LONG TERM VARIABILITY OF ANNUAL PRECIPITATION IN ARMENIA IN THE CONTEXT OF CHANGING CLIMATE

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Abstract: Paper title in English. This study concerns the analysis of temporal and spatial variability of precipitation in the Republic of Armenia in the second half of the twentieth century and the first decade of the twenty-first century. The study area includes Armenia where long–term measurements and observations of weather conditions have been performed within the national meteorological services of Armenia (43 meteorological stations). Their monthly data of precipitation taken from the measuring period of 1961–2012 will be implied in the study. The presence of trends in annual precipitation will be assessed by means of the Mann–Kendall test and autocorrelation function, as well as Khronostat program, including someparametric and non parametric tests.

Keywords: Long-term variability, precipitation trend, climate change

I. INTRODUCTION

Long-term trends in precipitation have been observed in recent decades in many regions of the world (Brunetti, et al., 2000; Brunetti, et al., 2004; Htway and Matsumoto, 2011; Kim et al., 2011; Villarini, 2011; Almazroui et al., 2012; Buishand et al., 2012). The variability of these trends is dominant for estimating impact on human activities. The analysis of changes in precipitation at different spatial and temporal scales has been of great concern during the past century.

In the Northern Hemisphere for the 21st century, a robust pattern of increased precipitation pole wards of about 45°N is projected by the IPCC (2007), due to the increase in water vapor in the atmosphere and the resulting increase in
vapor transport from lower latitudes. This is accompanied by decreased subtropical precipitation, although less so over Asia. On average, the frequency of precipitation over the global oceans is 10.9% (Stephens & Ellis 2008), varying in values 2- to 3-fold higher at high latitudes than in subtropical regions. Moreover, most mountain areas are in regions of medium to high temperature change, changes in precipitation vary considerably for different mountain areas (as well as in Armenia).

Several authors have analyzed precipitation variability in South Caucasus region. The precipitation changes have been studied in Armenia for the last 2 decades. “The First (1998) and “The Second National Communications on Climate Change (2010)” include assessment of Armenia's climate vulnerability to climate change and the general characteristics of adaptation. According to The Second National Communication (2010) and Climate change in South Caucasus region (2011) in the last 80 years the annual precipitations reduced by 6% as compared to the average of the 1961-1990 baseline period.

Chatrchyan (1999) analyzed long term meteorological daily data (temperature and precipitation) of 12 stations. They were compared with the results of numeric experiments of the climatic model of the Institute of Atmosphere Physics of Russian Academy of Sciences. Hayrapetyan (1999) evaluated atmosphere precipitation changes in the territory of the RA using data of 56 meteorological stations and sites for the 30-100 year range. Margaryan, Vardanyan (2007, 2013) studied and evaluated the regime of atmospheric precipitation in Armenia and in Syunik region (the southern part of the country). The features of spatial and temporal distribution of precipitation of the region were collected and analyzed in the research (the study period was 1913-2010). Margaryan et al. (2014) also analyzed the extreme index of precipitation in Shirak region (the north western Armenia) and etc.

These researchers studied the spatial patterns of precipitation and its yearly variations that prevail over different local and regional conditions. Yearly amount of precipitation in Armenia is small therefore it has a large variation (Fig. 1).
This study focuses on trend detection in annual precipitation in Armenia. The study was conducted to assess the effect of climate change (especially on precipitation) for Armenia at a regional scale and not at the local level taking into consideration the fact that Armenia is a high mountainous country and the relief has great influence on the formation of precipitation. The methods that were used by us are considered now and they have not been used for the territory of Armenia. The above mentioned tests till now have not been used for the Territory of Armenia (except Mann-Kandell test). So, in this article we gain some new results which describe the precipitation trend in Armenia for the last 5 decades.

II. MATERIAL AND METHODS

The 12-month average precipitation data for 43 stations was obtained from Hydro-meteorological center of Armenia. The data used for this study embraces 1961-2012 time period (precipitation is given by mm). The selected stations’ geographic description is given in Fig 2. These locations were chosen according to the following parameters: each of them should have good quality datasets, the data should be reliable and the data should have adequate record length.
The methodology applied in this study consists of the analysis of temporal characteristics, followed by the analysis of spatial variability and the identification of the discontinuities in precipitation’s time series. The main objective is detecting discontinuities in data series.

In order to determine the discontinuities in precipitation regimen in the period 1961 – 2012, some homogeneity, randomness and break tests are performed. We define a break as a low probability change at a certain moment. (Lubes et al., 1994). The randomness test is done due to Rank correlation test with computation variable value. The break tests permit to detect a change in a time series mean. The methods used to detect a break are: Pettitt test (Pettitt, 1979), the test „U”- Buishand (Buishard,1982), (Buishard,1984), Lee and Heghinian test (Lee, Heghinian,1977) and the segmentation procedure of Hubert (Hubert et al.,1989), (Hubert et al.,1993). Pettitt test is a non-parametric one.

For our scientific research we have applied Rank Correlation, Buishand’s and Pettitt’s tests’ results at 95% confidence level, because 99% confidence level for the natural sciences (in this case for Climatology) is not justified, while 90% confidence level of the results is not applicable.

The resultant Mann-Kendall test statistic (S) indicates how strong the trend in precipitation is and whether it is increasing or decreasing.
In order to remove serial correlation from the series, Von Storch and Navarra (1995) suggest pre-whitening the series before applying the Mann-Kendall test. The critical value of the lag-1 serial correlation coefficient ($r_1$) for a given significance level depends on whether the test is one-tailed or two-tailed (in our study we used one-tailed test).

Significant changes were observed in the application of this program in the territory of Armenia, which has been analysed taking into account the geographical location of the stations, topographical diversites, mountainous relief, climate formation aspects and etc.

The results have been compared to the world's observations, as well as with the results of the studies carried out in South Caucasus region.

III. RESEARCH AREA

The Republic of Armenia is located in Southern Transcaucausus, on a joint of Caucasus with Forward Asia and occupies a small part of the extensive Armenian plateau. On the North and East Armenia borders with Georgia and Azerbaijan, on the West and South-East with Turkey and Iran accordingly. The territory is 29,743 km². It is a mountainous country: 76.5% of the territory has altitudes of 1000-2500 meters above sea level. The country's average elevation is 1800 m a. s. l. with extremes ranging from 380 m a. s. l. (Debed River-bed) to 4090 m a. s. l. (summit of Aragats Mt).

The average annual precipitation amounts to 592mm. The most arid zones are the Ararat valley and Meghri region (southern part). The annual precipitation here is around 200-250 mm. Maximum precipitation is recorded in high mountainous areas at around 1000 mm per year. In Ararat valley, the average precipitation in summer months does not exceed 32-36 mm. (Second National Communication on Climate Change. Yerevan, 2010).

In Armenia the gradient of precipitation is very different and complicated from slopes to slopes. For example, in north eastern mountains the eastern and north estern slops are much more gently sloping than western and south western slopes. The amount of precipitation in estern slope is rising from 60 to 100mm in 30-50km and on the other hand in western slope it is decresing form 100 to 40-50 mm not more than in 5 km (Alexandryan, 1971). In the southern part this is much more complicated because the mountain ranges are vertical of air masses. Mostly here air masses which bring precipitation are from the Caspian Sea and the mountain ranges are considered barrier. The best example are Goris and Sisian towns. Goris is situated in 1398m above sea level and the mean annual precipitation is 737mm ( the station is in the windward slope) and in contrast this Sisian is in 1580m and has 373mm
annual precipitation (because the station is in a close mountainous valley) (Margaryan, 2013).

**IV. RESULTS AND DISCUSSIONS**

### IV.1 The trend analysis of precipitation series

The long-term average annual precipitation data has been analyzed by the above mentioned tests. The data received from the 43 studied stations provided almost the same results as Rank corellation, Buishand's and Pettitti's tests (Fig 3.).

![Fig 3. Rank correlation tests results](image)

According to them during the study period (1961-2012) precipitation changes were observed at 12 stations from 43 stations (north western, south weaster, the south of Aragats Mountain, the north of Sevan Lake, and almost all stations are in the northern slope of mountains). Moreover, in 6 stations the trend is negative, and in others - positive. The most significant trend is in Aragats station (negative S= -4.442) and for positive is in Sevan station (S=4.0855). From them 10 stations are located more than 1900 meters above sea level and 2 stations are above 1000m (Areni is in 1009m, Odzun is 1105m). In the last five decades for the rest of 31 stations significant changes have not occurred according to the tests above.
They gave significant trends for the regions having relatively high altitudes (except for a few high-altitude stations, where the changes were not detected. Thus, the precipitation changes were observed in around 27% of the area of Armenia.

The application of the procedure bayésienne of Lee and Heghinian show that in 1961 and 1962 17 stations have break. But those do not have so high values as they had in 2001 (the maximum changes happened in 2001). Other breaks were seen in 1987-2001 period, only Odzun has break in 1984. According to the Hubert's segmentation test (Scheffe’s test level of significance: 1%) there have not been observed series’ break in 20 stations from the studied 43. Moreover, in 5 stations the breaks are quite complicated (in north western and southern part), and they have three and more breaks, after which the average long-term precipitation values have changed sharply.

Due to Hubbert’s segmentation test it is clearly shown when and how the average values of the series have been changed during the studied period. There are 23 stations which have trends and in 12 stations those changes are positive and this has happened since 2000’s (almost in all 12 stations the changes began after the break of 2001).), and in the remaining 11 stations the series have been changed until 2000’s and all have had negative deviations, only in Ashotsq station a 7% increase in precipitation has been observed (this station's series has broken several times in 90's, and ones in 2003). From 12 increased stations in 6 the increase is about 19% (northern and central part, which are situated in the southern slope of the mountains). Minimum increases have been observed in Shorja 5% and maximum in Sevan 34% (in 1917m both of them). Those two stations are situated in the north eastern and northern part of Sevan lake.

In 10 stations where negative deviation was observed, maximum negative deviation are observed above than 2000m (for example 33% in Vorotan pass and Simyonovka). The minimum negative deviations were observed in ridge south and north (7% in Kajaran, 6% in Shamba, and 3% in Odzun). Compared with other subtropical mountain regions for example in Hindu Kush-Himalaya according to many climate models project monsoonal flows weaken, which leads to a precipitation decrease but in winter it increases. Precipitation has not changed significantly in Turkey except for the northeastern parts where it shows a consistent regional increase (which is also visible in northwestern parts of Armenia). The changes results are much more complicated and differ from region to region and from low altitude to high.
IV.2. Definition of precipitation indices based on Mann-Kendall test

Mann-Kendall test has provided us with approximately the same results as compared with the first three tests mentioned above.

Out of 43 series in 11 ones lag-1 is not significant at the 5% level, than the Mann-Kendall test. Thus we ‘pre-whitened’ those time series, but the others were applied to the original values of the time series. Autocorrelation plots for the meteorological variables at the 11 weather stations are presented in Fig 4. As shown, only positive serial correlations were obtained for precipitation. The strongest serial correlations were found at Semyonovka station.

For this test, the Null Hypothesis was accepted for 32 stations (this means that no trend is seen for these stations), while for 11 stations it is rejected (there are trends) (Table 1).

![Fig. 4 Lag-1 serial correlation coefficient for the meteorological variables at the weather stations](image)

**Table 1.** Results of the Mann-Kendall test for annual precipitation over the period 1961-2012

<table>
<thead>
<tr>
<th>name of station</th>
<th>h (m)</th>
<th>Z</th>
<th>P</th>
<th>S</th>
<th>Tau</th>
<th>D</th>
<th>Test interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amberd</td>
<td>2071</td>
<td>-3.273</td>
<td>0.0010</td>
<td>-403</td>
<td>-0.3160</td>
<td>1275</td>
<td>Rejected H₀</td>
</tr>
<tr>
<td>Aragats</td>
<td>3227</td>
<td>373</td>
<td>0.0001</td>
<td>-430</td>
<td>-0.3656</td>
<td>1176</td>
<td>Rejected H₀</td>
</tr>
<tr>
<td>Areni</td>
<td>1009</td>
<td>420</td>
<td>0.0229</td>
<td>174</td>
<td>0.2612</td>
<td>666</td>
<td>Rejected H₀</td>
</tr>
<tr>
<td>Ashtotsk</td>
<td>2012</td>
<td>2.967</td>
<td>0.0030</td>
<td>376</td>
<td>0.2835</td>
<td>1326</td>
<td>Rejected H₀</td>
</tr>
<tr>
<td>Ashtarak</td>
<td>1090</td>
<td>264</td>
<td>0.0222</td>
<td>122</td>
<td>0.3005</td>
<td>406</td>
<td>Rejected H₀</td>
</tr>
<tr>
<td>Semyonovka</td>
<td>2104</td>
<td>304</td>
<td>0.0001</td>
<td>-382</td>
<td>-0.3859</td>
<td>990</td>
<td>Rejected H₀</td>
</tr>
<tr>
<td>Sevan</td>
<td>1917</td>
<td>3.086</td>
<td>0.0020</td>
<td>369</td>
<td>0.3012</td>
<td>1225</td>
<td>Rejected H₀</td>
</tr>
</tbody>
</table>
The MK test Statistic (S) indicates that there is an increasing precipitation trend for the stations of Areni, Ashotsk, Ashtarak, Tashir, Sevan Lake. The S statistic, however, is not very strong for Areni and Ashtarak implying that the trend is not as strong compared to the other stations. And according to the S statistic results there is a decreasing precipitation trend for the stations of Amberd, Aragats h/m, Smeyonovka, Shamb, Vorotan pass, Yankh. The strongest result is observed in Aragats h/m, and the weakest is in Yankh station. These stations (beside Shamb 1475m) are higher than 2000m above sea level.

For Armenia Mann-Kendall test was used also in «Regional Climate Change Impacts Study for the South Caucasus Region» report (Georgia, 2011). In that work the study period embraces the period of 1935-2008 and the number of the stations studied is 30. The results of the analyzed stations are somewhat different from our results. In 6 of 30 observed stations there are trends, where only one is increased (Sevan lake), and remaining 5 have decreased trends (at Vorotan, Vanadzor, Talin, Amber, Aragats stations). According to our study there are no trends in Vanadzor and Talin stations, but in the above mentioned work there were (without taking into consideration the fact that the studied periods are different). In the mentioned report in Georgia in the stations where are trends are all positive, but in Azerbaijan the situation is

\[
\begin{array}{ccccccc}
\text{Station} & \text{1961} & \text{2012} & \text{S} & \text{1935} & \text{2008} & \text{p} \\
\hline
\text{Shamb} & 1475 & 396 & 0.0213 & -243 & -0.2348 & 1035 & \text{Rejected } H_0 \\
\text{Tashir} & 1507 & 2.103 & 0.0354 & 259 & 0.2031 & 1275 & \text{Rejected } H_0 \\
\text{Vorotan} & 2387 & 359 & 0.0210 & -228 & -0.2410 & 946 & \text{Rejected } H_0 \\
\text{Yankh} & 2334 & 192 & 0.0083 & -177 & -0.3155 & 561 & \text{Rejected } H_0 \\
\end{array}
\]

Fig. 4 Mann-Kedall test for annual precipitation over the period 1961-2012
the same like in Armenia (and increasing and decreasing). It is obvious that in Armenia the precipitation change is various and it is very difficult to find any regularity.

According to Kendall’s tau-based test, significant annual increasing trends have 5 stations, and for 6 stations annual trends of precipitation show significant negative trends, whereas the annual trends for 32 stations are non significant (Table 6). The most significant positive trend is observed in Sevan station, and negative - Semyonovka station.

V. CONCLUSIONS

The present research may provide knowledge of precipitation trends in Armenia. First, the changing trends in total annual precipitation can be clarified in the data series. The annual precipitation shows significant different kind of trends during the period 1961-2012 in Armenia. This study has shown vibrant evidence that most areas of Armenia have undergone shifts in their precipitation regimes. And it is also obvious, that the changes are not homogeneous inside the territory. The obtained results coincide comparing with the regions having the same geographical conditions.

If assessing for the whole territory of Armenia we could understand whether the sum of precipitation increased or decreased, and the result is the following. Precipitation has decreased by 16.5% (mean values of percentage of the decreased stations'), and increased by 17% (mean values of percentage of the increased stations), and they are almost the same value. According to the results the sum of the annual precipitation during the last five decades did not undergo any quantitative changes, but there are very visible qualitative changes inside the territory because of the complicated relief. The precipitation has positive trend in relatively low areas and valleys till 2000m, but it has negative trend most of all in high mountinous areas since 2000m. 3 stations out of 4 ones with negative trend of temperature are located higher than 1900m.

It is a fact that the precipitation change has been observed since 1990's over the most territory of Armenia. From this methods’ results we can conclude that global climate change has begun to influence the Armeinan climate (as well as the whole world) especially for the last 2 decades.

According to Hubbert’s segmentation test the stations with positive trends underwent changes after the break of 2000's, and until 2000's the stations have negative changes.

On running the Mann-Kendall test on precipitation data almost the same results with a little bit different description were provided.
According to the overall test results, there has been a regional variability in the annual precipitation in Armenia. Some parts of Armenia experienced greater decrease in precipitation, while some parts experienced increases and most of the territory is very indifferent to global climate change.

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