Water resources and wetlands, *Editors: Petre Gâştescu, William Lewis Jr., Petre Breţcan*
Conference Proceedings, 14-16 September 2012, Tulcea - Romania
ISBN: 978-606-605-038-8

THE DYNAMICS AND PROBABILISTIC CHARACTERISTICS OF THE ICE PHENOMENA OF THE DANUBE RIVER AND ITS KILIYSKY CHANNEL

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Abstract

The analysis of the long-term dynamics of the dates of the ice phenomena and their duration on the Danube river and its Kiliysky channel on the base of the total and difference integral curves, the statistical Fisher`s and Stjudent`s criteria, as well as the statistical significance of the linear trends was carried out. The earliest, the means and the latest dates of the appearance and disappearances of the ice phenomena, as well as their mean and the most duration were defined. The analytical curves of the binomial distribution of the dates of the ice phenomena and curves of the three-parameter gamma-distribution of the duration of the ice phenomena was created that allowed to define the probabilistic characteristics of the main phases of the ice phenomena.

Keywords: stationary, ice phenomena, climate change, long-term dynamics, integral curves, cycling fluctuations

1 INTRODUCTION

The ice phenomena on the Danube River influence essential on the activity of the water transport. The determination of the calculated characteristics of the ice phenomena of the Danube river and its Kiliysky channel was carried out in the past century (seventieth years) (Scherbak at al., 1970; Solopenko at al., 1974) that is why the modern generalization of the observed data has as scientific, so and practical importance. In many researches is indicated that the climate change is influencing directly upon water regime of the rivers and breach the stationarity of the observations data and as result the use of the traditional statistical methods of the processing of the observations data is impossible. The temperature of the air is one of the main factors of the forming of the ice phenomena on the rivers. The temperature tends to increase during the last decade that is why the researches of the long-term dynamics of the ice phenomena will allow to define the possible changes of their characteristics at time and will analyze the reasons of such changes. The goal of the research is the analyses of the long-term dynamics of the dates of the appearance of the ice phenomena and disappearances them, of the duration period with the ice phenomena, as well as the determination of the probabilistic characteristics of the ice phenomena the Danube River and its Kiliysky channel.

2 METHOD

The observations for ice phenomena on the Danube river (on territory of Ukraine) and its Kiliysky channel is carrying out on 4 hydrological gauges: Danube river - Reni town, Danube river (Kiliysky channel) - Izmail town, Danube river (Kislitsky channel) - Kislitsa village, Danube river (Kiliysky channel) - Kiliya town (Fig.1).

The analysis of the long-term dynamics of the ice phenomena was carried out by the total and integral curves, the statistical Fisher`s and Stjudent`s criteria and by statistical significance of linear trends. The estimation of the stationarity of the long-term fluctuations of the ice phenomena was carried out by an assessment of the statistical significance of the linear trends (MRAH, 2010). In turn, the statistical significance of the trends is defined by the statistical significance of the correlation coefficient (R). The correlation coefficient of this dependence is estimating on the relation to the standard deviation (σ_R):

$$R / \sigma_R \geq \beta \tag{1}$$

If as a result of the above-stated calculations it will appear that the trend significantly (at the given significance level) differs from zero, i.e. the double of standard deviation of the correlation coefficient is much less than of the correlation coefficient, it indicates no stationarity of the long-term fluctuations of the ice phenomena, i.e. the inhomogeneity its at time, and on the contrary, if $\sigma_R > R$ – the homogeneity of the ice phenomena at time. For 5 % of the significance level or for 95 % confidential limit $\beta=2$.

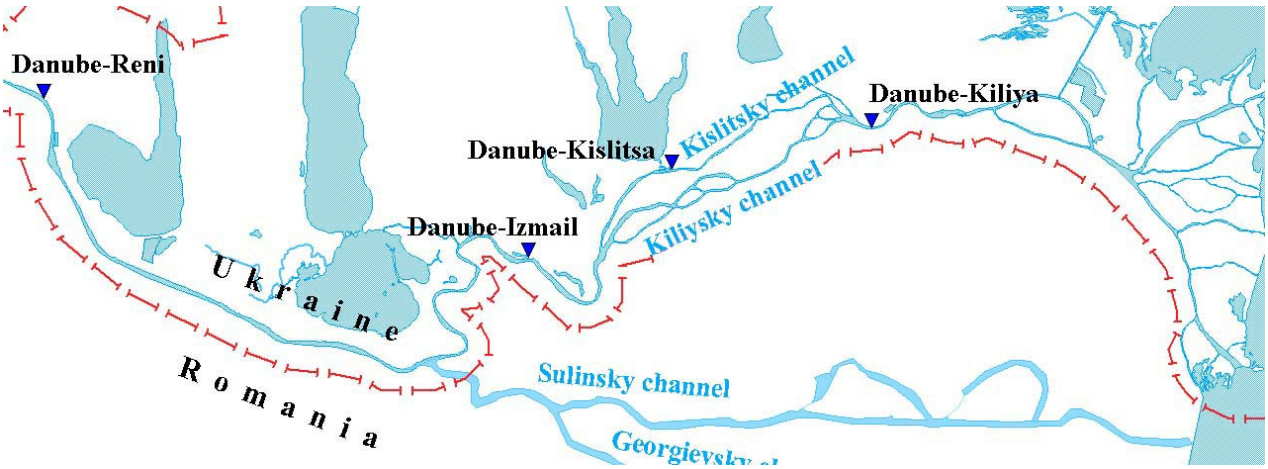

Figure 1 The location of the hydrological gauges on the Danube river and its Kiliysky channel

The standard deviation of the correlation coefficient for n >25 was defined according to:

$$\sigma_R = \left(1 - R^2\right) / \sqrt{n-1}\,, \tag{2}$$

where R – the correlation coefficient; n – the total number of the observation series.

The empirical probability of the ice phenomena was calculated according to:

$$P_m = \left[m / (n+1)\right] 100\%\,, \tag{3}$$

where m – the serial number on the observations series of the characteristics (appearance, disappearance, duration) of the ice phenomena which situated in decreasing order; n – the total number of the observations series.

When the probabilistic distribution of the dates of the main phases of the ice regime of the rivers is calculated then their statistical data were situated from early to late dates, i.e. the early dates have the small values of the frequency, but the late dates have the greater values of the frequency. For smoothing and extrapolations of the empirical curves of the distribution was used the binomial distribution.

The parameters of the analytical curves of the distribution of the dates of the ice phenomena (the mean value ($\overline{D}$), the standard deviation (σ_D), the coefficient of skewness (C_s)) were defined according to formulas (Ginzburg, 1973):

$$\overline{D} = \sum_{i=1}^{n} D_i\,, \tag{4}$$

$$\sigma_D = \sqrt{\sum_{i=1}^{n} \left(\overline{D} - D_i\right)^2 / (n-1)}\,, \tag{5}$$

$$C_s = \sum_{i=1}^{n} \left(\overline{D} - D_i\right)^3 \Big/ n\,\sigma_D^3\,, \tag{6}$$

where D – the date of the appearance of the phases of the ice phenomena on the river; i – the serial number of the date of the ice phenomena.

The determination of the dates of the ice phenomena of the different frequency was carried out according to:

$$D_{P\%} = \overline{D} + \sigma_D \Phi\,, \tag{7}$$

where Φ – the Foster`s number.

3 RESULTS

The dynamics of the dates of the ice phenomena and their duration has statistical significant linear trends (Table 1) that are indicated on the inhomogeneity of the observations data. However, the plots of the total integral curves have no significant points of the direction fracture of the curves. It indicates on the homogeneity of the observations data, i.e. on the absences of the influence of the anthropogenic factors and global and regional change of the climate (Fig. 2). The small detours from straight line have the nature fluctuations that depend on the cycles of the main phases of the ice regime (Fig. 3) When the total curves of the dates of the ice phenomena was creating for initial values for their numeric presentation are accepted the earliest dates of the appearance (the disappearance) of the ice phenomena. The analysis of the integral curves has shown that observations data for ice phenomena does not have of the full cycles (Fig. 3).

Table 1 The estimation of the significant linear trends of the long-term dynamics of the ice phenomena on the Danube river and its Kiliysky channel

The name of gauge	The equation of the trend	R^2	R	σ_R	$2\sigma_R$	The result
appearance of the ice phenomena						
Danube river - Reni town	y = 0.27x+40390	0.09	0.29	0.14	0.28	A
Kiliysky channel - Izmail town	y = 0.25x+40425	0.08	0.28	0.14	0.29	0
Kislitsky channel - Kislitsa village	y = 0.26x+40411	0.06	0.25	0.15	0.29	0
Kiliysky channel - Kiliya town	y = 0.23x+40468	0.12	0.34	0.14	0.28	A
disappearance of the ice phenomena						
Danube river - Reni town	y = -0.3442x+41630	0.09	0.30	0.14	0.28	A
Kiliysky channel - Izmail town	y = -0.4245x+41424	0.15	0.38	0.13	0.27	A
Kislitsky channel - Kislitsa village	y = -0.1891x+41324	0.02	0.15	0.15	0.31	0
Kiliysky channel - Kiliya town	y = -0.1987x+40979	0.04	0.21	0.15	0.30	0
duration of the ice phenomena						
Danube river - Reni town	y = -0.5689x+1144	0.19	0.44	0.13	0.25	A
Kiliysky channel - Izmail town	y = -0.5552x+1117	0.17	0.41	0.13	0.26	A
Kislitsky channel - Kislitsa village	y = -0.5273x+1064	0.12	0.35	0.14	0.27	A
Kiliysky channel - Kiliya town	y = -0.4304x+869	0.15	0.39	0.13	0.27	A

"A" – the statistically significant trend, i.e. inhomogeneous

"0" - the statistically insignificant trend, i.e. homogeneous

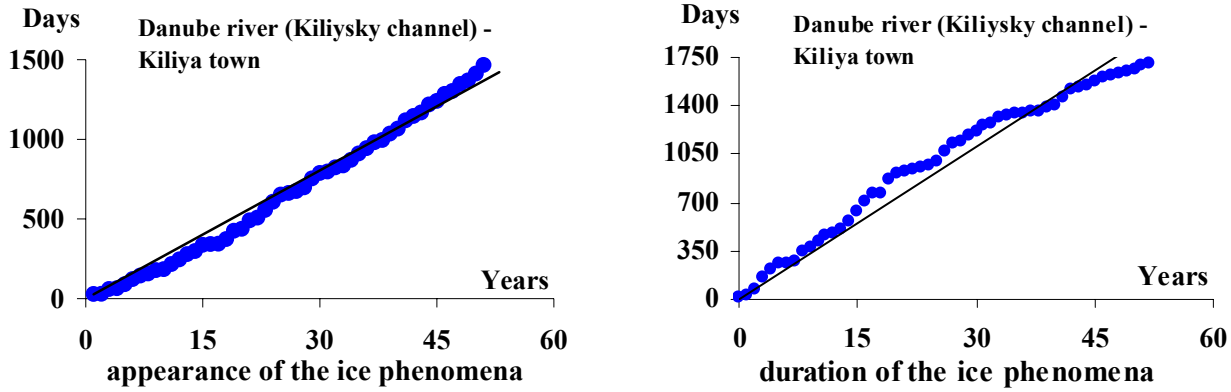

Figure 2 The total integral curves of the ice phenomena

The Danube river (Kiliysky channel) - Kiliya town gauge has the long observations series (since 1930), which has well denominated synchronous view with the observations on the other gauges. Hereupon, we can expect that the statistical significant and the insignificant trends in the observations data have the periodic natures, which depends on duration observations series and presence or absences of the full cycles. Therefore, the formation of the ice phenomena on the Danube River and its Kiliysky channel is the quasistationary that allows to carrying out the statistical processing of the observations data.

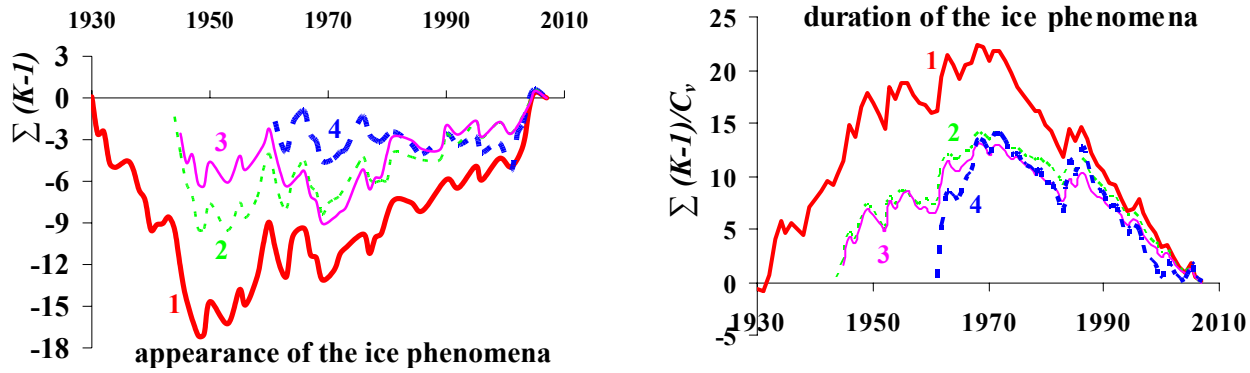

Figure 3 The difference integral curves of the fluctuations of the average annual discharges:
1 - Danube river (Kiliysky channel) - Kiliya town; 2 - Danube river - Reni town;
3 - Danube river (Kiliysky channel) - Izmail town; 4 - Danube river (Kislitsky channel) - Kislitsa village.

The quantitative estimation of the homogeneity of the observations data for ice phenomena and their duration is carried out by the statistical Fisher`s and Stjudent`s criteria at 5-% level of the significance with the interlinear and the in-row correlation. The observations data have interlinear and the in-row correlation simultaneously, except gauges: the Danube river - Reni town, the Danube river (Kiliysky channel) - Izmail town (disappearance), the Danube river (Kislitsky channel) - Kislitsa village (disappearance and duration). The presence of such correlations does not allow to use the generalizing Fisher`s and Stjudent`s criteria because they was developed apart for data, which have or the interlinear or the in-row correlation (Rozhdestvenskiy at al., 1990). The observed data for disappearance of the ice phenomena on the Danube river (Kiliysky channel) - Izmail town is homogeneous on the Fisher`s criterion and inhomogeneous on the Stjudent`s criterion.

In conditions of the relatively soft winter of the south of the Ukraine for ice regime of the Danube River are: the unstable of the ice phases at time, the absence in separate years of the freezing and, finally, the absence in separate years of the ice phenomena. So, according to the ice phenomena observations on the Danube River and its Kiliysky channel the freezing didn't observed in 57-81 % and the ice phenomena – in 31-35 % of winters (Table 2). The earliest, means and the latest dates of the appearance and disappearances of the ice phenomena, as well as their mean and the most duration were defined (Table 2).

Table 2 The dates of the appearance and disappearances of the ice phenomena, as well as their mean and the most duration on the Danube River and Kiliysky channel

The characteristic	The dates		The duration			
	appearance	disappearances	freezing	period (%events)	ice phenomena	period (%events)
Danube river - Reni town (1944-2008)						
average	12/01	12/02	6		20	
the earliest (least)	12/12/1945	02/01/1997	0	80 %	0	31 %
the latest (most)	07/02/1965	27/03/1956	83	1953-54	96	1953-54
Danube river (Kiliysky channel) - Izmail town (1945-2008)						
average	12/01	13.02	6		20	
the earliest (least)	12/12/1945	04/01/1997	0	81 %	0	35 %
the latest (most)	06/02/1976; 2005	27/03/1956	74	1953-54	91	1953-54
Danube river (Kislitsky channel) - Kislitsa village (1961-2008)						
average	13/01	10/02	10		17	
the earliest (least)	18/12/2001	07/01/1997	0	57 %	0	34 %
the latest (most)	16/02/2003	22/03/1985	74	1962-63	80	1962-63
Danube river (Kiliysky channel) - Kiliya town (1930-2008)						
average	10/01	15/02	10		22	
the earliest (least)	13/12/1945	01/01/1932	0	71 %	0	32 %
the latest (most)	08/02/1965	29/03/1954, 28/03/1956	82	1953-54	94	1953-54

The appearance of the ice phenomena on the study territory occurs practically simultaneously. So, for period 1930-2008 the earliest appearance of the ice phenomena observed the 12-13 December 1945, the latest - 16 February 2003. The earliest disappearance of the ice phenomena observed at the beginning of the January, the latest - at the end of the March. The mean duration of all ice phenomena is about 20 days and the freezing - 8 days. However, in the cold winters the freezing can observed about 3 months (the winter 1953-54). The most duration of the freezing changes from 74 to 83 days and the ice phenomena - from 80 to 96 days.

The analysis of the results for period 1930-2008 and the results for period 1931-1966 (Scherbak at al., 1970) shows that the dates of the appearance the earliest and the latest of the ice phenomena did not change. The mean dates of the appearance of the ice phenomena were changed since 4-5 January (1931-1966) at 10-13 January (1930-2008). Also since 70-th years of the past century are observing of the increase of the quantity of winters in which the ice phenomena are absent (It have zero duration). Such changes we can explain by following: the ice phenomena have the cyclic fluctuations also as runoff (Fig. 3). So, since 70-th years of the past century of the date of the appearance of the ice phenomena have the expressed increasing in cyclic fluctuations i.e. the appearances of the ice phenomena occurs at later dates, but disappearances - at earlier dates (the decreasing part of the cyclic fluctuations since 1968). This brings to decreasing of the duration of the ice phenomena (the decreasing part of the cyclic fluctuations since 1970) (Fig. 3).

The parameters of the analytical curves of the ice phenomena were determined by formulas (4-6). The dates of the main phases of the ice regime and their duration of the different frequency are presented in the Table3. For smoothing and extrapolations of the empirical curves of the duration of the ice phenomena was used the three-parameter gamma-distribution. The parameters such curves were defined by method of the most plausibility.

Table 3 The dates of the appearance, disappearance of the ice phenomena and their duration of the different frequency on the Danube River and Kiliysky channel

The name of gauge	Frequency, *P* %							$\overline{D}$	σ_D	C_s
	1	5	10	25	50	75	95			
the appearance of the ice phenomena										
Danube river – Reni town	04/12	15/12	21/12	31/12	11/01	23/01	08/02	12/01	16.5	0.01
Kiliysky channel – Izmail town	05/12	16/12	22/10	01/01	12/01	22/01	06/02	12/01	15.8	0.11
Kislitsky channel - Kislitsa village	10/12	19/12	24/12	02/01	12/01	23/01	08/02	13/01	15.7	-0.22
Kiliysky channel - Kiliya town	04/12	15/12	20/12	30/12	09/01	20/01	04/02	10/01	15.7	-0.04
the disappearance of the ice phenomena										
Danube river – Reni town	28/12	10/01	17/01	29/01	11/02	25/02	17/03	12/02	20.5	-0.12
Kiliysky channel – Izmail town	30/12	11/01	18/01	29/01	12/02	26/02	18/03	13/02	20.4	-0.17
Kislitsky channel - Kislitsa village	27/12	09/01	16/01	27/01	09/02	22/02	12/03	10/02	19.2	-0.05
Kiliysky channel - Kiliya town	25/12	09/01	18/01	31/01	15/02	29/02	21/03	15/02	21.7	0.07
the duration of the ice phenomena								$\overline{T}$	C_v	C_s
Danube river – Reni town	140	74	50	25	10	3	0	20	1.46	3.89
Kiliysky channel – Izmail town	101	74	59	32	9	1	0	20	1.24	1.48
Kislitsky channel - Kislitsa village	123	64	43	21	9	3	0	17	1.48	4.21
Kiliysky channel - Kiliya town	145	80	56	28	11	3	0	22	1.39	3.32

The value of the standard deviation (σ_D) characterizes the variability of the dates of the ice phenomena. For the dates of the appearance of the ice phenomena σ_D = 15.7-16.5 days and for the dates of the disappearance of the ice phenomena - σ_D = 19.2-20.5 days. The coefficient of skewness (Cs) characterizes the asymmetry of the distribution of the observations series of the ice phenomena relative to their average values. For the dates of the appearance of the ice phenomena Cs = -0.22-0.11 and for the dates of the disappearance of the ice phenomena - Cs = -0.17-0.07.

In spite of the fact that each of four gauges have their own individual particularity (the current velocity, the morphometrical characteristics of the river bed etc.), the same values of the mean dates of the appearance, disappearance of the ice phenomena, of the standard deviations and of the coefficients of skewness indicate that the predominating factor of the forming the ice phenomena for these gauges are the climatic particularities of this region.

4 CONCLUSIONS

The observed data for ice phenomena are the homogeneous, because the analysis of the total integral curves of the appearances, disappearances of the ice phenomena and their duration did not found of any significant points of the fracture of the curves directions that indicates on absence of the influence as anthropogenic factors, so and of the climate change.

The dates of the main phases of the ice phenomena (the appearances and disappearances) and the duration of the ice phenomena have the cyclic fluctuations, also as runoff.

Since 70-th years of the past century the dates of the appearance of the ice phenomena have the expressed increasing in cyclic fluctuations i.e. the appearances of the ice phenomena occurs at later dates, but disappearances - at earlier dates (the decreasing part of the cyclic fluctuations since 1968). This brings to decreasing of the duration of the ice phenomena (the decreasing part of the cyclic fluctuations since 1970). The presence of the statistical significant and non significant trends of the observations data have the periodic nature, which depends on duration of the observations series and of the presence or absences of the full cycles.

The using of the Fisher`s and Stjudent`s criteria for quantitative estimation of homogeneity of the observation data of the ice phenomena is much limited, because such data have the interlinear and the in-row correlation simultaneously.

The dates of the appearance, disappearance of the ice phenomena and the duration of the ice phenomena of the different frequency, as well as the parameters analytical curves will correct with increase of the length of the observed data and will become the clean data when the observation will have not less one full cycle.

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