Acta Sci. Pol.
Formatio Circumiectus 17 (3) 2018, 217–229
ENVIRONMENTAL PROCESSES

www.formatiocircumiectus.actapol.net/pl/ ISSN 1644-0765 DOI: http://dx.doi.org/10.15576/ASP.FC/2018.17.3.217

ORIGINAL PAPER Accepted: 31.08.2018

DROUGHT HAZARD ASSESSMENT IN THE PROCESS OF DROUGHT RISK MANAGEMENT

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ABSTRACT

Awareness of the potential threat of significant natural hazards necessitates the introduction of appropriate procedures allowing for effective and systematic actions aimed at eliminating, or at least partially mitigating the effects of such events. Due to the nature of drought and the complex process of its development, the cause and effect approach is widely used in assessing droughts. Naturally, this leads to the treatment of drought in terms of risk, which is defined as a derivative of hazards and consequences. Thus formulated definition of drought leads, in a broader context, to endeavours at minimizing the effects and reducing the size of losses, taking into account the prioritization of activities. An active drought risk management policy is necessary to achieve the safety of water resources in the face of current climate threats and expected further changes. The aim of this work is to present the original concept of drought risk assessment for the needs of strategic risk management as an integrated approach to the implementation of the drought management plan. Risk management is crucial and necessary to effectively reducing the effects of drought in a sustainable manner, in the context of meeting the needs of the population, the environment, and the economy. Risk management is a continuous process, consisting of logically arranged, consecutive events, actions, decisions and approvals, repeated cyclically in the course of monitoring the achieved results and implementing optional adaptations to the observed and forecasted changes. The risk management system presented in the work creates an organizational, methodical and functional framework, the implementation of which in the form of structural and IT solutions may be a tool for effective operation of plans aimed at counteracting the effects of drought on the level of particular water regions and river catchments. The proposed approach, based on strategic management in pursuit of sustainable assurance of water safety for social and natural systems, ensures durability of services of freshwater ecosystems responsible for maintaining biodiversity, maintaining life processes and regeneration of the environment, as well as providing people with economic benefits.

The integrated SPI-SRI index of coexistence of moisture conditions was used to assess the risk of drought. The aforementioned index made it possible to determine the likelihood of a drought in probabilistic terms, including the phase of atmospheric and hydrological drought in a given basin, which is a key element in drought risk assessment. The estimated return period of the threat of dry or very dry meteorological conditions leading to hydrological drought in the Nysa Kłodzka catchment was calculated as once every 7.2 years, and in the Prosna catchment, once every 8 years. This information can be used in planning actions aimed at minimizing the effects of drought, and in water management (for instance, on reservoirs) aimed at reducing these effects.

Keywords: consequences of drought, strategic risk management concept, decision making

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INTRODUCTION

Risk management is now increasingly used in the approach to many natural hazards. The current approach to drought in terms of risk is not clearly defined, despite the fact that drought is perceived, in its consequences, as the most expensive natural hazard in the world (Cook et al. 1999; Wilhite 2000). A particularly severe, long-term drought with a large territorial range can have devastating effects in the form of significant losses in yields, forest fires, intensification of soil degradation, desertification, increased competition for water resources as well as social violence (Bruins, Berliner 1998; Quiring, Papakryiakou 2003; Pausas 2004; MacDonald 2007; Shen et al. 2007). Grey and Sadoff (2007) introduced the term 'water safety', which means ensuring peace and political stability, while to achieve this goal they indicated the need to manage the risk related to non-delivery of water that poses a risk to people, the economy, and ecosystems. Hydrological and meteorological monitoring, preparation of planning documents, being elements of the prevention phase, are treated as parts of a cycle whose main purpose is to implement measures aimed at minimizing the effects of hazards should the latter materialize. A prerequisite for proper, sustainable water management is to understand the drought process, considered under the category of natural hazards (Wilhite 2000). The droughts of the 21st century are characterized by a longer duration and a greater spatial range, and they are increasingly severe due to the increasing demand for water (Allen et al. 2015). Severe droughts in recent years have led to significant economic losses, which in Europe are estimated at around 100 billion euro (Maxwell, Soule 2011; Tsakiris et al. 2013).

The purpose of this work is to present an original concept of drought risk assessment for the needs of strategic drought risk management, as an integrated approach to the implementation of drought management plans. The basis for implementation is a drought risk management system containing methodical, operational and adaptive solutions that support decision making in the conditions of uncertainty. Droughts tend to be long-lasting and have a large territorial range, and they occur as a result of the superimposition of several atmospheric and hydrological phenomena, whereas the evaluation of drought remains an up-to-date topic of scientific research (Dębski 1970; Wilhite, Glatz 1985; Rasmussen et al. 1993). In the hydro-climatological approach proposed by Hirschboeck (1988), the time series of climatic and hydrological elements characterizing the temporal and spatial variability of the phenomenon constitute the basis for the analyses. This contributed to the development of cause-and-effect methods for assessing and describing the phenomenon of drought in terms of time and space, including the intensity of the course that the drought takes. The occurrence of a drought cannot be prevented, but thanks to the understanding of the mechanisms of its formation, and the identyfication of conditions conducive to its spread, one can influence the reduction or mitigation of its consequences (Tokarczyk 2010). The multi-level impact of drought on the environment as well as on the economy, and the society directs the research conducted into the issues of drought occurrence towards focusing on demonstrating the need to monitor, assess and forecast the degree of drought risk. The implementation of an appropriate drought risk management system, taking into account risk management strategies and policies, processes, and procedures, will ensure a balanced approach to meeting the key needs of people and ecosystems as well as flexible response to the scenarios of projected changes together with the possibility of assessing the achieved results and verifying the undertaken activities.

IDENTYFYING DROUGHT

Definition of drought

In general, drought means the phenomenon of limited access to water, and it is understood as a cyclically occurring natural feature of climate, the extent of which is often difficult to determine (Svoboda et al. 2002, Sheffield, Wood, 2012; Eslamian 2014; Yihdego 2016; Yihdego, Eslamian 2016; Yihde, Webb 2016; Yihadanie et al. 2016). Over the years, drought has also been defined through the prism of its effects felt in the environment, economy, and society (Changnon 1987; Zelenhasic, Salvai 1987; Farat et al. 1995; Kogan 1995; Mager et al. 1999; Tate, Gustard 2000; Hisdal et al. 2001; Stahl 2001; Dubicki 2002; Lloyd-Hughes, Saunders 2002; Łabędzki, Bąk 2004; Lorenc et al. 2006).

In the present work, drought is understood as a cyclical (repeatedly appearing) phenomenon, with a regional range, meaning limited access to water, having a developmental nature evolving over time. It is a random event characterized by a certain intensity, duration, and spatial range. Such description of drought allows us to define it as a natural phenomenon that may pose a threat, the development of which includes the phase of meteorological, soil and hydrological drought. It also facilitates a categorized, systematic approach, and the inclusion of drought among natural disasters (Tokarczyk et al. 2017).

Drought as hazard

The drought is treated as a complex, multidimensional phenomenon, the appearance of which is often accompanied by negative effects observed in the environment (natural systems), in the society and the economy (social systems). It has the quality of a developing process. Its beginning is associated with long-term lack of rainfall or its shortage, and the accompanying high temperature of air. As a consequence of atmospheric drought, there are quantitative changes in the hydrological cycle. In addition, high evapotranspiration causes a reduction in surface runoff, a decrease in soil moisture, a decrease of flows in rivers, and a decline in the groundwater table. Droughts also have a socio-economic aspect expressed by water shortages understood as a deficit of water supply that prevents meeting social and environmental needs, resulting from natural causes, improper use of water resources, or human economic activity (Tsakiris et al. 2013). Therefore, the proper approach to assessing the effects of drought requires an assessment of direct effects in respective natural and social systems as well as an assessment of the multidimensional structure of their interconnections (see: Fig. 1).

Hazard is defined as a dangerous phenomenon, human activity or a condition that may result in loss of life, personal injury or other harmful effect to health, material damage, loss of means of living, social and economic disruption, and damage to the environment (UNISDR 2009). Quantitative assessment of drought hazard refers to the probable frequency of occurrence

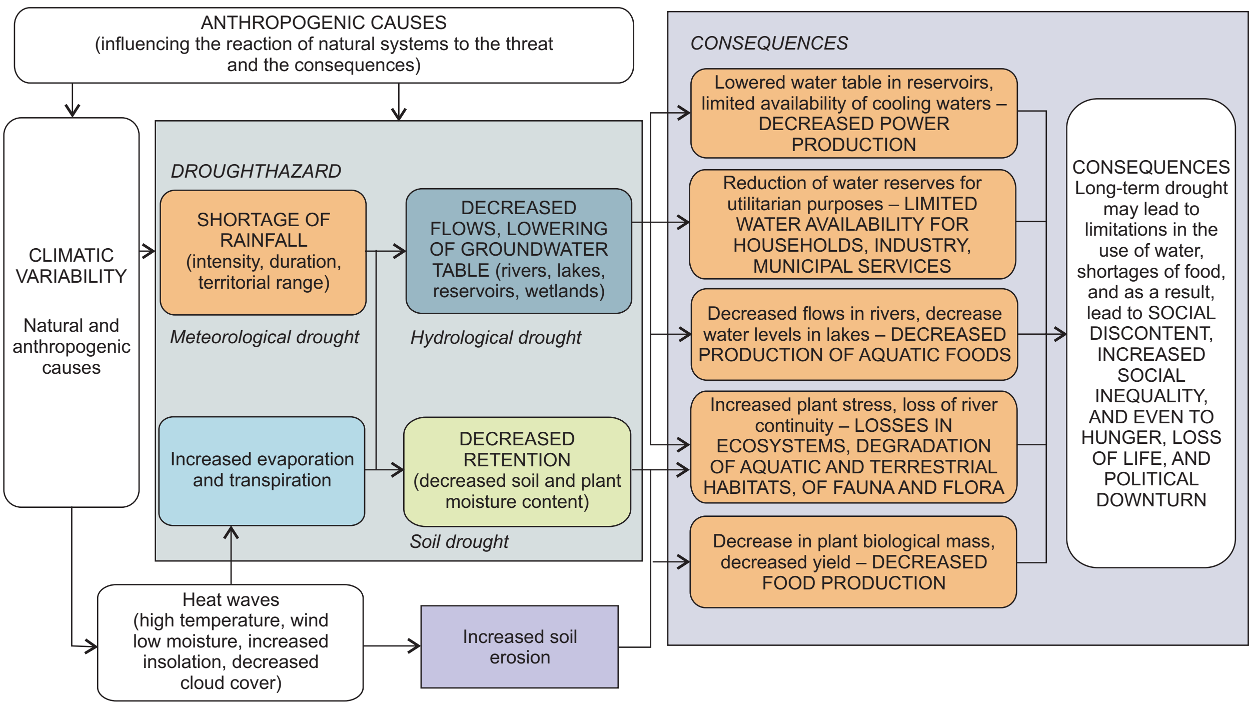

Fig. 1. Drought as hazard, and drought's consequences (based on WWF, GIWP 2016)

of drought of varying intensity, in different areas; and it is determined on the basis of historical data and scientific analyses.

Drought as risk

The risk of drought is understood as a property of the social and natural system, reflecting the interaction between the climatic hazard of meteorological and hydrological drought, and the social, environmental, and economic vulnerability (WWF, GIWP 2016). The two basic components, which are the subject of analysis and assessment of droughts risk include: (i) hazard – lack of precipitation, lower flows in rivers, lower groundwater table and (ii) consequences – resulting from hazards of a given scale, for instance, yield decrease or forest fires.

In risk analysis, it is crucial to understand and accept the uncertainty associated with its quantitative and qualitative assessment, which is the result of the complex nature of the phenomenon and its consequences. The consequences express the impact of drought on the economy, the society, or the environment, measures of which can be adopted in quantitative (monetary, nominal) or categorized qualitative (high, medium, low) form, as shown in table 1.

The assessment of drought in terms of risk requires a continuous, systematic, constantly developed and updated approach. The result of the risk assessment is the development of risk change scenarios and a catalogue of measures aimed at minimizing that risk. Reducing the risk is a long-term process. The process of drought risk mitigation should be of participatory nature, meaning that it should involve a wide range of stakeholders, such as national and local authorities, the community and civil society organizations, regional and sub-regional organizations, multilateral and bilateral international bodies, the scientific community, the private sector and the media.

Table 1. Assessment of the consequences of a drought with a specific intensity level expressed by means of selected indicators

HAZARD			CONSEQUENCES
Category	Palmer Hydrological Drought Index	Standardized Precipitation Index (SPI)	
Mild drought	–1.0 to –1.9	–0.5 to –0.7	Situation leading to the occurrence od drought: short-lasting dry periods negatively affecting plant vegetation (including cultivated fields and pastures); occurrence od drought: beginning of water shortages is felt; lack of complete regeneration of cultivated fields and pastures
Moderate drought	–2.0 to –2.9	–0.8 to –1.2	Slight losses in cultivated fields/pastures; low water levels in reservoirs, watercourses, wells; possible occurrence of water shortages in near future; necessary to introduce restrictions in water use (on voluntary basis)
Severe drought	–3.0 to –3.9	–1.3 to –1.5	Probable losses in cultivated fields/pastures; frequent water supply shortages; introducing restrictions in water use
Very severe drought	–4.0 to –4.9	–1.6 to –1.9	Substantial losses in cultivated fields/pastures; far-reaching (concerning a large area) water supply shortages or restrictions in water use
Extreme drought	Below –5.0	Below –2.0	Highly intensive and far-reaching losses in cultivated fields/pastures; water shortages in reservoirs, watercourses, and wells, causing the hazard of water scarcity

Source: National Drought Mitigation Center, Nebraska

MANAGING THE RISK OF DROUGHT

Risk management is a continuous, proactive and systematic process, based on generally applied risk management principles; adapted to different levels of territory, legislation and finance. As regards drought, risk management is focused on the assessment of hydro-meteorological hazard and its consequences in relation to natural and social systems together, along with counteracting this hazard and these consequences. The basic function of risk management process is its reduction of the risk to an acceptable level, through a rational compromise between costs and the achieved social, environmental, and economic benefits (see: Fig. 2).

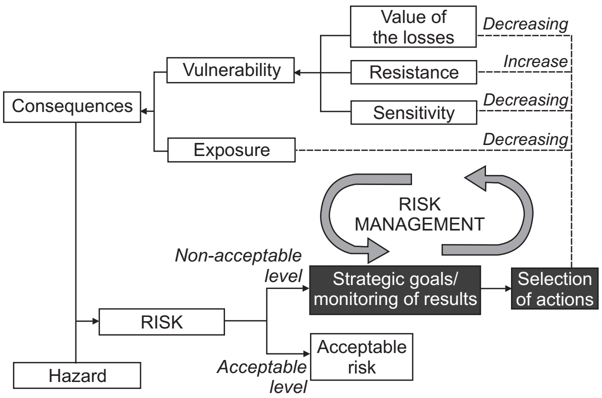

Fig. 2. Direction of drought risk management process

Source: Tokarczyk, Szalińska et al. 2017

Strategic management of drought risk, which applies the principles of a sustainable approach, consists in securing the current and forecasted water needs of the population, the economy, and the environment, while minimizing the resulting socio-economic losses. Strategic risk management of drought is based on a comprehensive, multidimensional, scalable approach, in an adaptive terms that is aimed at selecting and implementing options to counteract the effects of drought. This approach forces the development of a functional and methodological system, in which drought is understood in terms of risk, and which includes the following elements:

- diagnosis of the conditions of the system, as an emergent property of the climate, hydrological response of the basin to climatic conditions, and interaction of social and natural systems;
- identification of key needs (of the population and of the ecosystems dependent on water, as well as economic needs) for their achievement through a balanced compromise;
- drought risk management options at the stage of prevention, response, and recovery as well as adaptation;
- implementation of drought risk management methods and tools, including operational risk analysis and risk assessment, selection of optimal activities and continuous development and improvement of the system;
- assessment of results and methods of monitoring, and risk management control.

Construction and development of the system must respond to the current conditions, and allow for flexible implementation of future changes. Management is a logically ordered sequence of successive events, actions, decisions, and implementations, the effect of which is to reduce the level of risk down to the acceptable level. It allows identifying risks that may threaten the implementation of overriding objectives in the future.

DROUGHT HAZARD ASSESSMENT

Hazard assessment in terms of probability of occurrence, including the intensity, duration and territorial extent of drought occurrence, as well as the possibility of meteorological factors determining the drought and conditioning the propagation of rainfall deficit in individual components of the hydrological cycle, constitutes a key element of drought risk (see: Fig. 4).

The assessment of the hazard level is therefore expressed through the possibility of occurrence of a specific event or a sequence of events in the population of all possible events. Probability, as a measure of assessment, is dimensionless and associated with a specific time scale, for instance, the probability that the flow value falls below a certain threshold is expressed in the probability of failure to achieve in 1 year, 10 years, 100 years. The assessment of the degree of hazard can also be expressed qualitatively. An example of such an approach to assessing drought is the subsystem presented in Figure 5, where the assessment and forecast

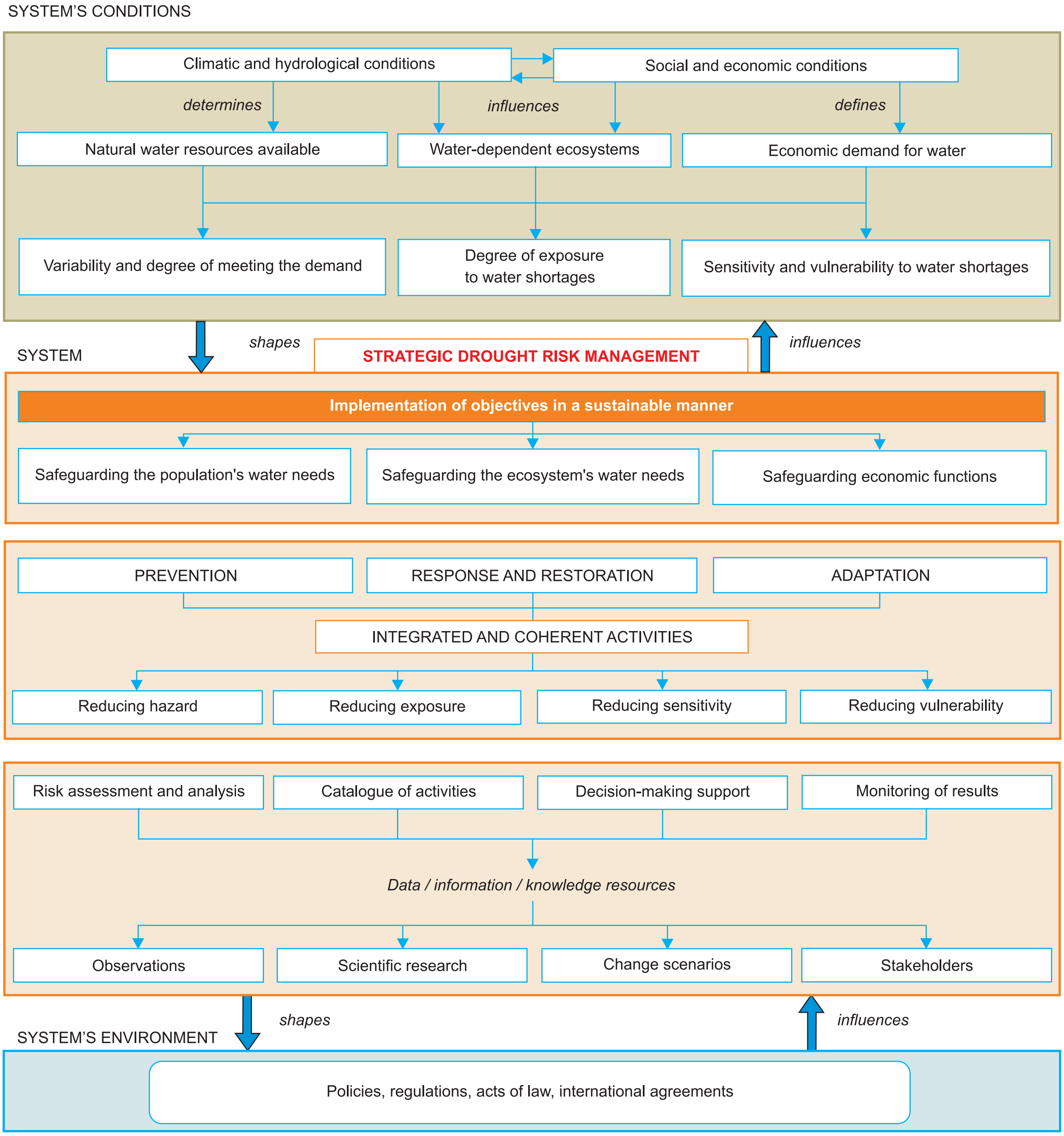

Fig. 3. Generalised diagram of strategic drought risk management

Source: Tokarczyk, Szalińska et al. 2017 based on WWF, GIWP 2016

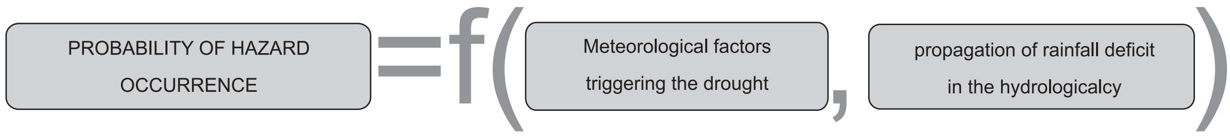

Fig. 4. Components of hazard assessment (based on WWF, GIWP 2016)

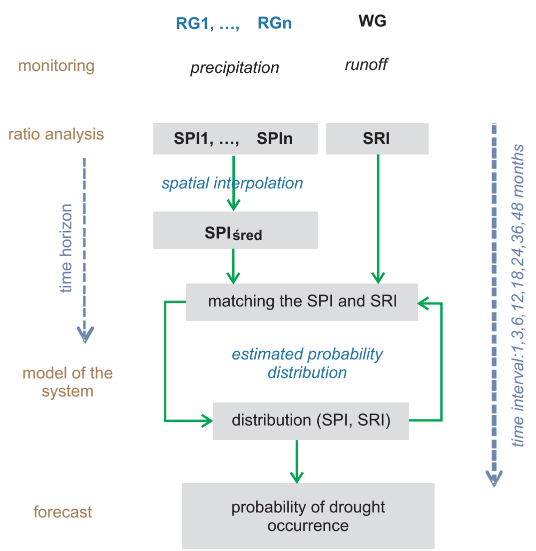

Fig. 5. Diagram of drought assessment, taking into account meteorological and hydrological conditions

of drought hazard in probabilistic terms is carried out on the basis of drought description and water shortage indicators – standardized precipitation index (SPI) for assessing moisture-related meteorological conditions, and standardized runoff index (SRI) for assessing hydrological conditions. In the aforementioned subsystem, during the analysis of the coincidence of meteorological and hydrological moisture conditions, the estimation is made of probability distribution describing the combined behaviour of meteorological factors shaping the droughts, and water deficiency in river flow. The estimated distribution describes the probabilities of drought of a specific intensity, duration occurring in the analysed area.

The application of index values facilitates a relatively easy interpretation of results in different climatic conditions, and for different time intervals. The key to the needs of the drought risk management system is to provide an appropriate set of indicators, allowing:

- identification of moisture conditions in various elements of the hydrological cycle (atmospheric, soil, hydrogeological, hydrological), in various time steps;
- reference of current moisture conditions to multi-annual mean values, representing normal conditions;
- assessing the intensity of drought, its duration and spatial variability, possibly in a normalized and dimensionless manner;
- presentation of complex processes and their mutual correlations (occurrence of drought, its devel-

Table 3. Identifying phases of drought according to SPI drought index (developed based on WMO 2012, Szalai, Szinell 2000, Łabędzki 2008)

SPI time scale	Drought identification	Application
SPI 1 (SPI for 1 month)	Short-duration drought	Monitoring of atmospheric drought
SPI 3 (SPI for 3 months)	Short-duration or seasonal drought	Monitoring of soil drought; well-correlated with soil moisture
SPI 6 (SPI for 6 months)	Seasonal drought	Monitoring of soil drought and hydrological drought; well-correlated with soil moisture and flows in rivers
SPI 12 (SPI for 12 months)	Medium-duration drought (lasting several months)	Monitoring of hydrological drought; well-correlated with flows in rivers
SPI 24 (SPI for 24 months)	Long-duration drought (lasting several years)	Monitoring of hydrogeological drought; well-correlated with groundwater levels

opment, and persistence of drought) by means of a simplified evaluation.

The presented subsystem can also be configured for probabilistic assessment of the other stages of drought development – the soil phase and the hydrogeological phase. In these cases, the meteorological factors that shape the droughts, expressed by the SPI index, will be better correlated with the use of other time scales for averaging indicators, as shown in Table 3.

An important element of the drought risk assessment and forecasting is the selection of threshold values for particular drought rating indicators in order to isolate individual phases of its development as it is growing up, and decline. They characterize the intensity of the drought in relation to the severity of its effects in the categorized approach: normal state / warning state / state of emergency, which is a key element in early warning systems. In addition, they are directly linked to the action program within management options, including the response and recovery phases, indicating the need to take or complete specific actions.

RESULTS

Comprehensive information on the frequency and intensity of meteorological and hydrological drought occurrence in the analysed catchment areas of Nysa Kłodzka and Prosna rivers was provided by the results of analyses carried out on the basis of SPI-SRI indicators. These catchments are characterized by different conditions, both in terms of climate and morphology. Nysa Kłodzka, up to the cross-section of the water gauge station in Kłodzko, encloses the mountain part of the catchment (the average slope in the catchment is over 7%) with high variability of thermal and precipitation conditions. The average annual temperature calculated in the multi-year period is about 10°C, with the average annual rainfall of over 700 mm. The Prosna river catchment, up to the cross-section of the water gauge station in Bogusław, is typical of lowland and agricultural areas. The average annual temperature is 8.5°C, with the average annual rainfall below 600 mm. In the analysed areas, the probability of occurrence of drought in probabilistic terms was assessed using the drought risk subsystem. First, the values of SPI and SRI indices for the years 1971–2015 were determined for different averaging intervals – 1, 3, 6, 12, 18, 24, 36, and 48 months. Next, the values of SPI indices, calculated for rainfall stations located in the areas of the analysed catchments and in their vicinity were subjected to Inverse Distance Weighting interpolation. Examples of timelines for appropriately selected pairs of SPI and SRI indicators for different averaging intervals are presented in Figure 6.

Then a correlative analysis of coexistence of humidity conditions was carried out. Correlations were tested for pairs of indices defined for different time periods: 1 month, 3 months, 6 months, 12 months, 18 months, 24 months, 36 months, 48 months. The results are presented in Tables 3 and 4. For both the studied catchments, the correlations are stronger for similar averaging times of the analysed indicators – whereas the higher symmetry of correlation is observed in the Nysa Kłodzka river catchment: the best results were obtained for SPI12-SRI12 and SPI18-SRI18 pairs. In the case of the Prosna river catchment, a shift of conditions is observed. The best result was obtained for longer times of averaging rainfall conditions versus runoff conditions: SPI6-SRI3, SPI12-SRI6, SPI18-SRI12.

Then, for the pairs of indicators with the best correlation, the probability of occurrence of drought in probabilistic terms was calculated, taking into account the phase of atmospheric and hydrological drought in a given catchment. Estimation of the probability distribution of the two-dimensional SPI-SRI variable was carried out using Kernel density estimation (Kulczycki, 2005). The Epanechnikov kernel is reported the most effective, but the decrease in effectiveness however using other standard kernels is slight (Podlaski, Roesch, 2014). The two-dimensional estimator (Epanechnikov kernel) enabled the determination of the probability of occurrence of SPI and SRI in a given class (very dry period – dry period – normal period – wet period – very wet period). Sample results are shown in Figure 7 and in Table 5.

In the light of the obtained results, it can be concluded that the return period of the hazard of dry or very dry weather conditions occurring that will lead to water shortage in the river flow can be assessed in the Nysa Kłodzka river catchment as once every 7.2 years, and in the Prosna river catchment, once every 8 years.

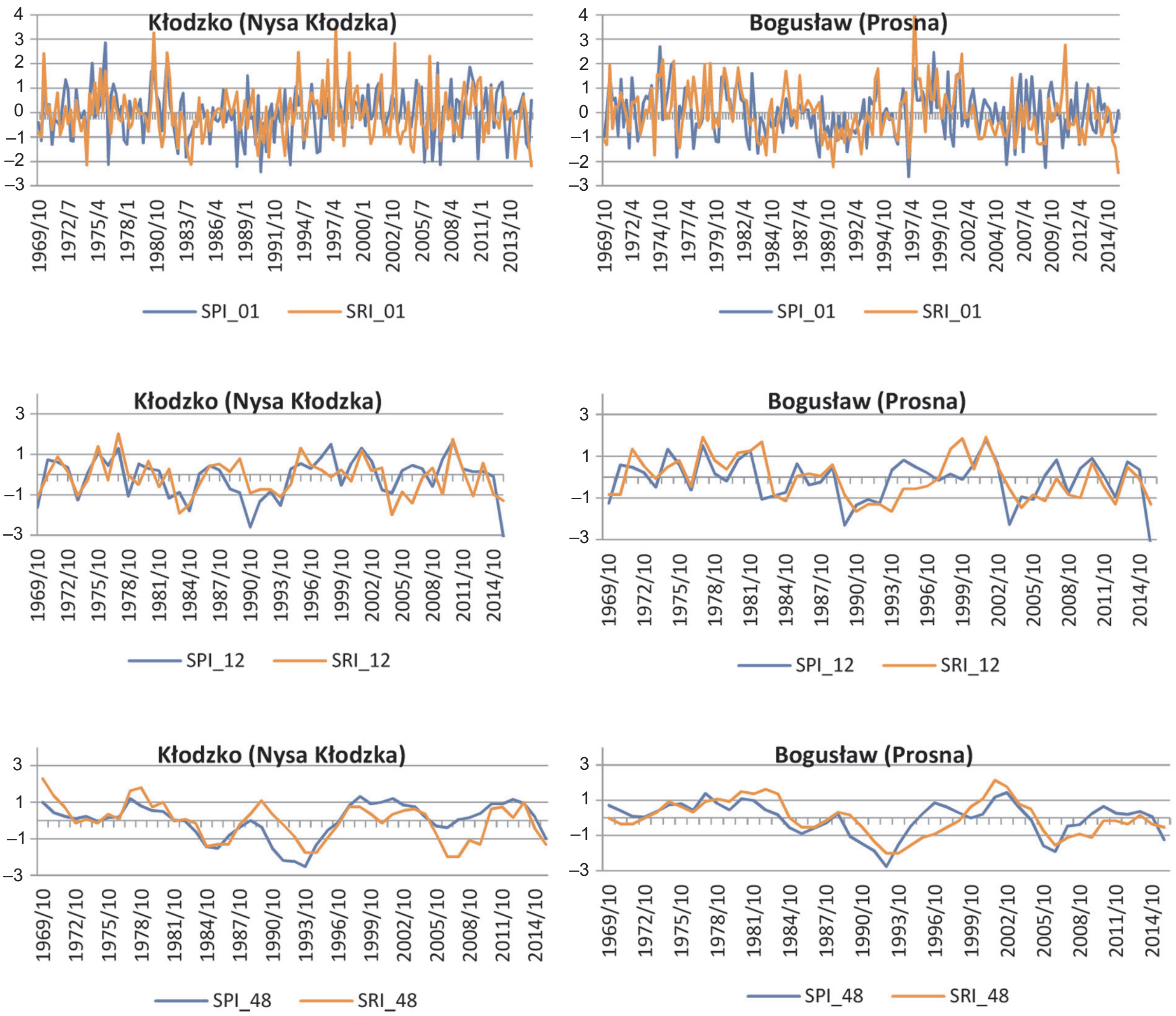

Fig. 6. Changes of SPI and SRI indicators in the studied catchments, in specific time intervals

Table 4. Results of the correlation of the SPI-SRI indicators for Nysa Kłodzka river catchment and Prosna river catchment, obtained at the significance level of $p < 0.05$

Nysa Kłodzka		SPI							
		1	3	6	12	18	24	36	48
SRI	1	0.42	0.59	0.57	0.40	0.35	0.32	0.25	0.17
	3	0.11	0.52	0.61	0.47	0.41	0.38	0.30	0.20
	6		0.32	0.61	0.60	0.48	0.47	0.35	0.24
	12		0.18	0.36	0.65	0.63	0.59	0.44	0.34
	18		0.17	0.32	0.53	0.66	0.66	0.54	0.42
	24		0.08	0.21	0.43	0.53	0.66	0.59	0.48
	36		0.09	0.18	0.29	0.38	0.50	0.65	0.63
	48				0.15	0.24	0.33	0.49	0.63

Prosna		SPI							
		1	3	6	12	18	24	36	48
SRI	1	0.47	0.66	0.68	0.61	0.54	0.44	0.38	0.39
	3	0.19	0.60	0.73	0.70	0.64	0.54	0.45	0.46
	6	0.11	0.35	0.67	0.77	0.72	0.66	0.52	0.53
	12		0.19	0.38	0.70	0.78	0.76	0.63	0.63
	18		0.16	0.29	0.52	0.73	0.78	0.70	0.66
	24		0.06	0.17	0.39	0.58	0.73	0.75	0.68
	36			0.13	0.25	0.39	0.53	0.75	0.76
	48			0.11	0.22	0.31	0.40	0.59	0.74

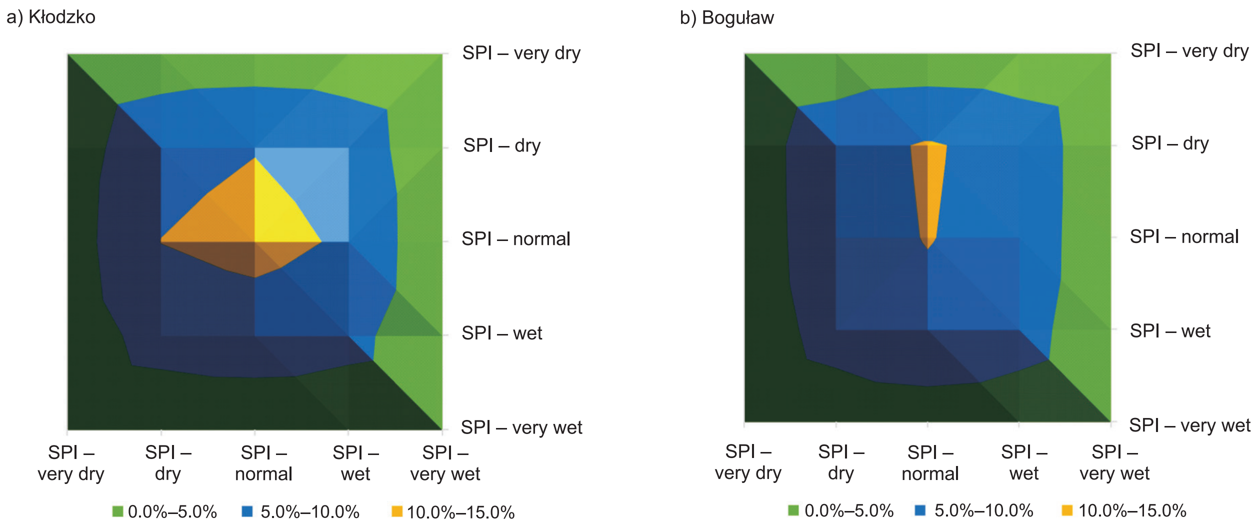

Fig. 7. Probability distribution of drought occurrence in the catchment of Nysa Kłodzka river (a) taking into account the atmospheric drought (SPI –12-month period) and hydrological drought (SRI – 12-month period) and in the catchment of Prosna river (b) taking into account the atmospheric drought (SPI – 12-month period) and hydrological drought (SRI – 6-month period)

Table 5. Probability distribution of drought occurrence in the catchment of Nysa Kłodzka river (upper panel) taking into account the atmospheric drought (SPI –12-month period) and hydrological drought (SRI – 12-month period)

Kłodzko	SRI – very dry	SRI – dry	SRI – normal	SRI – wet	SRI – very wet
SPI – very dry	0.6%	2.3%	2.7%	1.9%	0.3%
SPI – dry	2.1%	8.8%	10.1%	7.1%	1.1%
SPI – normal	2.4%	9.9%	11.2%	8.0%	1.2%
SPI – wet	2.0%	8.3%	9.5%	6.7%	1.1%
SPI – very wet	0.2%	0.8%	0.9%	0.6%	0.1%

Table 6. Probability distribution of drought occurrence in the catchment of Prosna river (lower panel) taking into account the atmospheric drought (SPI – 12-month period) and hydrological drought (SRI – 6-month period)

Bogusław	SRI – very dry	SRI – dry	SRI – normal	SRI – wet	SRI – very wet
SPI – very dry	0.4%	2.3%	2.2%	1.9%	0.6%
SPI – dry	1.6%	8.3%	8.1%	7.1%	2.1%
SPI – normal	2.0%	10.4%	10.2%	8.8%	2.6%
SPI – wet	1.6%	8.5%	8.4%	7.3%	2.1%
SPI – very wet	0.2%	1.1%	1.1%	0.9%	0.3%

CONCLUSIONS

Awareness of the danger of significant natural hazards necessitates the introduction of appropriate procedures allowing for effective and systematic actions aimed at eliminating or partially mitigating the effects of these events. Due to the nature of the drought and the process of its development, and the resulting generally used cause-and-effect approach in the assessment of drought, we are naturally inclined to treat drought in terms of risk, which is defined as a result of hazard and consequences. Defining drought in terms of risk makes it possible, in a broader context, to minimize its effects and reduce the size of the losses, taking into account the prioritization of activities. The risk management system presented in this work creates an organizational, methodical and functional framework, the implementation of which in the form of structural and IT solutions may be a tool for effective operation of plans to counteract the effects of drought on the level of water regions and catchments. Application of the integrated SPI-SRI index of coincident moisture conditions makes it possible to determine the likelihood of drought occurring in a probabilistic approach, taking into account the phase of atmospheric and hydrological drought in a given catchment. The

Tokarczyk, T., Szalińska, W. (2018). Drought hazard assessment in the process of drought risk management. Acta Sci. Pol., Formatio Circumiectus, 17(3), 217–229. DOI: http://dx.doi.org/10.15576/ASP.FC/2018.17.3.217

return period of the hazard of dry or very dry meteorological conditions leading to hydrological drought was assessed in the Nysa Kłodzka river catchment as once every 7.2 years, and in the Prosna river catchment, once every 8 years. This information can be used to plan actions aimed at minimizing the effects of drought, and to conduct appropriate water management (for example, of retention reservoirs) aimed at reducing these effects.

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OCENA ZAGROŻENIA SUSZĄ W PROCESIE ZARZĄDZANIA RYZYKIEM SUSZY

ABSTRAKT

Świadomość niebezpieczeństwa istotnych zagrożeń naturalnych wymusza potrzebę wprowadzenia odpowiednich procedur pozwalających na efektywne i systematyczne działania, których celem jest eliminacja lub częściowe ograniczanie skutków tych zdarzeń. Ze względu na istotę suszy i złożony proces jej rozwoju w ocenie suszy powszechnie stosowane jest ujęcie przyczynowo-skutkowe. W naturalny sposób skłania to do traktowania suszy w kategoriach ryzyka, które definiowane jest jako pochodna zagrożenia i konsekwencji. Taka definicja suszy pozwala w szerszym kontekście dążyć do minimalizacji skutków i ograniczania wielkości strat z uwzględnieniem priorytetyzacji działań. Aktywna polityka zarządzania ryzykiem suszy jest niezbędna do osiągnięcia bezpieczeństwa zasobów wodnych w obliczu aktualnych zagrożeń klimatycznych i spodziewanych zmian. Celem pracy jest przedstawienie autorskiej koncepcji oceny zagrożenia suszą na potrzeby strategicznego zarządzania ryzykiem jako zintegrowanego podejścia do realizacji planu zarządzania suszą. Zarządzanie ryzykiem jest kluczowe i konieczne do efektywnego ograniczania skutków suszy w sposób zrównoważony w zaspokajaniu potrzeb ludności, środowiska i gospodarki. Zarządzanie ryzykiem jest procesem ciągłym, składającym się z uporządkowanych logicznie, następujących po sobie zdarzeń, działań, decyzji i uzgodnień powtarzanych cyklicznie w toku monitorowania osiąganych rezultatów i wdrażania opcji adaptacji do obserwowanych i prognozowanych zmian. Przedstawiony w pracy system zarządzania ryzykiem tworzy ramy organizacyjne, metodyczne i funkcjonalne, których implementacja w postaci rozwiązań strukturalnych i informatycznych stanowić może narzędzie do skutecznego operowania planami przeciwdziałania skutkom suszy na poziomie regionów wodnych i dorzecza. Proponowane podejście, oparte na strategicznym zarządzaniu w dążeniu do zrównoważonego zapewnienia bezpieczeństwa wodnego systemów społecznego i naturalnego, zapewnia trwałość usług ekosystemów słodkowodnych odpowiedzialnych za utrzymywanie bioróżnorodności, podtrzymanie procesów życiowych i regenerację środowiska, a także zapewnienie ludziom korzyści gospodarczych.

Do oceny zagrożenia suszą zastosowano zintegrowany wskaźnik SPI-SRI współwystępowania warunków wilgotnościowych. Pozwolił on na określenie prawdopodobieństwa wystąpienia suszy w ujęciu probabilistycznym z uwzględnieniem fazy suszy atmosferycznej i hydrologicznej w danej zlewni co stanowi kluczowy element oceny ryzyka suszy. Oszacowany okres powtarzalności zagrożenia wystąpienia suchych lub bardzo suchych warunków meteorologicznych, prowadzących do suszy hydrologicznej wyniósł w zlewni Nysy Kłodzkiej na raz na 7,2 lata i w zlewni Prosny na raz na 8 lat. Informacje te mogą być wykorzystane do planowania działań minimalizujących skutki wystąpienia susz i prowadzenia gospodarki wodnej (np. na zbiornikach retencyjnych) ukierunkowanej na ograniczenie tych skutków.

Słowa kluczowe: skutki suszy, koncepcja strategicznego zarządzania ryzykiem, podejmowanie decyzji