DROUGHT EVALUATION IN GEORGIA USING SPI AND SpEI INDICES

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Abstract. *Drought is a frequent phenomenon in Georgia. Its frequency in some areas exceeded 40% in the 80-ies of the last century by certain early estimates. As a result of frequent droughts accompanying the global warming in past decades transformation of many types of natural landscapes has been observed. In study Pearson correlation coefficient (PCC), determination coefficient (R^2), and root mean square error (RMSE) criteria, which are among the strong statistical criteria, were used. In order to compare drought indices, scatter diagrams of indices were drawn and statistically evaluated. For this, R^2 and the RSME were used. Correlation between data sets is a measure of how well they are related. SPEI/SPI indices reflect complex mosaic character of Georgian climate change.*

Kkey words. *Drought indices, Pearson correlation, climate change Nature Based Solutions.*

Introduction

Economic and other losses from natural disasters are increasing throughout the world. According to the International Disaster Database (EM-DAT), over the last 70 years, hydro-meteorological disasters have shown the fastest rate of increase of all disaster types. In parallel, technological capabilities to manage such disasters have advanced rapidly.

Hydro-meteorological hazards such as severe floods, storm surges, landslides, avalanches, hail, wind-storms, droughts, etc. are expected become more frequent and severe due to climate change, degradation of ecosystems, population growth and urbanization [1,9]. Drought is a climatic event that cannot be prevented, but interventions and preparedness to drought can help to: (i) be better prepared to cope with drought; (ii) develop more resilient ecosystems (iii) improve resilience to recover from drought; and (iv) mitigate the impacts of droughts. Preparedness strategies to drought include: (a) geographical shifts of agricultural systems; (b) climate-proofing rainfall-based systems; (c) making irrigated systems more efficient; (d) expanding the intermediate rainfed-irrigated systems [2,3].

Using these statistical indicators, one can characterize the timing, frequency, intensity, duration and types of droughts which are helpful for planning, designing and maintenance of NBS for droughts (e.g. soil and water conservation measures, water harvesting ponds). Measures: Increasing soil infiltration, potentially reducing surface runoff, by free-draining soil, planting floodplain or riverside woods, reducing water flow connectivity by interrupting surface flows, by planting buffer strips of grass and trees. Seeding of deep rooting plants, enhancement of biodiversity, filtration strategies to reduce eutrophication and preserve water quality. Promote practices to reduce water usage, promoting alternative crops.

Below are listed various drought indices that are used worldwide [4].

Snowpack extent and snow water equivalent (SWE) are other important variables in Northern Europe and in **mountainous regions**. Snow contributes to water availability over the year also over far away wide regions that draw water from snow reservoirs.

Drought indicators based on **soil water content**, such as the Drought Observatories Soil Moisture Index Anomaly (**SMA**), the Drought Severity Index (**DSI**), or the Palmer Drought Severity Index (**PDSI**), aim to characterize the risks of plant water stress.

Indicators of **hydrological drought**, such as the European Drought Observatories Low-Flow Index (**LFI),** are usually based on threshold approaches to quantify the volume of water deficit in rivers and reservoirs.

Combined indicators blend several physical indicators into one high-level indicator of hazard (e.g., European Drought Observatories Combined Drought Indicator).

- **Soil Moisture Anomaly (SMA)**: This indicator measures anomalies of daily soil moisture (water) content, and is used to estimate agricultural drought conditions.
- **Anomaly of Vegetation Condition (FAPAR Anomaly)**: This indicator quantifies anomalies of satellite measured FAPAR (Fraction of Absorbed Photosynthetically Active Radiation) and is used to highlight areas of relative vegetation stress due to drought.
- **Low-Flow Index (LFI, only available for Europe)**: This indicator s used for near real-time monitoring of hydrological streamflow drought at European scale. LFI is derived from daily river discharge outputs produced by the JRC hydrological rainfall-runoff model (LISFLOOD) within the Copernicus EMS European Flood Awareness System. The indicator is useful to monitor hydrological drought.
- **Heat and Cold Wave Index (HCWI)**: This indicator is used to detect and characterize positive and negative extreme temperature anomalies (heatwaves as well as warm and cold spells) and is based on daily minimum and maximum temperatures.
- **Combined Drought Indicator (CDI; only for Europe)**: This indicator integrates information on anomalies of precipitation, soil moisture and satellite-measured vegetation conditions, into a discrete classification index. CDI is used to monitor the onset of agricultural drought, its evolution in time and space, and the recovery phase.
- **Risk of Drought Impact for Agriculture (RDrI-Agri; only on Global Drought Observatory)**: This is a categorized risk index, indicating the probability of having impacts from drought, with particular focus on vegetation. The RDrI-Agri combines hazard, exposure (in terms of total population, livelihood and assets), vulnerability (i.e., the propensity of exposed elements to suffer adverse drought-induced effects). The hazard is expressed as the combination of precipitation anomaly (SPI), anomaly of photosynthetic activity (fAPAR) and soil moisture anomalies.
- **Indicator for Forecasting Unusually Wet and Dry Conditions**: This indicator provides an early warning of unusually wet and dry cumulative periods forecasted over the next 1-, 3-, and 6-months in Europe (EDO) and the world (GDO). The indicator is derived from the statistical analysis of predicted Standardized Precipitation Index values (SPI-1, SPI-3, and SPI-6), calculated from the forecast of precipitation given by the ECMWF seasonal forecasting system (SEAS5). Only regions where an unusual wet or dry period (i.e., meeting a threshold SPI value) is forecasted with sufficient robustness (i.e., 40% of forecast members meet the threshold) are indicated. Levels of the indicator correspond to the return period of the forecast intensity and coherence.
- The **short-term MIDI** combines the Palmer Drought Severity Index (PDSI), Z-Index, 1-month Standardized Precipitation Index (SPI), and 3-month SPI to approximate drought impacts from changes in precipitation and moisture over a **short-term timeframe**.

The **long-term MIDI** combines PDSI, Z-Index, and 6-month, 1-year, 2-year, and 5-year SPI to to approximate drought impacts from changes in precipitation and moisture over a **long-term timeframe**.

Data and method

The standardized indices SPI and SPEI classify the precipitation and water balance anomalies with respect to the long term records. The index values directly indicate how frequent the current situation is expected to occur at the location and season of interest given the long term observations. The SPI (standardized precipitation index) classifies the precipitation sums on a particular date with respect to the sums of the same month in all years of the measurement record [5,6]. For this purpose, the precipitation sums of the whole record within one month around the respective date are transformed into a standard normal distribution around zero. The SPI is nothing else than these transformed precipitation sums. The SPI value hence directly indicates the frequency of the observed precipitation amount in the corresponding month as estimated from the whole observation record. The SPEI (standardized precipitation evapotranspiration index) is calculated in analogy to the SPI, using the cumulative water balance instead of precipitation sums. The SPEI hence represents the standard-normal distributed water balance.

The 1991-2020 year period meteorological observation data of the stations, that had continuous and homogenous series have been used.

AS it is evident from Table 1 correlation coefficient is high between inter-station all draught indices and is low between different stations. That can be explained by station elevation and heterogeneous type of precipitation. Thus draught indices are depended on site elevation and parameters involved in calculation, namely precipitation.

Draught indices of all stations for research 1991-2020 period are presented on charts (Fig.1-3).

Table 1. Inter and between stations Pearson correlation of draught SPEI-SPI (3,6,12 months) indices of for 1991-2020 period'

Station	Elev. (m)	Pearson SPI3-SPEI3	Pearson SPI6-SPEI6	Pearson SPI12-SPEI12	Station	Elev. (m)	Pearson SPI3-SPEI3	Pearson SPI6-SPEI6	Pearson SPI12-SPEI12
Telavi	586	0.951749	0.943172	0.928499	Tbilisi	431	0.925437	0.903093	0.873974
Akhaltsikhe	989	0.921328	0.900248	0.866863	Telavi/Gori		0.475601	0.484241	0.53356
Ambrolauri	544	0.960683	0.956609	0.960253	Akhaltsikhe/ Mta-Sabueti		0.509075	0.492155	0.503413
Gori	602	0.898262	0.867283	0.808437	Tbilisi/Kutaisi		0.314346	0.337496	0.443787
Mta-Sabueti		0.977971	0.980275	0.979545	Tbilisi/ Mta-Sabueti		0.300097	0.314582	0.433386
Pasanauri	1070	0.97667	0.965895	0.944941	Bolnisi/Pasanauri		0.242862	0.157741	0.262271
Poti	1	0.982357	0.986272	0.987388	Tbilisi/ Akhaltsikhe		0.430081	0.389833	0.433268
Kutaisi	113	0.980448	0.977414	0.978158					

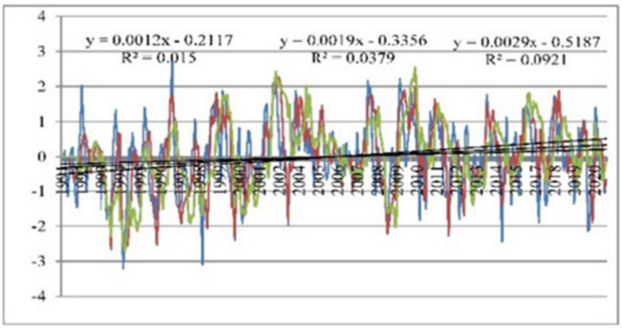

Fig.1. Akhaltsikhe SPI3,6,12 (blue, red, green) draught indices.

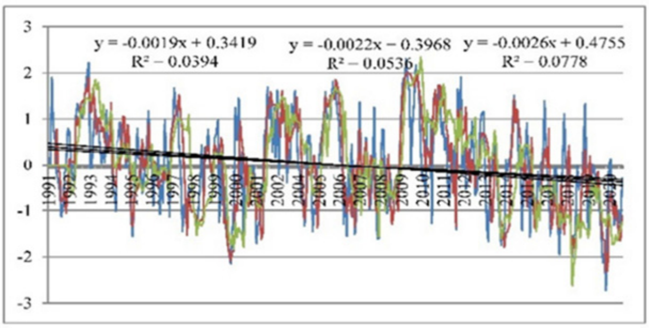

Fig. 2. Tbilisi SPEI3, (blue) 6 (orange), 12 (green) draught indices.

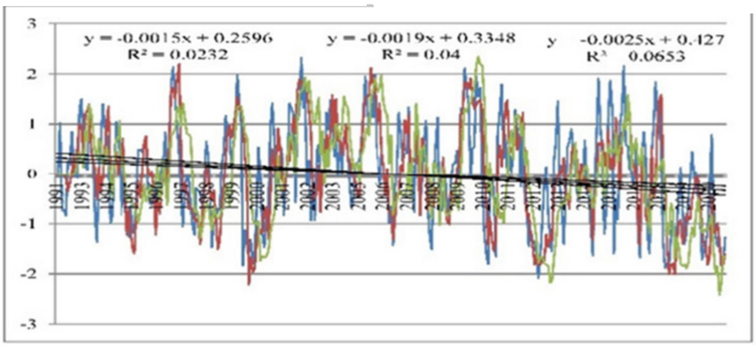

Fig.3. Gori draught SPEI3 (blue),6(red),12(green) indies.

Discussion

In study Pearson correlation coefficient (PCC), determination coefficient (R^2), and root mean square error (RMSE) criteria, which are among the strong statistical criteria, were used. R^2 ranges from 0 to 1, with higher values indicating less error variance. The **RMSE** is the square root of the variance of the residuals. It indicates the absolute fit of two data set and lower the RMSE the better performance is [7,8].

In order to compare drought indices, scatter diagrams of indices were drawn and statistically evaluated. For this, R^2 and the RSME were used. Correlation between data sets is a measure of how well they are related. The most common measure of correlation in stats is the Pearson Correlation. It shows the linear relationship between two sets of data (3month) PCC, which shows linear relationship between SPI-SPEI is quite high, while in cases of SPI-EDI, especially for Dedoplistskaro, Gori and Telavi and SPEI-EDI, Dedoplistskaro, Telavi is low.

RMSE (SPI-SPEI) is low especially for Khashuri and Telavi; (12month) PCC for SPI-SPEI is high R^2 is low for all stations. RMSE (SPI-SPEI) is low which means perfect fitting (Tab.1). The strongest relationship was observed among the indices in the same time periods. As time lag increases, the relationship between variables has been weakened.

It's interesting to count drought and wet day ratio at each stations. For Akhaltsikhe point wet day number exceeds drought one, severe drought day is approximately 3 and moderate- 50. At Gori station wet day number slightly exceeds drought day number, severe drought day equals 1 and moderate-60. At Telavi point drought day number greatly exceeds wet day number, severe drought day equals 5 and moderate-58. At Tbilisi point drought day number exceeds wet day one; severe drought day is 4 and moderate-62. At Kutaisi station wet day number exceeds drought one, severe drought day is 5 and moderate-55. At Mta-Sabueti both day types are approximately equal, severe drought day is 5 and moderate-54.

Conclusions

The drought indices are good indicators for climate change, as involved temperature and humidity variations. At selected research period 1991-2020 the drought SPEI, SPI indices for different stations show various tendencies. For this short time scale the slope of the trend lines are generally lower. The SPEI3 large fluctuations indicate on its sensitivity towards short-time precipitation and SPEI6 is sensitive to wet-dry periods fluctuation. The drought indices behavior is as follows: At Akhaltsikhe station all SPEI indices don't show any decreasing/increasing tendency while all SPI ones are increasing. At Ambrolauri both SPEI/SPI indices show decreasing tendency. For Bolnisi SPEI are decreasing while SPI-increased, at Pasanauri both SPEI/SPI are decreasing, at Gori SPEI indices decreased while SPI has increasing tendency, at Mta-Sabueti both SEI/SPI are increasing. For Poti station SPEI3 and 6 decreased while SPEI 12 increased as all SPI indices, which indicate on precipitation decreasing. For Kutaisi all drought indices are decreasing. At Tbilisi location except SPI6 and SPI12 all indices are decreasing that indicate that monthly precipitation are decreasing, while water vapor evaporation increased. At Telavi station all SPEI indices have decreasing tendency and SPI indices increasing, that indicates on precipitation amount increasing. Thus SPEI/SPI indices reflect complex mosaic character of Georgian climate change.

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