Global Water Partnership
Central and Eastern Europe

Integrated Drought Management
Programme in Central and Eastern Europe

Activity 5.4. Drought Risk Management Scheme: a decision support system

Recommendations for operational support system in drought risk management
(Milestone 3.2)

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1. Introduction

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

The presented report contributes to Output 3 of the Activity 5.4: **Framework for Drought Risk Management Scheme.**

The primary purpose of the work was to present a planning process (scheme) that can facilitate the preparation of decision support systems for drought risk management. Individual elements consisting on drought risk management scheme were identified and reviewed and their inventory in partnership countries were reported in the previous milestones (see Fig. 1).

The final step is to provide a Framework for Drought Risk Management Scheme presenting the interrelationships and functional linkages between these elements for decision support in drought oriented systems. Framework was based on institutional, methodological, public and operational structures serving to compose integrated body of methods (Fig. 2).

Elaborated recommendations for the decision support system in drought risk management are to serve as a common denominator for different regional and sectoral specifications. Introducing a common framework in the form of step-by-step process lead to compatibility and complementarity among different systems. Developed framework defines main principles for drought management that can be applied for various drought aspects.

Recommendations for operational support system in drought risk management concern application of selected drought indices in main parts of the risk management process: drought monitoring, early warning and risk assessment. Drought indices can help to improve drought mitigation efforts through more timely, effective and efficient assessment and response activities.

The report is organized into 5 major sections concerning:

1. **Institutional framework** (institutional component),

Section 1 discusses the institutional coordination set-up and key capacities required to develop the drought risk management systems (Step 1).

2. **Framework for drought risk assessment** (methodological component)

Section 2 outlines the necessary procedures for assessing drought risks. This entails the analysis of climate/hazard trends and other underlying vulnerability factors (Step 2).

3. **Framework for drought prevention measures** (public component)

Section 3 presents the interventions that depend on the risk profile within a given context. 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 (Step 3).

4. **Framework for decision support tools** (operational component)

Section 4 provides guidance and recommendations for developing and implementing decision system based on indicators achievable in given time-bounds to support drought risk management (Step 4).

5. **Appendix:** Recommendations for operational support system in drought risk management for agriculture in Poland.

Practical recommendations for development a decision support system are presented for agricultural drought in Poland along with the identification of actions that can be taken to reduce potential drought related impacts and risk.

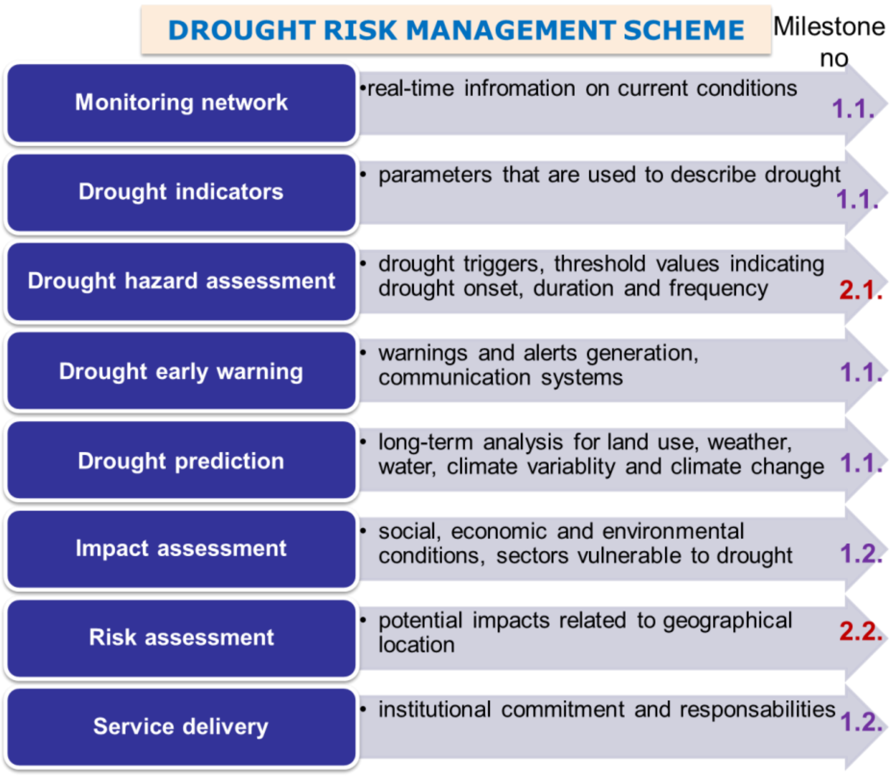


Fig. 1 Components of drought risk management scheme.

Fig. 2. Framework for drought risk management

2. Institutional framework

Successful drought risk management starts from identification of information required to trigger a decision. The most essential part of drought management system constitute monitoring and assessment of drought at different scales and timely dissemination of this information. Objective information on the prevalence of drought and its intensity along with its spatial and temporal dimensions is very critical for evolving drought mitigation strategies. The content of information is inherently combined with the institutions involved in risk management. Institutions provide information as well as they supply the information to other decision actors. I.e. the information requirements of scientific/research organisations for effective drought assessment and the requirements of government functionaries and farming community for drought management at community level differ in various issue. Therefore building management scheme commence from complementing and supplementing institutional-information matrix into integrated scheme.

Drought management requires joint efforts of institutions and organizations representing different fields of science and different levels of management (Fig. 3). A robust and broad-based institutional setting must be established as a preliminary step. The conditions required for the stakeholders' coordination structure include the participation of all key sectors with the strong champion institution assuming a leadership role. The joint effort should be supported by adequate financial and technical resources. The major challenge lies in bringing thise group together with inter connectivity and synergy. To provide integrated institutional and sectoral approach the institutional framework should be composed of institution related to water, meteorology, agriculture, environment and socio-economy. Integrating different management levels (federal, state, district, local/individual) requires tackling with different community participation and political commitment, networks and mechanism as well as resource availability. The aim of integration 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 analyzing such data. Integrated data base and drought related parameters are requires for the need of drought monitoring, early warning and drought impact assessment. Different management levels define the rules for access to information: requests, procedures and forms.

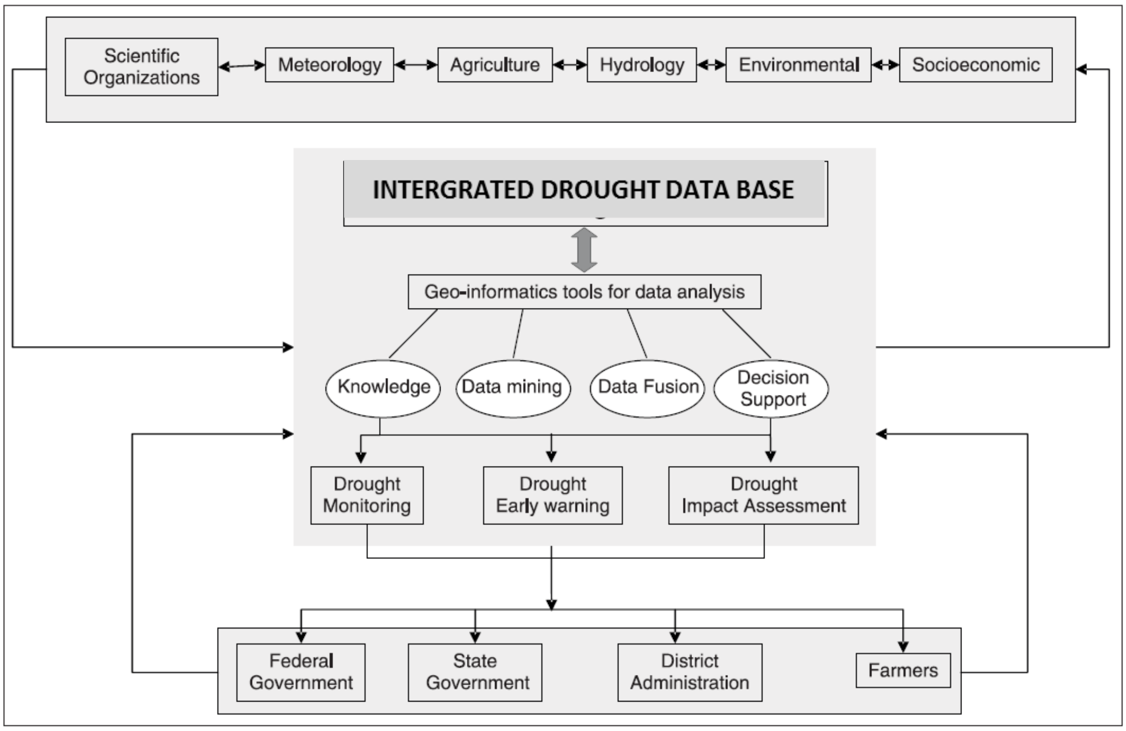


Fig. 3. Framework of institutional linkages (source: Roy, et al. 2010)

The inventory of institutional frameworks and the relevant information on drought exchange pattern in the countries participating in the Activity 5.4 were the subject of the Milestone 1.1 and 1.2.

The inventory of measures for drought assessment that are deployed in the national drought monitoring and early warning systems as well identification of the end-users at national level and their needs for the information on drought in countries were presented in Milestone 1.1. IDENTIFICATION OF THE NATIONAL MEASURES FOR DROUGHT SUSCEPTIBILITY (DROUGHT HAZARD) ASSESSMENT. Existing range of responsibilities of various bodies involved in drought management in particular country participating in activity 5.4 were presented in MILESTONE NO. 1.2. IDENTIFICATION OF THE NATIONAL MEASURES FOR DROUGHT VULNERABILITY ASSESSMENT.

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

In Poland there is no one uniform system for dissemination of information related to drought. There are some smaller systems (like POSUCH@ by IMGW, Monitoring and forecasting water deficit and surplus in agriculture by ITP and Agricultural Drought Monitoring System (ADMS) by IUNG) but they dedicated to specific drought analyses. The systems give information for the whole country in the same way but for some regions there are some more detailed programmes too (like Monitoring meteorological and agricultural drought in Kujawy region by ITP or Drought Analysis by RZGW in Cracow) – so information can be often dissipated.

In Romania 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 the specific information (air temperature, rainfall, ETP, soil moisture, crop water requirement) needed for assessment of drought occurrence. This data collected from the National Observation Network is analyzed and compared with the critical thresholds in order to evaluate the threat and make recommendations to decision-makers and farmers. The soil moisture maps, weekly agrometeorological information and seasonal forecasts which are updated daily according with the flow operational activity are free on the NMA web-page (www.meteoromania.ro) for informational and decisional purpose in terms of technological measures that can be applied in drought conditions.

The provided information was analyzed in terms of compatibility with the established framework in order to point out the potential for development.

In general, none of the countries involved in the activity presented full correspondence to the indicated institutional framework. Linkage between institution related to drought are limited and don't form a multidisciplinary platform of knowladge. However in every country there are dedicated institutions that are responsible for drought assessment or message dissemination. These institutions are associated with meteorology, hydrology and agriculture. Still institutional engagement from environmental and socioeconomy fields is missing. Therefore there is a need to amplify and expand the involvement of these institutions and set up interdisciplinary cooperation between engaged actors.

Also while concerning the structure of drought management levels in the participating countries a development towards strengthening dialogue and networks among disaster researchers, practitioners, and stakeholders is argued. A lack of integrated drought database limits effective information management and exchange to allow consistent knowledge collection and meaningful message dissemination.

A risk management approach provides an effective framework for internalizing drought into decision-making processes systematically rather than as a stand-alone issue that is addressed by single sector. The presented framework requires clear division of competence and tasks between responsible institutions: for data collecting/data analysis and drought forecasting, generation of alerts and warnings, for planning, developing drought mitigation measures and for crisis management and operational actions coordinators. These tasks should be performed and detailed on the national level.

3. Framework for drought risk assessment

Drought risk is a combined effect of drought hazard (likelihood) and drought consequence (vulnerability). Assessment of drought risk thus involves 1) gathering of climate/hazard data and 2) subsequent analysis of

vulnerability factors, using various tools and indicators. Drought hazard is determined by frequency, duration and severity of droughts. Drought impact on various ecosystems and economy depends on the vulnerability of the affected system. Drought risk cuts across sectoral spheres, e.g., agriculture, forestry and water and is constantly evolving and changing over time and geographic areas. Drought exposure is often defined geographically by assigning a spatially averaged value within administrative, landscape, and river basin boundaries. It is important to collect data about hazards and assess the vulnerability of a given community or system.
Hence, risk assessment is a multidisciplinary task that requires inputs from various sectoral practitioners, scientific experts and policy makers as well as the communities directly affected by hazards.

The risk management approach is based on the implementation of measures and actions after a drought event has begun and has become an emergency situation (Iglesias et al. 2009). Drought risk management needs to focus on pre-disaster activities more than has occurred in the past, in addition to consideration for preparedness, mitigation, and prediction/early warning actions that could reduce future impacts. Risk management activities should be guided by the following principles:

- drought risk is the combination of the natural hazard and the human, social, economic and environmental vulnerability of a community or country, and managing risk requires understanding these two components and related factors in space and time;
- increasing individual, community, institutional and national capacities is essential to reducing vulnerability to drought impact;
- impact assessment plays an important role in drought risk management, in particular, identifying most vulnerable groups and sectors during drought;
- drought monitoring and early warning systems play an important role in risk identification, assessment and management;
- changing climate and the associated changing nature of drought poses a serious risk to the environment, hence to sustainable development and the society.

The scheme of drought risk assessment with basic elements is shown on fig. 4.

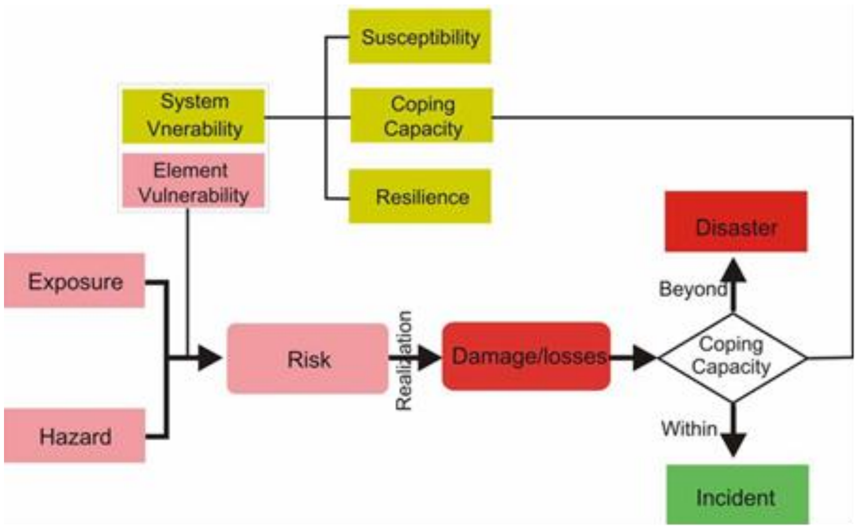


Fig. 4 Elements of drought risk assessment scheme, (source: Jianping Yan, 2010).

The first step to be taken in drought risk assessment is the collection of scientific information regarding climate variability and the frequency, severity and extent of extreme weather events. This process requires the gathering of historical climate/hazard trend data along a broad range of indicators. There is no single indicator is adequate to accurately define hazard benchmarks and thresholds. Of critical importance is the systematic comparison of multiple indicators in developing a holistic understanding of short-term climate variability and longer-term shifts

(Wilhite, Hayes and Knutson, 2005). A variety of indices and models are currently in use in the participating countries for the monitoring of meteorological, agricultural and hydrological drought.
Drought hazard defined by the frequency of occurrence of drought at various levels of intensity and duration provide vital information for drought risk management related to the impacts. Drought hazard mapping cater for information on drought prone areas. It enables identification of the elements at the risk and introduce mitigation measures adjusted to vulnerable areas.

Vulnerability refers to the characteristics and circumstances of communities, systems or asset which make them susceptible/resistant to the damaging effects of a hazard. Assessment of drought vulnerability level begins by measuring the nature and magnitude of drought hazard effects over time. This process entails the identification of direct and immediate consequences of a drought, which include reduced crop yields, groundwater depletion, as well as the tracking of secondary and longer-term impacts, including income and livelihood losses and migration of population.
In general, impact assessment is carried out by reviewing the past or current drought records. However, consideration should also be given to the potential drought impacts foreseen in the short to long-term future in accordance with the existing climate change scenarios.
Drought impacts are often diverse, comprising both structural and non-structural damages and covering a wider range of spatial and temporal scales, in contrast to other natural hazards, such as floods, hurricanes and earthquakes.
The targeting of impacts within specific sectors, population groups and activities allows to identify the individual element vulnerabilities. Mapping out the cause-effect relationships of such impacts helps us understand where the triggering factors exist, how these underlying factors interact with each other and how these dynamics create vulnerability/resilience within a given region and society.

Drought hazard assessment based upon the indices applicable to the participating countries were presented in Milestone no. 2.1. DEVELOPING METHODOLOGY FOR DROUGHT HAZARD MAPPING WITH THE USE OF MEASURES FOR DROUGHT SUSCEPTIBILITY ASSESSMENT. Resulting in the form of maps present temporal and spatial variation of drought hazard in order to identify drought-prone regions.
The selected indices were investigated in terms of providing information on drought hazard for agriculture and water resources sectors within different regional context. The following regional contexts were investigated:

a) SPI and EDI indices with respect to detection of agricultural drought in Lithuania
b) SPI with respect to detection of agricultural drought in Romania
c) SPI, SRI, EDI and FI with respect to detection of hydrological drought in Lithuania
d) SPI, SRI with respect to detection of hydrological drought in Poland.

a) In Lithuania the agricultural droughts lasts longer than one month and can be monitored by EDI index with different estimation timescale, however intra-monthly and intra-seasonal variability of droughts were captured only with EDI30, 60 or 90.
b) 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 analyzed periods. Identified extremely dry areas according to 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.
c) In Lithuania the meteorological drought indexes SPI and EDI have statistically significant relationship with hydrological drought indexes SRI and FI. The correlation between SPI and SRI is better with indexes calculated using longer time steps. The correlation during spring is weakest due to runoff formation from snowmelt. The relationship between meteorological and hydrological drought indexes depends on the properties of river catchment and climate. SPI and indexes 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 the meteorological droughts may be related to water resources shortage.

d) In Poland values of SPI to SRI indices were used to develop a two-dimensional variable for drought hazard assessment. The approach allows establishing five classes of combined SPI-SRI variable which represents: normal meteorological and hydrological conditions (0), wet both meteorological and hydrological conditions (1), dry meteorological conditions and wet hydrological conditions (2), dry both meteorological and hydrological conditions (3) and, wet meteorological conditions and dry hydrological conditions (4). Additionally for stochastic characterization of drought Markov chain models have been used. Statistical characteristics of Markov chain provides information that were used for drought hazard assessment:
    - probabilities of transition from one drought class to another, that represents proneness to drought formation;
    - return period of drought class which represent the probabilities of occurrence of the various drought classes;
    - expected residence time in drought class, which is the average time the process stays in a particular drought class before migrating to another class and represents the duration of that drought class;
    - the expected first passage time from one class to another that represents the average time period taken by the process to reach for the first time the given drought class starting from some other class.

Framework of drought vulnerability was presented in MILESTONE NO. 2.2. FRAMING METHODOLOGY FOR VULNERABILITY TO DROUGHT ASSESSMENT BASED ON AVAILABLE GIS INFORMATION INCLUDING POPULATION MAP, TYPE OF ECONOMIC.
The climate/hazard data collected and set of vulnerability factors identified helped to determine the relative risk in a given sector. Within the framework of the project the partnership countries have provided information on the regional context and indicated sectors of economy and elements of the system of the biggest drought risk. The identified elements were investigated in terms of applied methodologies for the vulnerability assessment. Element vulnerability refers to the degree of potential physical damage to the target elements at risk, such as particular crop spice, water users, forest biota etc. in response to a hazard event of a given intensity. Performed vulnerability analysis cinsited in building vulnerability functions that represents the relationship between potential damage or loss to a given element at risk against a specified event intensity. For Poland and Romania, the vulnerability functions were built for agricultural sector while in Lithuania for water resources.
In Poland, the vulnerability function was describing the relation between drought intensity expressed in terms of SPI indicator and the specific crop yield: late potato, sugar beet, winter wheat, winter rape and maize with the distinction of two classes of total available soil water.
In Romania, the vulnerability functions were built for maize and the sunflower. State of the crop vegetation was assessed with the use of satellite-derived indicators: NDVI, NDDI and NDWI. 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 for water needs crops (summer season).
In Lithuania, the vulnerability functionwere 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 Standardized Runoff Index (SRI) and Flow Index estimated from Frequency Duration Curve (FDC).

4. Framework for drought prevention measures

This section highlights the various procedures to be followed and conditions necessary to internalize drought management concepts and principles into development policies and planning frameworks at 1) national, 2) sectoral and 3) sub-national/local levels respectively.
Drought management at national level entails the detailed costing of drought impacts in a given country or region in monetary terms. The needed data for policy and decision-making can be derived from the historical and prospective analysis of drought impacts and their risks.

Quantifying and valuing the economic impacts of drought is a difficult task because the impacts occur at different levels, in both temporal and spatial terms, and the drought impacts can be distributed along a variety of sectors upon which the national economy is dependent.

There are a number of useful tools adopted in evaluating drought impacts. For example, a rough estimation of the drought costs in the agriculture sector can be partially derived by correlating the production of crop with precipitation levels in both drought and non-drought years (Pandey and Bhandari, 2007). Similar aggregate level estimates may be used for other directly/indirectly water-dependent sectors, such as energy, water and tourism, while attention also needs to be drawn to other non-water factors contributing to the variances in productivity and production.

Introducing drought risk management to national policy, planning and programmes requires addressing drought in an integrated and holistic manner. However, especially in a context of scarce resources and limited capacities as well as the different planning schedule, it may be required to target at first place the sectors that will lead to maximum risk reduction such as agriculture, water, energy or forestry.

Based on the analysis of vulnerabilities, drought risks concerns and drought risk management concepts should be integrated into the visions, goals and objectives of the sectoral policy and strategic frameworks, e.g., growth in crop productivity and production in the agriculture sector. On the sectoral level, the drought risk management principles should be incorporated into the given sector planning process in the forms of target, milestones, outcomes, and budgets, etc. For example, quantified data of drought costs in the agriculture sector will contribute to the development of drought-sensitive and field proven agricultural policies and the incorporation of drought mitigation measures, such as sustainable land management and water conservation, in the sectorial planning.

Integrating drought management at sub-national and local levels implies decentralizing drought risk management roles and responsibilities. It requires strengthening the capacity of local institutions to develop and implement drought-oriented programmes. This would include the allocation of adequate budgetary resources, the deployment of relevant technical personnel and the enhancement of their capacities to respond to the specific needs and concerns of drought-affected populations. Local resources and capacity needs should be incorporate into decision-making processes at higher levels. Local institutions representing the areas of particular interest and concern, for example, river basin management agencies and provincial authorities covering drought-prone dryland regions would inform and provide constructive insights into higher management levels. Local development policies include amongst others: local water and agriculture plans, land distribution schemes, afforestation and reforestation schemes, zoning and infrastructure, urban planning and sanitation.

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 planned activities aim at reducing the effect of shortage, through measures that are taken before, during and after drought. 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 1). Besides the technical measures, effective adaptation measures are needed by strengthening the resilience of societies and natural eco-system. Indeed, this requires an accurate prediction of climate change and scenarios building and greater cooperation and dialogue between water managers and climate community.

Drought mitigation plans should be integrative proactive and incorporate: drought monitoring and early warning system, drought risk and impact assessment, and institutional arrangement including mitigation response actions and programmes.

Table 1 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 recyckling 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 interbasin 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. Drought management measures need to be calibrated and tailored to the specific circumstances facing the affected communities and be in line with the context-specificity of drought risks. The high number and different types of measure requires a proper evaluation procedure selection for the choice of the best combination. Application of multicriteria analysis should take into account the point of views of different stakeholders on the different alternatives. This procedure based on sectoral approach.

5. Fremework for decision support tools

Drought risk is usually assessed in terms of its impacts on human activities, economic, social, and environmental systems. The purpose of drought risk assessment is to identify appropriate actions that can be taken to reduce the loss of the potential damage. Based on the drought risk assessment results, decision makers can visualize the hazard and appreciate the loss of agricultural producers, natural resource managers, and others (Zhang et al. 2011a, b). Most methods of drought risk assessment currently focus on the drought hazard and vulnerability.
When defining a drought, it is important to distinguish between conceptual and operational definitions (Wilhite and Glantz 1987). Conceptual definitions—those stated in relative terms (e.g., a drought is a long, dry period), where as operational definitions, on the other hand, attempt to identify the onset, severity, and termination of drought periods. Generally, operationally defined droughts can be used to analyze drought frequency, severity, and duration for a given return period (Mishra and Singh 2010). Therefore for the need of the operational drought risk management systems it is essential to study the frequency, severity, and spatial extent of drought as well as the infrastructural and socioeconomic ability of the region to anticipate and cope with the drought. The following steps can be used to identify the operational drought risk assessment:

– identify the drought hazard with regard to its spatial extends, frequency, and severity;
– identify and quantify drought vulnerability, e.g., people, economy, and structure exposed to the drought hazard;

– compute drought risk pattern from drought hazard and vulnerability.

A 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 countermeasures by addressing vulnerabilities through a risk management approach. Drought risk management system has several main components including a comprehensive database, an archive of drought impacts, predictions for drought changes in the near future, drought countermeasure assessment tools based on water saving actions and drought records management. The decision support system should contain:

1. drought monitoring and evaluation using hydro-meteorological observation data and drought indices,
2. future drought risk prediction considering weather forecasting information in each drought state,
3. drought countermeasures using risk management,
4. drought records management considering comparisons with drought assessments.

Ad. 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 drought management system. Effective management strategies requires adequate system for monitoring drought, reliable data points, defined procedures to calculate indices of drought prevalence and intensity. The need is to have a sound, operationally feasible, objective and economically viable system for drought monitoring and analysis. The detection, monitoring, and mitigation of disasters require gathering of rapid and continuous relevant information that are not effectively collected by conventional methods. Remote sensing tools and techniques make it possible to obtain and distribute continuous information rapidly over large areas by means of sensors operating in several spectral bands, mounted on aircraft or satellites. The remote sensing monitoring of drought can get frequent and sustained information on the surface characteristics. It can provide macro, dynamic, and real-time monitor data sources for 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 also change 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 visualization of hazard but also creates potential to further analyze this product to 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 then these data will managed and analyzed uniformly by the system database. GIS transformed the model to its language and analyzes the data by powerful analysis function, and then adds drought assessment early warning function into drought assessment system (Tao et al. 2011).
To evaluate current drought conditions, drought indices and indicators should be defined and applied to monitoring of the drought related data. 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 analyze the drought status, intensity, duration, and spatial extent of a drought as well as its impacts. Drought indices are commonly used to detect the potential risk of occurrence and severity of drought, and to study spatial–temporal reasoning. Many of these indices have been developed for detecting temporal variability and magnitude of the drought actions in interesting regions. In order to obtain more reliable results, there is a strong need for wider use of satellite data. The major potential advantage of the indices and satellite-derived products is seen in high spatial information content, which allows for providing drought risk maps.

An important activity to enhance drought assessment is a development of a unified index for drought severity assessment that integrates the data from different sources including integration of satellite data with the ground data. This combined approach can be a combination of the meteorological, agricultural, and hydrological droughts for multivariate drought characterizations. 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 interarrival time are critical for short- and long-term water management. There is much work done on this aspect; however, the gauged data used on spatial scale are unable to produce accurate results due to missing values as well as large distances between gauging stations. Therefore, the availability of remote sensing data will play a crucial role in overcoming these problems. Hence, regionalization of droughts based on remote sensing data needs to be explored. 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.

Ad.2. **Drought forecast and outlook**

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 water saving methods in order to reduce the impacts of drought related to water deficits with consideration for water demand during drought periods.

There has been considerable work in modelling various aspects of drought, such as identification and prediction of its duration and severity. Meteorological data is the most important element of drought forecasting. There are various methods for predicting meteorological data such as regression analysis, time series analysis, probability models, and artificial neural network models. One of the deficiencies in mitigating the effects of a drought is the inability to predict drought conditions accurately for months or years. 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 meteorological 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. There defined a drought criterion year 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.

Drought forecasting is a critical component of drought hydrology which plays a major role in risk management, drought preparedness, and mitigation. There has been considerable work done on modelling various aspects of drought, such as identification and prediction of its duration and severity. However a major research challenge is to develop suitable techniques for forecasting the onset and termination points of droughts. One of the deficiencies in mitigating the effects of a drought is the inability to predict drought conditions accurately for months or years in advance. The time series models as moving average, exponential smoothing, neural network, Markov chains have forecasting capability by providing information on time-related changes. Drought forecast and outlook assessments can inform a variety of drought countermeasure decisions including water saving actions.

Ad. 3. **Drought countermeasures**

Risk assessment is needed to assist decision makers in making better decisions and developing a plan for the effective preparation for and timely response to drought. In drought management a critical component of planning for risk management is the provision of timely and reliable decision support including drought countermeasures. Decision support for drought management is included in drought management to provide guidelines to decision makers about drought countermeasure responses. Any comprehensive drought management efforts should be centred on proactive strategies such as pre-drought preparation and planning, drought response plans and postdrought measures (Karavitis 1999). Drought mitigation and preparedness are the keys to reducing future drought impacts (Wilhite and Svoboda 2007). Decision makers commonly take action by selecting among alternatives. They analyze the consequences of each alternative and then present results to decision makers to let them choose. The risk assessment should consider the following aspects: failure occurrence, severity of failures (magnitude of the deficit), failure duration (time span when deficits occur) and economic impact of failures (Iglesias et al. 2009). Risk-based drought management can be characterized by drought severity, water deficit and the extent of drought-damaged areas with corresponding occurrence probabilities. Drought management plans are actions taken before drought occurs to minimize the risk of drought and provide additional information that usually does not reach decision makers. There are differences in expected effectiveness, impact, and economic costs among actions, so it is necessary 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 countermeasure 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.

Vulnerability mapping and hazard zonation are indispensable requirements to develop effective drought risk prevention measures. With a map of drought vulnerability, decision makers can visualize 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. Vulnerability to drought is dynamic and is influenced by a multitude of factors, including increases and regional shifts in population, urbanization, technology, government policies, land use and other natural resource management practices, desertification processes, water-use trends, and increasing environmental awareness. To 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.

Ad.4. **Drought records and history**

Historical records of drought management 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) implemented drought countermeasures.

Historical drought records management should be enhanced by subsequent contributions to determine drought countermeasures before planning, thereby improving the quality of decision-making and increasing the efficiency and effectiveness of drought management.

Drought records and history management involves the application of analytical tools to decision making. GIS tools are the most suitable environment for collection, storage and distribution various type of data, including spatial data.

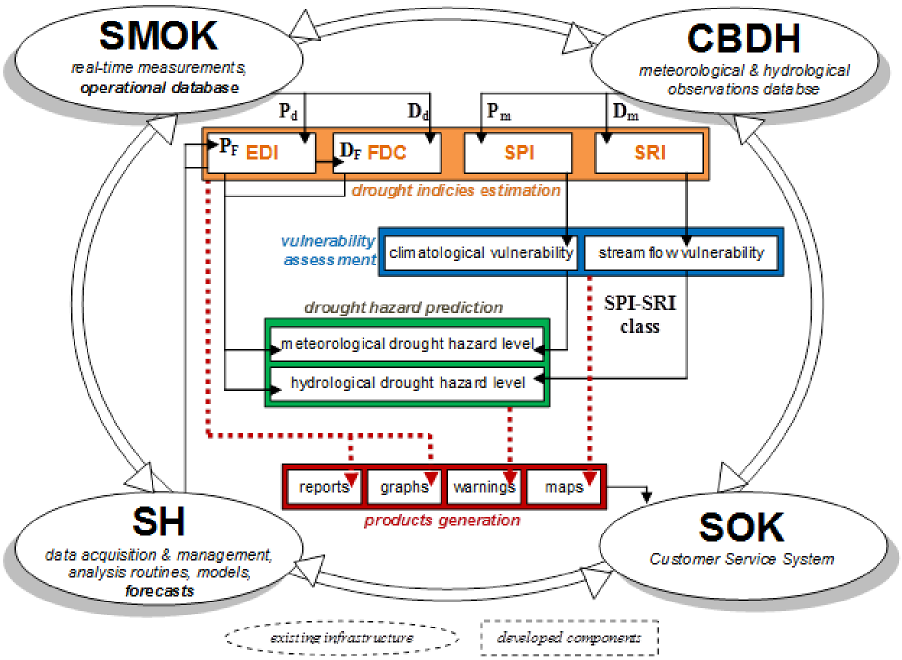
Geoinformatics constitute the geospatial data mostly available from various satelite platforms and the technology available for analysing of such data such as GIS (Geographic Information System) and GPS (Global Positioning System). Geoiformatics facilitate the cost effective, timely and customized information that allows to generate maps with accuracy and time effectiveness as well as quick dissemination of information to people.

The decision-making process of risk-based drought management discusses essential aspects of drought management that include decision support system approaches and multi-criteria decision analysis. Effective drought management depends on several factors: (a) analysis of drought risk assessment and response actions, (b) use of information obtained from modelling different drought components qualitatively for planning, and (c) recommended actions for improving the plan based on past drought management experiences.

The decision support system based on historical drought characteristics including drought duration, severity, intensity, etc. serves as an expert system that aids in the selection of appropriate response measures by comparing

existing conditions with a variety of historical drought climate scenarios stored in a database. Decision makers can determine the best course of action by investigating the performance of risk-based drought countermeasures in terms of reliability, resilience and vulnerability under different drought climate scenarios as well as suggest preparedness action plans using feedback on the performance of past drought countermeasures.
The risk assessment system will help decision makers understand the characteristics of drought impact in order to implement drought countermeasures since dry conditions may persist for long periods. The system can also provide a basis for making adjustments and improving this assessment for future drought events. The development of a procedure capable of evaluating drought risk management is critical for improving drought impact assessments, creating an impact archive, and providing decision makers with information for policy and management.
Long-term forecasts of drought risk on the basis of hazard and vulnerability assessment in the form of scenarios allow for preparation of drought countermeasures using risk management applications. Forecasting and early warning are of great importance for planning and preparing phase to undertake actions aimed at avoiding or minimizing the negative effects of droughts.
As the remote sensing technology makes more and more process, with the development of geographic information system (GIS) and Global Positioning System, the real-time monitoring of drought over the large areas can be achieved.

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. The description of the current state is reported in the Milestone 3.1: Drought risk management scheme for Odra river.
The system was lunched to run operationally for the selected catchments of the Odra River and the Wisla River basins. The crucial resulting products are presented on the website operated by IMWM-NRI: POSUCH@ (Operational System for Providing Drought Prediction and Characteristics) (http://posucha.imgw.pl/). The prediction of meteorological and hydrological drought hazard is performed as short term for 3-days and long-term for 3 months [Tokarczyk and Szalinska, 2013 *a*, *b*].



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

The existing system allows for comprehensive analysis of values of selected drought indices coupled with long-term data studies and short-term precipitation and discharge forecasts. Communication chart and specification of the transmitted information was developed to meet the requirements for decision-making tool. While the overall scheme remains the same a selection of different indicators and thresholds to assess drought allows for application in different sectoral approach i.e. agriculture, water supply etc.

6. Conclusions

The presented work performed within the Activity 5.4 was dedicated to elaborate a common approach among project partners to undertake development and integration of drought management systems and provide a framework for internalizing drought into decision-making process.
Providing integrated guidelines for framing drought risk management systems within the CEE countries is a step forward in attempt to establish common drought management policy. Identifying drought vulnerability in a specific region and sector is an important step (Hong and Wilhite 2004) for drought risk management. The challenge for development of drought risk management scheme is integration of different approaches and concepts arising from different national, regional and sectoral contexts. Project realization allowed to recognized 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 the output 1 and output 2.
The purpose of the output 3 was to present 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. The framework for drought risk management scheme was established on four components: institutional, methodological, public and operational. The framework for drought risk management scheme is based on proactive approach. A proactive approach consists of planning in advance the measures necessary to prevent drought impacts and reduce vulnerability to drought. This approach should include preparedness planning tools with continuous monitoring of drought variables and the status of water reserves. Therefore, adequate information is required for drought declaration as well as to avoid severe shortages through efficient drought management during drought periods (Mendicino and Versace 2007).

Institutional activities are important in planning and in accomplishing a complete plan for drought management. Their contributions includes a use of collection of operational planning models and decisive models of water management for water transfer within a watershed and water systems, steering retention of reservoirs, managing a distribution of water, coordinating the organization of the administrative water management from the local level to the central one, and introducing new regulations. Institutional solutions should consider local problems within a region, which result from the frequency of droughts, their character and the impact they exert upon various water users as well as those problems originating from the expected economic losses due to the water deficit.

In order to successfully introduce drought risk management approach into development processes, capacity and knowledge gaps in drought related data collection and sharing must be identified and an enabling policy and institutional environment established to bridge these gaps. A multiplicity of drought indicators clearly demonstrates that drought monitoring is a cross-cutting exercise, which does not necessary fall under the sole mandate of meteorological or hydrological services, but also relies on agricultural, environmental and socio-economic services. It is for this reason that roles and coordination mechanisms among the various technical branches of government engaged in the monitoring process must be clearly defined at both the national and local levels.

Availability of drought related data depends largely on the capacity for climate/hazard monitoring. This requires observation and research infrastructure. Accessibility to data often represents the main capacity constraint, as the climate/hazard data collection and management functions are fragmented, with limited coordination or exchange across sectoral boundaries, e.g., climatic data is typically managed by the meteorological institutions, while other drought-related data is maintained by different agencies, such as agronomic data by the agriculture institutions and hydrological data by the hydrological ones. Still even if a high degree of data collection, treatment, analysis and mapping skills exist, the monitored and compiled products are not effectively disseminated to concerned government departments and agencies. It is even more difficult for the data to find its way to local stakeholders in the affected communities in a timely and practical manner, due to the lack of effective communication channels. Consequently, the drought early warning information is not being reflected adequately in the decision-making process (UN-ISDR, 2007).

Furthermore, climate/hazard monitoring and early warning products must be tailored to suit the specific needs of users, so that they will be effectively incorporated into operational decision making. For example, the agriculture sector requires the data on the beginning and end of the rainy/dry season and the distribution of rainfall to identify the optimal timing of planting. The water sector may be more interested in changes in stream flow and reservoir levels for water resource planning for hydropower generation, irrigation and industrial/domestic uses (Wilhite and Svoboda, 2000).

Vulnerability is a context-specific rather than a generic condition. It combines various underlying factors, encompassing human, social, economic, political, physical and environmental dimensions. Although the observed impacts of a drought event can be similar from one place to another, each set of prevailing causal conditions vary significantly, and this may put one community at higher risk of future drought disaster than another.

A risk-based decision process for drought risk management integrates drought assessment, forecast, countermeasures, and records management.

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. Dynamic 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 proposed set of drought indices was done with the aim of their applicability in the country participating in the activity 5.4 (PO, LT, RO) as well as their relevance to the drought assessment in the sectors recognized as the most vulnerable to drought: agriculture and water resources. Drought indices allows to work out a common approach for defining and assessing drought hazard and vulnerability to meet the need of drought risk management. The rationale for the recommendations to develop decision support system based on operational drought indices was as follows:

Application scope. Drought indicators that use the measurements from standard climatological/hydrological monitoring network can provide drought risk information on operational basis**.** Another challenge to support decision making in is the development of the tools to combine multiple sources of information on drought and produce a single marker of drought situation in relation to the geographical location. Real-time applications promote methods based on easily accessible meteorological and hydrological information. The relevance of given drought index for the particular sector affected by drought have 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 critical issue due to the heterogeneity in spatio-temporal hydro-meteorological variability (Mishra and Singh, 2010). Standardized form of drought hazard assessment method allows for generation of maps across different region.

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.

A decision support system that performs drought climate scenarios analysis by examining a set of weather scenarios and water saving methods aims to help a decision maker prepare and make decisions based on a better understanding of the available choices and information provided about drought countermeasures among different alternatives. Drought management actions that are taken before the initiation of a drought event aim to reduce vulnerability to drought or to improve drought preparedness. Actions taken after the start of a drought are short-term actions meant to mitigate impacts of the drought. Decisions can be made to manage the drought risk in water shortage situations and to implement appropriate drought countermeasures in the near future. The ultimate goal for supporting decision in drought risk management is development of geospatial decision support tools to address spatial distribution of drought hazard and identify the most vulnerable regions with the application of remote sensing data and geoinformatics techniques. The unique capabilities of remote sensing satellites to provide comprehensive synoptic and multi-temporal coverage of large areas at regular intervals enable the development of operationally feasible system for real time drought monitoring and assessment. Geospatial technologies are also useful for hazard and vulnerability mapping to help 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.

It is expected that this document will provide useful guidance for the countries involved in the project in integrating drought risk management concepts and practices into development of planning and programme frameworks. Cooperation among project participants especially highlighted the importance of consolidating national and local experiences and developing materials to inform and guide future cooperation processes in a systematic and integrated manner. The obtained results shall be continuously reviewed with partners and stakeholders through various knowledge-sharing mechanisms, and revised to respond to changing circumstances.

7. Recommendations for operational support system in drought risk management for agriculture in Poland

The efficient decision support system for agricultural drought management requires a comprehensive tools for integrated agricultural drought management and reservoir operation during drought periods based on various drought climate scenarios and water saving actions.
The recommendations on how to assess drought risk, how to mitigate drought impacts and to create the catalogue of mitigation tools are the frameworks for drought risk management.
The developed framework for drought management scheme will contain the following elements:

1. drought related data and information concerning drought formation, exposure to drought and impacts of droughts,
2. a set of drought measures for various applications based on the information that is readily available,
3. methods for drought assessment and prediction,
4. concept for drought hazard and vulnerability to drought maps generation with the use of GIS techniques,
5. identification of drought management approach (immediate response or decrease vulnerability) to recover or mitigate direct and indirect impacts of drought within economic, environmental and social contexts.

The framework of the drought risk management scheme is demonstrated for the particular applications including a concept of combining drought hazard and drought vulnerability maps for the need of drought risk assessment.

General objective is to provide recommendations on the methodology for agricultural drought assessment used in Poland and to create the catalogue of mitigation tools. The following specific objectives have been set to achieve this general objective:

- to select a national indicator system consisting of meteorological and agricultural indicators suitable for identification of drought events in agriculture and assessment of the drought severity,
- to set a thresholds for the chosen indicators with the aim to define a different drought stages reflecting drought severity,
- to suggest a framework program of mitigation measures for agricultural drought with the aim to minimalize drought impacts,
- to suggest an early warning system tailored on Polish conditions.

The measures for agricultural drought hazard assessment, used in Poland are used for meteorological drought assessment, for meteorological drought is the primarily stage of any drought and the cause of agricultural drought. Drought hazard were assessed by meteorological drought indicators. Detailed description of indices contains Milestone no. 2.1. DEVELOPING METHODOLOGY FOR DROUGHT HAZARD MAPPING WITH THE USE OF MEASURES FOR DROUGHT SUSCEPTIBILITY ASSESSMENT and Milestone NO. 2.2. FRAMING METHODOLOGY FOR VULNERABILITY TO DROUGHT ASSESSMENT BASED ON AVAILABLE GIS INFORMATION INCLUDING POPULATION MAP, TYPE OF ECONOMIC.
For the purpose of drought management two factors are taken for the assessment of agricultural drought risk: (1) a climatic factor (hazard factor) defined as meteorological drought and measured by the SPI method, (2) an exposure factor (vulnerability factor) defined as potential crop yield reduction due to meteorological drought.

Meteorological drought

Standardized Precipitation Index (*SPI*) has been used in Poland for meteorological drought monitoring and assessment of its intensity since 2000. This index is recommended to use in meteorological drought monitoring. Because of great variability of precipitation in Poland, modification of the *SPI* in the scope of the threshold of the moderate drought class was proposed (Labedzki 2007). It was an attempt of applying this index to detect periods of mild drought, especially in shorter periods, e.g. months. The four-category classification as shown in the table 1 is recommended to use in Poland in the system of drought monitoring as an element of drought risk management.

Table 1. Recommended classification of the *SPI* values and meteorology drought category

SPI	Meteorological drought category
0.50 to -0.49	normal
-0.50 to -1.00	mild drought
-1.00 to -1.49	moderate drought
-1.50 to -1.99	severe drought
≤ -2.00	extreme drought

Agricultural drought

Index-based assessment of agricultural drought has been used in Poland within the conducted drought monitoring systems since 2005. The indices and the soil-crop parameters are estimated by using the CROPBALANCE model, which has been developed in Institute of Technology and Life Sciences (Labedzki 2006; Labedzki *et al*. 2008).

Crop Yield Reduction *YR* is recommended to quantify the effect of water stress and agricultural drought on crop. The method elaborated by Raes (Raes 2004, Raes *et al*. 2006) is recommended to calculate crop yield reduction *YR*:

$$YR = \left(1 - \frac{Y_{re}}{Y_p}\right) = 1 - \prod_{i=1}^{N}\left[\prod_{j=1}^{M}\left(1 - k_y\left(1 - \frac{ET}{ET_p}\right)\right)_j^{\frac{\Delta t_j}{L_i}}\right]_i \qquad (3)$$

where: Y_{re} – actual yield reduced due to water stress, Y_p – potential yield that can be expected under the given growing conditions for non-limiting water conditions, k_Y - yield response factor, *ET* – actual evapotranspiration under soil water deficit, ET_p – potential evapotranspiration under non-limiting water conditions, *N* – total number of growth stages, *M* – number of time steps with length Δt_j (days) during the growth stage *i*, Δt_j – the length of the period *j* in the growth stage *i* (days), L_i – the total length of the growth stage *i* (days), *j* – the number of the period in the growth stage *i*. The three-category drought classification is used (moderate, severe, and extreme drought), with the threshold value for the moderate drought category equal to *YR* = 0.1 (tab. 4). It means that 10% reduction of crop yield in relation to potential yield is not considered as a drought effect.

Table 4. Classification of agricultural drought according to yield reduction *YR*

Agricultural drought category	YR (%)
No drought – small yield loss	[0; 10)
Moderate drought – moderate yield loss	[10; 20)
Severe drought – heavy yield loss	[20; 50)
Extreme drought – very heavy yield loss	[50; 100]

7.1. Actions and measures for drought mitigation

The purpose of assessing vulnerability is to identify appropriate actions that can be taken to reduce vulnerability before the potential for damage is realized (Wilhelmi, Wilhite 2002). These actions should be identified within of pre-impact programs that are intended to reduce vulnerability and impacts (Wilhite *et al*. 2014).

Potential crop yield losses in Poland caused by meteorological drought of different intensity were shown in the previous report. A spatial differentiation of crop yield reduction depending on meteorological drought category and soils was determined. The less reduction is observed on the soil with greater total available soil water for all analyzed crops. Late potato is the most vulnerable crop to be damaged by drought. Its potential yield reduction can be more than 50% on light soils on most area of Poland during extreme meteorological drought. Least yield reduction is for winter wheat and winter rape. In most regions there is no negative effect of meteorological drought on yield of these crops. The spatial distribution of yield reduction of all crops shows the central, central-east and central-west part of Poland, where agriculture drought risk is the greatest. These regions of Poland are most threatened by agricultural droughts causing the greatest crop yield losses.

Various measures could be recommended, all of them are means to accomplish the strategic goal – controlling the negative effects of drought in agriculture. Drought mitigation measures can be divided into three groups, on account of the time of undertaking (actions):

- operational – undertaken when drought begins and in the time of its lasting,
- short-term – undertaken before drought in advance up to 5 years,
- long-term – undertaken in long perspective up to 25 years.

Because of possible increase in water shortage in agriculture due to droughts and unfavourable climate changes the main actions and measures should lead to achieve the strategic aims:

- increase of local water resources and their availability
- increase in water use efficiency
- decrease in water needs for crops
- intensification of irrigation

To achieve these goals, the following actions are distinguished:

1. Increasing water resources retention (in open waters) available for agriculture, mainly for irrigation.
2. Increasing soil water retention and its availability for plants.
3. Modification of the technology of water use on farms and in fields.
4. Improvement in the social awareness of droughts, their effects and countermeasures.

The actions can lead to achieve different strategic aims (tab. 5). They should increase water resources and their availability for agriculture, both in open waters (reservoirs, streams) and in soil, modify the needs of water users to force the need for saving water during droughts. A modification of the technology of water use on farms and in the field should play a great role. Minimizing the useless water outflow from fields, reclamation systems, streams etc. including drainage outflows and limiting crop water use are necessary. It may be may expected that further work should result in documents providing for the implementation of regional small retention development programs and irrigation development programs. Particular measures within the above actions are presented in table 5.

Table 5. Actions and measures for counteracting drought impact in agriculture and their expected effects

Action	Measures	Effects	Duration of action	Main goal
Increasing water resources retention (in open waters) available for agriculture	construction of small water retention reservoirs construction of water structures to restrict water outflow from fields different small water retention measures	adaptation of existing sources of small retention to requirements for agriculture with the possibility of their enlargement in the future more water available for irrigation collection of water in local reservoirs during periods of its excess (in spring and after abundant intensive precipitation) water retention and slowing runoff in small streams	Long-term Short-term	Increase of local water resources and their availability.
Increasing soil water retention and its availability for plants	technologies of soil cultivation that increase soil moisture and the degree of water utilization (e.g. soil loosening, deep plowing, organic fertilization) plant species selection in crop rotation (drought resistance plants, plants with a shorter vegetative period, lower water requirements, a deeper root system) fertilization and reclamation measures that aid the development of a strong root system introduction of deep-rooted plants with low water requirements irrigation	improvement of soil structure improvement of physical and water properties of soil layers increased infiltration enlarging the active layer of roots water uptake deeper rooting increased amount of water available for plants increased plant water use efficiency (more crop for a drop) decreased losses in crop yield	Short-term	Increase of local water resources and their availability. Increase in water use efficiency. Decrease in water needs for crops. Intensification of irrigation.
Modification of the technology of water use on farms and in fields	modernization of irrigation and water distribution systems to increase their effectiveness for supply and out-flow of water improvement of operation and management of irrigation and water systems usage of modern energy- and water-saving methods and techniques of irrigation implementation of new irrigation management techniques improvement and implementation of water distribution procedures towards dynamic and flexible water resources management with the use of multi-criteria optimization and modern automatic systems of monitoring of the state of water systems (groundwater table depths, stream water stages and stream flow discharge, monitoring of water structures) adjustment of water system control algorithms to changing climate	saving water increasing water use efficiency by multiple use of water minimizing useless water discharges from reclamation systems, including drainage outflows limiting water consumption for evapotranspiration improvement in energy- and water consumption efficiency of irrigation improvement of water use efficiency by crops improvement of existing infrastructure for storage and distribution of water increasing available water resources (in soils, streams, reservoirs)	Short-term Operational	Increase in water use efficiency. Decrease in water needs for crops. Intensification of irrigation.

Action	Measures	Effects	Duration of action	Main goal
	conditions and extreme weather events development of regional (local) systems of monitoring climate for the need of water system management development of telecommunication systems usage of remote-sensing methods and GIS in water system control			
Improvement in the social awareness of droughts, their effects and countermeasures	training brochures, leaflets, bulletins internet radio, television, newspapers	Raising the awareness of the society of the issues of drought and its mitigation	Long -term Short-term Operational	All

Early warning system

The system provides current and forecasted evaluation of water deficit and surplus for agriculture in selected, representative agricultural ecosystems and estimates potential reduction of crop yield due to water shortage. It has a module of medium- and long-term forecasting water deficits. Precipitation conditions are monitored using standardized precipitation index *SPI*, soil moisture - soil moisture index *SMI*, the deficit of water for crops - crop drought index *CDI* and the potential reduction of yield due to water deficit - yield reduction ratio *YR*.

One has to take into account some risk, restrictions and losses in crops and incomes. That is why an acceptable level of losses on various management levels - in a region, in a commune, on a farm - should be determined within the drought mitigation plans. A list of priorities is to be prepared to determine the permissible level of losses in agricultural production. This would enable planning the respective tasks and an optimum allocation of means for their accomplishment.

Actual determinants of various activities against drought in Polish agriculture are strictly connected with the state of water management in agriculture, particularly with the state of land-reclamation (amelioration). Basic reasons for the restricted possibilities of drought counteraction on agricultural areas lie in the negligence of the proper use of agricultural water systems and reclamation systems and facilities. Improvement of management, operation and maintenance of these systems will make mitigation measures more effective.

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