Analysis of trends in annual time series of precipitation in the Republic of Bashkortostan, Russian Federation

V M Gaponov¹, A N Elizaryev¹,³, S G Aksenov¹ and A Longobardi²

¹Department of Fire Safety, Ufa State Aviation Technical University, 12, K. Marx Street, Ufa, 450000, The Republic of Bashkortostan, Russia
²Department of Civil Engineering, University of Salerno, Via Giovanni Paolo II, 132 - 84084 - Fisciano (SA), Italy
³Water Problems Institute, Russian Academy of Sciences, Moscow, 3, Gubkina st., 119333, Russia

E-mail: elizariev@mail.ru

Abstract. Nowadays, the problem of climate change receives a wide resonance throughout the world. According to meteorological observations in Bashkortostan over the past 30 years, annual precipitation has increased. The occurrence of natural hazards is directly related to climate change, the number of which has been steadily increasing in recent years. If in the period from 1998 till 2005, their number in Bashkiria ranged from 5 to 11, then in 2010 it was recorded as 37, and as 34 in 2016. In this article, the object of study is the Republic of Bashkortostan, its territory is 142,947 km². Available data consists of annual time series of precipitation for 34 stations, they were analyzed to identify potential trends and their significance. As a first step, precipitation data was checked to assess the quality of the data, to find potential points of change in the time series. For this purpose, parametric (The Student’s t-test) and non-parametric (Pettitt’s test) statistical criteria were applied. Then, a statistical test was used to determine the significance of linear trends (the Mann-Kendall trend test and the Sen’s test). Thus, the main purposes of the article are to detect points of change, as well as, to check, with a help of parametric and non-parametric tests, annual trends for precipitation data.

1. Introduction

Nowadays, the problem of climate change is receiving a wide resonance throughout the world. This is confirmed in the articles of many authors [1-4]. Moreover, climate change in recent decades has been called unprecedented. Actually, the analysis of regular meteorological measurement data impartially confirms the increase of average global air temperature over the past century. According to the Hydrometeorological Center of Russia, the growth rate of average annual air temperature in Russia is 2.5 times higher than the growth rate of global temperature. Significant changes have occurred in precipitation. In general, on the territory of Russia, in the period 1976–2016, annual rainfall is growing by 2.1% in every 10 years. Spring precipitations are especially fast growing, 5.9% growth per 10 years (in Eastern Siberia it is up to 15–20% per 10 years). Some decrease in annual sums was noted in most of the European territory of Russia, in the Southern Urals, and in the Volga Federal District [5].

According to meteorological observations in Bashkortostan over the past 30 years, annual precipitation has increased. With an average level for the region of 499 millimeters per year, over the last decade it was 502 mm. Several researches prove this [6, 7]. The occurrence of natural hazards is
directly related to climate change, the number of which has been steadily increasing in recent years. If in the period from 1998 to 2005, their number in Bashkortostan ranged from 5 to 11, in 2010 it was noted 37, and in 2016 - 34 [8]. According to the IPCC, higher temperatures and increase in precipitation can raise the frequency of fires [9].

The most important indicators of climate are air temperature and rainfall [10].

In this article, the object of research is the Republic of Bashkortostan, its area is 142,947 km². Available data consists of annual time series of precipitation for the 34 stations, analyzed to identify potential trends and their significance.

As a first step, precipitation data was checked to assess the quality of the data, to find potential points of change in the time series. For this purpose, parametric (The Student’s t test) and non-parametric (Pettitt’s test) statistical criteria were applied. Subsequently, a statistical test was used to determine the significance of linear trends (the Mann-Kendall trend test and the Sen’s test). These tests were widely used in different countries, such as Italy, Iraq, China, India etc. Their effectiveness has been proven by many authors [11-16].

Thus, the main objectives of the article are to detect points of change, as well as to check, using parametric and non-parametric tests, trends on an annual basis for precipitation data.

2. Materials and methods

There are 34 weather stations in the Republic of Bashkortostan, Russia. Bashkortostan belongs to a temperate climate zone with an Atlantic-continenal climate. The climate is rather humid, the winter is moderately severe, the summer is warm. Thus, the average annual air temperature in the central and southwestern regions of the republic is +2, + 3°, and in the mountainous and northeastern regions 0, + 1°, respectively. The average temperature of the warmest month of July is 17-19°, in mountainous areas is 16°, the absolute maximum in the territory of the republic is 38-41°. The average temperature of the coldest month of January is -14, -16°, the absolute minimum is -50, -52°. In some cold years there are severe frosts for a long time. For example, in January 1969 during 21-23 days the minimum temperature was below -30°, within 12-15 days of them below -35°, within 3-8 days below -40°. The summer heat is increasing due to the neighborhood in the south of the republic with arid steppe territories of Orenburg and Chelyabinsk regions, as well as in Kazakhstan. Most of the precipitation (40-60%) falls during 3 summer months. Average annual rainfall is 400-550 mm, in mountainous areas 500-600 mm. Summertime is more typical for thunderstorms. The diversity of the climate is greatly affected by the relief. Ridges of the Ural Mountains, which stretched from north to south, create a sharp difference in the climatic conditions on the western and eastern hillides. [5]

Annual precipitation data were collected from the Bashkir Territorial Administration for Hydrometeorology and Environmental Monitoring (BashHMC) and from the All-Russian Research Institute of Hydrometeorological Information - the World Data Center (ARSRIHMI-WDC). The database includes annual records at 34 meteorological stations in the Republic of Bashkortostan from 1936 to 2009.

In order to detect change points, we used two tests: the parametric The Student’s t test [17, 18] and the non-parametric Pettitt’s test [19]. The non-parametric Mann-Kendall trend test [20-23] and The Sen’s test [24, 25] were used to detect the linear trend in time.

3. Change point detection methodology

As a preliminary step in any homogeneity analysis, it is very useful to make a schedule of time series in linear scale (Figure 1). A visual inspection of the site(territory) may reveal the presence of noticeable changes in the time series, which can be further investigated by statistical procedures. So, in some stations (for example, Askino) we immediately detect the presence of missing data. Failure in data collection and, thus, missed data have mainly occurred during the period 1940-1950, that is the period of the Second World War and immediately after it. Even if the missing data are not related to heterogeneity, there may be points of change during this period.
A series of homogeneous climate data is defined as a series in which changes are caused only by changes in weather and climate [26]. Climate factors do not really affect on most of the long-term climate series: changes in instruments, station locations, station environments, etc. They make climate data unrepresentative of temporal climate variability. Heterogeneities lead either to sharp discontinuities or to a gradual bias in the data, which can be detected using statistical tests. Actually, a large number of approaches have been proposed to detect change points, and when we use them to the same series, they can actually lead to conflicting conclusions due to different climatic elements relating to the time series under research [27]. For this reason, it would be advisable to apply a number of methods to detect points of change and compare. [28]

In order to detect change points, we used two tests: the parametric Student’s t-test [17, 18] and the non-parametric Pettitt’s test [19].

3.1 Results of the detection of change points analysis

The parametric Student’s t-test and the non-parametric Pettitt’s test were applied to detect discontinuities in the data set on long-term annual precipitation at 34 stations of the Republic of Bashkortostan from 1936 to 2009. For each meteorological station and for each test, the corresponding results are shown in Figure 2, for the significance level α = 5%.

From the article, it can be seen that the various approaches applied to long-term annual precipitation data show different results. Let us pretend that time series can be defined as non-uniform if two tests indicate this. Further, only homogeneous precipitation time series will be analyzed additionally to identify trends. The Student’s t-test indicates that a change point has been detected in all time series, but the probability of its occurrence is very small (p = 0.0001). Based on this, we will assume that the time series in which Pettitt’s test indicates a positive result are homogeneous. In this way, we can see, that at 16 meteorological stations, time series are non-uniform. Accordingly, they are excluded from the following trend detection analysis.

4 Trend Analysis

Trend in meteorological variables in the series of observations during the period under consideration [29]. We tested 18 meteorological stations, in which time series are homogeneous, to detect a linear trend in time. For this, the non-parametric Mann-Kendall trend test [20-23] and The Sen’s test [24, 25] were used.

4.1 Results of trend detection analysis

The tests, which we discussed above, were applied to detect a linear trend from precipitation data of 18 meteorological stations in the Republic of Bashkortostan for the period from 1936 to 2009, in which the time series are homogeneous. Whereas half of the time series turned out to be heterogeneous, it is difficult to talk about the general picture of changes in precipitation in the Republic of Bashkortostan. But in most cases, Sen’s slope is positive, which indicates an increase in annual precipitation amounts.
4 among 18 meteorological stations have a negative trend, but it is not significant. For illustrative purposes, a map was made (Figure 2). Based on the map data, made on the basis of the results of the Mann-Kendall test and the Sen test, it can be seen that most stations have a positive trend. The maximum positive trend was found at the Dyurtyuli meteorological station.

![Map of average annual precipitation decrease (negative trend, green scale) or increase (positive trend, blue scale) in millimeters per year.](image)

**Figure 2.** Map of average annual precipitation decrease (negative trend, green scale) or increase (positive trend, blue scale) in millimeters per year.

### 5. Conclusion

The main purpose of this research was to analyze the time series of precipitation, to identify potential trends and assess their significance over the wide (about 142,947 km²) territory of the Republic of Bashkortostan and over a long time interval (1936-2009). To this purpose, climate data on precipitation were preliminarily checked for data uniformity using parametric The Student’s t-test and non-parametric Pettitt’s test. It was found, that the time series of 16 meteorological stations are heterogeneous. Later on, only homogeneous time series (18 meteorological stations) were tested for trend detection on an annual scale, affected using non-parametric tests: the Mann Kendall test and the Sen test. According to the study, it was found that on an annual scale, the study area is experiencing a positive trend, even though in the eastern part, minor negative trends were observed.

The growth of precipitation represents a serious threat to the Republic of Bashkortostan, this leads to an increase in the probability of emergencies. An increased wind, a sharp drop of air temperature, and a thunderstorm accompany precipitation, thus greatly complicating the situation. They may cause injury and death.
6. Acknowledgments
The presented research was financially supported by the Russian Science Foundation (grant no. 17-77-30006).

References
[1] Kokorin A 2005 Climate Change: A Review of the State of Scientific Knowledge of Anthropogenic Climate Change RREC, GOF, WWF (Russia) p 20
[2] Cook J, Nuccitelli D, Green S, Richardson M, Winkler B, Painting R, Way R, Jacobs P and Skuce A 2013 Quantifying the consensus on anthropogenic global warming in the scientific literature Environmental research letters 8 1-7
[3] Asadi Zarch M A, Sivakumar B, Malekinezhad H and Sharma A 2017 Future aridity under conditions of global climate change Journal of Hydrology 554 451–469
[4] Shiqin Xu, Zhongbo Yu, Chuanguo Yang, Xiben Ji and Ke Zhang 2019 Trends in evapotranspiration and their responses to climate change and vegetation greening over the upper reaches of the Yellow River Basin Agricultural and Forest Meteorology 263 118-129
[5] Bashkir Hydrometeorology and Environmental Monitoring Department. Climate change and its effects 2015 Available at: http://www.meteorb.ru/
[6] Afanasev I, Volkova T and Elizaryev A 2014 Analysis of interpolation methods for the Republic of Bashkortostan, Russian Federation WSEAS transactions on environment and development pp 405-416
[7] Golovina A V 2012 Evaluation of the modern variability of the stock R. Belay (Republic of Bashkortostan) under the influence of natural and anthropogenic factors, Abstract of candidate dissertation (Kazan) p 25
[8] RBC-Ufa study: How climate change affects Bashkortia 2017 Available at: https://ufa.rbc.ru/ufa/29/06/2017/5954ddb39a7947defd54412b
[9] IPCC Working group III fourth assessment report, Summary for Policymakers 2007
[10] Myakisheva N V 2008 The climatic system of the Earth. A manual for masters. Direction ”Hydrometeorology”. Specialization ”Rational using and protection of water resources” (St. Petersburg: RSHU Publishers) p 95
[11] Longobardi A, Buttafuoco G, Caloiero T and Coscarelli R 2016 Spatial and temporal distribution of precipitation in a Mediterranean area (Southern Italy) Environmental earth sciences 75(3) 189
[12] Yavuz Selim Güzlül 2018 Multiple Şen-innovative trend analyzers and partial Mann-Kendall test Journal of Hydrology 566 685–704
[13] Prateek Verma and Sanjay Kumar Ghosh 2019 Trend analysis of Climatic Research Unit temperature for Gangotri glacier, India Dynamics of Atmospheres and Oceans 85 83–97
[14] Omar M A, Mahmood Agha, S Çağatay Bağçacı and Nermin Şarlık 2017 Homogeneity Analysis of Precipitation Series in North Iraq IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG) 5(3) II May-June 57-63
[15] Zhigao Zhou, Lunche Wang, Aiwen Lin, Ming Zhang and Zigeng Niu 2018 Innovative trend analysis of solar radiation in China during 1962-2015 Renewable Energy 675-689
[16] Bihrat Onoz and Mehmetcik Bayazit 2003 The Power of Statistical Tests for Trend Detection Türk J. Eng. Env. Sci. 27 247-251
[17] Hald A 1952 Statistical Theory with Engineering Applications (Wiley: New York)
[18] Panofsky H A and Brier G W 1968 Pennsylvania State University, University Park p 224
[19] Pettitt A N 1979 A non-parametric approach to the change-point problem Appl. Statist. 28(2) 126-135
[20] Mann H B 1945 Nonparametric tests against trend Econometrica 13 245-259
[21] Kendall M 1975 Multivariate Analysis (London: Charles Griffin &Company)
[22] Hirsch R M, Slack J R and Smith R A 1982 Techniques of trend analysis for monthly water quality data Water Resources Research 107-121
[23] Hirsch R M and Slack J R 1984 A nonparametric trend test Water Resources Research 727-732
[24] Sen P K 1968 Estimates of Kendall’s tau *J. Am. Stat. Ass.* 63 1379-1389
[25] Gilbert 1987 *Statistical Methods for Environmental Pollution Monitoring* (New York: John Wiley & Sons, Inc.)
[26] Conrad V and Pollak C 1950 *Methods in Climatology* (Cambridge: Harvard University Press)
[27] Reeves J, Chen J, Wang X L, Lund R and Lu Q Q 2007 A review and comparison of climate control data for climate data *J. Appl. Meteorol. Clim.* 46 900-915
[28] Longobardi A and Villani P 2010 Trend analysis in the Mediterranean area *Int. J. Climatol.* 30 1538–1546
[29] Gruza G and Rankova E 2003 The climate of Russia: warming continues *Science and life* [in Russian – Nauka i zhizn] 11