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Structure design of the drought risk assessment and mapping technology for adaptation of Ukrainian water sector to climate change

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SUMMARY

This paper suggests a structure design of drought risk assessment and mapping technology and a 6-stage implementation process regarding the country specifics of Ukraine.

"Stage-to-stage" implementation process involves collection of observational data for drought assessment (both field measurements and satellite data), data pre-processing, formulation of methodology for drought assessment, assessment of drought and mapping. The final stage of technology seeks next technical procedure with DI spatial database like spatial DI interpolation, visualizing resulting DI maps, publicly available DI maps publication. The creation of risk maps requires Geographical Information Systems (GIS) software. To carry out it, the spatial data analysis can be used for next GIS software: MapInfo, ERDAS, Intergraph, IDRISI, GRAM, ArcInfo, GRASS, AutoCAD maps etc. For the mapping of drought, the most widely used ArcGIS in Ukraine, developed by the Institute for Environmental Systems Research (ESRI), can be recommended. ArcGIS offers a unique set of capabilities for applying location-based analytics to drought mapping, contextual tools to visualize and analyse ground based and satellite data. It includes imagery tools and workflows for visualization and analysis, and access to the world's largest imagery collection.

Introduction

Drought is a complex phenomenon caused by a lengthy and significant deficit of precipitation accompanied by elevated air temperatures during the warm period of the year resulting in the depletion of water stock through evaporation and transpiration. Accordingly, long-term droughts reduce flow of rivers (hydrological droughts) and surface water supply. Droughts impact are often compounded by extreme and prolonged heat waves, the number of which has increased worldwide, as well as in Ukraine during last decades (Shevchenko et al., 2020).

Such changes may have adverse effects on agricultural, energy, transport, and social sectors, dependent on water resources. Adaptation strategies have to be developed in regional water resource management in order to avoid the risks and damages associated with such impacts, so that the readiness of the water-dependent sectors could be ensured to meet the future challenges.

Categories and definitions of droughts

The description of drought risk assessment and mapping is a key element of drought management, as it helps identify most of areas at the risk of drought, allowing communities to plan, as well as prepare for and mitigate possible impacts. Drought's risk is calculated as the probability of negative impact caused by interactions between hazard (probability of future drought events occurring based on past, current and projected drought conditions), exposure (scale of assets and population in the area) and vulnerability (the probability of assets and population being affected by drought in the area).

Drought is a complex natural hazard that impacts ecosystems and society in many ways. Many of these impacts are associated with hydrological drought (drought in rivers, lakes, and groundwater). Wilhite and Glantz (Wilhite and Glantz, 1985) categorized the definitions in terms of four basic approaches to measuring drought: meteorological, hydrological, agricultural, and socioeconomic. The first three approaches deal with ways to measure drought as a physical phenomenon. The last deals with drought in terms of supply and demand, tracking the effects of water shortfall, as it ripples through socioeconomic systems.

Meteorological drought is defined usually on the basis of the degree of dryness (in comparison to some "normal" or average amount) and the duration of the dry period. Definitions of meteorological drought must be considered as region specific since the atmospheric conditions that result in deficiencies of precipitation are highly variable from region to region.

Agricultural drought links various characteristics of meteorological (or hydrological) drought to agricultural impacts, focusing on precipitation shortages, differences between actual and potential evapotranspiration, soil water deficits, reduced groundwater or reservoir levels, and so on. Hydrological drought is associated with the effect of periods for precipitation (including snowfall) shortfalls on surface or subsurface water. The frequency and severity of hydrological drought is often defined in a watershed or river basin scale. Although all droughts originate with a deficiency of precipitation, hydrologists are more concerned with how this deficiency plays out through the hydrologic system. Hydrological drought is usually out of phase with or lag the occurrence of meteorological and agricultural droughts.

Description of the technology structure and implementation process

We propose to apply the phased implementation of this technology. The implementation process takes 6 stages (Figure 1).

In the first stage of the technology (***Collection of observational data for drought assessment***), all kinds of the information required for drought assessment must be collected. Data for drought risks assessments include that derived from remote sensing (Skakun at al., 2016), as well as field measurements, in case of possibility. For the calculation of typical drought, indexes SPI or SPEI is needed data of field measurement: daily and monthly values of temperature and precipitation, soil moisture. Remote drought monitoring is carried out on the basis of the use of the Normalized Vegetation Index (NDVI), or the normalized NWI water index, calculated by satellite data TERRA / MODIS and other satellites.

For the calculation of drought indices, availability of long time series of undisturbed, good-quality of observational data is essential. Observational data sources used in drought studies are either station data (e.g., meteorological stations, discharge gauging stations, groundwater wells) or gridded data (e.g., reanalysis data, satellite data). In hydrological drought studies, most commonly used data are streamflow measurements (Van Loon, 2015).

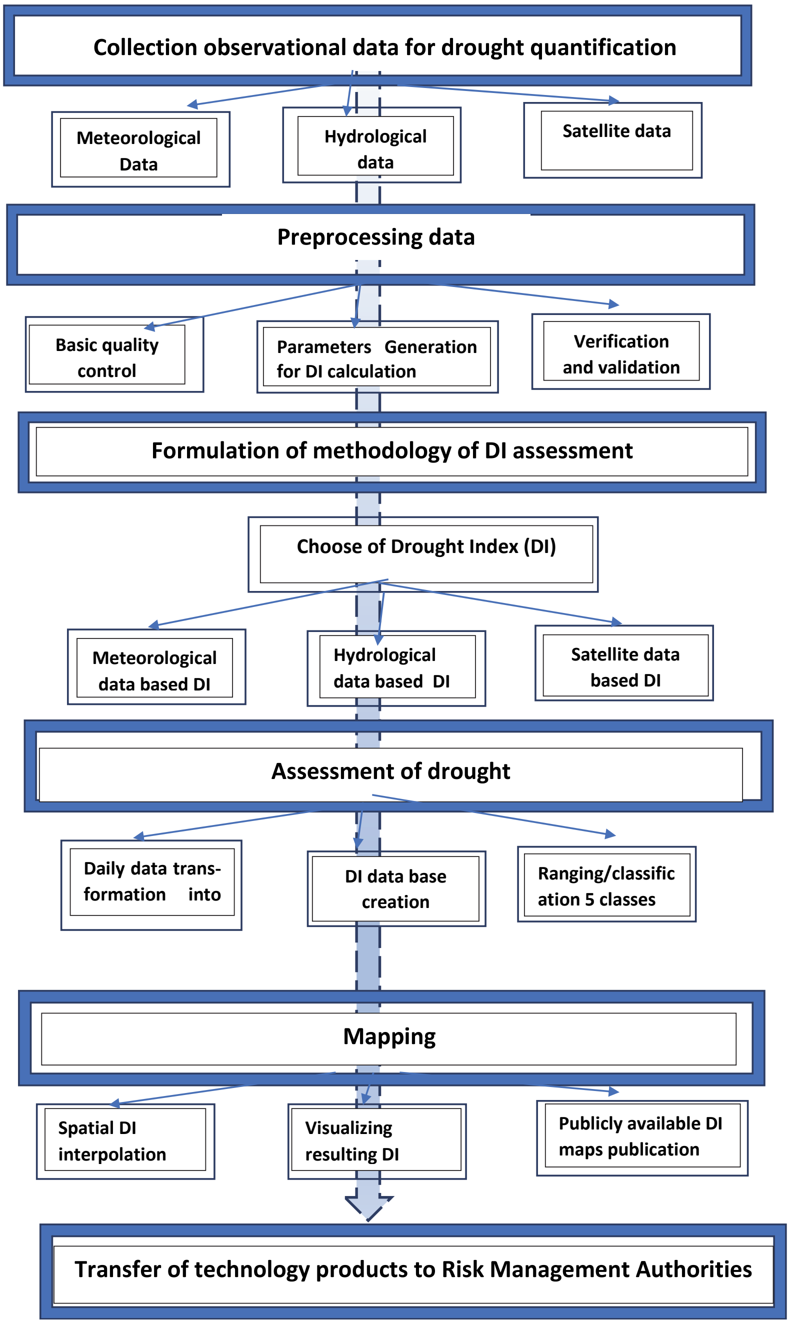

Figure 1 *The technological structure of drought assessment and mapping technology*

In the second stage of the technology (***Data pre-processing***) all data, including basic quality control, generation of meteorological, hydrological or satellite parameters required for drought indexes (DI) calculation, verification and validation must be processed.
In the third stage (***Formulation of methodology for drought assessment***), there must be the formulation of the technology for drought assessment and should be selected of type of DI (on the basis of meteorological, hydrological, or satellite observational data).

A group of drought indices are standardized drought indices. The set of standardized drought indices (including those focusing on hydrological drought) originate from the Standardized Precipitation Index (SPI).
SPI is the most-used standardized meteorological drought index. It is based on long-term precipitation records that are fitted to a probability distribution. This distribution is then transformed to a normal distribution, ensuring zero mean and unit standard deviation. Because precipitation has a high spatial and temporal variability, meteorological drought indices often use monthly values. SPI can be computed over several time scales (e.g., 1, 3, 6, 12 months, or more) and thus indirectly considers effects of accumulating precipitation deficits.
As precipitation is not only meteorological variable influencing drought conditions, some meteorological indices also include (a proxy for) evapotranspiration. As an alternative for SPI, can be used the Standardized Precipitation and Evapotranspiration Index (SPEI). SPEI considers the cumulated anomalies of the climatic water balance (precipitation minus potential evapotranspiration).
Standardized indices for the characterization of hydrological drought use different hydrological variables (from observed or simulated data) as input. Most common is a focus on streamflow, because streamflow is most measured, most easily simulated, and of most interest to water resources management. The Standardized Runoff Index (SRI) uses the simulated runoff and the Standardized Streamflow Index (SSI) focuses on (observed or simulated) streamflow.
The implementation of hydro-meteorological or hydrological indicators, such as the Normalized Difference Vegetation Index (NDVI) (uses light reflection from vegetation to detect changes in health including drought related stress), or Standardized Precipitation-Evapotranspiration Index (SPEI) (compares water availability to evapotranspiration rates) are common indicators in order to be used to assess drought risks that work by implementing the remote sensing to determine potential drought hazards. This data can then be coupled with data on population and assets in the area, as well as the community's vulnerability to damage by drought, to assess the drought risk.
For this technology, SPI index can be recommended, as recommended by WMO for drought monitoring over the world. SPI uses historical precipitation records for any location to develop a probability of precipitation that can be computed at any number of timescales, from 1 month to 48 months or longer. As with other climatic indicators, the time series of data used to calculate SPI does not need to be of a specific length. SPI can be calculated on minimum 20 years' worth of data, but ideally the time series should have a minimum of 30 years of data, even when missing data are accounted for.
When satellite data are used for identifying and monitoring drought, index NDVI is recommended. Radiance values measured in both the visible and near-infrared channels are used to calculate NDVI. It measures greenness and vigor of vegetation over a seven-day period as a way of reducing cloud contamination and can identify drought-related stress to vegetation. Input parameters: NOAA satellite data.
In the fourth stage (***Assessment of drought*)**, drought must be assessed, including daily data transformation into DI, DI database creation, DI ranging (5 classes of DI) /classification (Drought classification, 2020). Spatial data from the paper maps, remote sensors and records are required to be transformed into a digital format and create a spatial database of DI. Geographic references (longitude or latitude/columns and rows – spatial data) identify the spatial location of information collection.
In the fifth stage (***Mapping***), there must be the mapping of drought. This final stage of technology seeks next technical procedure with DI spatial database like spatial DI interpolation, visualizing resulting DI maps, publicly available DI maps publication. The creation of risk maps requires Geographical Information Systems (GIS) software. To carry out it, the spatial data analysis can be used for next GIS software: MapInfo, ERDAS, Intergraph, IDRISI, GRAM, ArcInfo, GRASS, AutoCAD maps etc.
Drought risk's modelling must also consider climate change trends in the area in order to calculate the effect they may have on drought's impacts. All spatial data's models use discrete spatial data objects such as points, lines, areas, volumes and surfaces. Attributes are both spatial and non-spatial and the digital description of objects characterize them and their attributes comprise of spatial data sets. Vector and raster models are commonly used in data organization
When an attribute is measured at sample point, it is spatially continuous and a single-valued surface. Interpolation methods are effective for converting points to an area representation. The interpolation process involves estimating the value of the modelled variable at a succession of point location, usually on a square lattice and is called gridding. The gridded values are treated as the pixels of a raster image.

These grid values are used in contour lining or surface modeling or as labelled line objects or polygon objects whose boundaries are the contours. The process of converting point data to data structure that represents a continuous surface is called contouring or surface modelling. Surface modelling is achieved through triangulation, distance weighing and Kriging (Nagarajan, 2010). For the mapping of drought, the most widely used ArcGIS in Ukraine, developed by the Institute for Environmental Systems Research (ESRI), can be recommended. ArcGIS offers a unique set of capabilities for applying location-based analytics to drought mapping, contextual tools to visualize and analyse ground based and satellite data. It includes imagery tools and workflows for visualization and analysis, and access to the world's largest imagery collection.

In the sixth stage (***Transfer of technology products to Risk Management Authority and other stakeholders***), there is a transfer of results and products of technology (drought risk maps, drought forecast, relevant drought information) to the Risk Management Authorities and other stakeholders. Risk Management Authorities in Ukraine are State Emergency Service (Risk Management Department), River Basin Authorities, Ministry of Agrarian Policy and Food, State Water Agency. Among other stakeholders, there can be insurance companies, state and private agrarian farms, municipalities in drought regions, NGOs and media.

Conclusions

Described technology can be very efficient instrument for adaptation measures in Ukraine. However functioning of this technology is possible only if there is high quality of meteorological and hydrological monitoring data according WMO standards provided by the National Meteorological and Hydrological Service (NMHS) It is necessary to undertake organizational measures within the structures of meteorological monitoring in order to create modern satellite, meteorological and hydrological data base; to train of experts for drought assessment and mapping; to increase of efficiency of insurance system.

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