SPATIAL DIFFERENTIATION AND DROUGHT INTENSITY IN THE UPPER SILESIA REGION, POLAND

WYPYCH AGNIESZKA[1], PALARZ ANGELIKA [1], KUBACKA DANUTA[2]

ABSTRACT. – Spatial differentiation and drought intensity in the Upper Silesia Region, Poland. Drought estimation and monitoring seems to be crucial both in agricultural activities as well as in water management. The aim of the study is to estimate the drought vulnerability of the Upper Silesia Region using selected drought indices. The evaluation was based on daily meteorological data from the period 1981-2010 and conducted for particular administrative units. On the basis of 30-years of observations the spatial distribution of drought phenomena as well as its intensity and duration was described. The communes particularly exposed to meteorological drought were indicated, also the regions where the phenomena are rare or even not observed. As the analyses were conducted using several drought indices, their applicability was evaluated for the region under consideration. The results showed that for drought monitoring over the region meteorological drought indices should be taken into account at the first stage but it is also necessary to diagnose the environmental conditions (especially geological formation and the relief). Despite high precipitation totals recorded the areas with very complex relief and unfavourable geological formation are prone to water shortage resulting the intensive run-off.

Keywords: meteorological drought, drought monitoring, Poland

1. INTRODUCTION

Drought is one of the most complex extreme phenomena, influencing human activity, mainly agriculture, forestry and water management (Field et al., 2012; Wang et al., 2014). Its occurrence is a result of inter-relationships between a group of factors: meteorological – precipitation, air temperature, humidity, sunshine duration and wing speed; hydrogeological – water table depth, spring efficiency, bed-rock features and environmental conditions – relief, soils or land-use (Tokarczyk, 2008). Therefore, is difficult to precise the unequivocal definition. For example, according to the report Gap Analysis of the Water Scarcity and Droughts Policy in the EU (2012) the precipitation shortage should be taken into consideration whereas Hisdal and Tallaksen (2000) emphasise the socio-economic importance of the phenomena. Regardless of the definition, four drought types can be distinguished – meteorological, agricultural, hydrologic and socioeconomic, being the following development stages (Wilhite and Glantz, 1985; Mishra and Singh, 2010).

[1] Jagiellonian University, 7 Gronostajowa Str. 30-387, Krakow, Poland
E-mail: agnieszka.wypych@uj.edu.pl

[2] Institute of Meteorology and Water Management – National Research Institute, 14 Piotra Borowego Str., 30-215, Krakow, Poland

The drought research is conducted concerning its main attributes: drought intensity, duration and spatial distribution with the use of different factors. Standardized Precipitation Index (SPI) and Palmer Drought Severity Index (PDSI) are between the most popular to distinguish meteorological drought (Moreira et al., 2008; Vasiliades and Loukas, 2009). Much the same are Integrated Surface Drought Index (ISDI), Vegetation Health Index (VHI) (Wang et al., 2014) as well as Climatic Water Balance or Sielianinov Hydrothermal Coefficient.

The main aim of the study is to estimate drought vulnerability of the Upper Silesia Region, Southern Poland using selected drought indices and to evaluate their applicability for the region under consideration.

2. DATA AND METHODS

This study is a part of the complex analysis towards drought monitoring, management and drought effects estimation adapted for the Upper Silesia Region by order and as instructed by National Water Management Authority, Poland.Although the main analysis includes all the drought hazard aspects, the issue of meteorological drought was chosen to be explored in this study, basing on selected indices. The spatial differentiation of meteorological drought phenomena as well as its long-time variability has been investigated. The analysis, though, diverse indices were used, enabled also to estimate their applicability for estimation: a) drought frequency, intensity and range, b) drought monitoring, c) drought forecasting.

2.1. Area of the study

This study was conducted for the water regions of the Little Vistula and the Upper Odra which are located in southern part of Silesia province in the Upper Silesia Region, Southern Poland (Fig. 1). The area of 8.000 square kilometres is environmentally differentiated. The southern part of the region – up 1557 m a.s.l. (Mt Pilsko) is the highest located, whereas the western edges, in Odra river basin, are the lowest – approximately 150 m a.s.l. (Fig. 1).

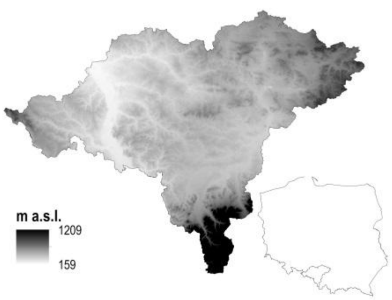

Fig. 1. ***The area of the study***

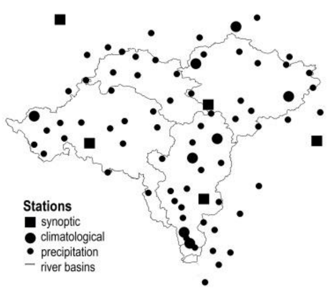

Fig. 2. ***Location of meteorological stations used in the study***

It is worth mentioning, especially while considering hydrological resources and water management, that the northern part of the region is hard pressed by human activity: coal mining as well as agriculture while the south represents much more natural environmental conditions.

2.2. Data

As a result of detailed analysis of available source materials (also towards the consideration of meteorological data) the period 1981-2010 was chosen as the basis for the study. Daily data of precipitation totals as well as air temperature, sunshine duration, wind speed and relative humidity values were obtained from 81 measuring points: 6 synoptic stations, 8 climatological stations and 67 rain gauges (fig. 2). Regarding the data failure or limited number of measured elements the missing values were interpolated between neighbouring stations or completed under homogenization procedures and WMO methodology (2003).

2.3. Drought indices

First and foremost the detailed analysis of precipitation totals (RR) and potential evapotranspiration (ETP) was conducted to identify the areas at drought risk. Regarding the source material (meteorological data) to calculate ETP Penman formula was used in its simplified form (Doroszewski et al., 2012) using daylight hours, sunshine duration, air temperature, wind speed as well as relative humidity at 12 UTC data.

Subsequently, the indices recommended in Poland for drought estimation (Jarząbek et al., 2013) were calculated and scrutinized. Three of them were selected – as the most representative – for this study purpose: Standardized Precipitation Index (SPI) because its comparability in different spatial and temporal scales (McKee et al.,1993), Climatic Water Balance (CWB) bringing the information about moisture content of the environment and Sielianinov Hydrothermal Coefficient (HTC) as a measure of precipitation efficiency within a given period (Farago et al., 1989).

The indices were evaluated for the running months. According to their methodology as well as to the methods adopted for this study, dry periods were defined to be the basis of drought frequency estimation and their intensity. Based on the climatological 30-years standard period, monthly drought hazard was detected for the whole area of the study. To precise the final information the degree of hazard was defined for each hydrological and administrative unit.

Regarding the lack of spatial information conformity for meteorological elements (precipitation and the others) to calculate the indices map algebra tool (ArcGIS) was implemented as well as the spatial interpolation methods commonly used in climatology: radial basis functions and empirical Bayesian kriging (Dobesch et al., 2007).

Detailed analysis for the values and also their long-term variability are presented for synoptic stations located in the area under consideration, i.e. Bielsko Biała, Racibórz, Katowice.

3. DROUGHT DISTRIBUTION AND INTENSITY

Although weather conditions in Poland vary within the year and in long-term and drought is naturally occurring, the problem is actually determined. Foremost because of its environmental and economic consequences dependant on the drought vulnerability of particular region (Łabędzkiet al.,2008).

The area under consideration is – as abovementioned – characterized by privileged precipitation conditions in general. Mean annual precipitation amount for the examined region total up to 800 mm. However it varies from less than 600 mm in the north-eastern part of the region up to 1300 mm in the south (the Beskids) (fig. 3). This spatial distribution pattern is changeless within a year. The highest, summer precipitation totals reach from 100 mm to more than 160 mm (respectively). During winter period the area differences are distinct. Southern part collects even 100 mm per month (mostly snow fall) whereas the north-western at least 20 mm. The described characteristics classify the region generally as humid or moderate humid except for the north-western edges.

The occurrence probability of drought expressed by SPI amounts from somewhat less than 10% up to 19% in maximum (fig. 4). It denotes the frequency of precipitation totals low enough (comparing to long-term mean) to contribute to drought occurrence. The spatial differentiation of this distribution is worth mentioning. The highest values, as probably expected, do not appear in the NW what perform the inconsiderable year-to-year variability of precipitation amount. Small, however undifferentiated totals recorded allows the area to adopt to relatively dry conditions. The most frequent drought occurrence (precipitation under-privileged) – more than 9% – can be observed in the autumn and in February (Table 1).

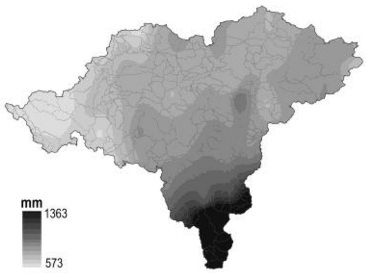

Fig. 3. ***Spatial differentiation of annual precipitation totals***

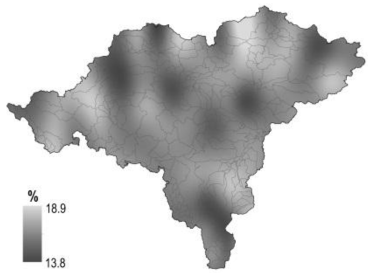

Fig. 4. ***Spatial differentiation of drought frequency by SPI ≤-1.0***

Particular attention should be paid to the fact that in September and October these are moderate droughts (>60% of all cases) whereas in April, the less humid month also with the precipitation totals often below average, almost 30% of droughts detected can be classified as extreme.

Table1.Drought frequency and intensity by SPI

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	drought frequency (%)											
	8.8	9.5	8.8	6.7	7.4	8.2	6.6	7.4	9.7	9.1	9.3	8.6
	drought intensity – frequency (%)											
moderately dry $(-1.5<SPI\leq-1.0)$	50.7	48.4	58.6	50.6	61.3	40.2	59.4	50.9	66.7	61.8	54.5	56.9
severely dry $(-2.0<SPI\leq-1.5)$	34.0	33.9	30.7	22	23.1	33.2	21.3	26.7	26.2	21.3	31.3	28.3
extremely dry $(SPI\leq-2.0)$	15.3	17.6	10.7	27.4	15.6	26.6	19.4	22.4	7.0	16.9	14.3	14.8

Drought occurrence, however, should not be related only to the abovementioned precipitation shortage defining meteorological drought by SPI. Air temperature variable is also very important.

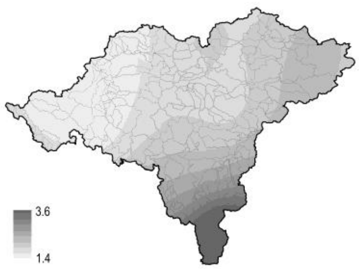

Fig. 5. ***Spatial differentiation of hydrothermal coefficient (HTC)***

The hydrothermal differentiation was described by Sielianinov coefficient (HTC). It brings together the temperature and precipitation therefore gives the information about moisture capability of the region formed mainly by thermal conditions.

Spatial distribution of HTC confirms the humidity privilige of the southern part (fig. 5) within the entire growing season (with the lowest HTC values in August). The driest are north and north-western areas (fig. 5), especially in August and in autumn months.

The analysis (both: spatial and temporal) of evapotranspiration was also be conducted as contributing to agricultural droughtdevelopment in consequence. Spatial distribution of ETP shows distinctly the lowest evapotranspiration intensity, in the south of the region, where during the most important growing season it is approximately 20 mm less then wherever else (fig. 6). The highest ETP values can be observed in the northern part in general. Within the warm half-year it is the NW whereas in the cold half – NE or even mid region. It results in the drought estimation according to the indices using ETP as one of the variables.

Climatic water balance (CWB) is one of the examples. Regarding high precipitation totals and relatively low evapotranspiration CWB over the examined

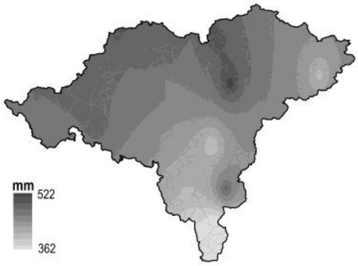

Fig. 6. ***Spatial differentiation of evapotranspiration (ETP)***

Fig. 7. ***Spatial differentiation of climatic water balance (CWB)***

region postulates – in general - the positive values all over the year when the whole analysed period is taken into consideration (fig. 7). April is the most dry month, when in the northern part the CBW values drop down to -22 mm. Nevertheless even though they are high enough not to be a threat. Critical CWB values, describing drought conditions for particular crops and plants, vary from -130 mm down to -360 mm, depending on the soil characteristics and the period.

The analysis of long-term averages enabled to estimate drought risk in the region under consideration. As it was stated, high precipitation totals and relatively low evapotranspiration assure stable moisture conditions. However, weather variability in Central Europe, including Poland, cause year-to year capriciousness of humid conditions, what is shown by long-term precipitation monitoring (SPI) (fig. 8). Although there is no significant tendency in precipitation changeability, the temperature growth still being observed (IPCC, 2013) may lead to more frequent and possibly more intense meteorological drought occurrence.

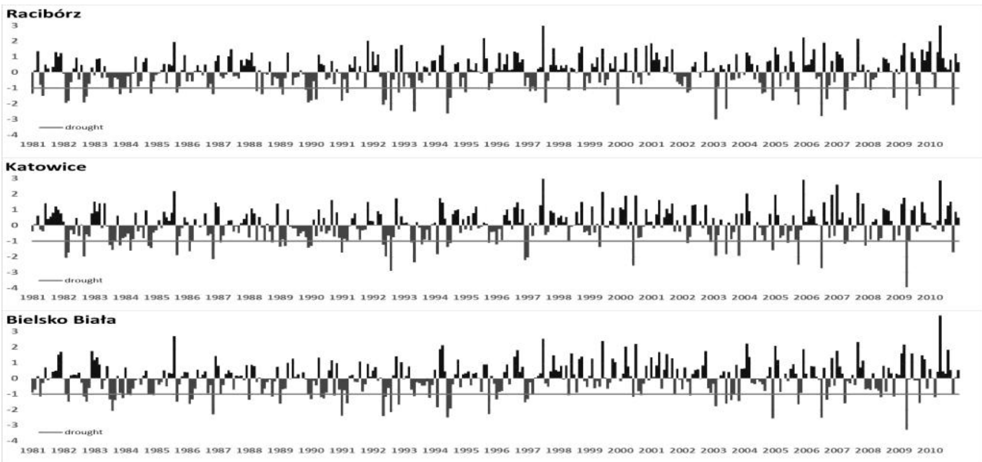

Fig. 8. ***Long-term variability of monthly SPI at selected stations***

With high temperature and intense evapotranspiration CWB is supposed to obtain values much lower than above mentioned -22 mm. The period 2011-2010 could be given as the example. In the northern part of the region the lowest CWB values were recorded at – 60 mm during the summer.

4. DISCUSSION

The high amount of different indices used for drought estimation due to its inter-disciplinarity, disable the univocal information about the drought phenomena itself as well as, probably more important, drought intensity. Considering additional variables (apart from precipitation) may classify the event at a different hazard level or even define the drought phenomena (not detected by RR). In the research already conducted (Łabędzkiet al. 2008) an attempt has been made to define the complex drought detection index. Nevertheless even though meteorological drought indices have been considered as the initial following by the hydrological and agriculture parameters. It is worth mentioning that regarding the different index formulas and temporal resolution they vary also due to their applicability (Fig. 9).

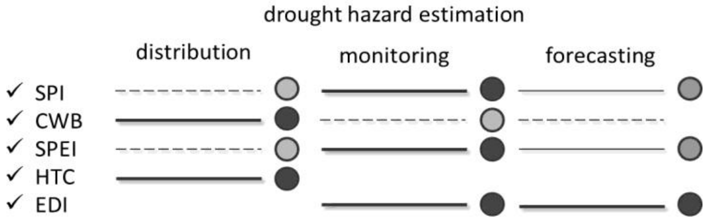

Fig. 9. ***Applicability estimation of selected drought indices***

Moreover, using the hydrological or agriculture indices with the additional environmental information (e.g. relief, land use, soils and bed rocks characteristics) gives broader, sometimes different, outcomes. The remaining results (not included in this paper) show definitely that the southern and western parts are characterised by often low tides. Despite the high amount of precipitation (especially in the south) regarding poor retention abilities (soil and slopes) the drought mitigation resistance was classified as very high. It is also confirmed by the information from the communes. The surveys' results show that drought events were diagnosed also in the areas at no meteorological drought risk.

5. CONCLUSIONS

The analysis conducted for drought risk estimation in Upper Silesia Region do not show any considerable danger. However regarding weather and climate variability it cannot be treated as nooccurrence possibility. Simultaneously, the analyses for the other drought types (hydrological, agrological) suggest permanent insightful drought monitoring. The complex index would probably the best but not only by aggregating the information but also by using different variables, giving the broad information about environmental moisture conditions.

REFERENCES

1. Banimahd, S.A., Khalili, D. (2013), *Factors influencing Markov Chains Predictability characteristics, Utilizing SPI, RDI, EDI and SPEI drought indices in different climatic Zones*. Water Resources Management *27 (11)*, 3911-3928.
2. Doroszewski, A., Jadczyszyn, J., Kozyra, J., Pudełko, R., Stuczyński, T., Mizak, K., Łopatka, A., Koza, P., Górski, T., Wróblewska, E.(2012), *Fundamentals of the agricultural drought monitoring system*. Water-Environment-Rural Areas *12, 2(38)*, 77-91 (in Polish with English summary).
3. Farago, T., Kozma, E., Nemes, Cs. (1989), *Drought indices in meteorology*. Időjárás*93*, 45-59.
4. Field, C.B., Barros, V., Stocker, T.F., Dahe, Q. (2012), *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: Special Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.
5. Hisdal, H., Tallaksen, L.M. (2000), *Drought Event Definition*, Technical Report No. 6,Assessment of the Regional Impact of Droughts in Europe
6. IPCC (2013), *Climate Change 2013: The Physical Science Basis. IPCC Working Group I Contribution to Fifth Assessment Report of the Intergovernmental Panel on Climate Chang*. Cambridge University Press, Cambridge, United Kingdom and New York, NY.
7. Jarząbek, A., Sarna, S., Karpierz, M.(2013), *Drought protection in water management planning – the methodol*ogy. National Water Management Authority, Poland
8. Łabędzki, L., Bąk, B., Kanecka-Geszke, E., Kasperska-Wołowicz, W., Smarzyńska, K.(2008), *Relationship between meteorological and agricultural drought in different agroclimatic regions in Poland.* Water-Environment-Rural Areas, series: Monographs *25* (in Polish with English summary).
9. McKee, T.B., Doesken, N.J., Kleist, J.(1993), *The Relationship of Drought Frequency and Duration to Time Scales*. Proceedings of the 8th Conference on Applied Climatology, 17, American Meteorological Society, Boston, MA, 179-183.
10. Mishra, A.K., Singh, V.P. (2010), *A review of drought concepts*, Journal of Hydrology*391*, 202–216.
11. Moreira, E.E., Coelho, C.A., Paulo, A.A., Pereira, L.S., Mexia, J.T.(2008), *SPI-based drought category prediction using loglinear models.* Journal of Hydrology *35*4, 116–130.
12. Tokarczyk, T.(2008), *Widely applied indices for drought assessment and Polish application*, Infrastructure and Ecology of Rural Areas*7*, 167-182 (in Polish with English summary).
13. Vasiliades, L., Loukas, A.(2009), *Hydrological response to meteorological drought using the Palmer drought indices in Thessaly*, Greece, Desalination *237*, 3–21.
14. Wang, Q., Wu, J., Lei, T., He, B., Wu, Z., Liu, M., Mo, X., Guangpo, G., Li, X., Zhou, H., Liu, D.(2014),*Temporal-spatial characteristics of severe drought events and their impact on agriculture on a global scale.* Quaternary International, 349, 10-21.
15. Wilhite, D.A.,Glantz M.H. (1985),*Understanding the Drought Phenomenon: The Role of Definitions*, Water International*10(3)*, 111–120.
16. WMO, 2003, *Guidelines on climate metadata and homogenization*. WMO-TD No. 1186.