STATISTICAL ANALYSIS OF ICE RELATED ISSUES ON THE DANUBE AT NOVI SAD

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Summary: *Statistical analysis of ice-jams and ice-drifts has been performed for the Danube at Novi Sad. The empirical cumulative distribution function of ice-jam/ice drift duration has been successfully set up, as well as the frequency distribution of the longest-lasting ice-jam/ice drift during the winter. Poisson distribution of the number of ice-drifts/ice-jams during winter could not be proven. The analysis indicated an increase in water level during ice-jams having a duration of at least 7 days.*

Keywords: *Ice-drifts, ice-jams, Danube, Novi Sad*

1. INTRODUCTION

The occurrence of ice on rivers brings a risk of backwater caused by ice-jam on the one hand; on the other hand, once the ice starts to melt and break up, ice sheets get loose and may endanger vessels and hydraulic structures (bridges, water intakes, river training works, revetments and so on) during ice-drifts. To learn about the possible risks, a statistical analysis of the basic ice-related data from the gauging station on the Danube at Novi Sad has been performed. The basic data of the Novi Sad gauging station are as follow:

- Id. Number: 42035
- Distance from the river mouth: 1254.98 km
- Watershed area: 254085 km^2
- The elevation of the water gauge "0" reference level above the Adriatic Sea: 71.73 m MSL

The analysis included the following data: year, the beginning, the end, and the duration of ice-drifts/ice-jams, water stage at the beginning and the end of ice-drifts/ice-jams, and the number of ice-drifts/ice-jams during winters from 1940/41 to 2016/2017. The period from

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21. December to 21. March of the following year is considered as a particular winter period consisting of 91 days.
In the analyzed period of 77 years data is missing for 1944/45. The rest of the data indicated ice-jams during 16 winters, while ice-drifts came up during 52 winters.
The randomness of the observed ice-drift/ice-jam data was proven by the Wald–Wolfowitz runs test, making them suitable for statistical analysis.

2. ANALYSIS OF ICE-JAMS

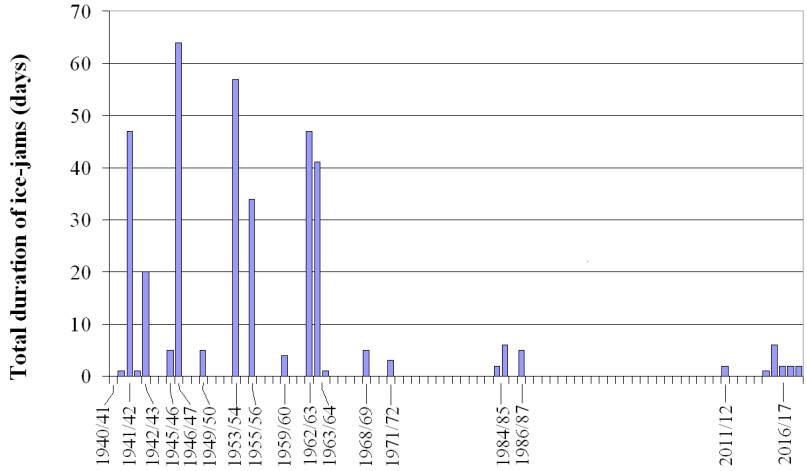

Figure 1. The total duration of ice-jams during each winter of the analyzed period

Fig. 1. showing the total duration of ice-jams during each winter of the analyzed period indicates a decreasing trend. The distribution function of ice-jam duration has been set up successfully, Fig.2.

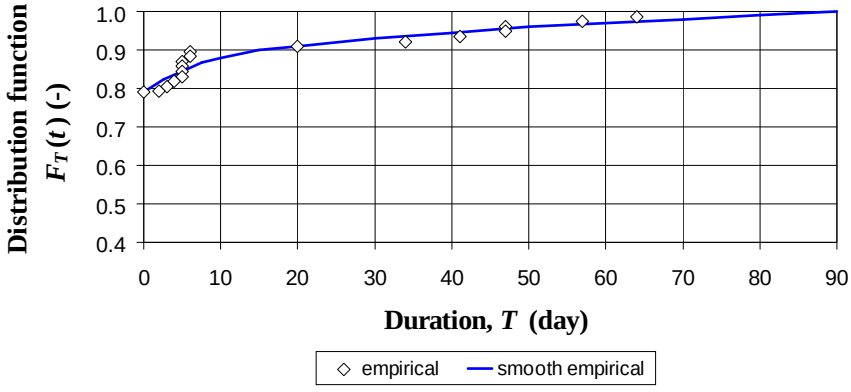

Figure 2. The empirical cumulative distribution function and the smooth empirical cumulative distribution function of ice-jam duration

The frequency distribution of the longest-lasting ice-jam during the winter period is also determined and presented in Fig. 3., where τ_{supT} denotes the time of showing up the longest-lasting ice-jam during the winter.

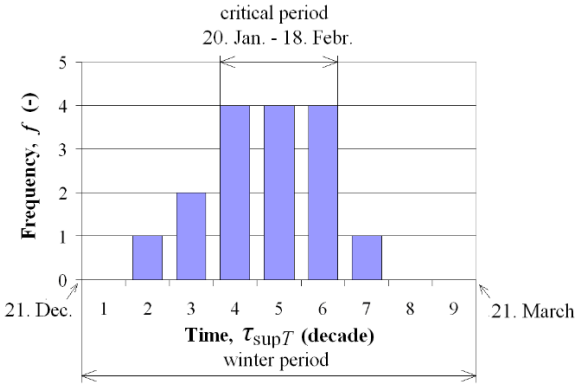

Figure 3. The frequency distribution of the longest-lasting ice-jam during the winter

The analysis has shown that the distribution of the number of occurrences of ice-jams during the winter doesn't follow the Poisson distribution, therefore the empirical distribution is to be used if necessary. Furthermore, a correlation between the duration of the ice-jam and the water level at the beginning/end of the ice-jam is not proven. The hypothesis that water level rises during ice-jams has also been tested. It has proven to be true in cases of long-lasting ice-jams and false in cases of short duration ice-jams.

3. ANALYSIS OF ICE-DRIFTS

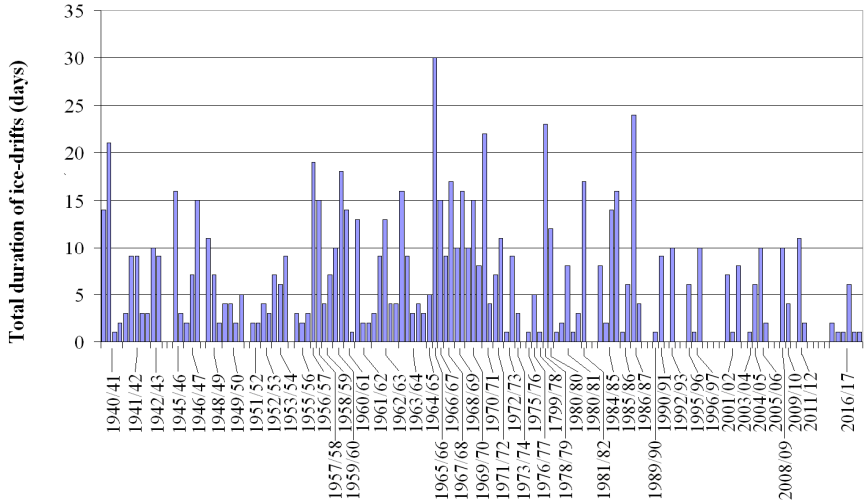

Figure 4. The total duration of ice-drifts during each winter of the analyzed period

Comparison of Figs 1. and 4. shows that ice-drifts occur more frequently than ice-jams. The distribution function of ice-drift duration has been established, Fig.5.

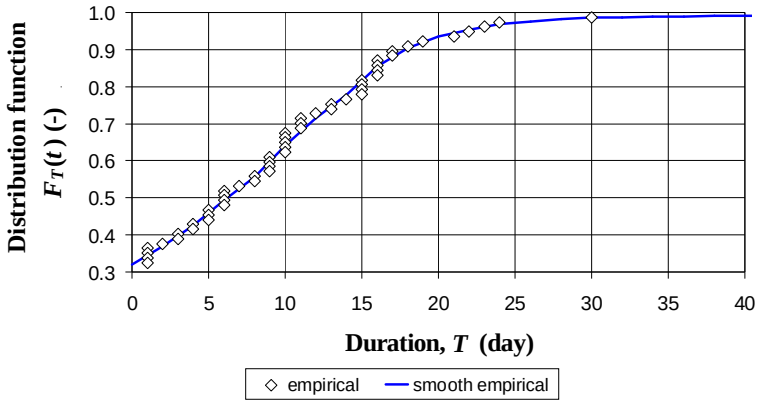

Figure 5. The empirical cumulative distribution function and the smooth empirical cumulative distribution function of ice-drift duration

The frequency distribution of the longest-lasting ice-drift during the winter period is also determined and presented in Fig. 6., where $\tau_{\sup T}$ denotes the time of showing up the longest-lasting ice-drift during the winter.

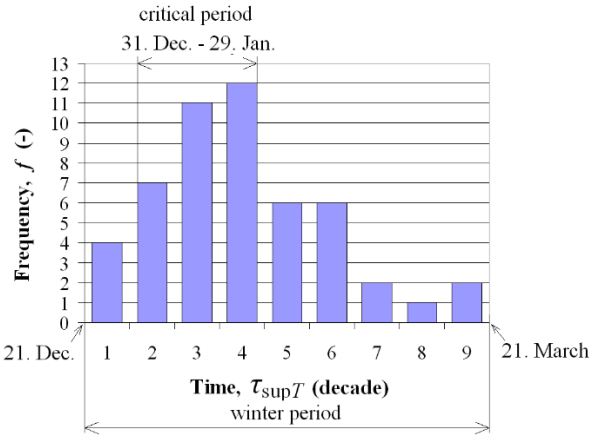

Figure 6. The frequency distribution of the longest-lasting ice-drift during the winter

The analysis has shown that the distribution of the number of occurrences of ice-drifts during the winter doesn't follow the Poisson distribution, however, the empirical distribution can be used in solving practical cases. Furthermore, a correlation between the duration of the ice-drift and the water level at the beginning/end of the ice-drift is not proven.

4. DISCUSSION AND CONCLUSIONS

In the analyzed period from 1940/41 to 2016/17, there was a total of 133 ice-drifts lasting together 828 days, resulting in an average duration of 7.33 days. In the same period, there were just 24 ice-jams lasting 363 days, with an average duration of 15.13 days. Therefore ice-drifts are much more frequent than ice-jams, while ice-jams last twice as long as ice-drifts.

Ice-drifts are probable during the whole winter period, while they are most likely in the third decade of January. Ice-drifts show up in a narrower time-frame, in January and February, and are the most likely in the first decade of February.

The maximum number of ice-drifts in a single winter is 6, while the most 5 ice-jams have been observed in a single winter. Even though the theoretical Poisson distribution of the number of ice-drifts/ice-jams during winter could not be established, a broader data set might prove the aptness of the Poisson distribution. The empirical distributions show that in a single winter occurrence of just one ice-drift/ice-jam is the most probable.

The distribution functions of the ice-drift/ice-jam duration indicate that ice-jams will occur in 21% of winters, while ice-drifts are likely in 68% of winters. The longest observed ice-jam lasted 64 days, while the longest ice-drift lasted 30 days.

Correlation between the ice-jam duration and water level at the end of the ice-jam has been tested, however, it didn't prove true.

The analysis of water level change during ice-jams has shown that water level has increased in 67% of the analyzed cases, while even a decrease of water level was documented in 29% of cases. Just in cases of long-lasting ice-jams (having duration $T_n \geq 7$ days) the water level was higher at the end than at the beginning. However, the rise of water level not even in cases of long-lasting ice-jams was monotonously increasing. It suggests that the ice-jam itself is not the only factor influencing the water level during the jam. Perhaps, the actual conditions and the hydrological/hydraulic events in the downstream river course (contribution of downstream tributaries to flow, the eventual surge caused by downstream ice-jams, human activity, design errors [1] and so on) might have their influence as well.

It is important to notice that ice-jams are less frequent in the last several decades. The last long-lasting ice-jam was observed even more than five decades ago, in 1964.

The analysis indicates that a statistical prognostic model for predicting the maximum water level during an ice-jam or a whole winter period is not yet feasible. For that, following the observed ice-related facts are outlined.

The variation interval of water-level at the ice-jam commencement is pretty wide: 71.51 – 75.92 m MSL meaning that backwater for ice-jam may superimpose with both high and low water levels. The lowest water level of 71.05 m MSL was observed during the longest observed ice-jam (01.01.1947. – 05.3.1947.) A maximum water level of 75.92 m MSL was documented at 11.3.1942. during a single day ice-jam. Furthermore, the maximum water level observed during ice-jams is 0.93 m lower than the maximum water level observed during ice-drifts, and even 4.08 m lower than the 1% high water at 80.00 m MSL.

Shorter ice-jams have caused a more intensive rise of water level than long-duration ice-jams did. The observed maximum intensity of water rise during an ice-jam was 25.2 cm/day.

The current analysis does not cover the earliest occurrence of ice on the Danube, neither the very latest date of ice during a particular winter, however, observations of this kind might be of use. Based on ice cover related records Magnuson et al. [2] reported increasing changes in the ice regime of rivers in the Northern Hemisphere over the recent 150 years. Concerning the Danube at Budapest, Takács et al. stated in [3] that the average ice-affected season shortened from 40 to 27 days, the average ice-covered season reduced from 27 to 7 days. This might happen for several reasons [4]:

- thermal pollution of the Danube (cooling system of nuclear power plant Paks in Hungary),
- chemical pollution,
- climate change, and so on.

It can be certainly stated that for the analyzed period the Danube was subject to all mentioned influences of recent origin, furthermore, the downstream boundary conditions have also been changing (backwater caused by the Đerdap dam, recent installation of river training works, etc.). Overlap of all these influences makes it impossible to sort their effects out, however, their joint impact is present for sure. Therefore, the analyzed period of 77 years might not be homogeneous, while breaking it down into homogeneous ones was not feasible for the low number of observed ice-related events.

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СТАТИСТИЧКА АНАЛИЗА ПОЈАВА ВЕЗАНИХ ЗА ЛЕД НА ДУНАВУ КОД НОВОГ САДА

Резиме: *Извршена је статистичка анализа ледостаја и ледохода за Дунав код Новог Сада. Успешно је успостављена емпиријска кумулативна функција расподеле трајања ледостаја/ледохода, као и расподела учесталости ледостаја/ледохода најдужег трајања током зимског периода. Није се потврдила Пуасонова расподела броја ледостаја/ледохода у току зиме. У случају ледостаја трајања већег од 7 дана анализа је потврдила повећање водостаја током ледостаја.*

Кључне речи: *Ледоход, ледостај, Дунав, Нови Сад*