World Academy of Science, Engineering and Technology
International Journal of Environmental and Ecological Engineering
Vol:10, No:1, 2016

Long Term Variability of Temperature in Armenia in the Context of Climate Change

Hrachuhi Galstyan, Lucian Sfîcă, Pavel Ichim

***Abstract*—**The purpose of this study is to analyze the temporal and spatial variability of thermal conditions in the Republic of Armenia. The paper describes annual fluctuations in air temperature. Research has been focused on case study region of Armenia and surrounding areas, where long–term measurements and observations of weather conditions have been performed within the National Meteorological Service of Armenia and its surrounding areas. The study contains yearly air temperature data recorded between 1961-2012. Mann-Kendal test and the autocorrelation function were applied to detect the change trend of annual mean temperature, as well as other parametric and non-parametric tests searching to find the presence of some breaks in the long term evolution of temperature. The analysis of all records reveals a tendency mostly towards warmer years, with increased temperatures especially in valleys and inner basins. The maximum temperature increase is up to 1,5°C. Negative results have not been observed in Armenia. The patterns of temperature change have been observed since the 1990's over much of the Armenian territory. The climate in Armenia was influenced by global change in the last 2 decades, as results from the methods employed within the study.

***Keywords*—**Air temperature, long-term variability, trend, climate change.

I. Introduction

As a mountainous country with arid climatic conditions, Armenia, with its entire territory, is vulnerable to global climate change. According to the Second National Communication of Armenia on Climate Change [25], Armenia is among the most sensitive countries in the Europe and Central Asia region in regard to climate change. Increased temperatures and reduced precipitation accelerate the desertification processes and will have a negative impact on public health and sectors which depend on the climate. Climate change will result in changes to natural ecosystems, which will also reflect on biodiversity and forest, alpine, sub-alpine and wetland ecosystems of Armenia. Significant changes have taken place in Armenia with regard to legislation and institutional structure of governance during recent years - after the preparation of the First National Communication of Armenia on Climate Change. New scenarios for climate change have been developed, which identify changes not only by seasons, but also by regions of Armenia [24], [25].

Air temperature changes have been studied in Armenia since 1990s. Important researches have been conducted by different scientists [24]-[27].

H. Galstyan is with Yerevan State University, Armenia (phone: +37455311580; email: hrachuhigs@gmail.com).

L. Sfîcă and P. Ichim are with "Alexandru Ioan Cuza" University in Iasi, Romania (e-mail: sfical@yahoo.com, pavel_ichim@yahoo.com).

"Climate change issues in Armenia, a collection of articles, First ED 1999" [26] and "Climate change issues in Armenia, a collection of articles, Second ED. 2003" [27] include assessment of Armenia's vulnerability to climate change and the general characteristics of adaptation measures. Melkonyan analyzed variability and predictability of climate changes on the territory of Armenia [7]. Zoryan analyzed evolution of variations of land surface temperature anomaly on the territory of the Republic of Armenia [17]. Possible scenarios of climate change in Armenia by results of numerical simulation using IAP RAS climate model have been analyzed by [9]. The results of model simulation are compared with the results of analyses of daily meteorological data of the temperature and precipitation over different stations situated in Armenia. Long term meteorological daily data (temperature and precipitation) of 12 weather stations have been analyzed by [1]. They were compared with the results of numeric experiments of the climatic model of the Institute of Atmosphere Physics of Russian Academy of Sciences. Melkonyan and Baloyan reported monitoring of climate in the Republic of Armenia. They wrote about one approach to the assessment of climate change on the territory of Armenia [8].

«Regional Climate Change Impacts Study for the South Caucasus Region» report was published in 2011 in Tbilisi, Georgia [23]. This report represents the first cooperative study on the impacts of climate change and adaptation in the South Caucasus involving all three countries in the region - Armenia, Azerbaijan and Georgia. The study considers four areas for investigation: recent historical and projected climate change, impacts of climate change on trans-boundary river basins, impacts of climate change on crop water and irrigation requirements in critical agricultural areas, and the effect of climate change on urban heat stress in selected cities in the region. In this work, «Mann-Kendall» trend is performed on the annual temperature and precipitation data of the weather stations in the South Caucasus. In this study, we have also used the same method, with some additional research.

The statistical methods are used to find out the changes in temperature for particular years of the studied long–term period. The existing climatological publications in Armenia include primarily studies and research papers on individual weather elements using several statistical methods, different from the ones used within the study.

II. Material and Methods

The main objective of this study refers to the determination of thermal characteristics in Armenia using some statistical methods (Khronostat program and Mann-Kendall test). They were conducted in 41 weather stations from Armenia and the average annual temperature data was obtained from Hydrometeorological Center of Armenia. The data used for this study were obtained in the period 1961-2012 (temperature is given in degrees Celsius °C). The network of weather stations across the republic belongs to the National Observation and Measuring Network supervised by the Armenian Hydrometeorological Center. 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 temperature series. The main objective was to detect discontinuities in the data series. In order to determine the discontinuities in temperature series during 1961–2012, several homogeneity, randomness, and break tests are performed.

We define a break as a low probability change at a certain moment. The randomness test is done due to Rank correlation test with computation variable value. The break tests enable to detect a change in a time series. The methods used to detect a break are: Pettitt test [11], the test „U"- Buishand, Lee and Heghinian test [5], and the segmentation procedure of Hubert [2]. Pettitt test is a non-parametric one.

Our focus on scientific research is proven by the application of results of Rank Correlation, Buishand's and Pettitt's tests with a 95% confidence level. Lee and Heghinian's Bayesian method results speak about "a posteriori" probability density of a break time position and break amplitude. Mann-Kendall trend analysis is common in environmental science [6]. The Mann-Kendall tests are done in R 3.0.3 with the package Kendall. The resultant Mann-Kendall test statistic (S) indicates how strong the trend in temperature is and whether it is increasing or decreasing (the sign of S indicates the slope of the trend). Significance level is set to 95% ($\alpha = 0.05$). If the p value is less than the significance level α (alpha), the hypothesis H_0 is rejected. Rejecting H_0 indicates that there is a trend in the time series, while accepting H_0 indicates no trend was detected and the result is said to be statistically significant. In order to remove serial correlation from the series, [16] suggests 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 diversities, mountainous relief, aspects of climate formation and etc.

The results have been compared to the global database of observations, as well as to the results of the studies carried out in the South Caucasus region. Regional climate conditions have been also analyzed and the trends describing the spatial distribution of temperature in Armenia were accurately displayed within the study.

III. Results and Discussions

A. The Global Trend Analysis, the South Caucasus Region and Armenia

Numerous climatologists [4], [10], [15], [21] agree that there has been a large-scale warming of the Earth's surface over the last hundred years or so. This warming up of the Earth during the 20th century brought with it a decrease in the area of the world affected by exceptionally cool temperatures, and, to a lesser extent, an increase in the area affected by exceptionally warm temperatures [10]. Some analyses of long time-series of temperatures on a hemispheric and global scale [4] have indicated a warming rate of 0.3-0.6℃ since the mid-19th century, due to either anthropogenic causes [4] or astronomic causes. The Third Assessment Report projections for the present century are that average temperature rises by 2100 would be in the range of 1.4-5.8℃ [21]. Records show that global temperatures, averaged world-wide over the land and sea, rose 0.6 ± 0.2℃ during the 20th century. A number of recent studies have been devoted to global, hemispherical, or regional long-term temperature variations. On a global scale, climatological studies indicate an increase of 0.3-0.6℃ of the surface air temperature, 0.5-0.7℃ for the Northern Hemisphere since 1860 [3], [10], while the eighth warmest years ever recorded were observed in the last years. Numerous other factors, such as variations in solar radiation and pollutant aerosols also contribute to climate change [12]. The IPCC (2007) further concluded that global temperature increases are likely to persist in the 21st century and will probably be accompanied by changes in precipitation and runoff amounts. Future climate change is more difficult to predict with great certainty at the regional scale due to spatial resolution limitations of current climate models and to the likely influence of unaccounted for factors such as regional land use change [20]. Climate change is occurring in the South Caucasus, too. In all three countries, there is a strong evidence of increased warming over the last century [18], [19], [23]-[25].

At country-level, Armenia, Azerbaijan and Georgia all show statistically increasing trends in mean annual temperature, mean daily minimum temperature and mean daily maximum temperature, though there are no trends in mean annual precipitation or the number of wet days per year. In terms of weather stations, about half in Armenia and Azerbaijan and about one quarter in Georgia show statistically significant trends in annual temperature. The evidence concerning annual precipitation is less convincing, although there are stations in Armenia and Azerbaijan that have experienced precipitation declines. In Georgia, there are no signs of decline in annual precipitation, but two stations in the southwestern part of the country show an increase in precipitation. This study also represents the first examination of extreme climate indices. Almost all the weather stations in all three countries have recorded increases in the duration of warm spells – either consecutive days above 25ºC or consecutive nights higher than 20ºC. However, there is no strong evidence that the maximum time gap between rainfall events is changing in the South Caucasus [23].

The annual average temperature in Azerbaijan increased by 0.5 to 0.6ºC since the 1880s, with the highest registered temperatures during the last 10 years. In Georgia from 1906 to 1995, the mean annual air temperature has increased by 0.1 to 0.5ºC in the eastern part of the country, whilst it has decreased by 0.1 to 0.3ºC in the west [13]. However, if calculating for the last 50 years the data shows a different trend: during the 1957 to 2006 the mean annual temperatures increased by 0.2ºC in the western part and by 0.3ºC in the eastern Georgia [18], [19]. Regional differences are also reported from Azerbaijan, with the highest temperature increase in the Greater Caucasus and Kura-Aras lowlands, and from Armenia, with the warmest regions in the Ararat lowlands and in the zone from the border of Georgia to Lake Sevan.

Deviations of annual air temperature and precipitation, recorded in Armenia between 1935-2007 from the average for 1961-1990, were estimated. According to the analysis of recorded hydro-meteorological data, the average annual temperature increased in the last 80 years by 0.85°C (highest result compared with the other two countries), and the annual precipitations, reduced by 6% compared to the average of the 1961-1990 baseline period. However, changes in temperature in various regions of Armenia and different seasons of the year show different trends. In summer months (June, July, August), the average air temperature has increased by 1^0C, while in winter months (December, January, February) temperature increase has not been observed. Air temperature deviations since 1994 have been only positive and reached their peak of 2.1^0C in 1998, which is the hottest year registered in Armenia in the entire observation period. During the last 15 years, anomalies of summer temperatures were positive, summers were extremely hot in 1998, 2000 and 2006, and the summer of 2006 was the hottest in Armenia in the entire period of 1929-2007 [24], [25].

The geographical distribution of changes to annual precipitation in Armenia in the north-eastern and central (Ararat valley) regions have become more arid, while the southern and north-western areas and Lake Sevan basin have had a significant increase in precipitation during the last 70 years. In the last decades (1975-2005), also an increase in the severity and frequency of dangerous hydrometeorological phenomena is recorded in Armenia. In the last 30 years, the total number of dangerous hydro-meteorological phenomena has increased by 1.2 cases and in the last 20 years - by 1.8 cases annually [23]-[25]. In addition, 13 of the 14 hottest years on record have occurred in the 21st century (especially 2007 and 2013). A very high temperature was recorded in the summer of 2014 compared with a normal value (especially in August) and the precipitation amount was very low since the autumn of 2013. Those aspects can show the fact that Armenia is much more vulnerable to climate changes in comparison with changes on a global stage.

B. The Trend Analysis of Temperature Series in Armenia

For analyzing temperature series, we have used the Khronostat program includes the following tests results: Rank's correlation (Figs. 1 and 2), Buishand's and Pettitt's tests, Lee and Heghinian's Bayesian method results, as well as Hubbert's segmentation values. Thus, by analyzing the test results of 41 weather stations, covering an area of 29,743 km^2, we are able to understand the impact of intense anthropogenic activity on climate changes in Armenia over the last decades, showing changes to the annual average temperature regime. Armenia has a difficult geographical position located between Black and Caspian seas and is characterized by a mountainous relief, aspects that are correlated with the distribution of dominant air masses within the country that influence the formation and modification of temperature field. Armenia, although a small country, has a wide variety of climatic conditions, caused mainly by the country's complex and rough topography, which affects the composition and direction of air masses which is difficult to forecast and study. Studying the temperature field, we have noticed that over the last 5 decades it has changed in large parts of the territory. The changes are only positive and a large part of Armenia (almost 78% of the weather stations) between 1961-2012 registered variations in the distribution of annual mean temperature, while the remaining 22% due to their geographical position and climatic conditions show no change in the temperature regime (around Aragats mountain, the north-eastern part of Sevan lake and the southern part). In addition to that is the fact that the annual average temperature in Aragats station is negative (-2.5˚C) and it is located at 3227 m. Fig. 3 clearly shows that these weather stations have particular geographical distribution (by Rank Correlation test - 95% confidence level).

Buishand and Pettitt's tests were distributed to a larger area than the Rank's correlation where the data series showed no significant trend. Buishand's test has not reported result for Masrik area (southeastern part of Sevan lake), Aragast h/m, Artik, Kapan stations.

According to Pettitt's test, there is no trend in the south and west part of Mount Aragats, relatively small areas of the Ararat valley, the southeastern and north western part of Sevan lake and in the southern part of Armenia. This method put focus on the quantitative approach to research in contrast with the qualitative analysis. Due to Hubbert's segmentation and Lee and Heghinian's Bayesian methods, the ongoing changes in the series can be estimated, in order to find the tipping point of the year or years of rapid change in the value of the series.

The representation of average temperature change during different decades leads to the elaboration of a map. According to these analyses conducted in 27 stations the mean values have been changed after the 1990s and in 7 stations no changes were observed. Temperature change has been observed after the 1990's in most of the territory (in 24 stations temperature change is observed after 1994). Most of the breaks happened before the 2000's but the highest results were registered in 1994. Due to these statistical methods it is obvious that in 1994 (one of the hottest years in the last 5 decade) the series of temperature show visible changes.

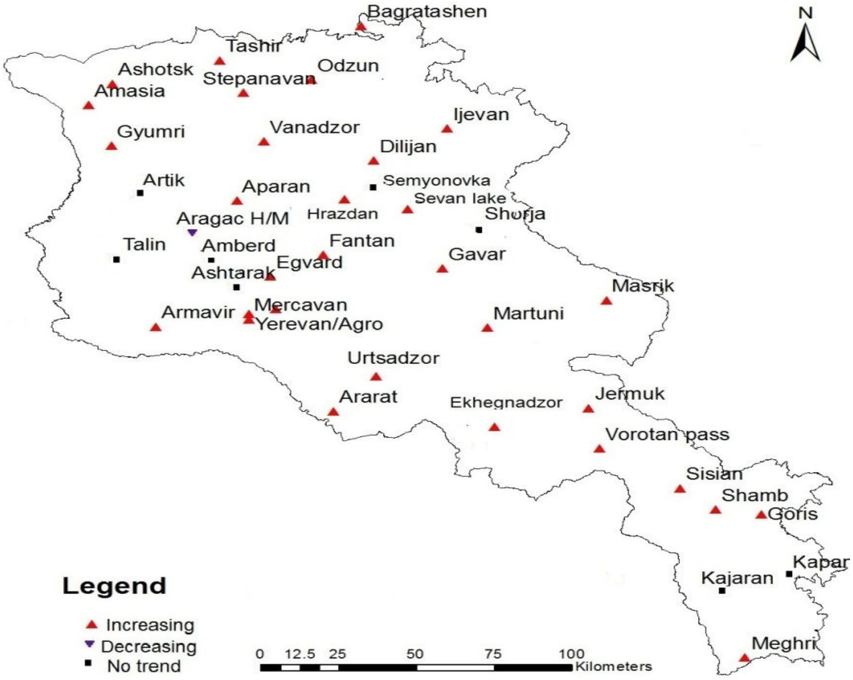

Fig. 1 Rank correlation tests results (point data)

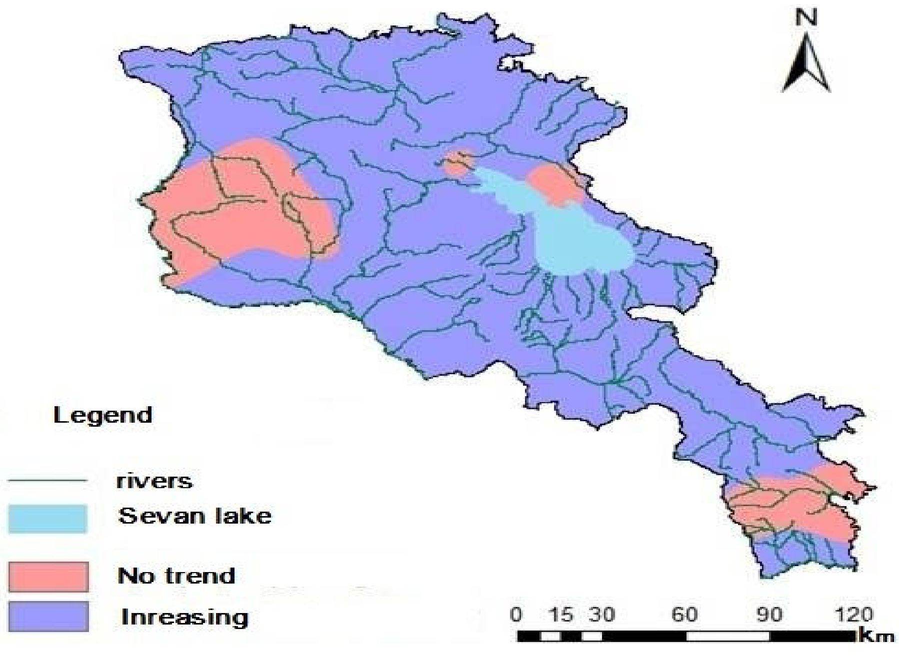

Fig. 2 Rank correlation tests results (interpolated results)

According to Hubbert's segmentation method in the last 50 decades only positive changes have been observed. For 32 stations have a noticeable increasing temperature from 0,23 till 1,44˚C. The most sensitive areas of climate change are considered the arid and lowlands located in the mountainous region of Armenia. The largest increase have been observed around 1000 m (Meghri, Urtsadzor, Yerevan/Arabkir, Bagratashen and Yeghegnadzor stations) up to 1˚C which have arid climate conditions, higher than 1000 m falls below 1˚C (Goris, Ashotsq) (Fig. 3).

Compared with the changes in the precipitation regime within our territory, we can assure that the trends obtained show a positive correlation with temperature changes, but variations of precipitation are much more complicated. The results obtained when these methods were employed are very close to the results of the Second National Communication on Climate Change [25] and Climate Change Impacts Study for the South Caucasus [23]. The average mean temperature increase with 0,85˚C in two of the results compared to the baseline period (1961-1990).

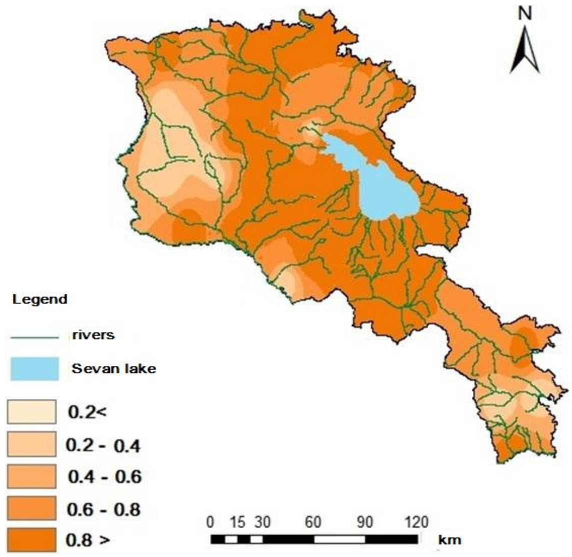

Fig. 3 Hubert segmentation tests results

C. Definition of Temperature Indices Based on Mann-Kendall Test

The non-parametric Mann-Kendall test has provided us with approximately the same results as compared with the first three tests. The analysis was obtained by Mann-Kendall after eliminating the effect of significant lag-1 serial correlation from the time series. Out of 41 series in 13 ones lag-1 is not significant at the 5% level, therefore they have been pre-whitened before using in the Mann-Kendall test (the others were applied to the original values of the time series). Autocorrelation plots for the meteorological variables are presented in Fig. 4. As shown, only positive serial correlations were obtained for temperature. The strongest serial correlations were found at Kapan and Bagratashen stations (up to 1000m above sea level).

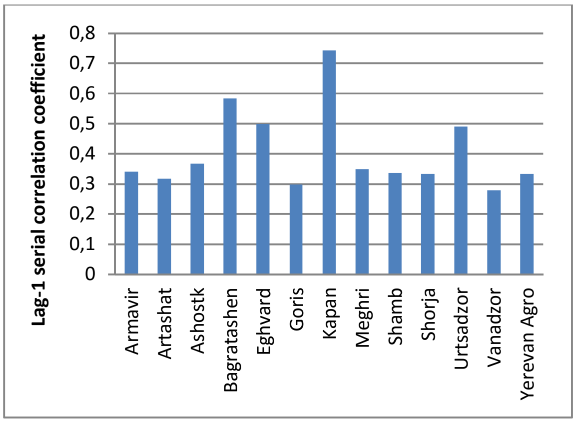

Fig. 4 Lag-1 serial correlation coefficient for the meteorological variables at the weather stations for temperature

TABLE I
MANN-KENDALL TEST RESULTS FOR MEAN TEMPERATURE OVER THE PERIOD 1961-2012 IN SEVERAL WEATHER STATIONS

Name of station	Z	P	S	Tau	D	Test interpretation
Artashat	2.9080915	0.0036364	340.6402	0.28966	1176	**Rejected H_0**
Dilijan	2.8782381	0.003999	362.20774	0.2840845	1275	**Rejected H_0**
Eghegnadzor	3.1270847	***0.0017655***	281.45355	***0.343236***	820	**Rejected H_0**
Fantan	2.7657256	0.0056796	354.85012	0.2676094	1326	**Rejected H_0**
Goris	2.7109032	0.00671	339.72795	0.2664533	1275	**Rejected H_0**
Martuni	2.7264622	0.0064017	340.38187	0.2669662	1275	**Rejected H_0**
Sevan Lake	2.626442	0.0086283	338.17727	0.2550357	1326	**Rejected H_0**
Tashir	2.7121334	0.0066852	349.24533	0.2633826	1326	**Rejected H_0**
Vanadzor	2.8484065	0.0043939	344.96377	0.2816031	1225	**Rejected H_0**
Vorotan pass	2.6898287	0.0071489	325.82331	0.2659782	1225	**Rejected H_0**
Yerevan/Arabkir	3.3439694	***0.0008259***	***417.2651***	***0.3272667***	1275	**Rejected H_0**

After pre-whitening the time series, we have the following results. The Null Hypothesis was accepted for 17 stations (this means that no trend is seen for these stations), while for 24 remaining stations it is rejected (trends were found). Table I includes the interpretation of only 11 of the most significant stations where we have positive trends. Temperature change affects 60% of the territory, underlying the fact that there are only positive trends in contrast to precipitation (5 stations have decreased trends).

Spatial distribution of weather stations with increasing and no trends for the annual data series during the period 1961–2012 is presented in Figs. 5 and 6. As shown, the significant increasing trends in annual temperature were recorded in 22 of the observed stations. The strongest significant increasing trend is recorded in Yerevan/Arabkir station. According to Kendall's trend test, Eghegnadzor and Yerevan/Arabkir are very significant. Yerevan/Arabkir and Yerevan/Agro stations are located in the capital city, so the temperature increase can also be related with the industrial development and heavy duty transport of the city.

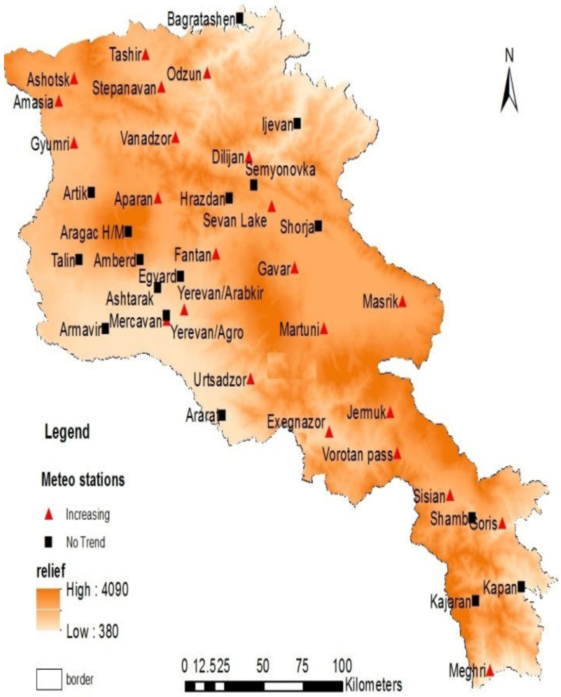

Fig. 5 Mann-Kendall test for average annual temperature over the period 1961-2012 (point data)

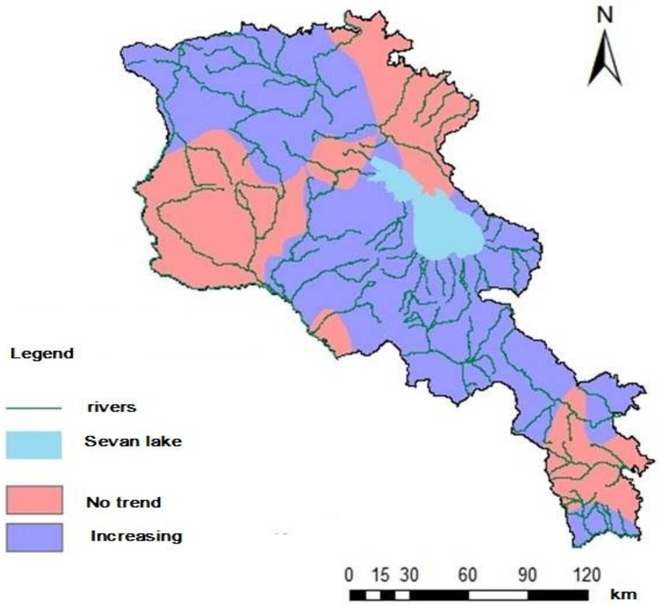

Fig. 6 Mann-Kendall test for average annual temperature over the period 1961-2012 (interpolated results)

For Armenia Mann-Kendall test was also used in «Regional Climate Change Impacts Study for the South Caucasus Region» report [18]. Within that work, the period of study comprises the period of 1935-2008 and the number of the stations studied is 30. In 15 out of the 30 observed stations trends are detected, with positive changes (we have analyzed 41 stations for 1961-2012 period). The results of the analyzed stations are approximately the same compared with ours. The difference is that in this work the analyze has been done for a dense network of stations taking into consideration the lag-1 correlation coefficient for the meteorological variables recorded in the weather stations (which makes our research more accurate and reliable). In Georgia and Azerbaijan, the situation is similar to that in Armenia (increasing or no trends) [23].

Significant increases in the temperatures regime of the country, especially in valleys (for example Ararat valley) are believed to be a result of desertification [25] and the increasing frequency of Iranian originated heat waves for the last half century.

Trying to find out some regularity or to understand the main direction of changes we identified that the changes in north western part are considered the continuous part of eastern Turkey and the yearly averages calculated for the temperature series show significant cooling in north-eastern parts and not significant warming in eastern parts of Turkey (as in Armenia). The significant warming in southern and southeastern parts of Turkey also can influence the southern temperature changes in Armenia [14]. Therefore, the results are very complicated and need deeper analyzes and conclusions.

Air masses were blocked (as an advection) over the area as the increased values of this method show.

In Armenia the extension of mountains, river valleys, slopes, and slope orientations have significant impact on atmospheric circulation processes. Depending on the type of synoptic processes, the occurrence of various meteorological phenomena in the mountainous regions has very different effects. The fact that in the inner part of the basins and on the inner slopes the temperature increases, was clearly shown by our results. Weather conditions in the mentioned areas are very dry with high temperature. Therefore, the inner regions are very vulnerable and the temperature is getting higher and higher compared with open valleys and opposite slopes [22]. For example, the western and southern part of Mount Aragats has an unchanged temperature (the principal air masses come from west and north-west) over the last 5 decades but in contrast, the situation has changed in Gegharkunik region or the Sisian valley, and the air masses movement is blocked.

IV. Conclusions

The present research may provide knowledge of temperature trends in Armenia. Firstly, the changing trends in total annual temperature are pointed o in the data series. The annual temperature shows significant different kinds of positive trends during the period 1961-2012 in Armenia. This study has shown clear evidence that most areas of Armenia have undergone shifts in their temperature regimes. In addition, it is also obvious that the changes are not homogeneous inside the territory. The obtained results coincide with those of the regions having the same geographical conditions.

Assessment of the whole territory of Armenia has contributed to a better understanding on whether the annual temperature range increases or decreases. As a result, an increase in temperature was registered in about 60% of the territory (increased mean value percentage rate within the weather stations). According to these results, the annual temperature during the last five decades underwent not only quantitative changes, but complicated relief caused visible qualitative changes within the territory.

Observations through the 1990s have revealed changes in temperature in most parts of the country [24]–[27]. Following the results of these methods, we can conclude that global climate change has begun to influence the Armenia's climate especially over the last 2 decades.

According to Hubbert's segmentation test with only positive trends for 58% of the territory underwent changes after the break during the 1990s, and 19 stations have changes after 1994. The stations located below 1000 m have the highest increase in temperature (up to 1.5˚C). On running the Mann-Kendall test on temperature data, similar results were provided with a small difference in description.

According to the overall test results, there has been a regional variability in the annual temperature regime in Armenia. Some parts of Armenia experienced greater increase in temperature, while some parts experienced less increases or no trend. For future adaptation, we need to develop some methods and plans knowing what has happened, what is going to happen in Armenia.

REFERENCE

[1] Chatrchyan S (1999) The analyze of meteorological data and possible scenarios of climate change in Armenia, Climate change issues in Armenia, A collection of articles, 1st edn., Yerevan:37-49
[2] Hubert P, Carbonne J (1993) "Segmentation des séries annuelles de débits de grands fleu vesa fricains". Bulletin de liaison du CIEH 92:3-10.
[3] Jones P (1988) Hemispheric Surface Air Temperature Variations: Recent Trends and an Update to 1987,Journalof Climate Vol. 1:654-660
[4] Jones P ,Wigley T, Wright P (1986) Global Temperature Variations between 1861 and 1984, Nature, Vol. 322: 430-434
[5] Lee A, Heghinian S (1977) A Shift of the Mean Level in a Sequence of Independent Normal Random Variables - A Bayesian Approach, Technometricsvol.19, n°4:503-506.
[6] Mann, H.B. (1945) Nonparametric tests against trend. *Econometrica* 13: 245-259.
[7] Melkonyan H (1999) Variability and predictability of climate changes on the territory of Armenia, Climate change issues in Armenia, A collection of articles, 1st edn., Yerevan:10-15.
[8] Melkonyan H, Baloyan A (2003) About one approach to the assessment of climate change on the territory of Armenia, Climate change issues in Armenia, A collection of articles, 2nd edn, Yerevan:270-276.
[9] Mokhov I, Eliseev A, Semenov B (1999) Possible scenarios of climate change in Armenia by results of numerical simulation with using of IAP RAS climate model, Climate change issues in Armenia, A collection of articles, 1st edn., Yerevan:22-36.
[10] Parker D, Horton E (1999) Global and Regional Climate in 1998, Weather, Vol. 54:173-184.
[11] Pettitt A (1979) A non - parametric approach to the change-point problem, Applied Statistics vol.28, n°2:126 – 135.
[12] Scafetta N, West B (2005) Estimated Solar Contribution to the Global Surface Warming Using the ACRIM TSI Satellite Composite, Geophysical Research Letters, Vol.32: L18713.
[13] Stokes C, Gurney S, Shahgedanova M, Popovnin V (2006) Late 20th century changes in glacier extent in the Caucasus Mountains, Russia/Georgia, Journal of Glaciology (52):99-109.
[14] Tayanc M, ulasim, Dogruel M, Karaca M (2008) Climate change in Turkey for the last half century. Springer Science + Business Media B.V., Climatic Change (2009) 94:483–502.doi: 10.1007/s10584-008-9511-0.
[15] Vinnikov K, Grody N (2003) Global Warming Trend of Mean Tropospheric Temperature Observed by Satellites, Science, Vol. 302: 269-272.
[16] Von Storch H, Navarra A (1995) Analysis of Climate Variability — Applications of Statistical Techniques, Springer- Verlag, New York: 334
[17] Zoryan Z (1999) Evaluation of variations of in land air temperature anomaly (LATA) on territory of the Republic of Armenia, Climate change issues in Armenia, A collection of articles, 1st edn., Yerevan:16-21.
[18] Georgia's Initial National Communication Under The United Nations Framework Convention On Climate Change, (1999) Tbilisi
[19] Georgia's Second National Communication to the UNFCCC (2009), Tbilisi.
[20] IPCC (Intergovernmental Panel on Climate Change) Climate change (2007) The physical science basis. In: Solomon Q, Qin D, Manning M, Chen Z et al, Contribution of Working Group 1 to the 4th assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.
[21] IPCC, Climate Change 2001: Impacts, Adaptation and Vulnerability, In: mccarthy J, Canziani O, Leary N, Dokken D, White K et al, Contribution of Working Group II to the Third Assessment Report of the (IPCC),World Meteorological Organisation and United Nations Environment Programme, Cambridge University Press, Cambridge.
[22] Nersisyan A (1964) Climate in Armenia, Arm. State Hydromet., Yerevan.
[23] Regional Climate Change Impacts Study for the South Caucasus Region (2011), Tbilisi.
[24] The First National Communication of The Republic of Armenia under the United Nations Framework Convention on Climate Change (1998), Yerevan.
[25] The Second National Communication on Climate Change (2010), "Lusabats" Publishing House, Yerevan.
[26] Climate change issues in Armenia, a collection of articles, First ED (1999), Yerevan, 373p.
[27] Climate change issues in Armenia, a collection of articles, Second ED (2003), Yerevan, 353p.