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Climate change in urban versus rural areas

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Abstract

The most important anthropogenic influences on climate are the emissions, changes in land use, such as urbanization aural areasnd agriculture. The urban environment has distinctive bioclimatical factors in relation to rural areas. The process of urbanization alters natural surface and atmospheric conditions. Urban areas are characteristic by increased rainwater surface runoff, increased temperatures and decreased evaporation. Exactly evaporation warms the rural surface more than the urban. The paper concerns on the impacts of urbanization that are evaluated by observations in cities with those in rural areas – not so populated and with smaller built areas. We use and asses the difference between trends in monthly average temperatures and trends in monthly precipitations in the cities and the corresponding trends in rural areas. For the trend analysis, the Mann-Kendall nonparametric test is used. Our results show differences in trends in villages and cities. Observed are increased trends in temperature and decreased trends in precipitation due to urban and land-use changes.

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Keywords: Precipitation; temperature; trends;

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1. Introduction

Climate change and global warming are commonly detected throughout studies of variability of climatic parameters such as rainfall, temperature, lake's level, runoff and groundwater. Nowadays, study of long-term temperature variability has been a topic of particular attention for climate researchers as temperature affects straightaway human activities in all domains [1]. Climate change and global warming are worldwide recognized as the most significant environmental dilemma the world is experiencing today [2-5]. Concern in climate change and global warming has brought great interest to climate scientists leading to several studies on climate trend detection at global, regional and also local scales.

A number of studies have indicated that there is some relationship between urbanization and climate change. Gill et al. [6] present output from energy exchange and hydrological models showing surface temperature and surface runoff in relation to the green infrastructure under current and future climate scenarios. The implications for an adaptation strategy to climate change in the urban environment is also presented. Karaca et al. [7] study regional climate change and investigate the effects of urbanization and climates of two largest cities in Turkey: Istanbul and Ankara. A significant upward trend is found in the urban temperatures of southern Istanbul, which is the most highly populated and industrialized part of the city compared to its rural parts. Northern stations do not show any warming trend; instead, they have a cooling trend. The urban station in Ankara does not show any warming trend. Quantification of the urban heat island under a changing climate over all Anatolian Peninsula was studied by Kindap et al. [8]. Safari [1] examines the long-term modification of the near surface air temperature in Rwanda. The analysis of the annual mean temperature showed for all observatories a not very significant cooling trend during the period ranging from 1958 to 1978 while a significant warming trend was furthermore observed for the period after the 1978 (to 2010) mainly where Kigali, the Capital of Rwanda is situated. Bornstein [9] found that there is less intense and less frequent urban surface temperature inversion in New York City than in the surrounding nonurban regions. In Europe, the response to climate change of rural leaf–stem area in summer and clouds and rural soil moisture in winter explains the majority of this variability. Climate change increases the number of warm nights in urban areas substantially more than in rural areas. These results provide evidence that urban and rural areas respond differently to climate change. Thus, the unique aspects of the urban environment should be considered when making climate change projections, particularly since the global population is becoming increasingly urbanized [10]. The research of Kalnay and Cai [11] suggested that half of the observed decrease in the diurnal temperature was due to urban expansion and other land use changes. Sertel et al. [12] indicated that urbanization increased the average temperature in Turkey according to the results of simulation with the Weather Research and Forecasting (WRF) regional climate model (WRF). The study [13] aims to identify the impact of urban land use change on regional temperature and precipitation in summer in the Beijing-Tianjin-Tangshan Metropolitan area during 2030–2040 based on the analysis of the simulation results of WRF model. The results indicate that urbanization has the potential to increase temperature and precipitation in the summer of 2030–2040. Urbanization can also influence the regional precipitation [14]. Huff and Vogel [15] found that the urban surface was the main factor affecting the spatial and temporal pattern and the intensity of short-term rainfall in St. Louis, USA. Approach to assessing probabilities of human influence on global temperature could be transferred to other climate variables and extremes allowing enhanced formal risk assessment of climate change [15].

Urban growth and climate change are two major forcing on local climate [4]. The hypothesis of our research is that urban areas as compared to those over surrounding non-urban – mostly rural regions have warmer air temperatures and lower precipitation. Our study is focusing on the area of the eastern Slovakia and is solved in local scale.

Nomenclature

x_j , x_k	data values at time j and k
N	number of all pair's x_j and x_k
n	number of data points
m	number of tied groups (a set of sample data having the same value)
S	Mann-Kendall statistics

Z	test statistics based on normal distribution
t	test statistics for sequential Mann-Kendall test
Greek symbols	
α	significance level
β	median of slope of all data pairs

2. Material and methods

2.1. Data

The data for the study was provided by Slovak Hydrometeorological Institute. We have compiled a database of average monthly temperatures and precipitation over climatic stations in eastern Slovakia. We have implemented the following criteria: urban stations are selected in towns having population over 10,000, and rural stations with population of less than 10,000. Temperature and precipitation data are from 1962 to 2014, it means 53 years. We have analyzed a total of 16 climatic stations (6 urban and 10 rural, 3 of them are in mountainous area). These stations are highlighted in Table 1 and Table 2.

2.2. Study area

The geographical location of the climatic stations under the study is shown in Fig. 1.

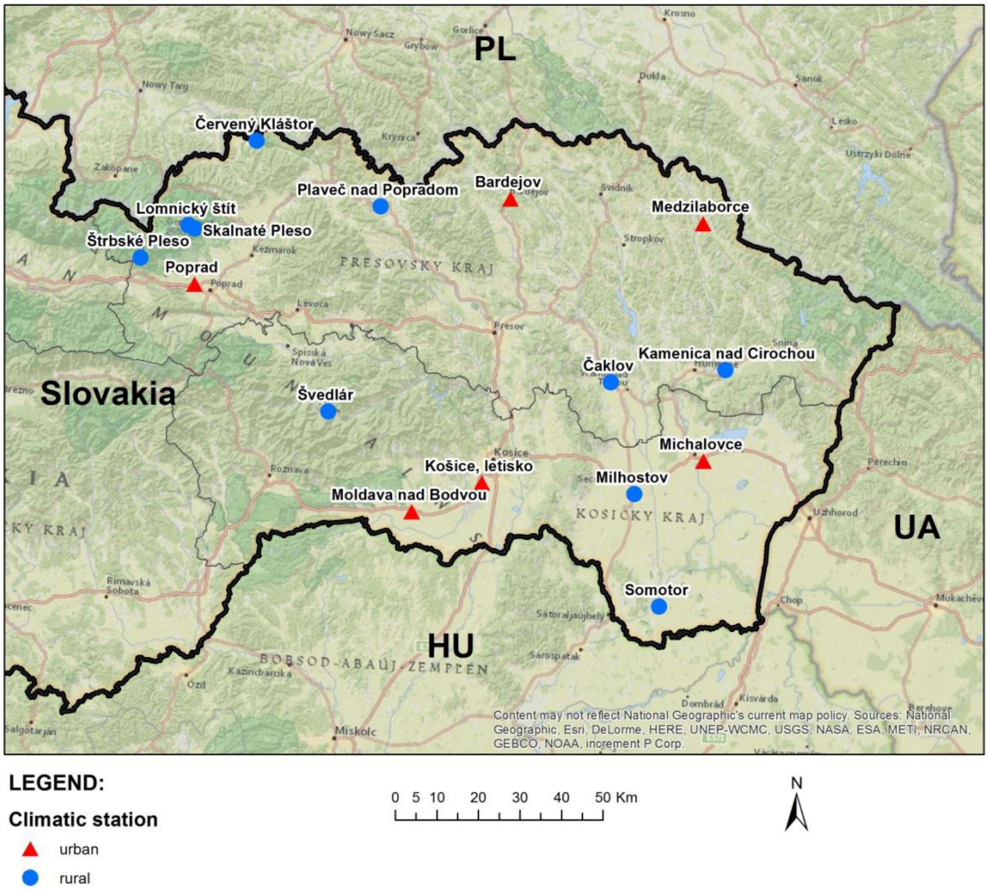

Fig. 1. Location of climatological stations.

The study area is not overcrowded, the biggest city is Kosice and it has above 240,000 inhabitants. The other urban areas under the study are depicted in Table 1. The geographical location of rural climatic stations under the study are shown in Table 2.

Table 1. Geographical location of urban climatic stations

Station	Population (31.12.2012)	Latitude	Longitude	Altitude
Poprad	104,297	49°04´08´´	20°14´44´´	694
Moldava nad Bodvou	11,152	48°36´10´´	20°59´56´´	204
Bardejov	77,841	49°17´22´´	21°16´26´´	312
Košice	240,164	48°40´20´´	21°13´21´´	230
Medzilaborce	12,319	49°15´12´´	21°54´50´´	305
Michalovce	110,899	48°44´24´´	21°56´43´´	110

Table 2. Geographical location of rural climatic stations

Station	Latitude	Longitude	Altitude
Lomnický štít	49°11´43´´	20°12´54´´	2,635
Skalnaté Pleso	49°11´22´´	20°14´09´´	1,778
Štrbské Pleso	49°07´10´´	20°03´48´´	1,322
Švedlár	48°48´38´´	20°42´32´´	477
Červený Kláštor	49°23´14´´	20°25´27´´	469
Plaveč nad Popradom	49°15´35´´	20°50´45´´	485
Čaklov	48°54´09´´	21°37´52´´	138
Milhostov	48°39´47´´	21°43´26´´	105
Somotor	48°25´17´´	21°49´06´´	100
Kamenica nad Cirochou	48°56´20´´	22°00´22´´	176

2.3. Statistical analysis

Many tests for the detection of significant trends in meteorologic time series can be classified as parametric and non-parametric methods. The Mann–Kendall (MK) test [17, 18] is a rank-based nonparametric test for assessing the significance of a trend, and has been widely used in hydro-meteorological trend detection in many studies.

In this study non-parametric Mann-Kendall test is used for the detection of the trend in a time series. Mann-Kendall test is following statistics based on standard normal distribution (*Z*), by using Eq.(1).

$$Z = \begin{cases} S - 1/\sqrt{Var(S)} & \text{if} \quad S > 0 \\ 0 & \text{if} \quad S = 0 \\ S + 1/\sqrt{Var(S)} & \text{if} \quad S < 0 \end{cases} \tag{1}$$

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}\left(x_j - x_k\right) \tag{2}$$

$$\operatorname{sgn}\left(x_j - x_k\right) = \begin{cases} +1 & \text{if} \quad \left(x_j - x_k\right) > 0 \\ 0 & \text{if} \quad \left(x_j - x_k\right) = 0 \\ -1 & \text{if} \quad \left(x_j - x_k\right) < 0 \end{cases} \tag{3}$$

$$\mathrm{Var}(S)=\left[n(n-1)(2n+5)-\sum_{i=1}^{m}t(t-1)(2t+5)\right]/18 \quad (4)$$

where n is the number of data points, m is the number of tied groups (a set of sample data having the same value).

According to this test, the null hypothesis H0 states that the depersonalized data (x_1, …, x_n) is a sample of n independent and identically distributed random variables. The alternative hypothesis H1 of a two-sided test is that the distributions of x_k and x_j are not identical for all $k, j \leq$ n with $k \neq j$.

The value α is called the significance level; we choose $\alpha = 0.05$ and $Z_{\alpha/2}$ is a table value for normal distribution, in this case $Z_{\alpha/2} = 1.95996$. Hypothesis H0 - no trend is if ($Z < Z_{\alpha/2}$) and H1 - there is a trend if $Z > Z_{\alpha/2}$. The value of Z gives further information about any increasing or decreasing of the trend, but not its magnitude exactly [19-23].

The magnitude of the trend was determined using Sen`s estimator. Sen's method assumes a linear trend in the time series and has been widely used for determining the magnitude of trend in hydro-meteorological time series [24-28]. In this method, the slopes (β) of all data pairs are first calculated by

$$\beta=\mathrm{Median}\left((x_j-x_k)/(j-k)\right) \quad (5)$$

for $i = 1, 2, ..., N$, where x_j and x_k are data values at time j and k ($j > k$), respectively and N is a number of all pairs x_j and x_k.

A positive value of β indicates an upward (increasing) trend and a negative value indicates a downward (decreasing) trend in the time series.

Climate change can be detected by the Kendall coefficient t (Mann test) and when a time series shows a significant trend, the period from which the trend is demonstrated can be obtained effectively by this test. In a time series, for each element y_i, the number n_i of elements y_j preceding it ($i > j$) is calculated such that $y_i > y_j$.

The test statistic t is then given by,

$$t=\sum n_i \quad (6)$$

and is distributed very nearly as a Gaussian normal distribution with an expected value of

$$E(t)=\frac{n(n-1)}{4} \quad (7)$$

and a variance of

$$\mathrm{var}t=\frac{n(n-1)(2n+5)}{72} \quad (8)$$

A trend can be seen for high values of $u(t)$, where,

$$u(t)=\frac{[t=E(t)]}{\sqrt{\mathrm{var}t}} \quad (9)$$

This principle can be usefully extended to the backward series and $u_i = -u(t_i)$ can be obtained. The intersection of the $u(t)$ and $u'(t)$ curves denotes approximately the beginning of the trend. This is called the sequential version of the Mann-Kendall test [8, 29]. If a Mann-Kendall statistic of a time series is higher than 1.96, there is a 95% significant increase in that particular time series. If the result is just the reverse; lower than - 1.96, there is a 95% significantly decreasing trend in the series. Also, results between 0.5 and 1.96 indicate increasing, -0.5 and -1.96 indicate decreasing trends, and 0.5 and -0.5 indicate no trend. The Mann-Kendall statistics are then plotted on a map in order to show the spatial distribution of both the significant and non-significant temperature or precipitation trends.

3. Results and discussion

Temperature and precipitation time series in climatic stations in eastern Slovakia were analysed to understand trends in urban and rural areas. As can be seen in Fig. 2, as of 2014, average temperatures in climatic stations are higher than temperature in 1962. Average temperature increase in station Milhostov (rural) as well as in Michalovce (urban) over 2 °C. Fig. 3 presents monthly average precipitation in the same stations. There is only slight increase in precipitation over the study period.

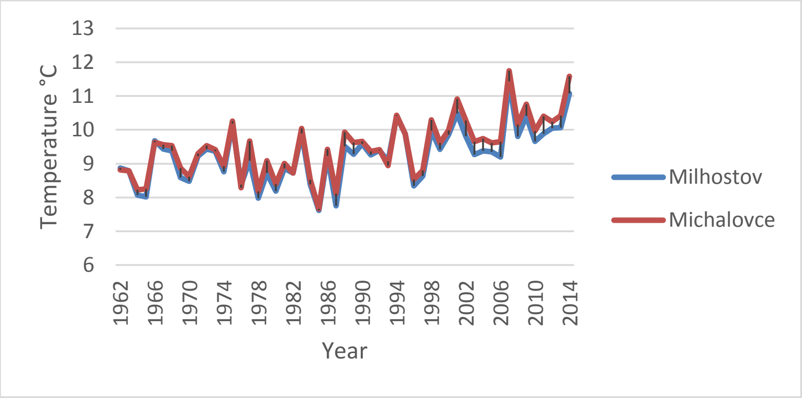

Fig. 2. Course of average monthly temperature.

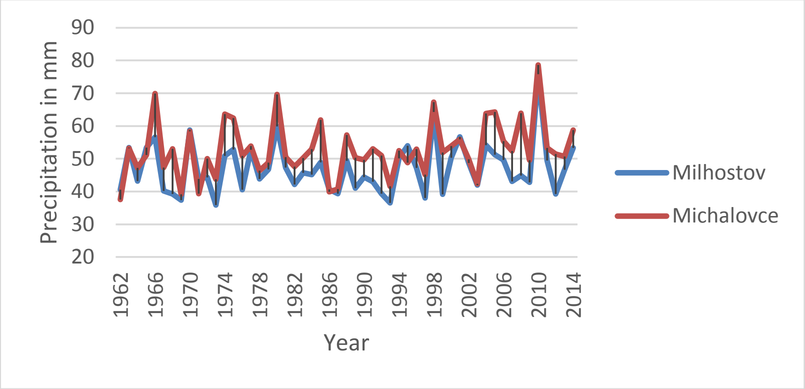

Fig. 3. Course of average monthly precipitation.

The both stations are situated in same geographical conditions; they are close to each other. The temperature is a little bit higher in Michalovce, urban station and also the precipitation is higher in the same climatic station.

Trends in monthly average temperatures and precipitation at individual climatic stations were investigated with the Mann-Kendall trend test [17, 18]. The magnitude of the trend was determined using Sen`s estimator (5). Trend of the monthly average temperatures for the urban stations are presented in Table 3 and for the rural stations are presented in Table 4. In urban stations, Mann-Kendall statistics and Sen`s estimator suggest statistically significant increase mainly for the spring and the summer, from April to August. There is also increasing trend in rural stations during the summer time, however these stations prove also decreasing trend in temperatures during the fall. Lomnický štít and Skalnaté Pleso are mountainous stations and these show an increasing trend more often. The statistically significant trends are presented by bold values.

Trends of the monthly average precipitation are presented in Table 5 for urban climatic stations and in Table 6 for rural climatic stations.

Table 3 Trends in temperature in urban climatic stations

Station	Hydrological year											
	November	December	January	February	March	April	May	June	July	August	September	October
Poprad	0,019	0,025	0,044	0,026	0,028	**0,053**	**0,029**	**0,037**	**0,040**	**0,052**	0,004	0,017
Moldava nad Bodvou	0,016	0,023	**0,061**	0,023	0,032	**0,045**	0,021	**0,031**	**0,042**	**0,055**	0,009	**0,025**
Bardejov	0,014	0,029	**0,067**	0,027	0,035	**0,041**	**0,024**	**0,033**	**0,044**	**0,044**	0,008	0,012
Košice	0,024	0,030	**0,060**	0,029	**0,043**	**0,058**	**0,032**	**0,044**	**0,053**	**0,064**	0,016	**0,026**
Medzilaborce	0,017	0,033	**0,076**	0,028	0,023	**0,041**	**0,026**	**0,040**	**0,054**	**0,053**	0,015	0,023
Michalovce	0,018	0,026	**0,063**	0,023	0,034	**0,046**	**0,028**	**0,042**	**0,051**	**0,059**	0,012	0,020

Table 4. Trends in temperature in rural climatic stations

Station	Hydrological year											
	November	December	January	February	March	April	May	June	July	August	September	October
Lomnický štít	**0,034**	0,032	0,027	0,018	0,012	**0,048**	**0,031**	**0,038**	**0,054**	**0,051**	0,002	0,016
Skalnaté Pleso	**0,035**	**0,036**	**0,034**	0,016	0,023	**0,053**	**0,032**	**0,037**	**0,047**	**0,051**	0,002	0,017
Štrbské Pleso	0,010	0,009	0,011	-0,010	-0,001	0,025	0,016	0,020	**0,033**	**0,033**	-0,018	-0,006
Švedlár	0,015	0,035	**0,067**	0,031	**0,032**	**0,040**	**0,024**	**0,031**	**0,036**	**0,041**	0,005	0,022
Červený Kláštor	-0,006	0,016	**0,053**	0,015	0,003	0,008	-0,010	0,000	0,015	**0,016**	-0,022	-0,003
Plaveč nad Popradom	0,007	0,019	**0,054**	0,022	0,016	0,018	0,008	0,011	**0,028**	**0,036**	-0,011	0,004
Čaklov	0,016	0,022	**0,061**	0,022	0,032	**0,040**	**0,027**	**0,042**	**0,045**	**0,057**	0,012	0,019
Milhostov	0,014	0,025	**0,060**	0,023	0,026	**0,037**	0,017	**0,033**	**0,043**	**0,053**	0,004	0,022
Somotor	0,008	0,021	**0,061**	0,021	0,029	**0,037**	0,010	**0,028**	**0,030**	**0,040**	-0,004	0,009
Kamenica nad Cirochou	0,014	0,030	**0,070**	0,028	0,032	**0,044**	**0,027**	**0,040**	**0,047**	**0,055**	0,008	0,023

Table 5. Trends in precipitation in urban climatic stations

Station	Hydrological year											
	November	December	January	February	March	April	May	June	July	August	September	October
Poprad	-0,274	-0,041	0,079	0,048	0,143	-0,078	0,242	0,008	**1,089**	-0,138	-0,047	0,288
Moldava nad Bodvou	-0,303	0,018	0,111	-0,068	-0,248	0,058	-0,020	0,084	0,423	-0,467	-0,226	0,206
Bardejov	-0,185	-0,130	**0,284**	0,106	0,028	-0,174	0,464	0,321	0,800	-0,363	0,050	0,131
Košice	-0,344	0,154	0,064	-0,032	-0,253	0,083	0,107	0,176	0,236	-0,495	-0,127	0,068
Medzilaborce	-0,035	-0,133	0,286	0,258	0,159	-0,229	**0,597**	0,174	0,464	**-0,693**	0,167	0,020
Michalovce	-0,191	0,191	**0,261**	0,184	-0,156	0,058	0,277	0,152	0,133	-0,192	0,224	0,009

Table 4. Trends in precipitation in rural climatic stations

Station	Hydrological year											
	November	December	January	February	March	April	May	June	July	August	September	October
Lomnický štít	**1,197**	**1,152**	**2,209**	**2,013**	**2,148**	**1,450**	**1,311**	0,624	**1,433**	0,133	0,254	0,494
Skalnaté Pleso	0,010	-0,076	**0,606**	0,464	**0,620**	0,088	0,434	-0,147	0,600	-0,600	-0,093	0,267
Štrbské Pleso	-0,017	-0,059	0,507	0,053	**0,532**	0,107	0,150	0,291	1,105	-0,100	0,004	0,330
Švedlár	-0,082	0,094	0,114	-0,105	-0,102	-0,100	0,395	0,526	0,940	0,277	0,267	0,420
Červený Kláštor	-0,040	-0,129	0,034	0,167	0,300	0,000	0,392	0,422	**1,161**	0,025	0,346	0,297
Plaveč nad Popradom	-0,104	-0,089	0,110	0,200	0,217	-0,032	**0,681**	0,669	**1,132**	-0,400	0,216	0,291
Čaklov	-0,190	0,148	0,175	0,117	-0,075	-0,150	0,247	0,161	0,371	-0,430	0,207	0,178
Milhostov	-0,179	0,041	0,003	-0,040	-0,150	-0,058	0,226	-0,021	0,246	-0,230	0,176	0,110
Somotor	-0,142	0,195	0,117	0,157	-0,105	0,108	0,163	-0,122	0,264	**-0,595**	0,321	0,149
Kamenica nad Cirochou	-0,105	-0,113	0,091	0,003	-0,267	-0,095	0,213	-0,167	0,705	-0,551	0,175	0,100

There is no clear trend in precipitation for urban and differently rural station. The trend in precipitation is decreasing in August and November and increasing in January, February, May, June, and July.

As an example, annual time series of average temperatures for the urban stations of Michalovce and rural station Milhostov and their sequential version of the Mann-Kendall test graph are presented in Fig. 4 and Fig. 5. In Mann-Kendall plots, as of 1962, Michalovce (urban) station has a minimum temperature of 8,8°C, which increased to 11.6°C in 2014. Similar trend is seen for Milhostov (rural) station. Significance of the trend has been identified by Mann-Kendall statistics where the area above the line passing 1.96 represents the 95% significance level. Both Michalovce and Milhostov stations show a significant increase starting by mid to late 1970s.

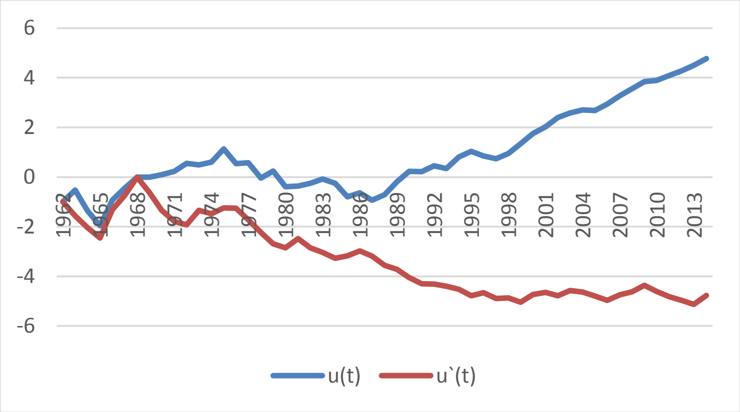

Fig. 4. Sequential Mann-Kendall test for temperatures in Michalovce (urban station).

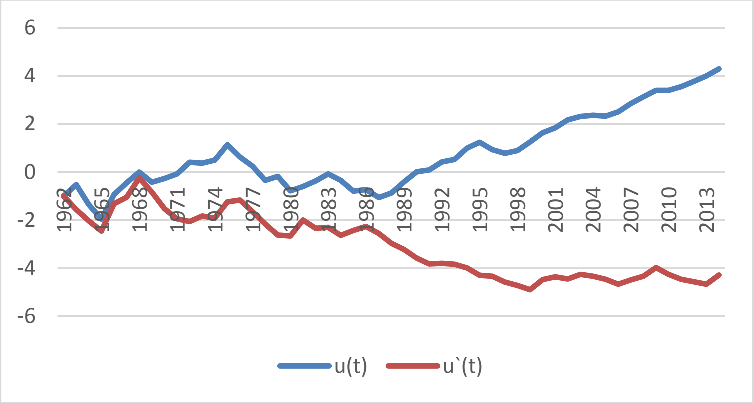

Fig. 5. Sequential Mann-Kendall test for temperatures in Milhostov (rural station).

4. Conclusion

Materials such as stone, concrete, and asphalt tend to trap heat at the surface [30] and a lack of vegetation reduces heat lost due to evapotranspiration [31]. Heat islands develop in areas that contain a high percentage of non-reflective, waterresistant surfaces and a low percentage of vegetated and moisture-trapping surfaces [32]. The addition of anthropogenic heat and pollutants into the urban atmosphere further contributes to the intensity of the urban heat island effect [33, 34].

The urban environment has distinctive biophysical features in relation to surrounding rural areas. These include an altered energy exchange creating an urban heat island, and changes to hydrology such as increased surface runoff of rainwater. Such changes are, in part, a result of the altered surface cover of the urban area. For example less vegetated surfaces lead to a decrease in evaporative cooling, whilst an increase in surface sealing results in increased surface runoff. Climate change will amplify these distinctive features [6]. This paper explores the important role that the green infrastructure, i.e. the greenspace network, of a city can play in adapting for climate change. It uses the conurbation of Greater Manchester as a case study site. The paper presents the evaluation of average monthly temperatures and precipitation in climatic stations in eastern Slovakia according to their localization - in urban or in rural areas. The results show differences in temperature in urban areas, which are higher than in rural areas. It proves previous studies as well as our hypothesis. There is no difference in precipitation in urban and rural areas. Generally in the study area we have observed increasing significant trends in temperature and also increased but mostly not significant trends in precipitation.

Acknowledgements

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