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Research Article

ESTIMATION OF THE LONG-TERM TENDENCIES AND HOMOGENEITY OF THE AVERAGE ANNUAL WATER TEMPERATURE AND AIR TEMPERATURE IN THE SIVERSKYI DONETS RIVER BASIN (WITHIN UKRAINE)

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ABSTRACT

According to the scientific researches of many scientists in the world, the climate fluctuations causes changes of the whole complex hydrometeorological factors. The main factor that determines the thermal regime of the rivers is air temperature. In this paper, the long-term tendencies of the average annual water temperature and air temperature in the Siverskyi Donets River Basin (within Ukraine) was researched. The period of observation on gauging stations is the start of observations till 2013 inclusive (the longest period is 1947-2013). The methodological approaches are based on the use of hydro-genetic methods. It was found that series of observations of the hydrometeorological data is homogeneous and synchronous. However, the fluctuations of the average annual water temperature are not always synchronous phase. The tendency to increase the average annual water temperature of rivers, caused by corresponding increase of air temperature, was found.

Keywords: average annual water temperature, average annual air temperature, homogeneity, asynchronicity phase, hydro-genetic analysis.

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1. INTRODUCTION

The water temperature is an important natural property of the river system because it affects the hydrological, hydrochemical, hydrobiological processes and determines the use of the river waters in industry, utilities, agriculture, recreation and other [5]. The thermal regime of rivers is formed by the heat exchange between the water mass and environment (atmosphere and the channel bed). At that, in summer more intensive heat exchange occurs with the atmosphere, and in winter – with the lithosphere. The ratio between the elements of the thermal balance (absorption of direct and diffuse solar radiation, exchange with the atmosphere, heat loss on evaporation or input of the heat at condensation) varies along with meteorological conditions [21]. The main factor that determines the thermal regime of the rivers is air temperature [3, 12]. The fluctuations of water temperature usually correspond to the changes of air temperature in general. However, the uniqueness of the relation between air temperature and water temperature in the rivers is disturbed by local features that are characterised for the river as a whole or for its individual sections. The appreciable impact on the formation of the thermal regime of the rivers has groundwater, which in winter is much warmer and in summer – colder than the water of rivers. Also, the thermal regime of rivers is in a significant degree determined by human economic activity [4, 10, 19].

The analysis of publications related to the impact of climate warming of Ukraine and other countries of the world on the temperature regime of the rivers indicates significant changes of water temperature [9, 11, 14, 20, 22, 23, 24, 26]. In addition, according to projections and researches, significant changes of water temperature of the rivers throughout this century will occur and they occur due global warming [24]. Thus, the thermal regime of the rivers is one of the issues that have significant scientific and practical interest.

The topic of this paper is determined not only by the fact that in the current climate conditions it is important to investigate the water temperature and by the fact that most of rivers of study basin feel the impact of human economic activity. It leads to changes in thermal regime in turn. So, the goal of this paper is investigatation of the long-term tendencies and homogeneity of the average annual water temperature and air temperature in the Siverskyi Donets River Basin. It will allow to reveal possible changes and to analyze reasons for these changes.

2. MATERIAL AND METHODS

2.1. Study area

Siverskyi Donets River is the largest river in eastern Ukraine and the largest tributary of the Don River (Fig.1).

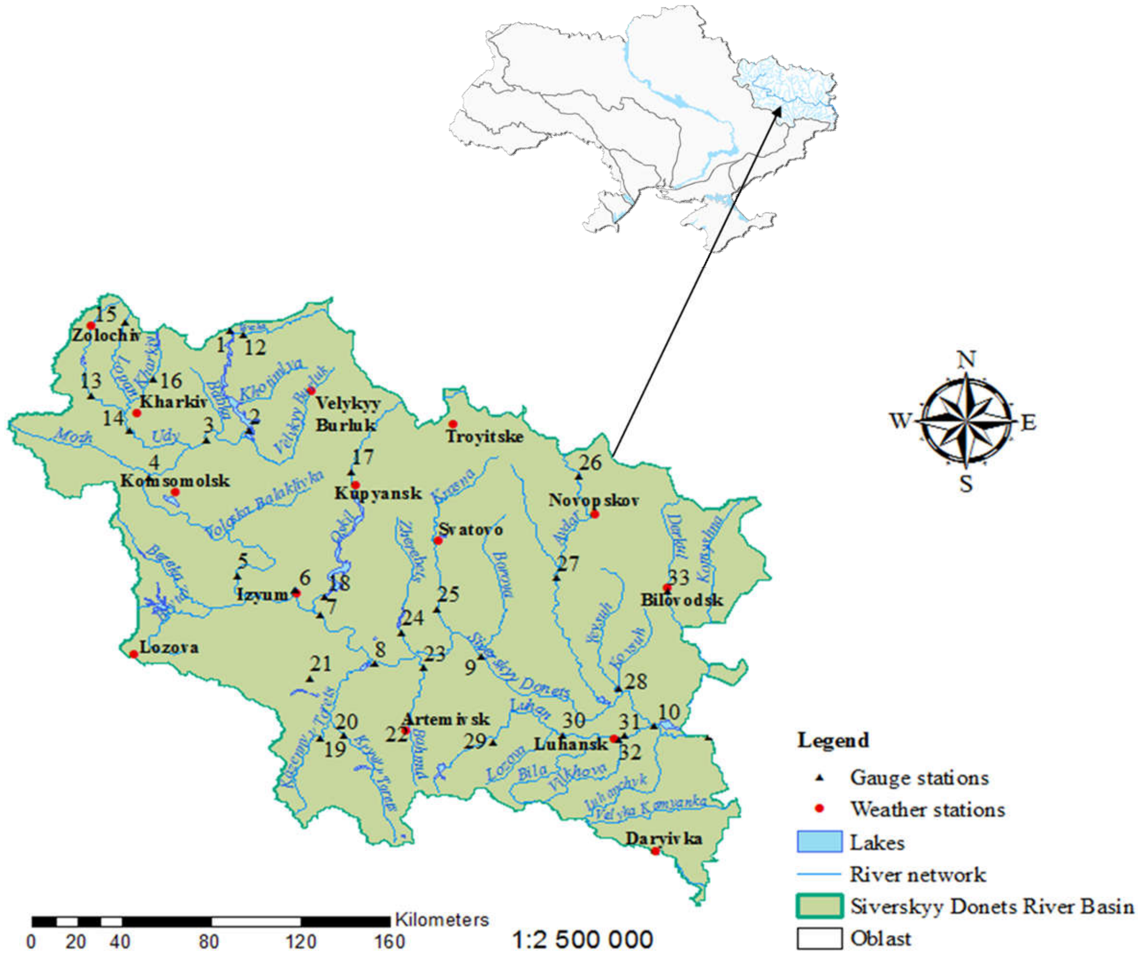

Fig.1. Location of the river water gaugings and weather stations in the Siverskyi Donets River Basin (within Ukraine) used in this study (numbering of stations is based on Table 3).

The total length of the river is 1053 km, and the area of its drainage basin is 98 900 km². The average slope to the mouth is 18 cm per 1 km. The source of the river is on the southern slopes of the Central Russian Upland in Belgorod region (Russia) (51°01'41" N, 36°57'53" E). Then it flows through the territory of Kharkiv, Donetsk and Luhansk region of Ukraine and it enters into the Don River within Belgorod region (Russia) (47°36′02″N, 40°54′50″ E). The Ukrainian part of the basin due to its size and impact on the runoff is main (the length of the river is 700 km, the area of its drainage basin – 54 500 km² within Ukraine) (55% of the total the catchment area) [21].

Hydrographically the Siverskyi Donets River Basin can be divided into: 1) the left-bank part where the most significant rivers are flowing out on the south-western slopes of the Central Russian Upland; 2) the right-bank part where the rivers are flowing from the western, southern and eastern slopes of the Donetsk ridge. In the upper part the width of the valley of the Siverskyi Donets River is 8-12 km, near the Zmiyiv town – up to 60 km, downstream it varies from 4 to 26 km. In the upper part to the Belgorod town, the floodplain is narrow, swampy, the width of the river is 10-20 m. In the lower part the valley is expanding and the width of the floodplain is 3-4 km. Almost on all the way to the city of Izyum the valley is rich in numerous lakes and in places it is swampy. The channel is meandering, especially to the fall of the Oskil River. Long-term average annual water discharge in gauging section Siverskyi Donets River – Kruzhylivka village is 137 $m^3 s^{-1}$ (1957-2010) [15].

The thermal regime of most rivers in the Siverskyi Donets River Basin is significantly influenced by human economic activities. That is dumping of industrial and domestic waste water, mine water into the rivers. Furthermore, in winter the mine water is warmer, and in summer it is sometimes colder than water in the rivers. Therefore, the human economic activity is more affecting in the winter and during the transition periods. For example, the average water temperature for ten days, is not lower than 1-2 °C on the gauging station Vilkhova River-Luhansk town, even in harsh winters.

In addition, the runoff of the Siverskyi Donets River is very overregulated, that, in turn, is changing the regime of the velocities and depths, and leads to changes in thermal regime [16].

2.2. Data and methods

Database of the average monthly water temperature of the Siverskyi Donets River Basin was created in the first stage of the investigation. Thirty-three water gauging stations were selected for this study (Table 1). The period of observation on these gauging stations is from 24 (Lopan River – Kozacha Lopan village) to 61 years (Vilkhova River – Luhansk town) (since the start of observations till 2013 inclusive) (Table 3) [15, 17].

Table 1. List of gauging stations in the Siverskyi Donets River Basin

(F – catchment area, L – length from the mouth)

River	Water gauge	F, (km^2)	L, (km)	River	Water gauge	F, (km^2)	L, (km)
1	2	3	4	1	2	3	4
Siverskyi Donets	Ohirtseve village	5540	943	Oskil	Kupyansk town	12700	121
Siverskyi Donets	Pechenihy village (below)	8400	874	Oskil	Chervonooskilska HES (below)	14700	12
Siverskyi Donets	Chuhuyiv town	10300	837	Kazennyi Torets	Rayske village	936	72
Siverskyi Donets	Zmiyiv town	16600	793	Kryvyi Torets	Oleksiyevo-Druzhkivka village	1530	13
Siverskyi Donets	Protopopivka village	19400	650	Sukhyi Torets	Cherkacke village	1310	21
Siverskyi Donets	Izyum town	22600	602	Bahmut	Artemivsk town	433	50
Siverskyi Donets	Yaremivka village	38300	573	Bahmut	Siversk town	1560	11
Siverskyi Donets	Starodubivka village	44400	510	Zherebets	Torske village	857	16
Siverskyi Donets	Lysychansk town	52400	430	Krasna	Chervonopopivka village	2540	20
Siverskyi Donets	Stanytsya-Luhanska village	66800	298	Aydar	Bilolutsk village	2250	183
Siverskyi Donets	Kruzhylivka village	73200	263	Aydar	Novoselivka village	6370	107
Vovcha	Vovchansk town	1330	5.8	Yevsuh	Petrivka village	784	8.5
Udy	Peresichna village	905	75	Luhan	Kalynove village	751	130
Udy	Bezlyudivka village	3300	42	Luhan	Zymohirya town	1820	66
Lopan	Kozacha Lopan village	189	65	Luhan	Luhansk town	3510	22
Kharkiv	Tsyrkuny village	890	23	Vilkhova	Luhansk town	814	0.9
				Derkul	Bilovodsk village	1380	110

The average annual water temperature for each year was calculated on the basis of the average monthly water temperature. However, for each gauging stations, the number of years in the observation period is different, because the average values in some years for some months are missing. This, in turn, does not allow to calculate correctly the average annual value of water temperature. Therefore, such years were not taken into account for analysis.

Data from 14 weather stations were used to analyze average annual air temperature.

According to [25], for processing of the observational data, one must adhere to the conditions of homogeneity and stationarity of the members of a statistical series [12]. In this paper the hydro-genetic analysis of homogeneity of the average annual water temperature and air temperature was carried out. Methodological approaches to the assessment of the homogeneity and stationarity of hydrological series based on hydro-genetic methods (the mass curves, the difference integral curves, the combined chronological graphs) are used. This approach was developed by Gorbachova [6].

The mass curve is a graph of the accumulation of values of the variable in time [2, 7]. In the graph the axis of the ordinate is plotted with the scale for increasing values of the temperature and the axis of the abscissa – with periods in calendar order. As a result of the consistent accumulation of temperatures we obtain a mass temperature curve. If the mass curve will not be characterized by "jumping", "emissions" or unidirectional deviation, then the water temperature of the river in the study area will be homogeneous, and conversely. The mass curve is defined by formula [18]:

$$W = \sum_{t=1}^{T} w(t), \quad (1)$$

Where W is the total flow of the river for period time T and $w(t)$ is the flow of *t-th* year.

Analysis of long-term fluctuations of hydrometeorological elements was carried out by the residual mass curve (the graphs of successive accumulation of the deviations from arithmetic average) that allows to clearly identify periods of increasing or decreasing of the studied characteristic and to establish clear limits for individual periods [2, 7]. The residual mass curve is defined according to [2]:

$$\frac{\sum_{t=1}^{T}(k(t)-1)}{Cv} = f(t), \quad (2)$$

Where Cv is the variation coefficient of streamflow, $k(t)=Q(t)/Q_0$ is the modular ratio,

$Q(t)$ is the discharge of *t-th* year and Q_0 is the average discharge for the time period *T*.

The combined chronological graphs of hydrometeorological characteristics allow defining synchronicity (asynchronicity) and synchronicity phase (asynchronicity phase) of long-term fluctuations of the studying characteristic on the various rivers within the one hydrological homogeneous area. In turn, the synchronous fluctuations indicate on the homogeneous climatic conditions in study area [7].

For comparison of the results the graphs of the long-term dynamics and the residual mass curves were created in the modular ratio (K_A) according to:

$$K_A = A_i / \overline{A}, \quad (3)$$

Where A_i is the value i-element of the series and $\overline{A}$ is the average of the series.

In order to analyze the relation between the average annual air temperature and the average annual water temperature the matrix was created of their pair correlation coefficients.

The graphical processing of input observations data was carried out using program Hydroparser, which is the project available on the Internet site GitHub (developer is Oleksandr Zabolotnii). The map showing river gauges and weather stations in the Siverskyi Donets River Basin (within Ukraine) is created by author. Layer of the river basin edge is automatically extracted from SRTM HydroSHEDS conditioned DEM (by Dmytro Hlotka conducted at UHMI, "Implementation Act № 1050/0/6-17 from 6 June 2017") and are officialy used in Ukraine for RBD and sub-basins delineation under the EU WFD (Water Framework Directive). The schematic map of the Siverskyi Donets River Basin within Ukraine was taken by following link: http://river.land.kiev.ua/seversky-donets.html.

3. RESULTS AND DISCUSSION

The synchronous fluctuations of the air temperature are observed at all weather stations, although they are located in the different parts of the study area (Fig. 2). It indicates the same influence of air temperature on the water temperature of rivers at all gauging stations.

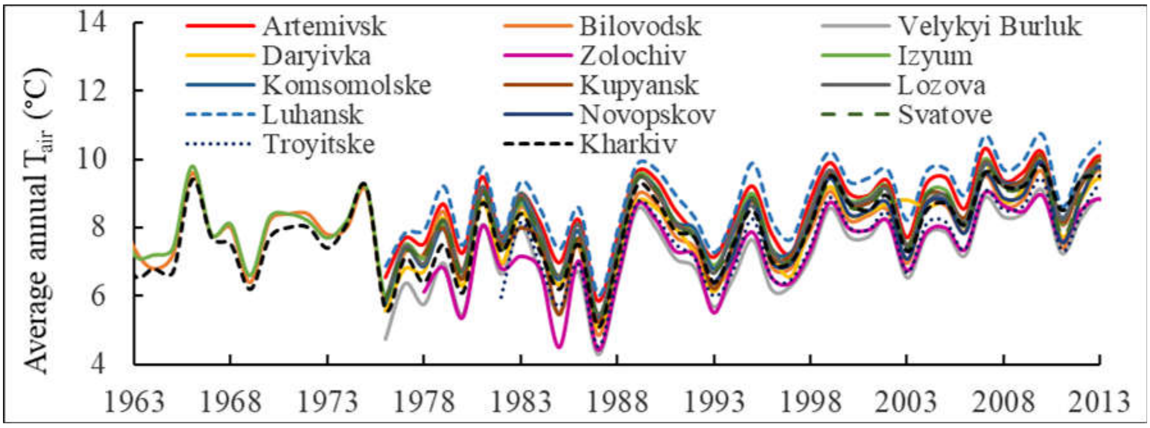

Fig.2. Long-term fluctuations of average annual T_{air} in the Siverskyi Donets River Basin

Time series of the average annual water temperature in the study basin has synchronous fluctuations in all 33 hydrological points. It is indication that the observations data are homogeneous. The examples of such fluctuations for some rivers are shown on Fig. 3.

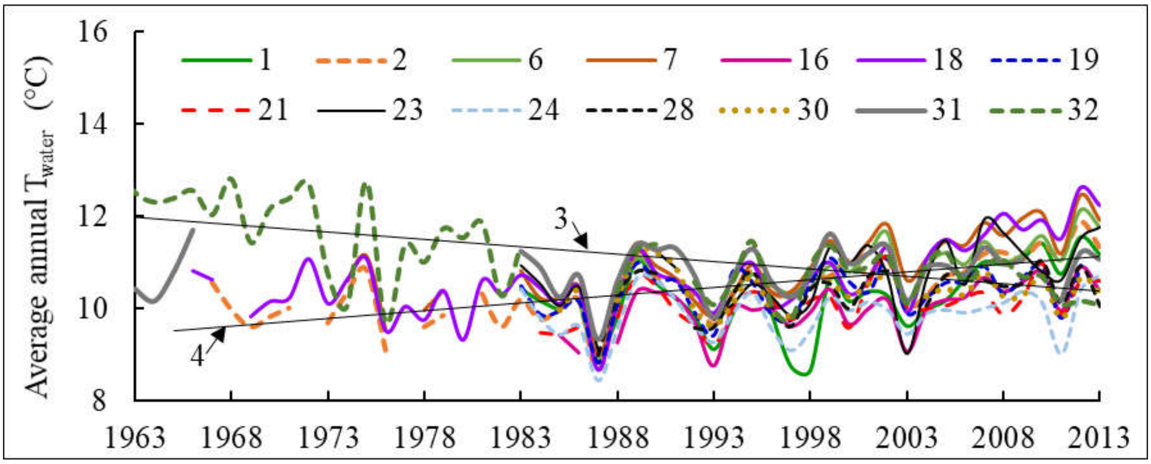

Fig.3. Long-term fluctuations of average annual T_{water} in the Siverskyi Donets River Basin: line of trend of the gauge: 3 – Vilkhova River – Luhansk town; 4 – Siverskyi Donets River – Pechenihy village (below) (numbering of stations is based on Table 3).

According to combined chronological graphs, the average annual air temperature at all weather stations (Fig.2) and water temperature almost at all gauging stations (Fig.3) in the Siverskyi Donets River Basin has total increasing tendency. At 8 gauges, the tendency to decrease the average annual temperature of water, caused by significant anthropogenic influence in some years, is observed (Fig. 3). According to observations data at all gauges the average value of the long-term average annual water temperature of rivers of the Siverskyi Donets River Basin has different study period (Table 3). It does not allow to carry out the correct comparative analysis for long-term period at all gauges. Thus, the common period for calculation was chosen. It is 2004-2013. For most gauges average value the long-term average annual water temperature of rivers of the Siverskyi Donets River Basin ranges from 8,8 °C (Lopan River – Kozacha Lopan village) to 14,6 °C (Udy River – Bezlyudivka village) for this period (Table 2). Average annual water temperature for some gauges was calculated only for last available continuous periods (Siverskyi Donets River – Chuhuyiv town – 11,3 °C and Luhan River – Luhansk town – 10,8 °C for 2011-2013; Kryvyi Torets River – Oleksiyevo-Druzhkivka village – 12,6 °C and Aydar River – Bilolutsk village – 10.0 °C for 2009-2013). For hydrological point Kazennyi Torets River – Rayske village the average value is calculated until 2012.

The analysis change of average value of average annual water temperature for two decades (1994-2003 and 2004-2013) has been carried out. Since the average annual water temperature is synchronous in all 33 gauging stations (Fig. 3), 17 gauges with the longest observation period (from 20 years of continuous observation) are selected for the study. According to Table 4, the average value of water temperature for 2004-2013 in compare to 1994-2003 has increased from 0.1 °C (Krasna River – Chervonopopivka village and Sukhyi Torets River – Cherkacke village) to 1.2 °C (Oskil River – Chervonooskilska HES (below)).

Table 2. Avarage value of average annual T_{water} (°C) for different study period in the gauges of the Siverskyi Donets River Basin

River	Water gauge	1965-2013	1969-2013	1974-2013	1979-2013	1984-2013	1989-2013	1994-2013	1999-2013	2004-2013	2009-2013
Siverskyi Donets	Ohirtseve village	-	-	-	-	-	-	-	10,7	10,9	11,2
Siverskyi Donets	Pechenihy village (below)	-	-	-	-	10,6	10,8	10,9	11,0	11,1	11,4
Siverskyi Donets	Zmiyiv town	-	-	-	-	-	11,7	11,7	12,0	12,2	12,6
Siverskyi Donets	Protopopivka village	-	-	-	-	-	-	-	-	11,7	11,9
Siverskyi Donets	Izyum town	-	-	-	-	-	-	11,0	11,2	11,3	11,5
Siverskyi Donets	Yaremivka village	-	-	-	-	11,0	11,2	11,3	11,6	11,7	11,9
Siverskyi Donets	Starodubivka village	-	13,2	13,0	12,9	12,8	12,8	12,6	12,8	13,0	13,4
Siverskyi Donets	Lysychansk town	-	-	-	-	-	-	-	-	11,8	11,8
Siverskyi Donets	Stanytsya-Luhanska village	-	-	-	-	-	-	-	12,3	12,5	12,6
Siverskyi Donets	Kruzhylivka village	-	-	-	-	-	-	-	-	12,3	12,5
Vovcha	Vovchansk town	-	-	-	-	-	-	-	-	10,2	10,2
Udy	Peresichna village	-	-	-	-	-	-	9,5	9,6	9,7	9,8
Udy	Bezlyudivka village	14,1	14,2	14,3	14,3	14,6	14,6	14,4	14,6	14,6	14,7
Lopan	Kozacha Lopan village	-	-	-	-	-	-	8,6	8,7	8,8	9,1
Kharkiv	Tsyrkuny village	-	-	-	-	-	10,1	10,2	10,2	10,4	10,5
Oskil	Kupyansk town	-	-	-	-	-	-	10,3	10,4	10,4	10,6
Oskil	Chervonooskilska HES (below)	-	10,7	10,7	10,8	10,9	11,0	11,2	11,4	11,8	12,0
Kazennyi Torets	Rayske village	-	-	-	-	10,3	10,5	10,5	10,6	10,6	10,6
Sukhyi Torets	Cherkacke village	-	-	-	-	-	10,2	10,2	10,3	10,3	10,5
Bahmut	Artemivsk town	-	-	-	11,2	11,4	11,6	11,6	11,8	11,8	11,7
Bahmut	Siversk town	-	-	-	-	-	-	10,8	11,0	11,2	11,2
Zherebets	Torske village	-	-	-	-	9,9	10,0	9,9	10,0	10,1	10,1
Krasna	Chervonopopivka village	-	-	-	-	-	9,3	9,4	9,5	9,5	9,6
Aydar	Novoselivka village	-	-	-	-	-	-	-	-	11,1	11,4
Yevsuh	Petrivka village	-	-	-	-	-	-	-	-	10,5	10,5
Luhan	Kalynove village	-	-	-	-	-	-	-	10,6	11,0	11,0
Luhan	Zymohirya town	-	-	-	-	-	-	-	-	10,4	10,4
Vilkhova	Luhansk town	-	-	-	-	-	-	10,7	10,7	10,6	10,3
Derkul	Bilovodsk village	-	-	-	-	-	-	-	-	10,5	10,5

Table 3. Long-term average annual T_{water} in the gauges of the Siverskyi Donets River Basin (N – number of years present in the study period, % – percentage of missing data)

№	River	Location of the gauging station	Study period	T_{water}, (°C)	N, years	%
1	2	3	4	5	6	7
1	Siverskyi Donets	Ohirtseve village	1966-2013	10.3	31	35
2	Siverskyi Donets	Pechenihy village (below)	1965-2013	10.4	45	8
3	Siverskyi Donets	Chuhuyiv town	1981-2013	10.2	29	12
4	Siverskyi Donets	Zmiyiv town	1955-2013	11.6	44	25
5	Siverskyi Donets	Protopopivka village	1982-2013	11.2	29	9
6	Siverskyi Donets	Izyum town	1981-2013	10.8	28	15
7	Siverskyi Donets	Yaremivka village	1966-2013	10.9	39	19
8	Siverskyi Donets	Starodubivka village	1963-2013	13.4	50	2
9	Siverskyi Donets	Lysychansk town	1953-2013	11.8	51	16
10	Siverskyi Donets	Stanytsya-Luhanska village	1950-2013	13	45	30
11	Siverskyi Donets	Kruzhylivka village	1958-2013	12.6	52	7
12	Vovcha	Vovchansk town	1981-2013	9.7	30	9
13	Udy	Peresichna village	1983-2013	9.3	30	3
14	Udy	Bezlyudivka village	1958-2013	13.9	51	9
15	Lopan	Kozacha Lopan village	1983-2013	8.5	24	23
16	Kharkiv	Tsyrkuny village	1985-2013	10	28	3
17	Oskil	Kupyansk town	1982-2013	10.1	30	6
18	Oskil	Chervonooskilska HES (below)	1966-2013	10.7	47	2
19	Kazennyi Torets	Rayske village	1983-2012	10.3	30	0
20	Kryvyi Torets	Oleksiyevo-Druzhkivka village	1950-2013	12.3	53	17
21	Sukhyi Torets	Cherkacke village	1966-2013	10.1	30	38

22	Bahmut	Artemivsk town	1970-2013	11.3	41	7
23	Bahmut	Siversk town	1970-2013	10.7	32	27
24	Zherebets	Torske village	1966-2013	9.9	33	31
25	Krasna	Chervonopopivka village	1983-2013	9.2	30	3
26	Aydar	Bilolutsk village	1955-2013	9.6	33	44
27	Aydar	Novoselivka village	1955-2013	10.7	26	56
28	Yevsuh	Petrivka village	1983-2013	10.3	27	13
29	Luhan	Kalynove village	1955-2013	10.1	36	39
30	Luhan	Zymohirya town	1975-2013	10.5	29	26
31	Luhan	Luhansk town	1958-2013	11	38	32
32	Vilkhova	Luhansk town	1947-2013	11.4	61	9
33	Derkul	Bilovodsk village	1970-2013	9.8	37	16

Table 4. Average value of average annual water temperature (T_{water}) of the Siverskyi Donets River Basin for two periods (T – temperature difference between two periods)

River	**Water gauge**	**T_{water} (°C)**		**T, (°C)**
		1994-2003	**2004-2013**	
Siverskyi Donets	Pechenihy village (below)	10,6	11,1	0,5
Siverskyi Donets	Zmiyiv town	11,3	12,2	1,0
Siverskyi Donets	Izyum town	10,7	11,3	0,6
Siverskyi Donets	Yaremivka village	10,9	11,7	0,8
Siverskyi Donets	Starodubivka village	12,2	13,0	0,8
Udy	Peresichna village	9,3	9,7	0,4
Udy	Bezlyudivka village	14,3	14,6	0,4
Lopan	Kozacha Lopan village	8,8	8,4	0,4
Kharkiv	Tsyrkuny village	10,4	9,9	0,5
Oskil	Kupyansk town	10,4	10,2	0,2
Oskil	Chervonooskilska HES (below)	10,6	11,8	1,2
Sukhyi Torets	Cherkacke village	10,2	10,3	0,1
Bahmut	Artemivsk town	11,4	11,8	0,4
Bahmut	Siversk town	10,4	11,2	0,8
Zherebets	Torske village	9,8	10,1	0,2
Krasna	Chervonopopivka village	9,3	9,5	0,1

Average value of the long-term average annual air temperature within the basin ranges from 7,2 °C (weather stations Velykyi Burluk and Zolochiv) to 8,9 °C (weather station Luhansk) for period 1976-2013, and from 7,7 °C (weather stations Kharkiv) to 8,1 °C (weather stations Izyum) for period 1944-2013 (Table 5).

Table 5. Long-term average annual air temperature (T_{air}) at weather stations in the Siverskyi Donets River Basin

№	Weather station	$T_{air,}$ (°C)	Study period	№	Weather station	Study period	$T_{air,}$ (°C)
1	Artemivsk	8.5	1976-2013	**8**	Kupyansk	1976-2013	8.2
2	Bilovodsk	7.8	1944-2013	**9**	Lozova	1976-2013	8.2
3	Velykyi Burluk	7.2	1976-2013	**10**	Luhansk	1976-2013	8.9
4	Daryivka	7.9	1976-2013	**11**	Novopskov	1993-2013	8.4
5	Zolochiv	7.2	1976-2013	**12**	Svatove	1976-2013	8.1
6	Izyum	8.1	1944-2013	**13**	Troyitske	1982-2013	7.6
7	Komsomolske	8.2	1976-2013	**14**	Kharkiv	1944-2013	7.7

According to hydro-genetic analysis of the mass curves of the average annual air and water temperature in study basin it was found that series of observations is homogeneous, because there was received the visually homogeneous series with no significant "jumping" or unidirectional deviations (Fig. 4 a; Fig. 5 a, c, e, g, i, k, m, o, q). Some sligth variations in the curves direction are associated with long-term fluctuations (Fig. 4 b; Fig. 5 b, d, f, h, j, l, n, p, r).

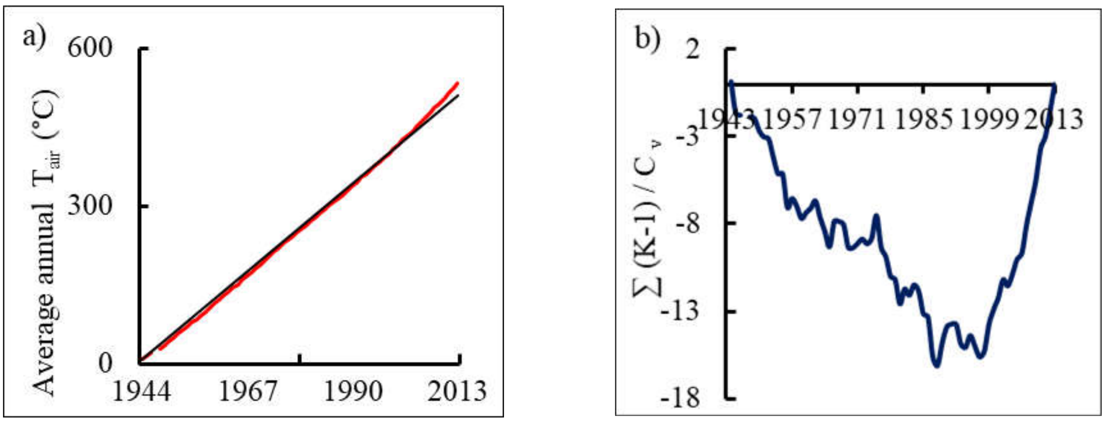

Fig. 4. The mass curve (a) and residual mass curve (b) of the average annual air temperature (°C) of the weather station Kharkiv in the Siverskyi Donets River Basin

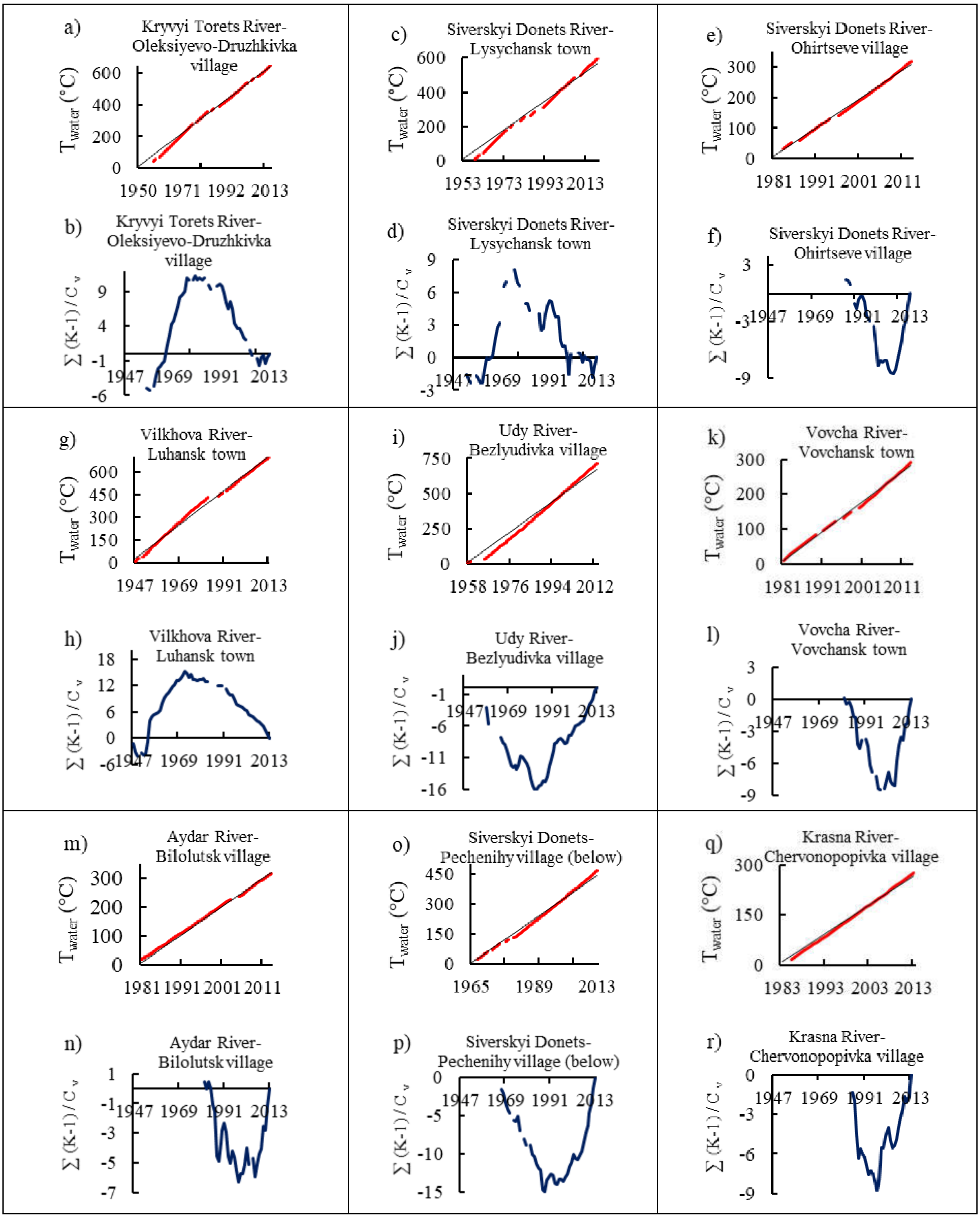

Fig. 5. The mass curves (a, c, e, g, i, k, m, o, q) and residual mass curves (b, d, f, h, j, l, n, p, r) of the average annual water temperature (°C) in gauges of the Siverskyi Donets River Basin

The graphs of the residual mass curves of the average annual water temperature and air temperature for all 33 gauges and 14 weather stations of the study basin were created (Fig. 6).

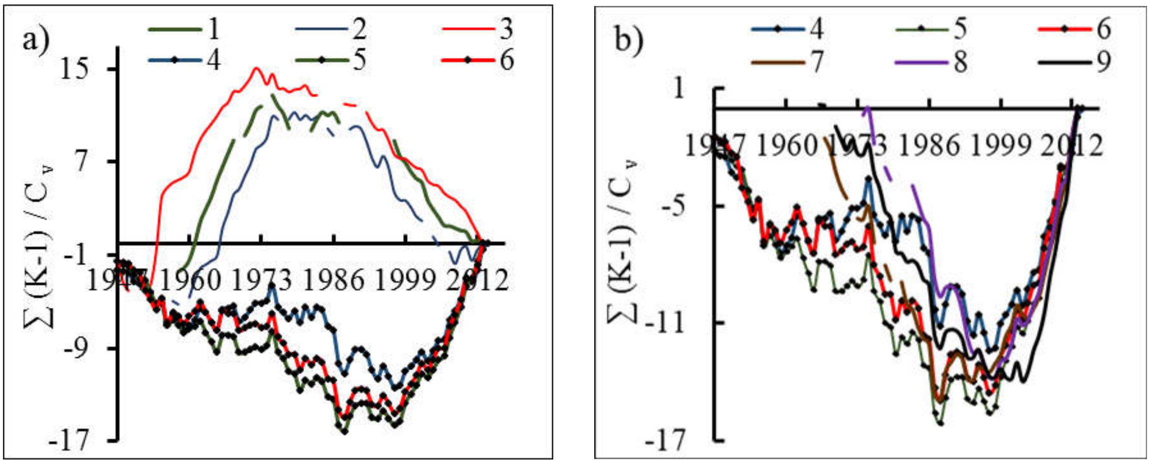

Fig. 6 – The residual mass curves of the long-term fluctuations of the average annual water temperature (°C) (1 – Siverskyi Donets River – Stanytsya-Luhanska village; 2 – Kryvyi Torets River – Oleksiyevo-Druzhkivka village; 3 – Vilkhova River – Luhansk town; 7 – Siverskyi Donets River – Pechenihy village; 8 – Siverskyi Donets River – Yaremivka village; 9 – Oskil River – HES Chervonooskilska (below)) and air temperature (°C) (4 – weather station Bilovodsk; 5 – weather station Kharkiv; 6 – weather station Izyum) in the Siverskyi Donets River Basin.

The almost all curves (Fig. 6) indicate that at the end of the 80s of the 20th century the average annual air temperature and water temperature of rivers has increasing tendency. The exceptions are 8 gauging stations (Fig. 6a), which at the same time have decreasing tendency. One can assume that one of the factors of decreasing of water temperature on these stations is the reduction of capacity the of thermal power station and, thus, dumping heat (e.g., Luhansk power station worked less powerfully in the second half of the 90s of the 20th century than in 1975-1990). However, for the period 1991-2013, at all 33 gauging stations there is the same increasing tendency in water temperature since the late 90's of the 20th century – the beginning of the 21st century.

The Ukrainian and foreign scientists indicate in their researches that the increase of air temperature at the late 80's and early 90's of the 20th century led to changes of water temperature of other rivers of our planet [11, 13, 20, 22, 27]. That means, the results of this study are confirmed by researches of other scientists that air temperature has a major effect on the water temperature of the river. Some deviation from the main tendency is caused by local features and anthropogenic impact [13, 26].

Fig. 6 also shows that the curves of the average annual water temperature during the study period are synchronous. In addition, it coincides with fluctuations in average annual air temperature (Fig. 6b), and this means that series of observations of the above-indicated hydrometeorological characteristics are homogeneous. However, the residual mass curves of water temperature for 8 gauging stations (Luhan River – Zymohirya town, Luhan River – Luhansk town, Vilkhova River – Luhansk town, Kryvyi Torets River – Oleksiyevo-Druzhkivka village, Siverskyi Donets River – Kruzhylivka village, Siverskyi Donets River – Starodubivka village, Siverskyi Donets River – Lysychansk town, Siverskyi Donets River – Stanytsya-Luhanska village) are in asynchronous phase relative to other curves of 25 gauging stations and air temperature of all 14 weather stations (Fig. 6a). In turn, this indicates the human impact on the water temperature of these rivers, because these gauging stations are located in the area of river valley of the Siverskyi Donets River, that has the most intense technogenic load in the Luhansk and Donetsk region of Ukraine [28].

In order to analyze the relation between the average annual air temperature and the average annual water temperature the matrix was created of their coefficients of pair correlation. Since the average annual air temperature is synchronous in all 14 meteorological stations (Fig. 2), the weather station Belovodsk with the longest observation period are selected for the study. Due to the absence of observational data in some years, it is impossible to carry out the correlation analysis for long-term period for individual stations. So, 4 periods to compare the results were selected: 1) 1966-2013 – for stations with the longest observation period without gaps; 2) 1975-1990 – period of strong anthropogenic impact for some stations; 3) 1981-2013 – available period for most stations; 4) 1991-2013 – the period of increasing tendency of water temperature at all stations. According to the results of the correlation analysis, it was found that the correlation coefficient between the temperature of water and air is high (from 0.70 to 0.93) on most gauging stations. The least close correlation between these two variables is observed for gauging stations, which are under the significant influence of industrial waters (Table 6). If there is no value in the table, it indicates the absence of observational data. The gauging station Siverskyi Donets River – Stanytsya-Luhanska village was closed from 1989 to 1996, therefore, the correlation coefficients in the table are not available for these study periods.

Table 6. Coefficients of pair correlation between the average annual air temperature and the average annual water temperature in the Siverskyi Donets River Basin

River	Location of the gauging station	Study period			
		1966-2013	1975-1990	1981-2013	1991-2013
1	2	3	4	5	6
Siverskyi Donets	Ohirtseve village	-	-	0.76	0.74
Siverskyi Donets	Pechenihy village (below)	0.75	0.84	0.79	0.76
Siverskyi Donets	Chuhuyiv town	-	-	0.77	0.71
Siverskyi Donets	Zmiyiv town	-	-	0.77	0.78
Siverskyi Donets	Protopopivka village	-	-	0.85	0.72
Siverskyi Donets	Izyum town	-	-	0.76	0.78
Siverskyi Donets	Yaremivka village	-	0.93	0.85	0.86
Siverskyi Donets	Starodubivka village	0.34	0.59	0.38	0.54
Siverskyi Donets	Lysychansk town	-	-	0.49	0.65
Siverskyi Donets	Stanytsya-Luhanska village	-	-	-	-
Siverskyi Donets	Kruzhylivka village	-	-	0.50	0.62
Vovcha	Vovchansk town	-	-	0.79	0.72
Udy	Peresichna village	-	-	-	0.86
Udy	Bezlyudivka village	0.33	0.33	0.35	0.46
Lopan	Kozacha Lopan village	-	-	-	0.68
Kharkiv	Tsyrkuny village	-	-	-	0.78
Oskil	Kupyansk town	-	-	0.85	0.78
Oskil	Chervonooskilska HES (below)	0.79	0.89	0.81	0.77
Kazennyi Torets	Rayske village	-	-	-	0.77
Kryvyi Torets	Oleksiyevo-Druzhkivka village	-	-	-	0.66
Sukhyi Torets	Cherkacke village	-	-	-	0.65
Bahmut	Artemivsk town	-	0.44	0.60	0.73
Bahmut	Siversk town	-	-	0.84	0.80
Zherebets	Torske village	-	-	0.86	0.79
Krasna	Chervonopopivka village	-	-	-	0.72
Aydar	Bilolutsk village	-	-	0.90	0.85
Aydar	Novoselivka village	-	-	-	0.86
Yevsuh	Petrivka village	-	-	-	0.66
Luhan	Kalynove village	-	-	0.78	0.72
Luhan	Zymohirya town	-	-	-	0.70
Luhan	Luhansk town	-	-	-	0.82
Vilkhova	Luhansk town	-	-	-	0.55
Derkul	Bilovodsk village	-	0.86	0.80	0.81

The relation between the average annual values of the water temperature and air is shown in the form of curves for 1966-2013 (Fig. 8). They clearly demonstrate the close corelation between the annual mean values on the gauging station Siverskyi Donets River – Pechenihy village (below) (Fig. 7 a). This gauging station is located in the upper part of the basin (Kharkiv region).

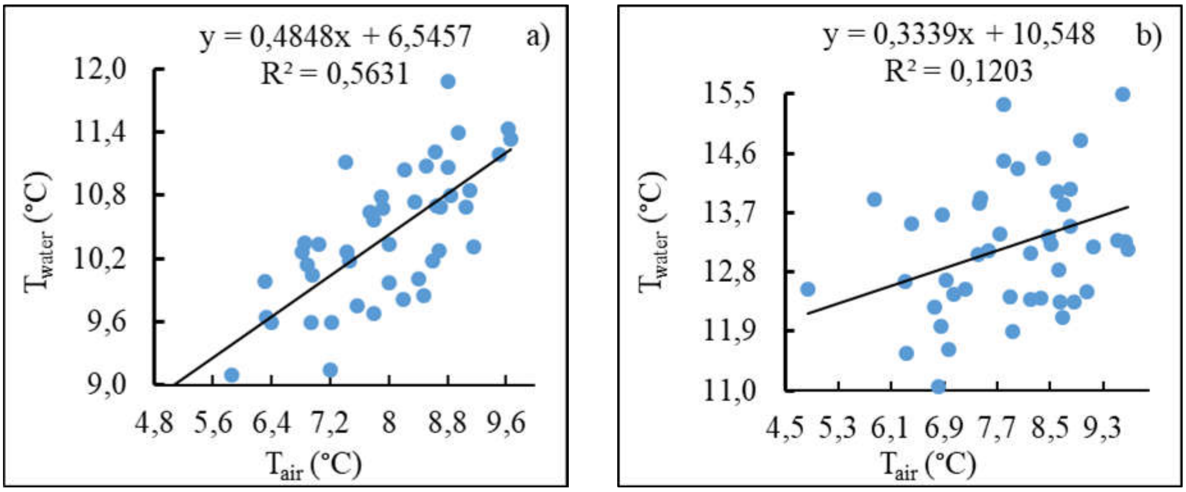

Fig. 7. The relation between the average annual water and air temperatures in the Siverskyi Donets River (1966-2013) (a – weather station Bilovodsk and water gauge Siverskyi Donets River – Pechenihy village (below); b – weather station Bilovodsk and water gauge Siverskyi Donets River – Starodubivka village)

The average annual water temperature on the gauging station Siverskyi Donets River – Starodubivka village has a slight correlation with the average annual air temperature (Fig. 7 b). This gauging station is located in the lower part of the basin within Ukraine (Donetsk region), where the area of the study basin has the largest industrial load.

4. CONCLUSION

The estimation of the long-term tendencies (from start of observations till 2013 inclusive) and homogeneity of the average annual water temperature of the rivers and average annual air temperature in the Siverskyi Donets River Basin (within Ukraine) was carried out by hydro-genetic methods. The analysis of the mass curves allowed to visually determine the homogeneity of the series of observations of the water temperature and air in the study basin, because these curves do not have unidirectional deviations or significant "jumping". Some sligth variations in the curves direction are associated with long-term fluctuations. The results of this study by the rezidual mass curves showed that the long-term fluctuations of the average annual air and water temperature in the Siverskyi Donets River Basin are synchronous and in synchronous phase. The exceptions are 8 gauging stations, because their residual mass curves of the average annual water temperature are synchronous, but they are in asynchronous phase relative to curves of other 25 gauging stations and curves of the average annual air temperature of all 14 weather stations. In general, it was found that there is tendency to increase the average annual water temperature of rivers, that is caused by corresponding increase of air temperature, from the end of 80s of the 20th century in the Siverskyi Donets River Basin. The opposite tendency in the long-term fluctuations, caused by anthropogenic influence, mainly show the gauging stations with the least close correlation between the air temperature and water temperature.

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