ASSESSING DROUGHT RECURRENCE USING NONLINEAR APPROACH

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REPORT ON THE RESULTS OBTAINED WITHIN THE COORDINATED PROJECTS FOR 2014

GHHD

The project is oriented to analysis of long enough time series of precipitation in 4 countries in order to find retrospectively the meteorological drought periods (i.e. prolonged period with less than average precipitation and high temperature) in order to infer the recurrence rate of droughts. The participants of the project were informed several times on the format of the data needed for analysis, but the meteo-data are obtained only from Algeria.

Up to now we have the long enough time series (150 years) of precipitation and temperature in Georgia and 1988-2013 from Algeria. We intend to calculate The Standard Precipitation Index (SPI) or the Palmer Drought Severity Index to measure the duration and intensity of the long-term drought-inducing patterns as well as they persistency/anti-persistency.

Drought is a major natural disaster that can have considerable impacts on society, the environment and the economy. In Europe alone, the cost of drought over the past three decades has amounted to over 100 billion Euros. By the end of this century, droughts in Europe are expected to be more frequent and intense due to climate change and increased water use (Forzieri, G. et al Hydrol. Earth Syst. Sci., 18, 85–108, 2014). Long-standing result from global-coupled models has been a projected increase in summer drying in the mid-latitudes in a future, warmer climate, with an associated increased likelihood of drought. Summer dryness is expected to increase in the Mediterranean, Central and Southern Europe during the 21st century, leading to enhanced risk of drought, longer dry spells and stronger soil-moisture deficits.

In order to assess drought occurrence it is necessary to have a definition of drought.

If the weather pattern lasts a short time (say, a few weeks or a couple months), the drought is considered short-term. But if the weather or atmospheric circulation pattern becomes entrenched and the precipitation deficits last for several months to several years, the drought is considered to be a long-term drought. We intend to calculate widely accepted Standardized Precipitation Index (SPI) is a probability index that considers only precipitation. The SPI is an index based on the probability of recording a given amount of precipitation, and the probabilities are standardized so that an index of zero indicates the median precipitation amount (half of the historical precipitation amounts are below the median, and half are above the median). The index is negative for drought, and positive for wet conditions. As the dry or wet conditions become more severe, the index becomes more negative or positive. The SPI is computed by for several time scales, ranging from one month to 24 months, to capture the various scales of both short-term and long-term drought.

Georgia: The drought recurrence probability is high enough in Georgia – in some regions it reaches 40%. Droughts occur most notably in the Kakheti, Shida Kartli and Imereti regions. The 2000 drought in Kakheti and Kvemo-Kartli regions affected 696,000 people and caused economic loss of $200 million. In the recent past, drought cycle for Georgia has changed from 15-20 years to 6 years. Over the period 1995 to 2009, droughts inflicted on agriculture reported economic loss of 400 million GEL.

Algeria: Reconstruction of drought severity index for the region from 1456-2002 by analysis of tree ring records show that a single drought year occurred between 12 and 16 times per century, although the number for the 20th century was 19.

Greece: The short-time drought occurrence in Greece is high – of the order of 1 per year. From the estimation of the SPI on 3- , 6- and 12-months-time scales shows that the frequency of mild and moderate drought conditions is approximately of the same order of magnitude over the whole Greek territory. On 6- and 12-months-time scales it was found that in almost all cases and for both time scales, the persistence is statistically significant.

Turkey: As a semi-arid country, Turkey is already familiar with this concept. It went through extremely dry periods in the years 1928-1930, 1950-1951, 1973-1974, 1988-1989, 1994-1996, 2000-2001 and 2006-2008.The official figures point at a significant increase in not only the frequency, but also the intensity of droughts in the country and with global climate change affecting the Mediterranean basin in particular, it seems even drier days await Turkey.

Data

The data necessary for analysis should be presented by participants in the following form:

Station (name, coordinates)

Year Month, day	Max. Temperature	Precipitation	Drought information (if available, econ. losses)	Remarks (if available, drought severity index)

Methodology

The approach to be used is illustrated below on the precipitation data from Georgia.

Why is it necessary to use nonlinear dynamics tools for climate change studies? The matter is that atmospheric flows, an example of turbulent fluid flows exhibit signatures of nonlinear dynamics and chaos. They are characterized by self - similar fractal fluctuations of all space - time scales ranging from weather scale of days and month to climate scales tens and more years. Such types of dynamics of natural processes, when forming patterns have different character on different time and space scales, is too complex to be described by traditional (linear) statistical methods. Besides potential of scaling analysis, nonlinear dynamics reveals hidden nonlinear structures in sequences, which at the first glance seem to be random, in other words, reveal order in seemingly disordered data. As a rule such complex dynamics is difficult to be quantified. Fortunately in the last years new methods were developed, which allow to range quantitavely different levels of complexity allowing detection, identification and ordering from fully random (white noise) to more ordered types of systems behavior.

Thus used nonlinear dynamics tools give new important quantitative information on climate patterns – the degree of order in climatic time series, long-term correlations and their variation with space and time scales, the recurrence of extreme events and on their persistence or anti-persistence.

In order to quantify scaling features in temperature data sets we'll use method of Detrended Fluctuation Analysis - DFA [Peng, et al. 1994, 1995] as well as Recurrence plots (RP) and Recurrence Quantitative Analysis (RQA).

The Standardized Precipitation Index (SPI)

We started from traditional method of Standardized Precipitation Index (SPI) calculation often used to detect drought and wet periods at different time scales. SPI becomes important characteristic because droughts affect a large number of people worldwide and cause tremendous economic losses, environmental damage and social hardships. As mentioned above among other indices developed to monitor droughts (Palmer, 1965; Gibbs, 1987; McKee et al., 1993; Meyer et l., 1993) calculation of SPI is most convenient.

Computation of the SPI begins with building a frequency distribution from precipitation data at a location for a specified time period. In our case we selected time period from 1956 to 2006 for Tbilisi. For this period quality of daily precipitation data is best comparing to earlier data bases what was important because the calculation of the SPI requires that there is no missing data in the time series.

As usual gamma probability density function was fitted to the precipitation data and the cumulative distribution of precipitation was determined. Next equiprobability transformation was made from the cumulative distribution to the standard normal distribution with a mean of zero and variance of one. This procedure gives the SPI (Edwards and McKee, 1997). Generally the SPI can be computed for any time period, we started from 1-month window. These monthly SPI values we analyzed for the entire period of observation as well as for consecutive 10 year windows.

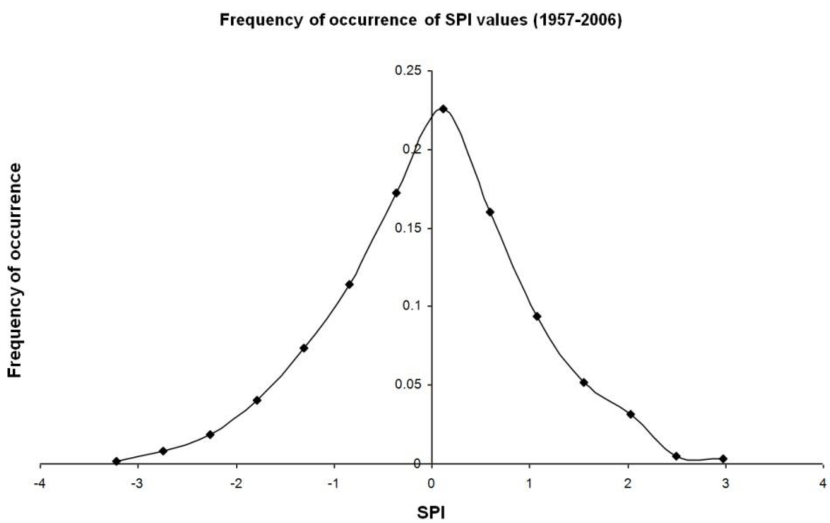

Fig. 4.1. Histogram of frequency of occurrence of one month SPI values for Tbilisi in 1957-2006.

We see in Fig. 4.1, that SPI have maximum at positive values what may be regarded as indication of prevalence of wet events for this time period.

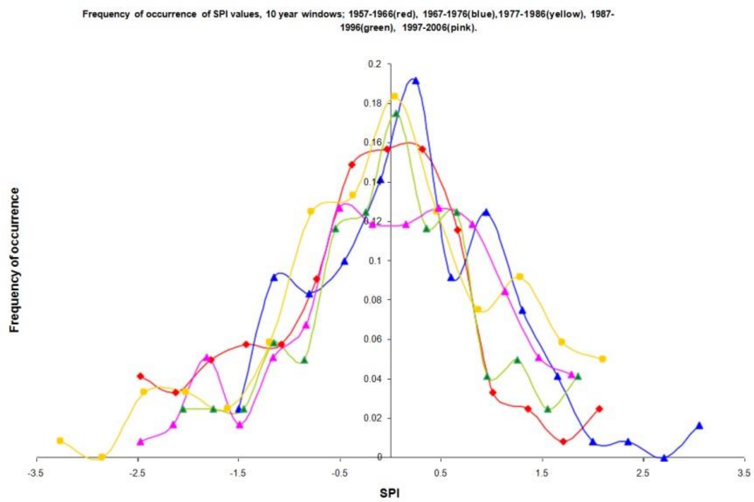

Fig. 4.2. Histogram of frequency of occurrence of one month SPI values for Tbilisi for consecutive 10 year windows.

In Fig.4.2, results of calculation of frequency of SPI occurrence for the 10 year windows is presented. We see prevalence of wet events and just in the last analyzed window (1997-2006) dry events become to prevail. This may be regarded that for last decades chances for drought increases for Tbilisi location.

Detrended fluctuation analysis (DFA)

Next we proceed to DFA analysis. This is well known method to quantify long-range time-correlations in the investigated data sets [Peng, et al. 1993]. This technique provides a quantitative parameter (DFA scaling exponent) that gives information about the correlation properties of analysed nonstationary data sets.

In DFA, the time series x(k) (of length N), is firstly integrated and the so-called “profile” Y(i) is determined. Then Y(i) is divided into boxes of size n, and in each box of length n, the polynomial local trend Yn(i) is calculated and removed from the profile. The root mean square fluctuation of the integrated and detrended series is then calculated:

$$F(n) = \sqrt{\frac{1}{N} \sum_{i=1}^{N} \left[Y(i) - Y_n(i) \right]^2}$$

This process is repeated for all the available scales (box sizes n). If the relationship between F(n) and n is a power-law, the signal is fractal:

Scaling exponent α = 0.5 corresponds to white noise while α>0.5 correspond to persistent behavior accordingly [Peng, 1993]. In Fig. 3 results of DFA analysis of monthly rainfall data is presented.

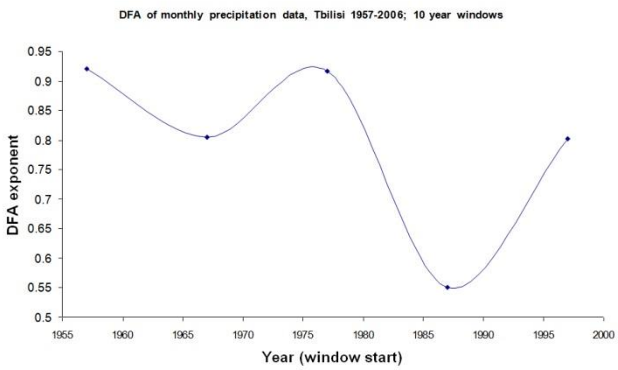

Fig. 3. DFA analysis of rainfall data for Tbilisi, 1957-2006.

We see that rainfall data for Tbilisi shows changed dynamics for considered time period. Clear trend of shift to less persistent behavior is indicated with min (i.e. closest to randomness) in 10 year window prior to mentioned above shift to the prevalence of dryer events in SPI.

References

Edwards DC, McKee TB. 1997. Characteristics of 20th Century Drought in the United States at Multiple Time Scales. AtmosphericScience Paper No. 634; 1–30.

Palmer WC. 1965. Meteorological drought. US Department of Commerce Weather Bureau Research Paper No. 45.

Gibbs WJ. 1987. A Drought Watch System. World Climate Programme. WMO/TD No. 193, wcp-134; 1–22. McKee TB, Doesken NJ, Kleist J. 1993. The Relationship of Drought Frequency and Duration to Time Scales. Proceedings of the Eighth Conference on Applied Climatology. American Meteorological Society: Boston; 179–184.

Meyer SJ, Hubbard KG, Wilhite DA. 1993. A crop-specific drought index for corn: I. Model development and validation. Agronomy Journal 86: 388–395.

Peng, C. K., J. Mietus, J. Hausdorff, S. Havlin, H. E. Stanley, and A. L. Goldberger (1993), Long-Range Anticorrelations and Non-Gaussian Behavior of the Heartbeat, Phys. Rev. Lett. 70, 1343-1346.

ECMHT

The best criterion to define the level of drought is to identify the humidity of soil. One of the areas in mountainous regions distinguished for its aridity is the South-East end of Zagatala zone. As the height increases, the decrease in evaporation and the increase of rainfall reduces the probability of the drought. However, in some cases, the drought can be found even in alpine-steppe. In total, the approximate area of drought territories is up to 30 thousand km2.

During the drought the air temperature and indicators of humidity deficiency are significantly high, at around 1 pm the temperature observed is 4-50C higher than annual rate, and the actual temperature for mountainous districts is 25-

300C. Wind is low during drought due to the presence of anticyclone type of weather. However, in some cases, dry winds of 10-15 m/s speed can be observed. Drought is a natural phenomenon and it occurs as a result of prolonged humidity deficiency. Droughts are defined in three main ways.

1. Meteorological drought is brought about when there is a prolonged period with less than average precipitation. Although it was not a serious problem in Greater Caucasus before, now the climate change increased the risk of its generation. Meteorological drought also damages water supply of forests significantly. As a result, chestnut-trees and oak-trees dry gradually in central and lower mountainous areas.

River station	Annual flow		Minimum summer flow		Minimum winter flow		Maximum flow	
	K	R%	K	R%	K	R%	K	R%
1966								
Ayrichay – BashDashagil Damarchik outfall	0.71 0.72	78.7 89.4	0.74 0.74	73.5 80.0	0.61 0.74	81.6 88.0	0.62 0.37	53.3 45.8
1971								
Ayrichay – BashDashagil Damarchik outfall	0.78 0.62	72.3 96.1	0.66 0.58	79.6 94.7	0.78 0.66	71.4 96.4	0.59 2.40	55.6 12.5

Table 1 - Impact of Meteorological Drought to River Flow

2. Hydrological drought is brought about when the water reserves available in sources fall below the statistical average or when there is no water in riverbeds for prolonged period. Hydrological drought occurs in the area mainly from the end of June until the beginning of September, due to the fact that this is intensive irrigation period, it causes serious water deficiency. Hydrological drought is related to climate change and meteorological drought. Along with reducing snow in mountains, increase of temperature in winter months also causes the early start of high-flow period. So, the snowmelt process ends by the end of June, and hereby the amount of water in the river severely decreases or completely dries out.

Sometimes hydrological drought period in the rivers can last up to 7-8 months. In this period the river flow constitutes 20-30% of annual flow. Therefore, water use is limited for a significantly long period during the year.

As mentioned above, water scarcity occurs as a result of meteorological and hydrological drought. Water scarcity is defined as the lack of available water resources to meet the daily domestic and economic water demands of a certain region. It increases the weakness of the communities. In essence, water scarcity is divided into physical and economic water scarcity.

1. Physical water scarcity is characteristic for all the villages away from the river-bed. This problem is found in a number of villages of Zagatala and Oguz districts. Increase of temperature in summer months decreases precipitation, hereby resulting in reduction of water in the rivers and severe decrease of water in rivers, drying out of springs and therefore, there is water scarcity in summer months. The population has troubles with watering cattle and daily water supply.

2. Economic water scarcity is defined as the problems generated due to the lack of water supply of the communities for economic reasons. It can happen even in the regions with many water resources.

Due to the fact that the region has a multiple number of problems, systematic approach is needed to solve them. Particular adaptation and mitigation strategies reducing the impacts of climate change need to be worked out for each river. Therefore, we offer taking complex measures to study these problems more deeply. These measures could include cultivation of more drought-tolerant plants, save on water (this could be achieved by training the population), reducing the risk of disaster through the effective environmental management and systematic efforts by elaborating the factors causing disasters and increasing the readiness level of the population, improvement of readiness for flood and drought, raising awareness of executive powers and municipalities, raising public awareness (conducting trainings for people to understand the importance of forests and water resources better).

ANALYSIS OF PRECIPITATION IN AZERBAIJAN ON MONTHLY BASIS

Depending on orographic features, influence of air masses entering the territory of the country and local circulation between the Caspian Sea and dry area, variability of monthly, seasonal, annual and daily maximum precipitation is very big.

The highest rainfall in the territory of the Republic falls to Lankaran Natural-economic zone (1600- 1800 mm) and the lowest rainfall is in Absheron and Kur-Araz (200-350 mm).

Annual average precipitation constitutes 477 mm. The maximum daily rainfall was recorded in Bilasar station of Lankaran in 1955 (334 mm). The rate of annual precipitation in Balakan-Zagatala region changes between 1000-1600 mm.

On the Southern slope of Greater Caucasus, in Shamakhi annual average precipitation is 600-1000 mm. In comparison with annual rates (1961-1990), monthly rainfall rates for 1991-2012 as influenced by the climate change are as follows.

Table 1 Changing tendency of precipitation in 1991- 2012 in comparison with the period of 1961 -1990 (standard rates) (monthly, %)

Stations:	Months											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Mashtagha	-10	21	-25	-30	-17	-19	67	-35	33	-3	50	18
Oil Rocks	-25	-44	-41	-25	-39	-30	-56	-53	-19	-14	4	-38
Astara	-9	29	-7	-7	14	1	-4	-25	-7	-25	20	-9
Bilasuvar	-22	-10	-3	-18	18	-35	-5	-61	15	-5	11	-19
Jafarkhan	-15	-4	4	-19	-3	-34	-3	-11	24	-34	14	-31
Yevlakh	-1	-28	44	-13	-18	-38	-19	-19	42	-52	-21	-2
Gadabay	-21	-3	4	8	-8	-8	2	-5	12	-18	7	-37
Ganja	+15	-33	+20	-20	-12	-18	-36	-16	+36	-35	+40	-16
Agstafa	-43	-2	4	8	-10	-18	-34	-10	35	-16	26	4
Shaki	-11	-6	-1	-9	-5	12	-20	5	16	-37	18	-6
Alibay	-13	12	14	4	-2	3	1	20	40	-11	20	2
Altiagaj	-16	18	-3	-35	-3	-14	-9	-17	-13	-2	24	-12
Guba	-11	29	-4	-33	-16	-14	-13	22	18	5	19	11

Giriz	-29	0	-2	-34	-20	-23	-29	-10	31	-14	36	-17

In January and February, excluding only a few stations, the amount of precipitation reduced between 1- 44%, while in March in the areas excluding Absheron Peninsula, Lankaran, the Southern part of Kura-Araz Lowlands and Greater Caucasus, the increase in precipitation amount was observed. In April and May excluding a few stations, the general decrease trend with different intensiveness rates was marked in precipitation. In June, July and August the decrease of rainfall was observed in most of the areas. In September excluding only two areas, the precipitation increased, while in October it started to reduce, and increase again with different intensiveness rates in November. In December the rainfall increased at some stations, while decreasing at the others. Statistically significant decrease was recorded only at Gadabay station.

Table 2 Changing tendency of precipitation in 1991- 2012 in comparison with the period of 1961 -1990 (standard rates) (seasonal, %)

Stations	**Seasons**				**Year**
	Winter	**Spring**	**Summer**	**Autumn**	
Mashtagha	8	-25	-11	25	4
Oil Rocks	-38	-35	-54	-7	-29
Astara	3	-2	-14	-8	-7
Bilasuvar	-17	-3	-38	5	-8
Jafarkhan	-18	-6	-38	-6	-13
Yevlakh	-15	-2	-30	-19	-16
Gadabay	-17	-4	-2	-3	-5

Distribution of Precipitation at Various Heights and Their Comparison with Multi-annual Norm (1961-1990) X mm

Years	**Heights, m**					**Within the territory of the Republic**
	□ 0	0 - 200	201-500	501-1000	□1000	
Norm 1961- 1990	334,5	327.5	478.0	534.3	639.7	476,5
Average annual 2006	390.1	321.7	436.8	592.4	569.7	462.3
Difference, mm	55.6	-5.8	-41.2	58.1	-70	-14.2
Average annual 2007	313.1	319.8	540.5	623.1	664.2	492.8
Difference, mm	***-21.4***	***-7.7***	***62.5***	***88.8***	***24.5***	***16.3***
Average annual 2008	***340.4***	***298.3***	***307.2***	***681.9***	***644.3***	***445.1***
Difference, mm	***5.9***	***-29.2***	***-170.8***	***147.6***	***4.6***	***-31.4***
Average annual 2009	***372.8***	***396.3***	***471.0***	***551.2***	***650.2***	***482.6***
Difference, mm	***38.3***	***68.8***	***-7***	***16.9***	***10.5***	***6.1***

Average annual 2010	**364.5**	***396.9***	***450.7***	***766.1***	***619.3***	***527.0***
Difference, mm	***30.0***	***69.4***	***-27.3***	***231.8***	***-20.4***	***50.5***
Average annual 2011	512,4	451,2	459,0	822,3	782,3	563,3
Difference, mm	177.9	***123.7***	***-19.0***	***288.0***	***142.6***	***86.8***
Average annual 2012	***348,5***	**298,2**	**347,9**	**628,4**	**689,7**	***453,0***
Difference, mm	+14,0	***-29,3***	***-130,1***	***+94,1***	***+50,0***	***-23,0***

ECPFE

The relevant data are being elaborated by a special team of the National Observatory of Athens. This team with scientific responsible Dr Gerasopoulos, communicates relatively with the EC of Georgia.