Integrated Drought Management Programme

Global Water Partnership
Central and Eastern Europe

Drought Risk Management Scheme - a decision support system

TECHNICAL NOTE

Integrated Drought Management Programme
in Central and Eastern Europe

Drought Risk Management Scheme: A decision support system

Technical note on achievements of the Integrated Drought Management Programme in Central and Eastern Europe (IDMP CEE) Demonstration project

Tamara Tokarczyk[a)],***Wiwiana Szalińska[a)], Leszek Łabędzki[b)], Bogdan Bąk[b)], Edvinas Stonevicius[c)], Gintautas Stankunavicius[c)], Elena Mateescu[d)], Daniel Aleksandru[d)]***
Poland: [a)] Institute of Meteorology and Water Management, National Research Institute, Wroclaw Branch(IMGW-PIB),
[b)] Institute of Technology and Life Sciences (ITP)
Lithuania: [c)] Vilnius University, Department of Hydrology and Climatology (VU)
Romania: [d)] National Meteorological Administration (NMA)

This report presents the results from the Demonstration Project Drought Risk Management Scheme: a decision support system, which was part of the wider Integrated Drought Management Programme in Central and East Europe (IDMP CEE). Based on the results of the demonstration project and the expertise of the people involved, recommendations for the development of a decision support system were made.

1. Introduction

Risk management for droughts is defined as the process of identifying and understanding the relevant components of drought risk, and analysing alternative strategies to manage that risk (Knutson et al. 1998; Hayes et al. 2004). Risk management thus involves the application of analytical tools for decision making, as well as the development of management strategies that appropriately deal with uncertainty and the perception of risk.

The primary purpose of this work was to present a planning process (scheme) that can facilitate the preparation of the decision support system for drought risk management.

Main result of the project is the development of a 'Framework for Drought Risk Management', outlining the interrelationships and functional linkages between different elements for supporting decision-making in drought oriented systems. The framework is based on institutional, methodological, public, and operational components creating an integrated body of methods (Fig. 1).

1. **Institutional component** – the institutional coordination set-up and key institutional capacities required to develop drought risk management systems.
2. **Methodological component *(Framework for drought risk assessment, Framework for drought vulnerability assessment)*** outlines the necessary procedures for assessing drought risks. This entails the analysis of climate/hazard trends and other underlying vulnerability factors.
3. **Public component *(Framework for drought prevention measures)*** presents the interventions that depend on the risk profile within a given context. It provides an overview of the types of drought risk management options that can be adopted for ensuring immediate responses, enhancing short-term preparedness, and promoting long-term resilience.
4. **Operational component *(Framework for decision support tools)*** provides guidance and recommendations for developing and implementing a decision-support system that is based on indicators that are achievable in a given timeframe to support drought risk management.

Fig. 1. Framework for drought risk management

The developed decision support system in drought risk management is meant to serve as a common framework for different regional and sectoral specifications. Introducing a common framework in the form of step-by-step process leads to comparability among different systems. The developed framework defines the main principles for drought management that can be applied to various aspects of drought. Furthermore, the recommendations for developing an operational support system in drought risk management concern the application of a number of drought indices in main the part of the risk management process, including drought monitoring, an early warning system, and risk assessment. The next section outlines each component of the framework in detail.

2. Institutional component

Drought management requires a joint effort of institutions and organisations representing different fields of science, and different levels of management. **To ensure an integrated institutional and sectoral approach, the institutional framework should be composed of institutions related to water, meteorology, agriculture, environment and socio-economy.** Integrating different management levels (federal, state, district, and local/individual) requires tackling different political commitments, networks and mechanism, including grassroots organisations, as well as resource availability. The aim of this integrated approach is to build a common high quality drought related database that is accessible with the use of geo-informatics tools, and supported with geospatial tools for analysing such data.

The checklist for developing such an institutional framework, and the relevant information on drought exchange patterns as well as an inventory of measures for drought assessment from the participating countries was presented in the IDMP CEE report Identification of the national measures for drought susceptibility (drought hazard) assessment. The current responsibility of various bodies involved in drought management in the participating countries was presented in the IDMP CEE report: Identification of the national measures for drought vulnerability assessment.

Examples from participating countries:

The Lithuanian Hydrometeorological Service (LHS) under the Ministry of Environment is responsible for identification of droughts. In the occurrence of a drought, the LHS warns the Ministry of Agriculture. The Ministry of Agriculture coordinates the actions of all institutions involved in drought management, and makes a list of municipalities affected by drought, and informs the insurance companies.

In Poland, there is no central system for dissemination of information related to droughts. There are some systems like POSUCH@ by IMGW, the monitoring and forecasting water deficit and surplus in agriculture by ITP, and an Agricultural Drought Monitoring System (ADMS), but these are focusing on specific drought analyses. Nevertheless, these systems cover the whole country, and for some regions some more detailed programmes complement them.

In Romania, the National Meteorological Administration (NMA) forms a necessary component of any strategy to mitigate weather and climate related risks including droughts. The weekly Agrometeorological Bulletin includes specific information (air temperature, rainfall, ETP, soil moisture, crop water requirement) needed for assessing drought occurrence. The data collected from the National Observation Network is analysed and compared with critical thresholds, in order to evaluate the threat and make recommendations for decision-makers and farmers.

In general, none of the countries involved had a fully integrated institutional framework. The linkages between institutions related to drought are limited and the institutions do not constitute a multidisciplinary platform of knowledge. However, in each country there are dedicated institutions that are responsible for drought assessment, or dissemination of information. These are meteorological, hydrological and agricultural institutions. Institutional engagement from environmental and socioeconomic fields is still missing. Therefore, there is a need to amplify and expand the involvement of these institutions and set up interdisciplinary cooperation between engaged actors.

3. Methodological component

3.1. Framework for drought risk assessment

The risk for drought is a combined effect of drought hazard (likelihood) and drought consequence (vulnerability). Drought hazard is defined by the frequency of occurrence of drought at various levels of intensity and duration, and this data is crucial for drought risk management for assessing the impacts. **Drought hazard mapping cater for information on drought prone areas. It enables identification of the elements at the risk, and introduces mitigation measures adjusted to vulnerable areas.**

A drought hazard assessment based on applicable indices was presented in the IDMP CEE report Developing methodology for drought hazard mapping with the use of measures for drought susceptibility assessment. The results in the report are presented in the form of maps which present temporal and spatial variation of drought hazard in order to identify drought-prone regions.

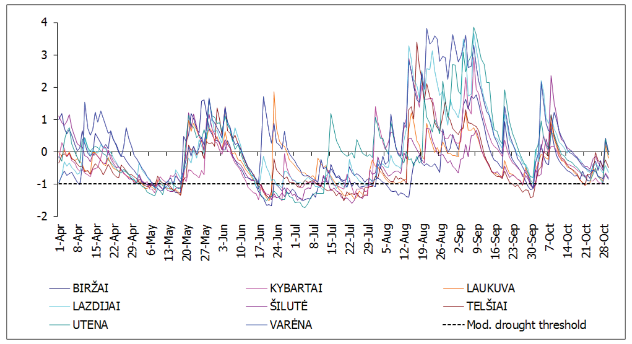
The different indices were selected on the basis of providing information on drought hazard for agriculture and water resources sectors within different regional context. The following indices were investigated:

a) Standardized Precipitation Index (SPI) and Effective Drought Index (EDI) with respect to detection of agricultural drought in Lithuania;
b) SPI with respect to detection of agricultural drought in Romania;
c) SPI, Standardized Runoff Index (SRI) , EDI and Flow Index (FI) with respect to detection of hydrological drought in Lithuania;
d) SPI, SRI with respect to detection of hydrological drought in Poland.

Examples from participating countries:

In Lithuania, agricultural droughts last longer than one month and can be monitored by the EDI index with different estimation timescale. However, intra-monthly and intra-seasonal variability of droughts were captured only with EDI 30, 60 or 90.

a)



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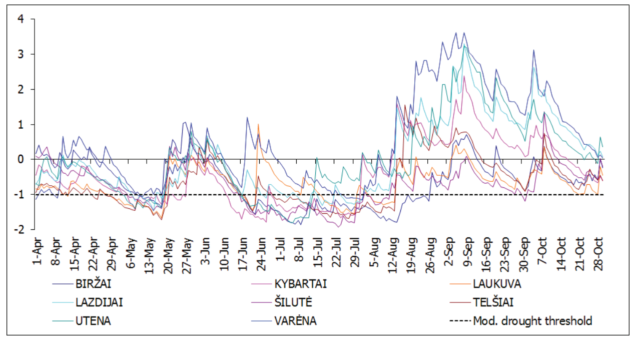

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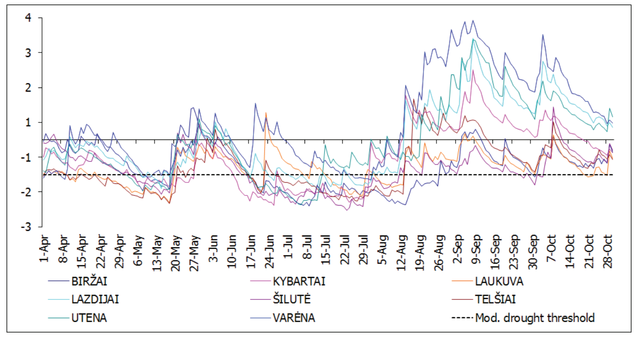

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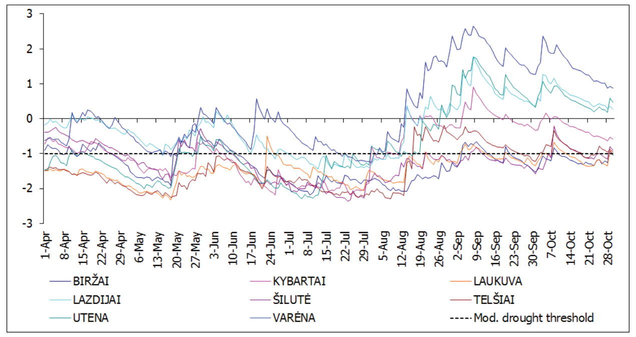


Fig. 2. The Effective Drought Index (EDI) course estimated for 8 Lithuanian meteorological stations in warm season (Apr 1 – Oct 31) of 2006 as: EDI30 (a), EDI90 (b), EDI120 (c), EDI365 (d).

The meteorological drought indices SPI and EDI illustrate a statistically significant relationship with hydrological drought indices SRI and FI. The correlation between SPI and SRI is stronger if the indices are calculated using longer time frames. The correlation during spring is the weakest due to runoff formation from the snowmelt. The relationship between meteorological and hydrological drought indices depends on the properties of the river catchment and climate. Indices calculated for shorter time steps better represents the hydrological response in catchments where the water accumulation capacity is smaller, and where the part of surface and fast subsurface runoff in total river runoff is large. Moderate and severe drought periods identified by EDI usually coincide with the reduction off runoff, but only during July-September when meteorological droughts could be related to water resources shortage.

[1] SPI (Standardized Precipitation Index (McKee et al. 1993) – is based on a long term precipitation record at a station fitted to a probability (gamma) distribution, which is then transformed into a normal distribution so that the mean SPI is zero. In the study, SPI is computed with a 1 and a 3 months step. SPI values are standardized representing deviations of the transformed precipitation totals from the mean.
[2] EDI (Effective Drought Index) (Byun, Wilhite 1999) – is a measure of precipitation needed for a return to normal conditions. It is calculated with a daily time step. First step is calculation of weighted precipitation accumulation over a defined preceding period (EP). In the study, this period is set on 30, 60, 90 and 365 days. The concept of the EDI is a standardized daily difference between EP and the climatological mean of EP (MEP) for each calendar day. EDI values are standardized, which allows for comparing drought severity at different locations regardless of climatic differences among them.
[3] SRI (Standardized Runoff Index), (Shukla, Wood 2008) is assessed similarly to SPI. It is used to classify hydrological drought. SRI is the unit standard normal deviate associated with the percentile of hydrologic runoff characterising selected period of time. Computation of SRI involves fitting a probability density function (PDF) to a given frequency distribution of monthly runoff for a gauge station. This cumulative probability is then transformed to the standardised normal distribution with mean zero and variance one, which results in the value of SRI.
[4] FI (Flow Index) (US Geological Survey, http://water.usgs.gov) – represents the empirical cumulative frequency of discharges as a function of the percentage of time, which the discharge value is exceeded. FI is estimated from Frequency Duration Curve (FDC) and constructed for each calendar day basing on long-term discharge data. Each FI is divided into 5 classes, which correspond to the humidity conditions.

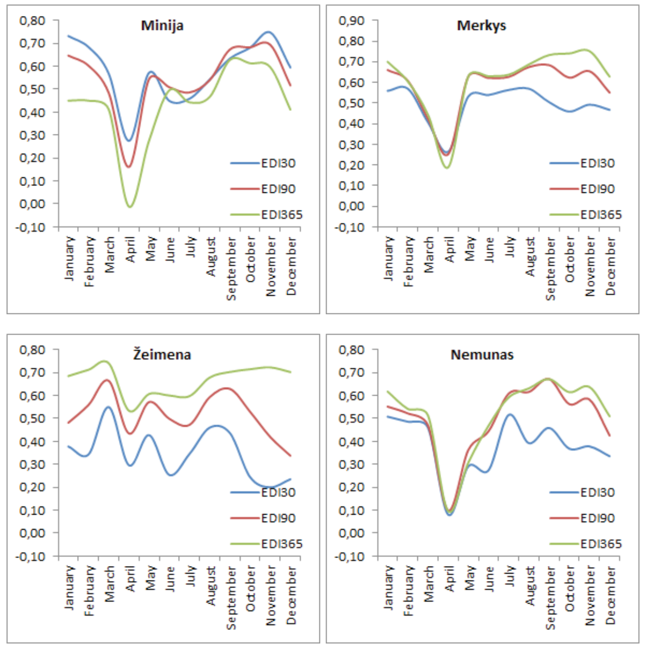


Fig. 3. Seasonal variation of correlation coefficient between EDI and daily discharge

In Romania, a 3-month SPI (SPI3) was evaluated in terms of capturing precipitation trends during the important vegetation phases (reproductive and early grain-filling stages, the growing season etc.) for the observed drought events. Zoning the soil moisture reserves shows good correspondence with the 3-months SPI spatial distributions for all analysed periods. Areas identified as extremely dry according to the SPI indicator were corresponding to extreme pedological drought estimated from soil moisture reserves. Areas that were found to be near normal according to SPI were overlapping with the satisfactory supply of soil moisture reserves.

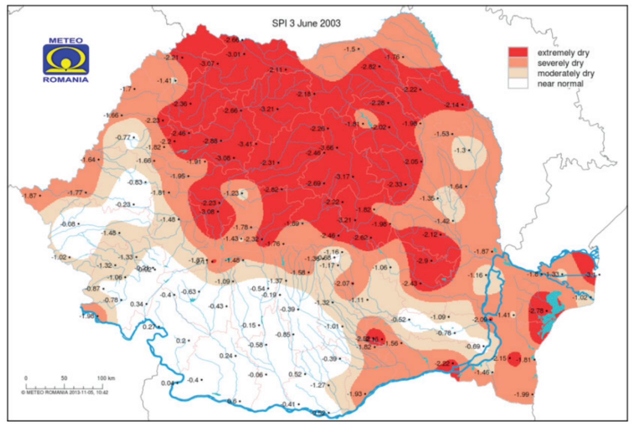
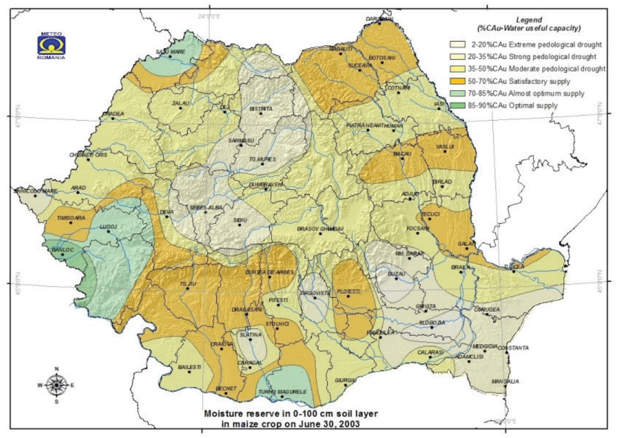


Fig 4 a) The 3 – month SPI values

In Poland, drought hazard was investigated in terms of conditions contributing to the drought formation process by looking at the atmospheric and hydrological phases. Stochastic analysis of the developed SPI-SRI indicator allows the dynamics of the transition between drought phases and the recurrence and duration of dry conditions to be assessed. Values of SPI to SRI indices were used to develop a two-dimensional variable for drought hazard assessment. The approach allows the establishment of five classes of combined SPI-SRI variable which represents: normal meteorological and hydrological conditions (0), wet meteorological and hydrological conditions (1), dry meteorological conditions and wet hydrological conditions (2), dry meteorological and hydrological conditions (3) and, wet meteorological conditions and dry hydrological conditions (4) (Tokarczyk, Szalinska, 2014).



b) Soil water reserve in the critical period for maize crop over 0-100 cm

Fig. 5. The SPI vs. SRI correlation plots for the coupled meteorological and hydrological stations for a) Nysa Klodzka and b) Prosna study basin

For drought hazard assessment Markov chain models were used as:

- probability of transition from one drought class to another, which represents proneness to drought formation;
- return period of drought class, which represent the probabilities of occurrence of the various drought classes;
- expected residence time, which represents the anticipated duration of persistence of each class;
- the expected first passage time, which represents number of months required to move from one class to another.

For the analysed basins, the biggest differences were found in the value of expected time to move from wet conditions to meteorological dry ones, and in the value of probability of occurrence of hydrological drought. There is a high coincidence of dry meteorological and hydrological conditions, resulting in severe droughts. The coincidence of dry meteorological and hydrological conditions was observed almost every four months and lasted more than 1.5 months, on average. The duration of hydrologically dry conditions was found to be typically between 1.2 and 1.4 months. The situation when the effect of meteorologically dry conditions is attenuated by hydrological wet conditions within the same month is relatively rare. Meteorologically dry conditions lasted typically less than 1.4 months. Good correspondence was found between months classified as hydrometeorologically dry (SPI-SRI Class 3) and drought periods of long duration. Intensive but short-term droughts corresponded to the SPI-SRI Class 4.

3.2. Framework for drought vulnerability assessment

The framework for drought vulnerability was presented in the IDMP CEE report *Methodology for drought vulnerability assessment* based on available GIS information including population map, type of economic.

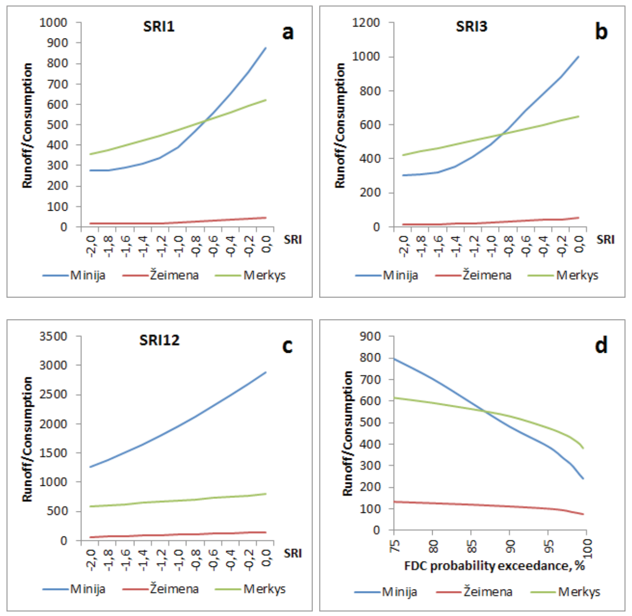
Within this framework, the countries participating in the study have provided information on the regional context, and indicated sectors of the economy and elements of the system that are mostly vulnerable to droughts.

The identified elements were investigated through applied methodologies for vulnerability assessment. Element vulnerability refers to the degree of potential physical damage to the target elements at risk, such as particular crop species, water users, and forest biotope in response to a hazard event of a given intensity. Performed vulnerability analysis consisted of outlining a vulnerability index that illustrates the relationship between potential damage and loss to a given element at risk against specified event intensity. For Poland and Romania, the vulnerability index was outlined for agricultural sector, while it was outlined for water resources in Lithuania.

Examples from participating countries:

In Lithuania, the vulnerability index was developed for the losses described as the ratio of surface water resources to surface water consumption. Drought intensity was expressed in terms of value of the Standardized Runoff Index (SRI) and Flow Index.

Fig. 6. Vulnerability index in Lithuania



In Romania, the vulnerability functions were estimated for maize and sunflower. The state of the crop vegetation was assessed with the use of satellite-derived indicators: NDVI[5], NDDI[6] and NDWI[7]. Drought hazard was expressed with the use of the following indicators: heat stress (HS), Standardized Precipitation Evapotranspiration Index (SPEI), and available water content of the soil (%AWC) during the critical period (summer season).

[5] NDVI (Normalized Vegetation Index) (Jiang & Huete, 2010) is computed using the red and near-infrared (NIR) bands of an image
[6] NDDI (Normalized Difference Drought Index) is calculated on the basis of NDVI and NDWI
[7] NDWI (Normalized Difference Water Index) (Gao 1996) is a satellite-derived index from the Near-Infrared (NIR) and Short Wave Infrared (SWIR) channels

Table 1 Components of Drought Vulnerability Index

Vulnerability level	Scales								
	Heat stress (HS)			SPEI			Soil Moisture (SM)		
No	0	No stress	<10	0	No deficit	<-0.99	0	No deficit	100% AWC
Low	1	Low stress	11-30	1	Low deficit	-1.99 to-1	1	Low deficit	65-100 % AWC
High	2	Moderate stress	31-50	2	Moderate dry	-2.99 to-2	2	Moderate deficit	35-65 % AWC
Extreme	3	Strong stress	>51	3	Very dry	<-3	3	Strong deficit	0-35 % AWC

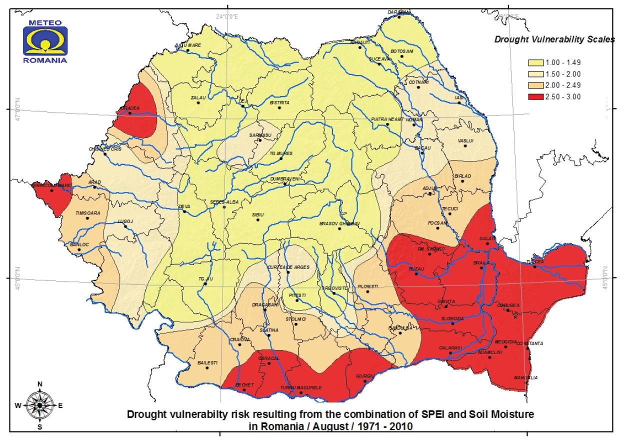


Fig. 7. Drought Vulnerability Index (DVI) for maize during the critical period for water needs (August).

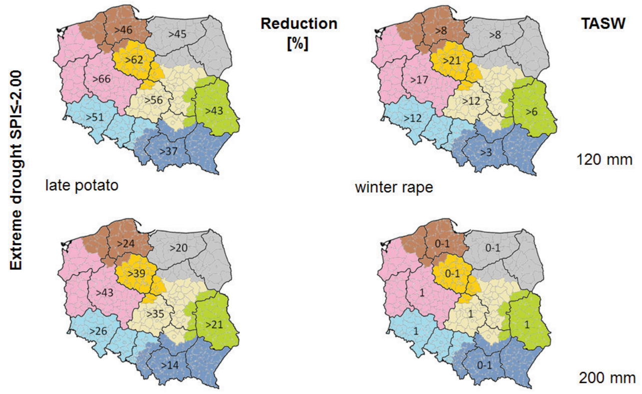


Fig. 8. Spatial distribution of Vulnerability Index in Poland

In Poland, the vulnerability index described the relation between drought intensity expressed in terms of the SPI indicator, and the specific crop yield for late potato, sugar beet, winter wheat, winter rape and maize, with the distinction of two classes of total available soil water.

4. Public component (Framework for drought prevention measures)

Integrating drought management at sub-national and local levels implies decentralising drought risk management roles and responsibilities. **It requires strengthening the capacity of local institutions to develop and implement drought-oriented programmes.** Based on the defined drought risk profile, a series of risk management options and adaptive measures are to be identified to help enhance local coping capacities.

The primary concern of droughts is water shortage. Most of the planned activities aim to reduce the effect of water shortages through measures that are taken before, during and after droughts. **A proactive approach to drought is equivalent to strategic planning of management for drought preparation and mitigation.** Planning consist of two categories of measures, both planned in advance (Rossi et al. 2003): (i) long-term actions, oriented to reduce the vulnerability of drought i.e. to improve the reliability of each system to meet future demands under drought conditions by set of appropriate structural and institutional measures; (ii) short-term actions, which try to face an incoming particular drought event within the existing framework of infrastructures and management policies (Table 2).

Table 2 Long and short-term drought management

Category	Type of actions	
	LONG TERM ACTIONS	SHORT TERM ACTIONS
Demand reduction	economic incentives for water saving dry crops in place of irrigated crops water recycling in industries	public information for water saving restriction in some urban water uses restriction of irrigation crops mandatory rationing
Water supply increase	reuse of treated wastewater inter-basin water transfer building new reservoirs or increase of storage volume of existing reservoirs construction of farm ponds control of seepage and evaporation losses	improvement of existing water system deficiency use of additional sources of low quality or high exploitation cost use of groundwater reserves increased diversion by relaxing ecological or recreational use constraints
Impact minimization	education activities for improving drought preparedness reallocation of water resources based on water quality requirements development of early warning systems insurance programs	temporary reallocation of water resources public aids to compensate income losses tax reduction or delay of payment deadline public aids for crops insurance

Drought management requires selection of the most appropriate combination of long term and short-term actions with reference to the vulnerability of the specific sectoral needs and to drought severity.

Application of a multi criteria analysis should take into account different views of stakeholders for the different alternatives.

5. Operational component (Framework for decision support tools)

Decision support systems should be designed to delineate a wide range of multiple alternative responses to improve drought management decision-making (Karavitis 1999; Merabtene et al. 2002). **Effective drought management can be achieved by monitoring current drought conditions, predicting future drought development, and proactive implementation of drought prevention by addressing vulnerabilities through a risk management approach. The decision support system should contain:**

- **drought monitoring and evaluation using hydro-meteorological observation data and drought indices;**
- **future drought risk prediction considering weather forecasting information in each drought stage;**
- **drought prevention measures using risk management;**
- **drought records management considering comparisons with drought assessments.**

5.1. Drought assessment and monitoring

Monitoring and assessment of drought conditions at different scales and timely dissemination of information constitute the most vital part of a drought management system. Effective management strategies require an adequate system for monitoring drought, reliable data points, and define procedures to calculate indices of drought prevalence and intensity. The detection, monitoring, and mitigation of disasters require rapid gathering of continuous relevant information that is collected by innovative methods. Remote sensing tools and techniques make it possible to obtain and distribute continuous information rapidly over large areas. The remote sensing monitoring of drought can get frequent and sustained information of the surface characteristics, and it can provide real-time and dynamic monitoring of drought (Zhang et al. 2011a, b). For the last three decades, advancements in the fields of GIS and remote sensing (RS) have greatly facilitated the operation of drought risk assessment. Most data required for drought risk assessment have a spatial component, and changes over time. Therefore, the use of GIS and RS has become essential. It is evident that GIS has a great role to play in drought risk assessment because natural hazards are multi-dimensional. The main advantage of using GIS for drought risk assessment is that it not only generates a visualisation of hazard, but also creates potential to further estimate probable damage due to drought hazard. Drought risk assessment requires up-to-date and accurate information on the terrain topography and the use of the land. The remotely sensed images from satellites and aircrafts are often the only source that can provide this information for large areas at acceptable costs (Wipulanusat et al. 2009). A meteorological station can connect to GIS and keep receiving meteorological information directly entered into GIS, and this data will then be managed and analysed uniformly by the system database. GIS transform the model to its language, and analyses the data using a powerful analysis function, and then adds drought early warning function into drought assessment system (Tao et al. 2011).

A common tool used in drought risk assessment is to use observable meteorological and hydrological data to estimate drought indices, which are applied either as an individual index or as a composite with other indices. Drought has been classified into indices using various hydrological, meteorological and other parameters such as precipitation, evapotranspiration, runoff and other water supplies. These indices can be used to analyse the drought status, intensity, duration, and spatial extent of a drought as well as its impacts. The major potential advantage of the indices and satellite-derived products is seen in high spatial information content, which provides drought risk maps. This combined approach can be a combination of the meteorological, agricultural, and hydrological droughts for multivariate drought characterisations. There is also a possibility for deriving different drought indices based on multiple types of droughts (Mishra and Singh 2011). Spatio-temporal drought analysis based on the combination of duration, severity, area, and frequency are critical for short- and long-term water management. The linkage between large-scale atmospheric patterns and regional droughts can be another way for exploring space–time variability of droughts from local to regional scale. There is a need to develop an approach to convey the results of research to decision makers.

5.2. Drought prediction

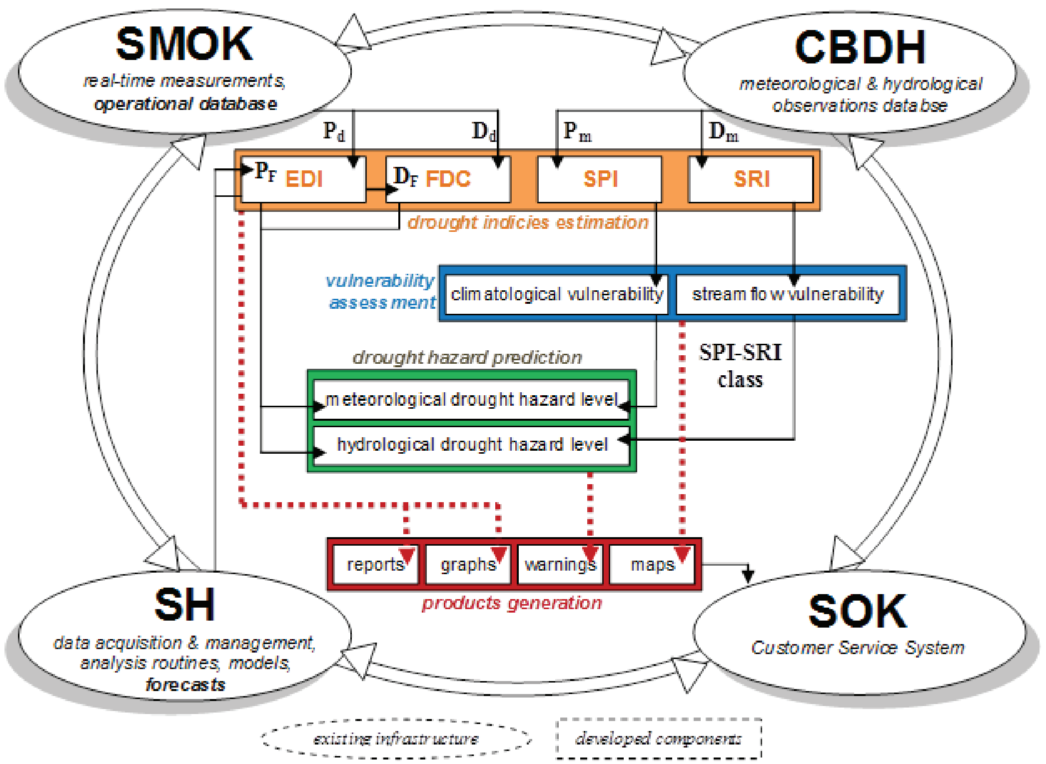
Drought management is necessary to predict drought development and real-time drought prediction is possible based on changes in drought development identified using historical meteorological patterns. **Drought forecasting is a critical component of drought management that plays a major role in risk management, drought preparedness and mitigation (Mishra and Singh 2011).** A decision support system should be developed for various drought climate scenarios, as well as for water saving methods in order to reduce the impacts of drought related to water deficits with consideration for water demand during drought periods.

There are various methods for predicting this, such as regression analysis, time series analysis, probability models, and artificial neural network models. To predict drought conditions, it is necessary to consider meteorological data for the near future. Future drought climate scenarios can be investigated based on precipitation anomalies derived from past data. To predict daily weather data for the near future, a frequency analysis is employed using monthly effective precipitation computations. This form of forecasting, which is based on the partitioning of past observed data, has the potential to provide reliable one year-ahead forecasts of weather data sets. The drought criterion year defined as the severe duration, severity drought that occurred in annual meteorological series (Yoo et al. 2012). It is also possible to forecast drought development in different drought criterion years as a first step, and then determine daily drought indices based on drought patterns in order to predict the impact of a drought. Various historical drought climate scenarios should be evaluated to gain an understanding of drought characteristics to predict potential increases in the severity, intensity and duration of future droughts.

5.3. Drought risk preventive measure

Risk assessment is needed to assist decision makers in making better decisions and developing a plan for the effective preparation and timely response to drought. A critical component of planning is a timely and reliable decision-support system including drought preventive measures. Decision makers commonly take action by selecting among alternatives. Analysis of the consequences of each alternative allows choose the best among others, taking into account occurred conditions.

The risk assessment should consider the following aspects: failure occurrence, severity of failures (magnitude of the deficit), failure duration (time period when deficits occur) and economic impact of failures (Iglesias et al. 2009) to propose suitable and applicable drought management plans. These plans may depend on non-structural measures such as irrigation water saving through a reservoir water supply via structural measures such as construction of a pumping station. Implementation of a drought management plan is more effective if actions are grouped together into drought climate scenarios. To achieve efficiency, there should be a few drought prevention measure scenarios, such as regulating water irrigation. Drought risk management is based on a comparison of past and current drought conditions, and is used to predict the impact of future drought climate scenarios and water saving scenarios. Drought management requires the selection of appropriate long-term and short-term drought management actions with reference to drought vulnerability. With a map of drought vulnerability, decision makers can visualise the hazard risk and convey vulnerability information to other sectors to ensure that they will act in a timely and effectively way to tackle drought-related losses. To



P_d – daily precipitation, P_m – monthly precipitation, P_F – precipitation forecast
D_d – daily discharges, D_m – monthly precipitation, D_F – discharge forecast

Fig. 9. Hydrometorological drought hazard assessment system operated by Institute of Meteorology and Water Management (source: Tokarczyk, Szalinska, 2013)

determine drought vulnerability, the most important and most difficult task is to select the factors and to determine the weighting of those factors, which are commonly subjective and may vary between regions.

5.4. Drought records and history

Historical records of droughts can provide useful information such as (a) the occurrence of current drought conditions based on modelling and drought characteristics considering different drought parameters, (b) current water demand in relation to reservoir water levels, (c) potential drought risk and impacts in terms of different drought components assessed in the evaluation of a combination of several drought climate scenarios, and (d) implementation of drought risk preventive measures.

Drought records and history management involves the application of analytical tools for decision-making. GIS tools are the most suitable environment for collection, storage and distribution of various types of data, including spatial data. Geoinformatics constitute the geospatial data mostly available from various satellite platforms and the technology available for analysing such data such as GIS (Geographic Information System) and GPS (Global Positioning System).

The presented operational risk assessment approach is directed towards better understanding drought occurrence trends, vulnerability and impacts of droughts for particular drought prone areas with the use of operational drought indices. This methodology is the base for the elaboration and development of the operational decision support system for drought risk management in the Odra River basin (http://posucha.imgw.pl/) (Tokarczyk and Szalinska, 2013).

The existing system allows for a comprehensive analysis of the values of the selected drought indices coupled with long-term data studies and short-term precipitation and discharge forecasts. Communication charts and specification of the transmitted information was developed to meet the requirements for a decision-making tool. While the overall scheme remains the same, a selection of different indicators and thresholds to assess drought allow application in different sectors, e.g. agriculture, water supply etc. More information in regards to this can be found in the IDMP CEE report Drought Risk management scheme for Odra river.

6. Conclusions

The challenge for developing a drought risk management scheme was primarily the integration of different approaches and concepts arising from various national, regional, and sectoral contexts. Project implementation recognised drought vulnerability and management strategies that were developed and applied in the participating countries. An overview of essential concepts definitions and methodology associated with drought risk management, at national, sub-national and sectoral levels, was the subject of outputs of the project. They were also a **basic roadmap for integrating, developing, and planning drought risk management tools at different levels, based on best practices, lessons learned and experiences introduced by project partners**. Drought hazard assessment is the decisive information for operational support system in drought risk management. Recommended methodology for drought hazard assessment is based on drought indices. Nature of drought in terms of its onset, progression, intensity and impacts requires improved tools and high quality data to capture the spatial and temporal dimensions of drought by complementing and supplementing different indicators. The selection of the proposed set of drought indices was done with the aim of their applicability in the country participating in the project, as well as their relevance to the drought assessment in the sectors recognised as the most vulnerable to drought: agriculture and water resources.

The rationale for the **recommendations to develop a decision-support system based on operational drought indices was as follows** (based on the IDMP CEE report *Recommendations for operational support system in drought risk management*):

- **Application scope.** Drought indicators that use measurements from standard climatological/hydrological monitoring network can provide drought risk information on operational basis. Another challenge to support decision-making is the development of the tools to combine multiple sources of information on drought, and produce a single marker of the drought situation in relation to the geographical location. Real-time applications promote methods based on easily accessible meteorological and hydrological information. The relevance of the given drought index for the particular sector affected by drought has to be primary verified.
- **Temporal scale**. Drought hazard assessment for different sectors vulnerable to drought may require different temporal resolution. Drought indices are capable to be run for the diverse periods and capture the significant variations of meteorological and hydrological conditions.

- **Spatial scale**. Drought risk has to be primary managed in the regional and local context. The local scale is a critical issue due to the heterogeneity in spatio-temporal hydro-meteorological variability. A standardised form of a drought hazard assessment method allows generation of maps across different regions.
- **Frequency analysis**. Time series of the drought indices classes can be stochastically investigated and provide information on the proneness of a basin to drought formation, evolution and persistence. Also real-time drought prediction is possible based on changes in drought development identified using historical drought patterns.

The ultimate goal for supporting decision in drought risk management is the development of geospatial decision-support tools to address spatial distribution of drought hazard with the application of remote sensing data and geoinformatics techniques. Geospatial technologies are also useful for hazard and vulnerability mapping to help the development of long-term strategies of drought management.

Research on decision-support systems should be advanced for issuing warnings, assessing risk, and taking precautionary measures, and the effective ways for the flow of information from decision makers to users need to be developed. There is also a need to develop decision-support systems under climate change scenarios as well to quantify uncertainties.

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This demonstration project is part of the ***Integrated Drought Management Programme in Central and Eastern Europe*** *which supports the governments of Bulgaria, the Czech Republic, Hungary, Lithuania, Moldova, Poland, Romania, Slovakia, Slovenia and Ukraine in the development of drought management policies and plans. It also builds capacity of stakeholders at different levels for proactive integrated drought management approach and tests innovative approaches for future drought management plans.*

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ISBN: 978-80-972060-4-8