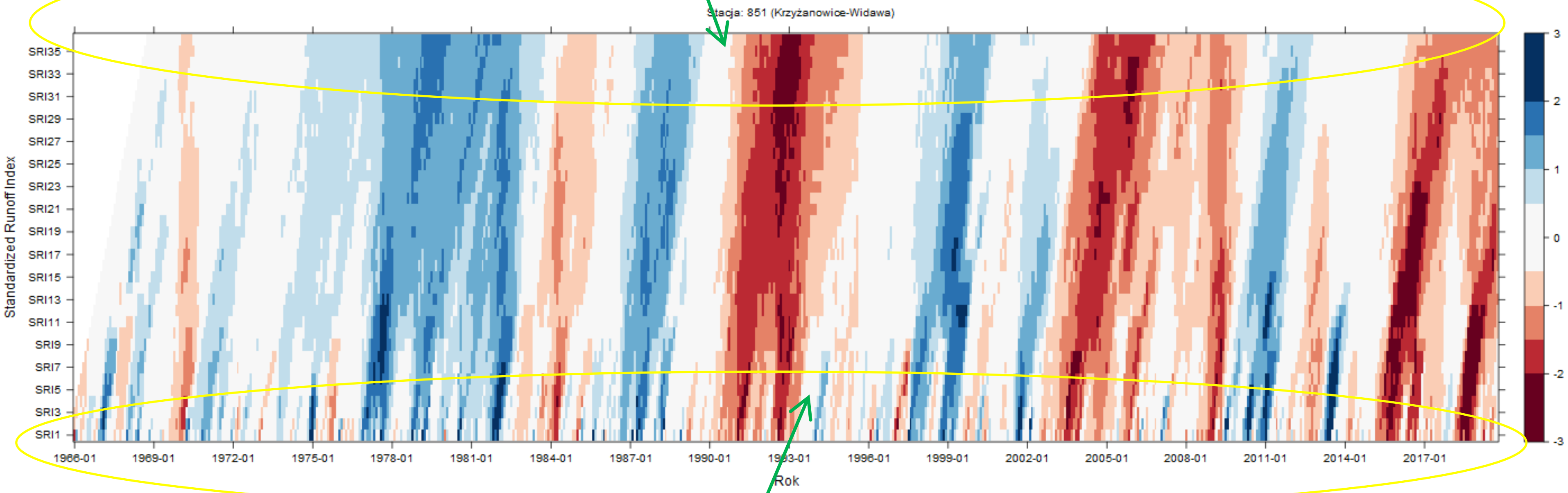


METEO IMGW-PIB meteo.imgw.pl

Standardised Runoff Index SRI

long-term variation of hydrological conditions

Widawa, w. Krzyżanowice



short-term variation of hydrological conditions

The Hovmoller-type diagram

DROUGHT HAZARD ASSESMENT

METEO IMGW-PIB
meteo.imgw.pl

Hazard	observed frequency	observed trend	climate change projections up to 2050	Hazard level
EHD	several times a year	rising	intensity may become critical over the **next few years**	5
CDD	over a dozen days a year	rising	intensity may become critical over the **next few years**	5
HW	several times a year	rising	intensity or frequency may become critical over the **next few years**	5
DS	several times a year	rising	intensity may become critical over the **next ten years**	5
LF	every 3-5 years	rising	intensity or frequency may become critical over the **next ten years**	4
MD	every 2-3 years	no significant trend	intensity or frequency may become critical over the **next decades**	4
HD	every 3-5 years	rising	intensity or frequency may become critical over the **next ten years**	4

DROUGHT RISK ASSESSMENT: SENSIVITY ANALYSIS

METEO IMGW-PIB
meteo.imgw.pl

sector	Sensitivity factors	Unit	Relevance
population	population density	[no./km^2]	The higher the population density, the higher the density of the built environment and the higher the potential of thermic stress
	children under 6 years old	[no./km^2]	The higher the proportion of potentially state-dependent, or family-dependent people, the lower the response capacity
	people over 65 years old	[no./km^2]	
economy	main economy sectors	list of sectors	The larger the number of water-intensive industries the higher the sensitivity
	budget structure	[%]	
	gross domestic product	per capita	The richer the society, the higher the response capacity
land cover	green space and protected areas	[%]	The higher the share of green space the lower the potential of thermic stress. Large share of green spaces and protected areas increases sensitivity to drought due to the need for watering;
	impermeable area	[%]	Lower the share of impermeable areas the higher infiltration and retention capacity and lower impacts
	biologically active area	[%]	
energy	energy supply structure (fossil, renewable)	%	The higher the cooling water demand, the higher the sensitivity of the urban power supply
	electrical energy consumption per sector	TWh	

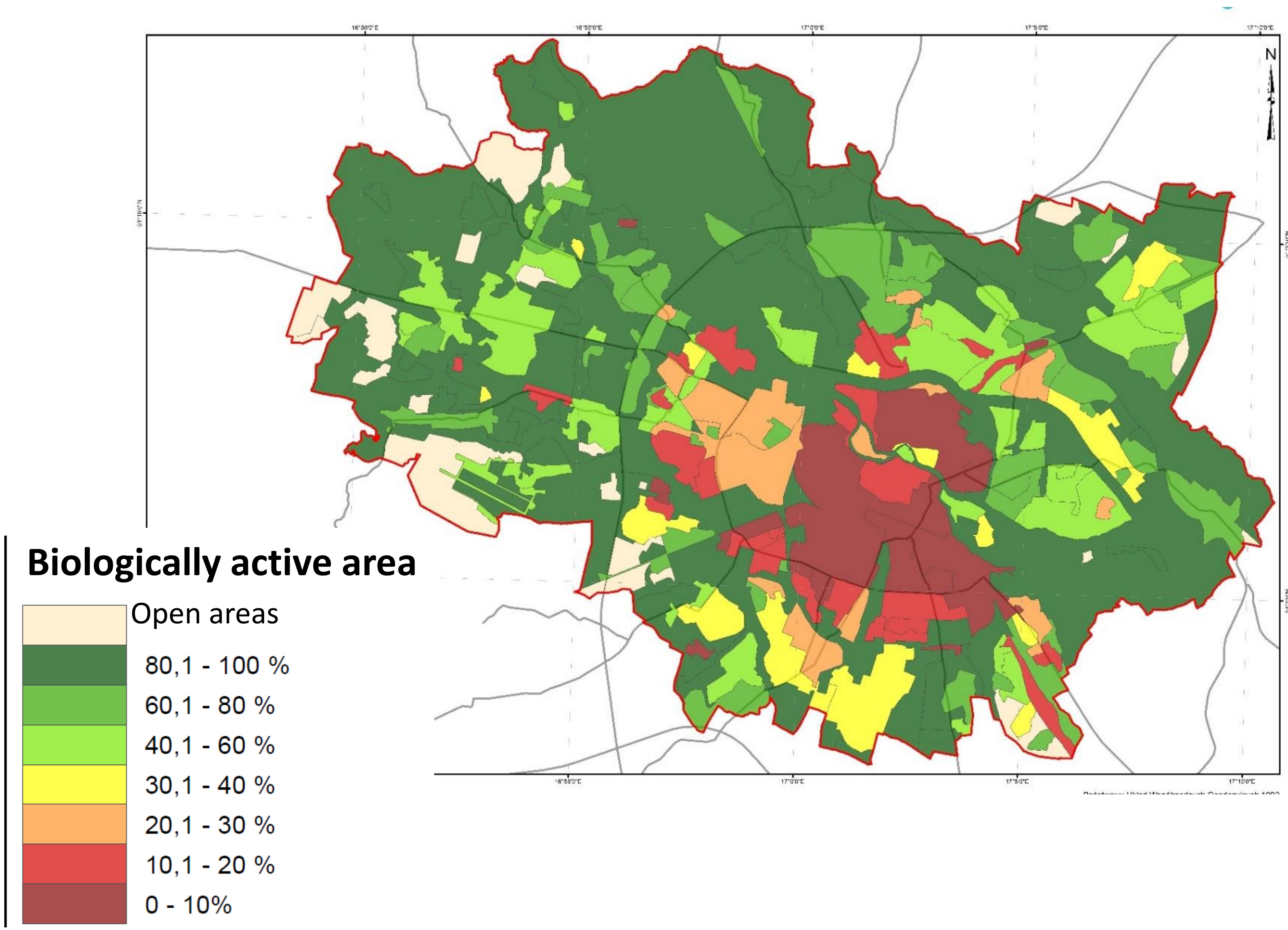
DROUGHT RISK ASSESSMENT: SENSIVITY ANALYSIS

METEO IMGW-PIB
meteo.imgw.pl

sector	Sensitivity factors	Unit	Relevance
water management	water channel density	km/km^2	The change in density is an indicator of the periodic loss of the water network (rivers, small natural and artificial watercourses) and an increase in susceptibility to the effects of drought
	municipal water supply	%	The higher the share of the surface water for municipal water supply or the city's reliance on only one source of water supply the higher sensitivity to drought and low flows events. The efficiency of a water supply system decreases its sensitivity to drought
	water consumption structure (total, industry, agriculture and forestry, domestic water consumption,)	m^3/year water consumption per capita	The higher the water use per sector/per capita, the higher sensitivity to drought and low flows events
transportation	rail tracks	[km]	The increase in track length increases the risk of problems in rail transport due to high temperatures
	road density (total length of main roads per square meter)	[km/km^2]	High density road areas reduce infiltration and retention. High temperatures cause deformation of bituminous surfaces.
	public transport vehicles without air conditioning	[%]	Reduced thermal comfort of passengers during hot weather
hea lthc are	hospital emergency wards hospital beds	per capita per capita	The more emergency wards/ hospital beds, the higher city's response capacity

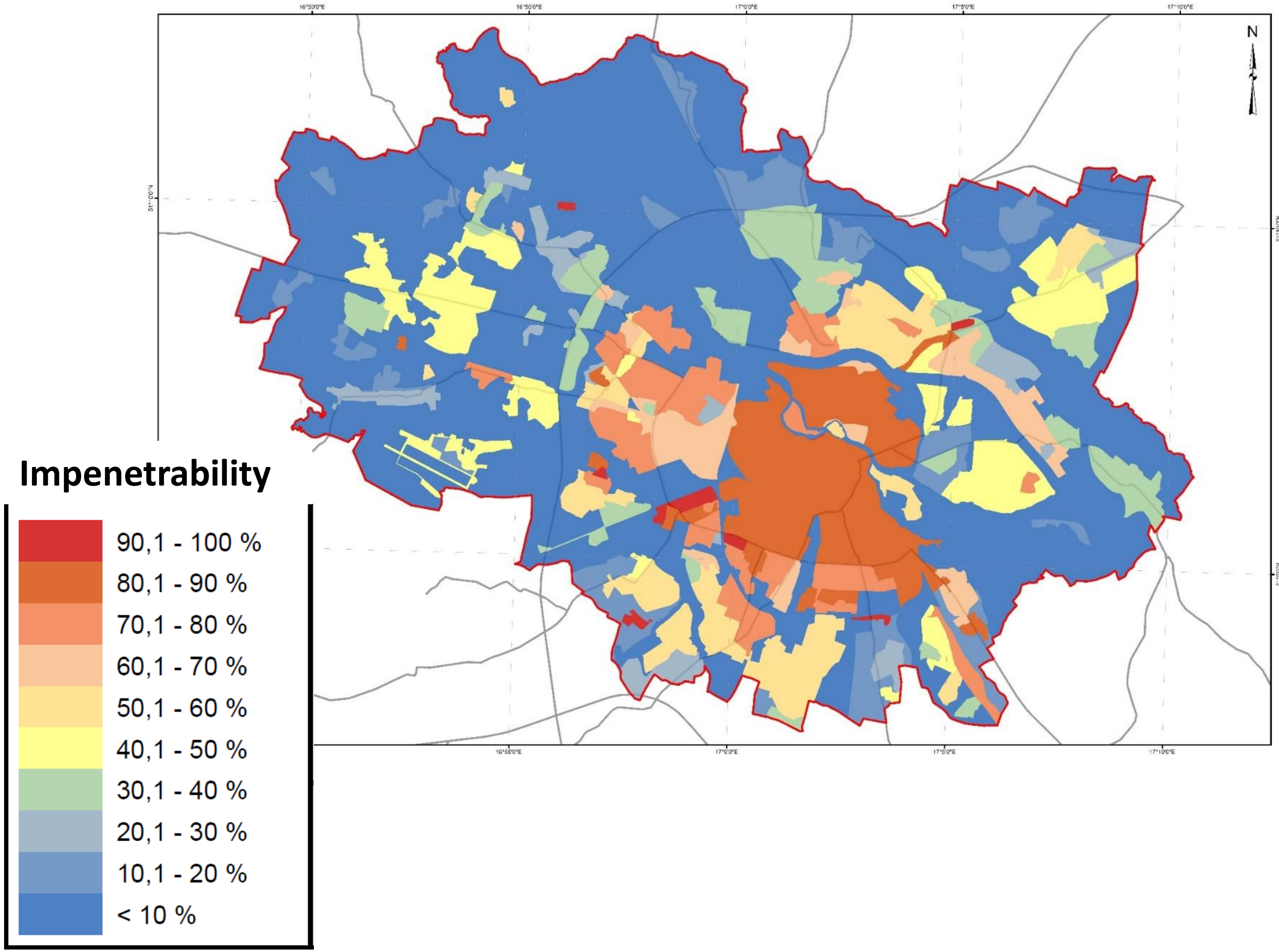
DROUGHT RISK ASSESSMENT: SENSIVITY ANALYSIS

METEO
IMGW-PIB
meteo.imgw.pl



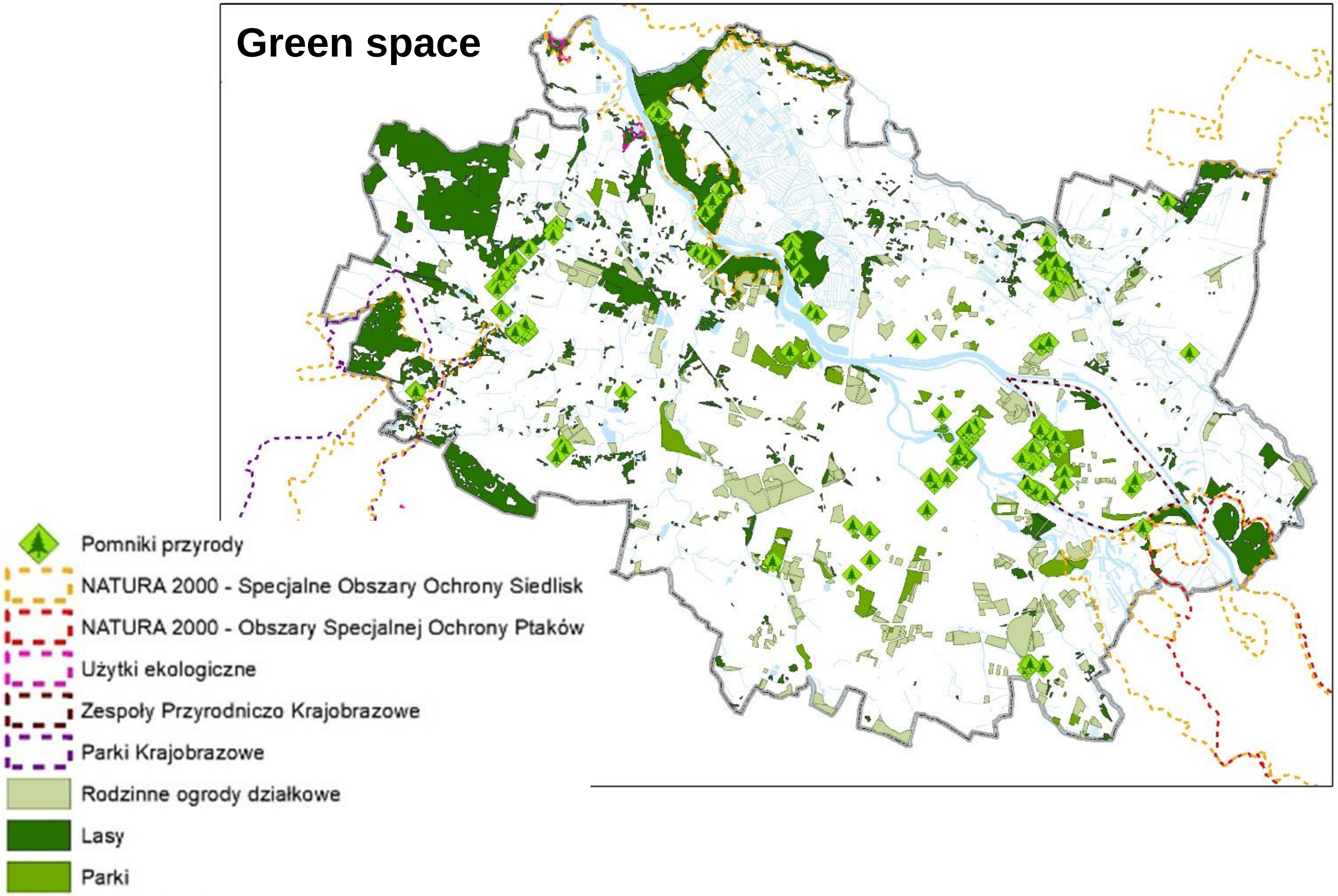
DROUGHT RISK ASSESSMENT: SENSIVITY ANALYSIS

METEO
IMGW-PIB
meteo.imgw.pl



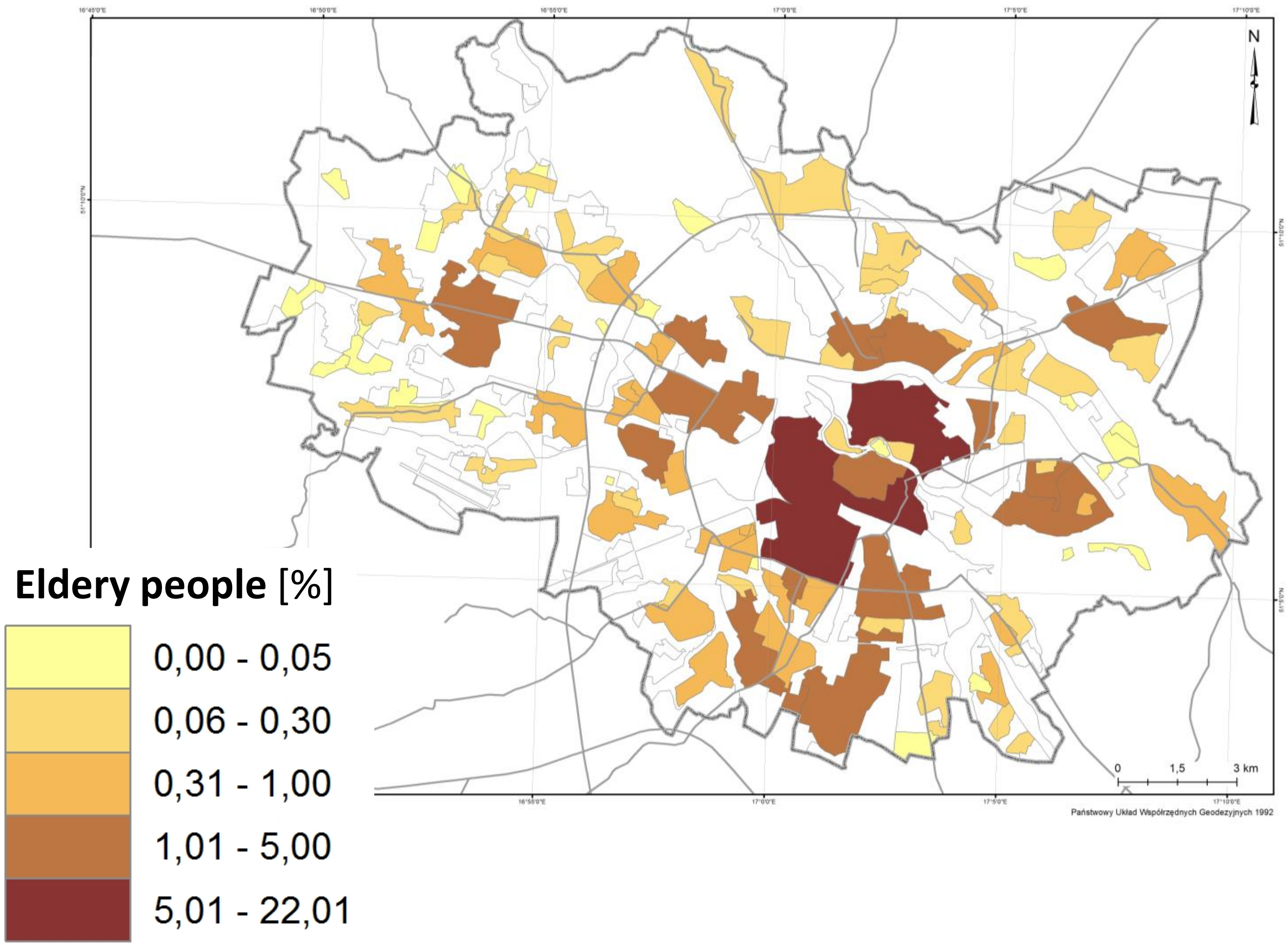
DROUGHT RISK ASSESSMENT: SENSIVITY ANALYSIS

METEO
IMGW-PIB
meteo.imgw.pl

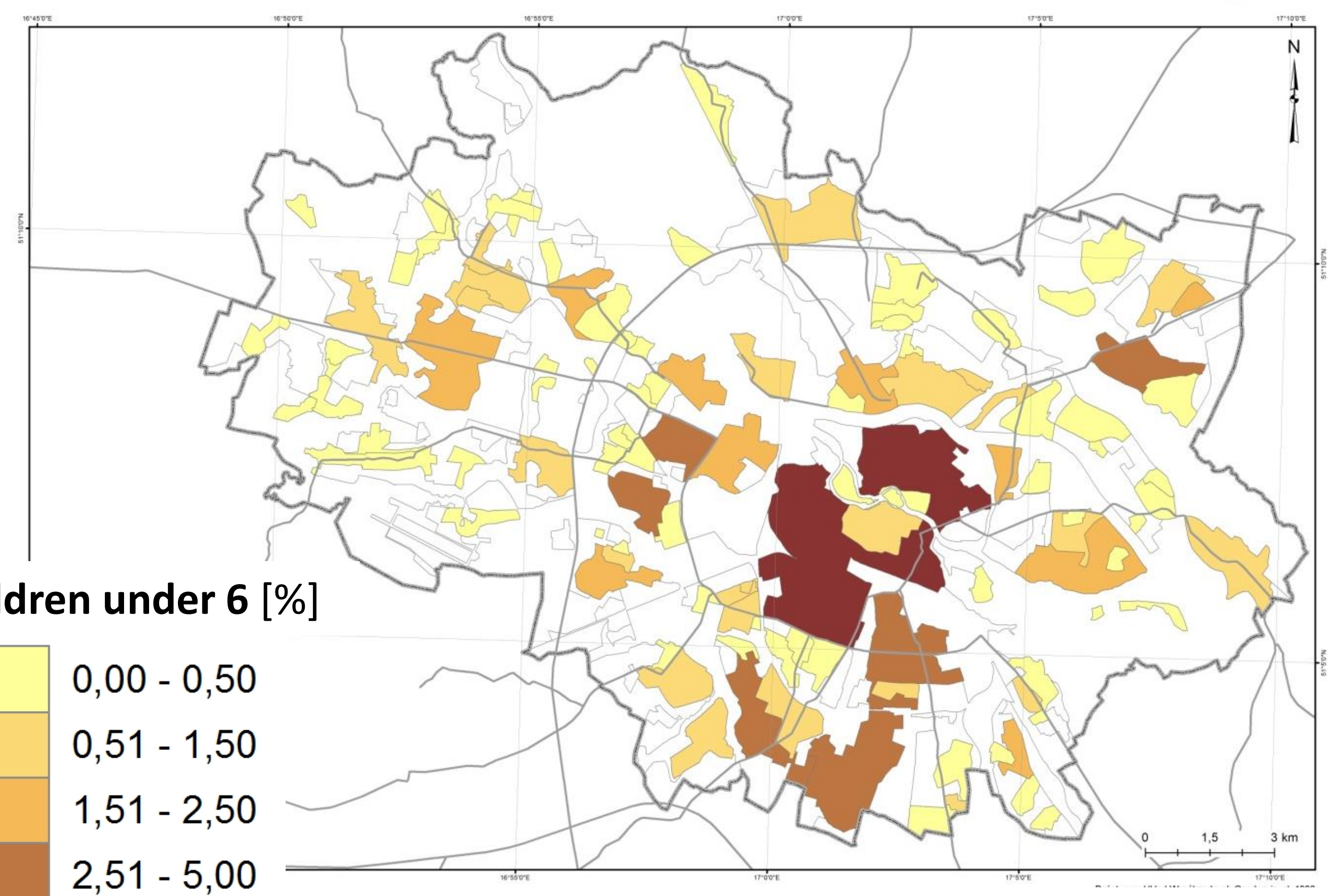


DROUGHT RISK ASSESSMENT: SENSIVITY ANALYSIS

METEO
IMGW-PIB
meteo.imgw.pl



DROUGHT RISK ASSESSMENT: SENSIVITY ANALYSIS

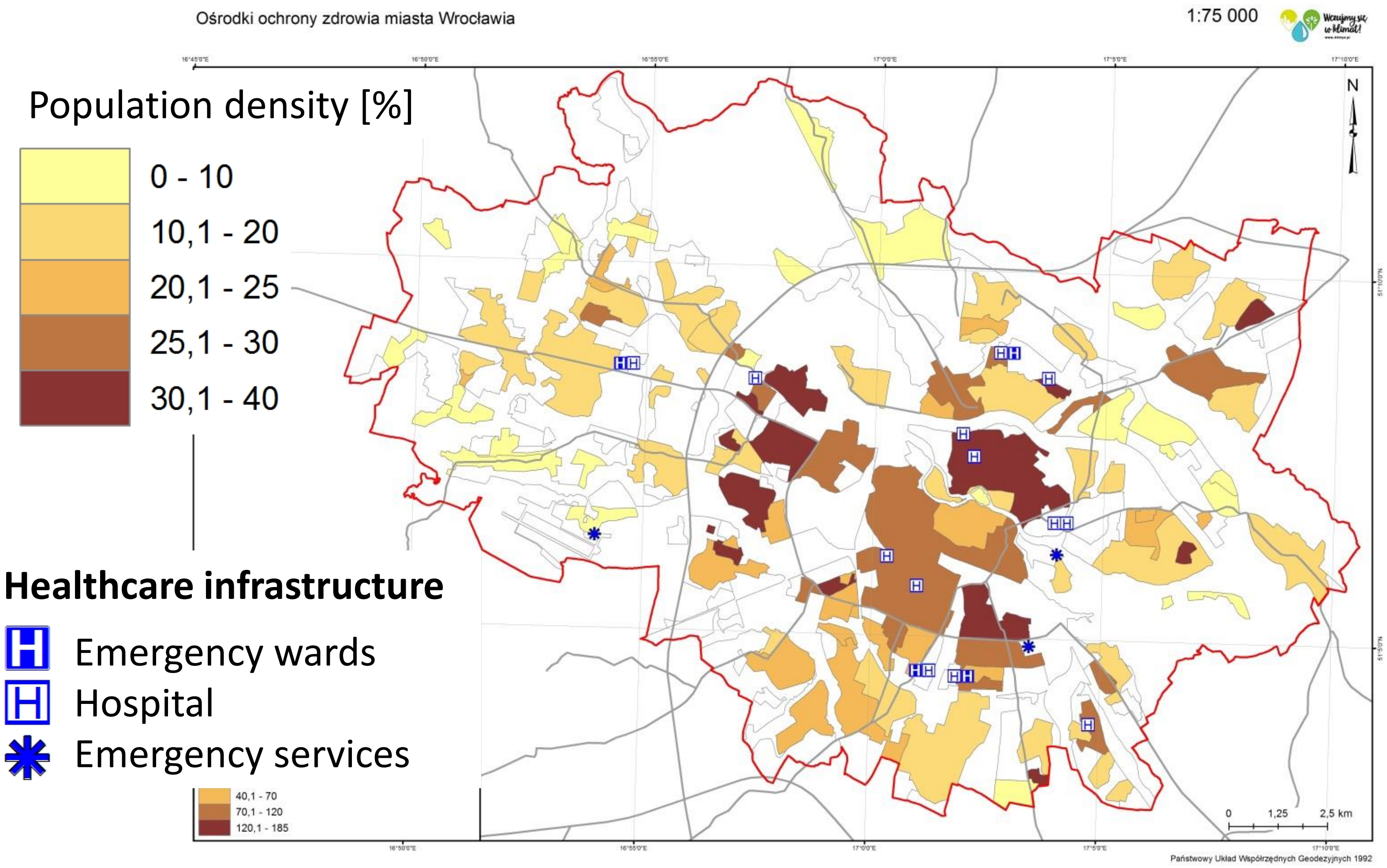


Children under 6 [%]

- 0,00 - 0,50
- 0,51 - 1,50
- 1,51 - 2,50
- 2,51 - 5,00
- 5,01 - 15,00

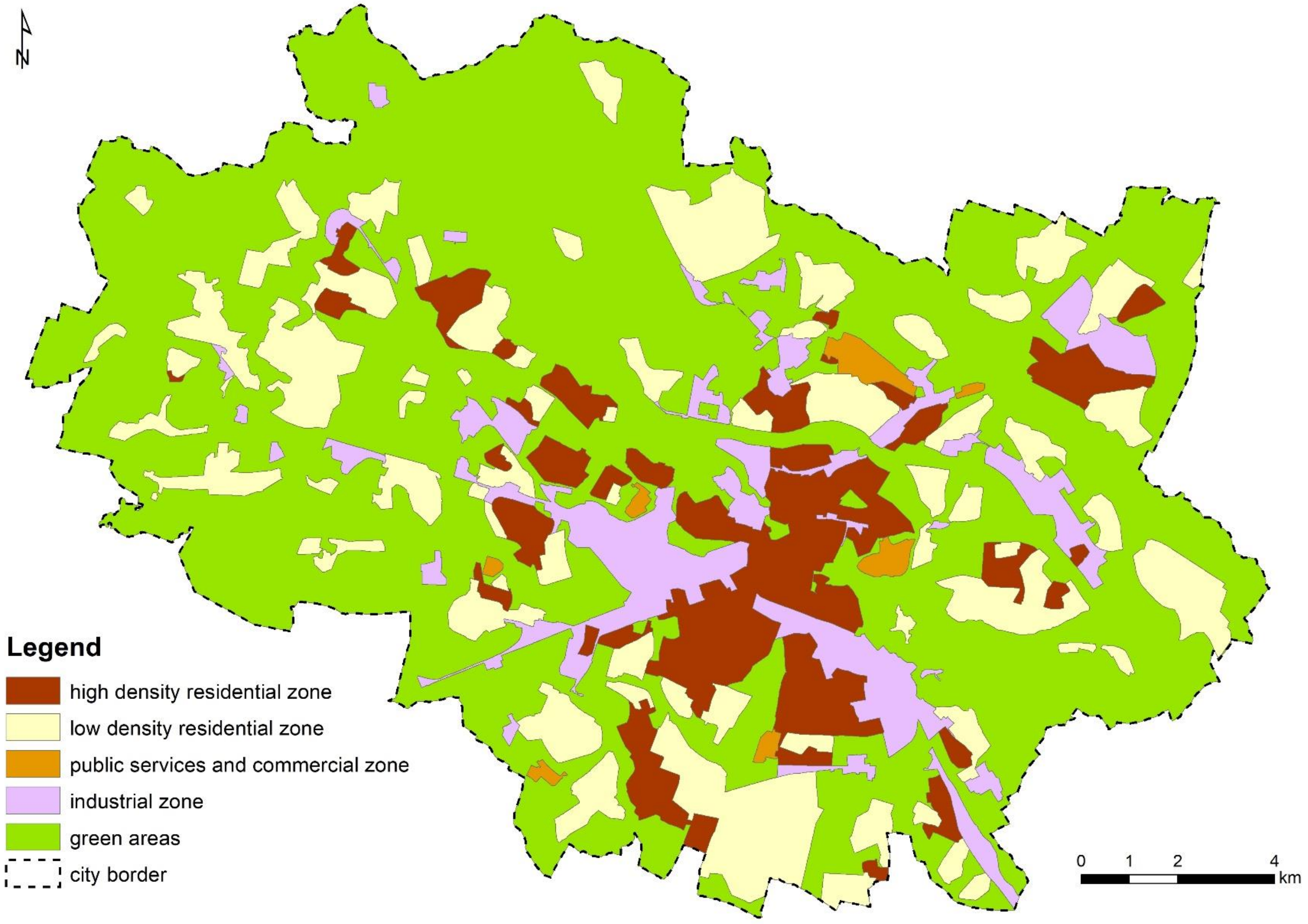
DROUGHT RISK ASSESSMENT: SENSIVITY ANALYSIS

METEO
IMGW-PIB
meteo.imgw.pl

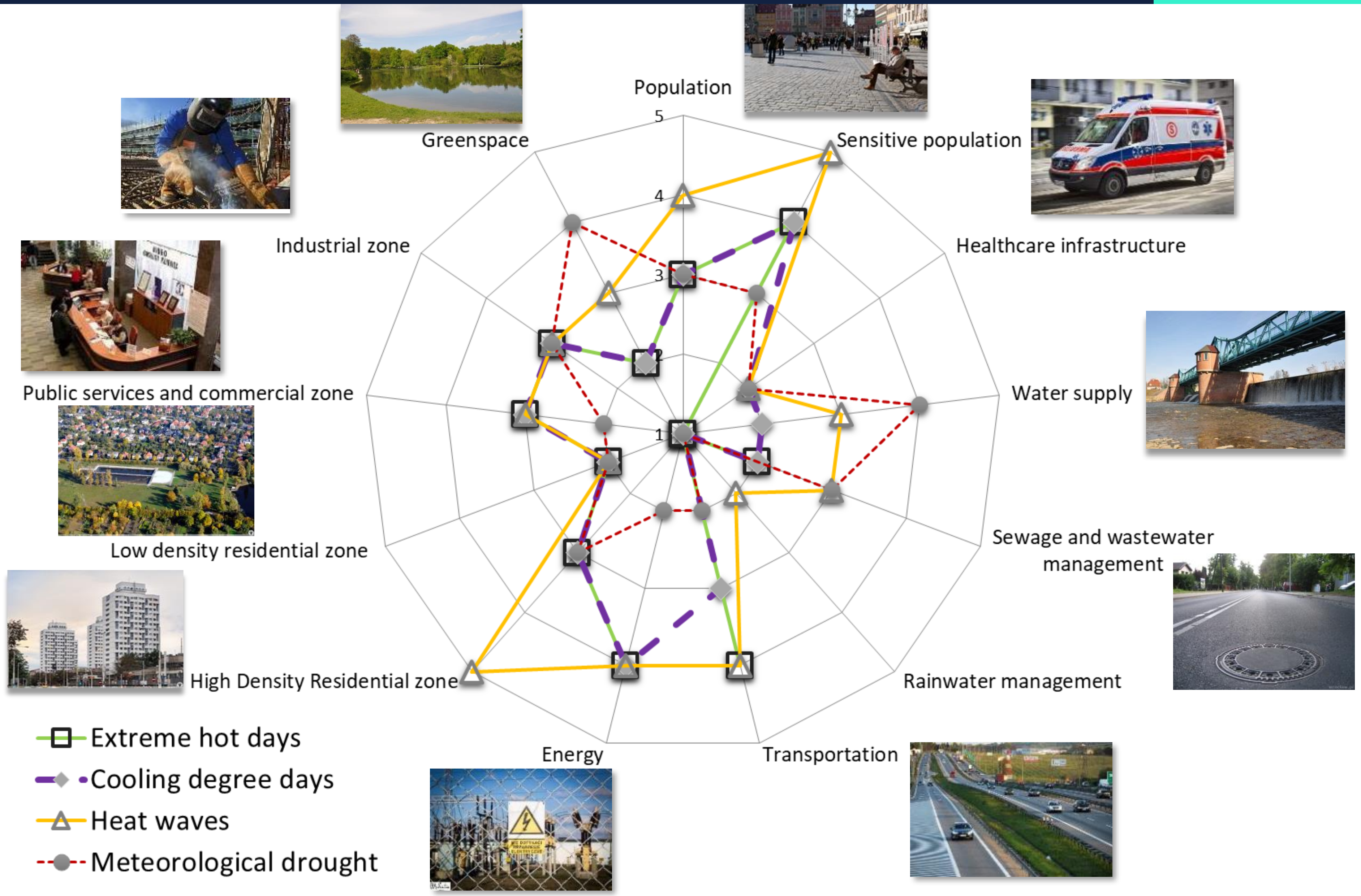


DROUGHT RISK ASSESSMENT: VOULERABILITY AREAS

METEO
IMGW-PIB
meteo.imgw.pl

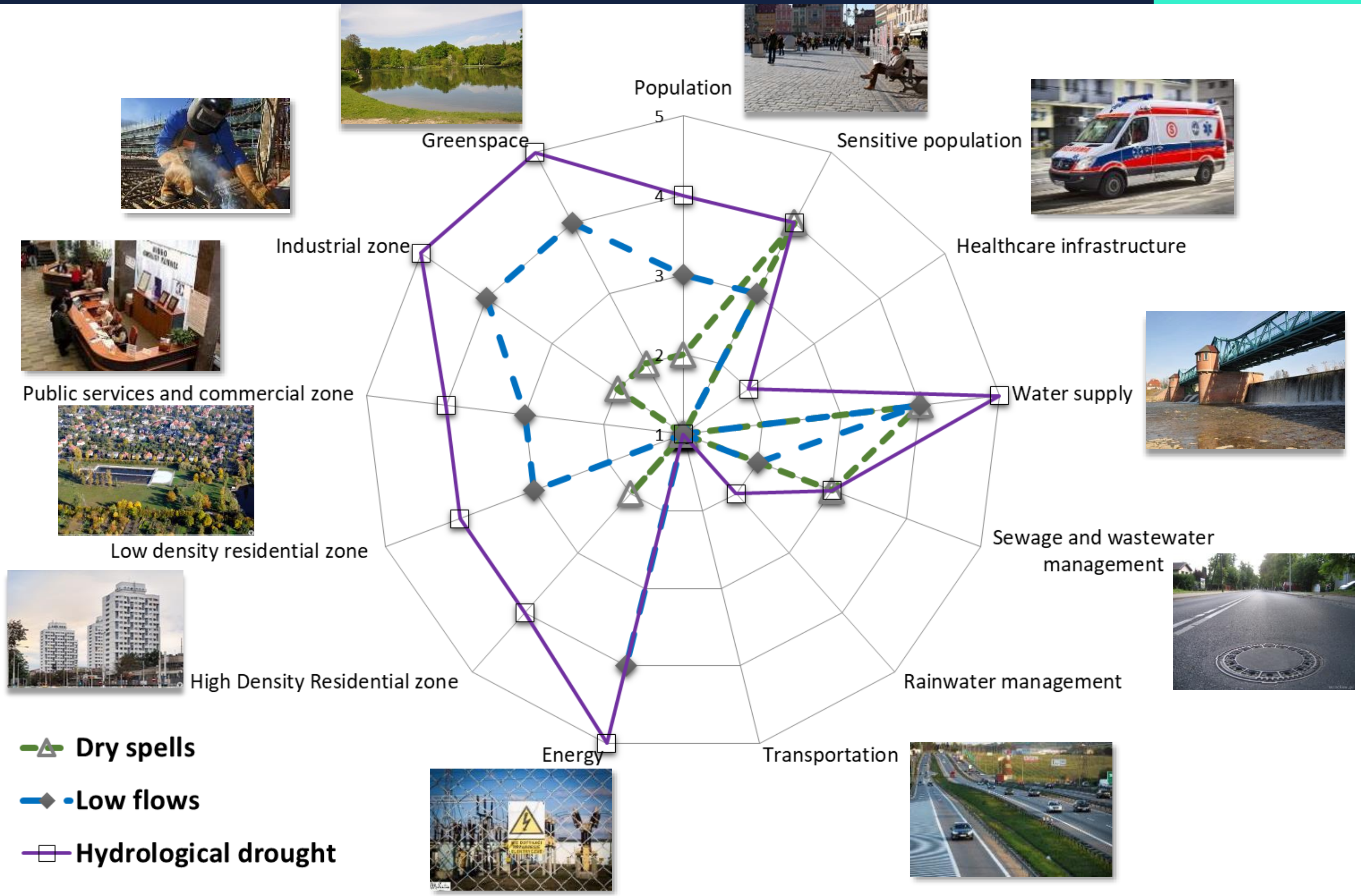


DROUGHT VOULERABILITY ASSESSMENT



DROUGHT VOULERABILITY ASSESSMENT

METEO
IMGW-PIB
meteo.imgw.pl



DROUGHT RISK ASSESSMENT

analyzying long-term patterns + future scenarios

Potential consequences	Probability of hazard event occurrence				
	low (1)	occasional (2)	medium (3)	high (4)	very high (5)
catastrophic (5)	medium risk	medium risk	high risk	high risk	very high risk
critical (4)	low risk	medium risk	medium risk	high risk	very high risk
serious (3)	low risk	low risk	medium risk	high risk	high risk
marginal (2)	low risk	low risk	medium risk	medium risk	high risk

reported consequences of historical drought events
literature studies
potential lossess

experts judgments

- *size of losses,*
- *disruptions in functioning, activities, services,*
- *time and expenses needed to return to the conditions from before the event*

DROUGHT RISK ASSESSMENT

City component voulnerable to drought	RISK LEVEL						
	EHD	CDD	HV	LLDS	LF	MD	HD
Population	H	H	V	H	H	M	M
Sensitive population	V	V	V	H	H	M	M
Healthcare infrastructure	M	H	H	M	M	L	M
Water supply	M	H	H	V	H	M	H
Sewage and wastewater management	H	H	H	H	H	M	M
Rainwater management	M	M	H	M	M	L	M
Transportation	V	H	V	M	M	L	L
Energy	V	V	V	M	M	M	H
High Density Residential zone	H	H	V	H	H	L	M
Low density residential zone	H	H	H	M	M	M	M
Public services and commercial zone	H	H	H	M	M	M	M
Industrial zone	H	H	H	H	H	M	H
Greenspace	H	H	H	H	H	M	H

Risk matrix is to help to identify and prioritize a set of measures aimed to reduce identified drought risks.

DROUGHT RISK REDUCTION MEASURES

Included in the "Plan for adapting the City of Wrocław to climate change by 2030"

Development of the system of information on drought and related hazards

Improvment of outdoor human thermal comfort

Adaptation of the urban transportation system to climate change

Development of the green-blue infrastructure system

Development of rainwater management system

Upgrading water supply safety

Managing energy system reliability and peak demand

Sustainable spatial city development

Dziękuję / Thank you

Autor (imię i nazwisko/Centrum/Wydział/Zespół/Inne)

DD/MM/RRRR, miejsce

METEO
IMGW-PIB
meteo.imgw.pl