# Forecasting the Probability of Ice Drift in the Bulgarian Section of the Danube River

**Yuriy Dachev, Hristo Hristov**

**Abstract:** The Danube River is the only inland waterway in the Republic of Bulgaria. The Bulgarian section of the river is located in its lower reaches. The river is included in the general network of European inland waterways as a trans-European transport corridor VII. The Rhine-Main-Danube channel connects Western and Eastern Europe providing excellent opportunities for direct navigational links between the Black Sea and the North Sea. It is a convenient waterway to many European countries and their industrial centers. Due to the specific nature of the river, there are various hazards to navigation on it, such as sediment, sills and ice drift. Predicting the formation of sediment is difficult as it depends on many factors. The areas and boundaries of the sills are well known and the Executive Agency for Exploration and Maintenance of the Danube (EAEMD) takes measures to ensure their safety. Ice drift is another major hazard to navigation on the river. The article analyzes the hydro-meteorological information about the Bulgarian section of the Danube River for a period of 20 years. The interdependencies of hydro-meteorological data with respect to the prerequisites for ice formation and ice drift on the river are researched. On this basis, a methodology has been proposed to determine the probability of ice drift in the Bulgarian section of the river.

**Index Terms:** European Inland Waterways, Rhine-Main-Danube channel, The Danube River, Hydro-meteorological elements, Hazards to Navigation, Ice Drift, Forecasting

## 1 THE RIVER DANUBE – PART OF THE EUROPEAN INLAND WATERWAYS

The Danube River is located west of the Black Sea in Central and Southeastern Europe, flowing through 11 European countries. It is the second longest river in Europe after the river Volga. Its basin is 817 000 km$^2$ and includes over 300 tributaries. The city of Donaueschingen in Germany has been accepted as the origin point of the river. It flows into the Black Sea near the city of Sulina, Romania, forming a delta.

The total length of the Danube from Sulina to Donaueschingen is 2857 km. Of these, 2414 km are navigable, which is the stretch from Sulina to the city of Kelheim in Germany. The Rhine-Main-Danube channel makes the Danube part of a transcontinental river route between the Black sea and the North Sea, known as the Trans-European Transport Corridor VII. (Fig. 1)

The total drop in the height of the river from the origin point to the delta is 464.3 m, the average slope being 16 cm/km (0.016%). The Danube flows into the Black Sea forming three main branches - Kiliyski (northern), Sulinski (middle) and Georgievski (southern). The measurement of the river in kilometers starts from Sulina (km 0) and ends at Donaueschingen (km 2859). The kilometers are counted against the current because of the navigation on it. [1], [2], [3], [8], (Fig. 2).

Depending on the features of the geographical areas through which the river flows, it is divided into three sections [1], [2]:

• **Upper Danube.** It starts from Donaueschingen (km 2857) and ends at the mouth of the Morava River on the border between Austria and Slovakia (km 1880). The total drop in the height of this section is 328.4 m, the average slope being 17.5 cm/km. The river bed has many shallows and stone sills. A total of about 1820 m$^3$/sec of water flows into the Upper Danube from its tributaries. The low water current rate ranges from 3.6 km/h to 8.0 km/h.


***Fig. 1*** *European inland waterways*

- **Middle Danube.** It starts at the mouth of the Morava River (km 1880) and ends at the port of Turnu Severin (km 931). The width of the river in its upper reaches up to 420 m and in the lower - up to 2200 m, except for the Cataracts (km 967 - 970) where it is 150 m. The total height drop in the Middle Danube is 101.5 m. The slope from km 1880 to km 1810 is 35.4 cm/km. In the Cataract area the slope increases significantly, reaching up to 2 m/km. The large slope difference leads to large differences in flow velocity for the different sections. It ranges from 2.9 km/h to 7.9 km/h except at the Cataracts, where it reaches 18 km/h. A total of about 4,100 m3/sec of water flows into the Middle Danube from its tributaries.
- **Lower Danube**. It starts from Turnu Severin (km 931) and ends at the mouth - Sulina (km 0). It flows into the Black

---

- *Yuriy Dachev, Professsor PhD, Nikola Vaptsarov Naval Academy, Varna, Bulgaria, E-mail: urida@abv.bg*
- *Hristo Hristov, Assistant Professsor PhD, Nikola Vaptsarov Naval Academy, Varna, Bulgaria, E-mail: hristov_1980@mail.bg*

Sea forming three main branches - Kiliyski, Sulinski and Georgievski. The Sulinski branch is the deepest and most full-flowing, with a guaranteed depth of 7.30 m. The river delta is 3500 km$^2$, 75 km long and 65 km wide.

The river has another access to the Black Sea through two canals: the Romanian “Cherna voda – Constanta” and the Ukrainian “Reni - Vilkovo - Black Sea”. The Lower Danube is a typical plain river. The right bank (downstream) is high and the left bank is low and floodable. The section features many islands and branches. The overall height drop in the Lower Danube is 34.4 m. The slope decreases evenly downstream, varying from 5 cm/km at the beginning to 1 cm/km at the mouth. The current rate on the Lower Danube fairway is from 3.3 km/h to 4.5 km/h, and from Braila (km 172) to Sulina (km 0) it is 2 km/h. About 700 m$^3$/sec of water flows into the Lower Danube from its tributaries.

The Bulgarian section of the river with a length of 470.2 km is in the Lower Danube. It is bounded between the mouth of the Timok River (km 845.5) and Silistra (km 375.3). The slope of the river ranges from 4 cm/km to 4.4 cm/km and the current rate is about 3.3 km/h. The width of the river varies from 750 to 2200 m and the depth from 4 to 30 m. Over 70 of the total 120 alluvial islands along the river are Bulgarian. The Bulgarian Danube bank is high and amphitheatrical, with predominant heights between 100 and 150 m. Its highest point is at Oryahovo - 226 m.


***Fig. 2*** *Kilometer mark on the Danube*

In 1948, a Convention on the Navigation on the Danube River was signed in Belgrade, on the basis of which the Danube Commission was established. It consists of 11 European member countries - Austria, Bulgaria, Germany, Romania, Hungary, Moldova, Ukraine, Slovakia, Serbia, Croatia and Russia. Other seven European countries are observers - France, the Netherlands, the Czech Republic, Greece, Turkey, Cyprus and Montenegro. The Commission ensures the free and safe navigation on the river. The rules are regulated in the document “Rules for navigation on the Danube”. The seat of the Commission is in Budapest. The official languages are German, Russian and French. [4], [5], [6]

In order to regulate navigation on the river and to ensure its safety, the fairway (shipping channel) is marked by shore and floating navigational marks. [6], [9]


***Fig. 3*** *Above ground center of GPS point*

In 2017, the European Union adopted Directive (EU) 2017/2397 regulating a uniform standard for the professional qualification of the European Inland Navigation personnel. [7]

The Executive Agency for Exploration and Maintenance of the Danube River (EAEMD) – Ruse has constructed a high-precision geodetic GPS network in order to perform topographic and hydrographic surveys on the Bulgarian section of the river. New 198 GPS points have been created. They are fixed with a concrete foundation and an underground centre. (Fig. 3) The network is measured by using Global Navigation Satellite Systems (GNSS) and is linked to the European Geodetic Reference System (EUREF).

The geographical coordinates of the GPS points are defined in the WGS-84 coordinate system and the rectangular coordinates in the 1970 and BGS-2005 coordinate systems. Altitudes of GPS points are defined in the European Altitude System EVRS.

The GPS network takes pictures of quay walls, estuaries, facilities and sections of the river. The measurement data is of high accuracy and is used to fill in the pilot and electronic navigational charts (Inland ECDIS) for the Bulgarian section of the river.

## 2 DISTRIBUTION OF THE HYDRO-METEOROLOGICAL ELEMENTS IN THE BULGARIAN SECTION OF THE DANUBE RIVER

The data of the average monthly distribution of hydro-meteorological elements in the Bulgarian section of the Danube River have been obtained on the basis of the processing of statistical hydro-meteorological information for a representative period of 20 years (1994-2013) from 6 meteorological stations located along the river - Novo selo, Lom, Oryahovo, Svishtov, Ruse and Silistra.

They are an important factor in predicting the state of the waterway in a section of the river during the year and especially the occurrence of ice and ice drift.

- **Distribution of the temperature (t)**

**Table 1** Monthly average daily temperature (t) for the period 1994-2013 in the Bulgarian section of the Danube River, in (**$^o$C**)

| Meteo | Month |
| --- | --- |

| station | I | II | III | IV | V | VI |
|---|---|---|---|---|---|---|
| Novo selo | 0.1 | 1.9 | 7.2 | 12.7 | 18.4 | 22.0 |
| Lom | 0.2 | 2.3 | 7.2 | 12.8 | 18.5 | 22.2 |
| Oryahovo | 0.1 | 2.0 | 6.9 | 12.9 | 18.7 | 22.3 |
| Svishtov | - 0.2 | 2.2 | 7.4 | 13.2 | 18.9 | 22.8 |
| Ruse | - 0.3 | 2.2 | 7.4 | 13.3 | 19.0 | 22.8 |
| Silistra | 0.3 | 2.4 | 7.0 | 12.6 | 18.4 | 22.3 |

| Meteo station | Month | | | | | |
|---|---|---|---|---|---|---|
| | VII | VIII | IX | X | XI | XII |
| Novo selo | 24.3 | 23.6 | 17.9 | 11.9 | 5.8 | 0.6 |
| Lom | 24.2 | 23.7 | 18.4 | 12.4 | 6.2 | 1.0 |
| Oryahovo | 24.5 | 24.0 | 18.8 | 13.0 | 6.1 | 0.9 |
| Svishtov | 24.9 | 24.5 | 19.0 | 12.7 | 6.3 | 0.9 |
| Ruse | 24.9 | 24.6 | 19.1 | 12.9 | 6.6 | 1.0 |
| Silistra | 24.2 | 23.8 | 18.7 | 12.9 | 7.1 | 1.5 |

Based on the results in Table 1, the months of the year are differentiated into five temperature groups:

**Table 2** Temperature groups

| Group | Months | Temperature range |
|---|---|---|
| 1 | **December January February** | -0.3°C / 2.4°C |
| 2 | **March November** | 5.8°C / 7.4°C |
| 3 | **April October** | 11.9°C / 13.3°C |
| 4 | **May September** | 17.9°C / 19.1°C |
| 5 | **June, July August** | 22.0°C / 24.9°C |

It can be seen from Tables 1 and 2 that the first group is the most critical regarding the probability of ice formation and the occurrence of ice drift in the Bulgarian section of the river. The group includes the months of December, January and February, during which the air temperature drops to below 0°C. Although the air temperature is above 0°C in December, it is in the range of 0.6 ÷ 1.5°C. In December, there was a sharp decrease in temperature compared to November with a difference of 5.0 ÷ 5.5°C. The steady downward trend in the temperature to reach values close to 0°C persists in January, with temperatures reaching negative values in some places (Ruse and Svishtov).

- **Distribution of the atmospheric pressure (P)**

**Table 3** Monthly average atmospheric pressure (P) for the period 1994-2013 in the Bulgarian section of the Danube River, in (hPa)

| Meteo station | Month | | | | | |
|---|---|---|---|---|---|---|
| | I | II | III | IV | V | VI |
| Novo selo | 1020,9 | 1016,0 | 1016,9 | 1013,8 | 1014,1 | 1013,9 |
| Lom | 1021,3 | 1019,3 | 1017,1 | 1014,2 | 1014,6 | 1014,2 |
| Oryahovo | 1020,5 | 1018,7 | 1016,3 | 1013,2 | 1013,4 | 1013,0 |
| Svishtov | 1020,8 | 1018,7 | 1016,3 | 1013,2 | 1013,4 | 1013,0 |
| Ruse | 1020,3 | 1018,3 | 1016,3 | 1013,4 | 1013,6 | 1013,2 |
| Silistra | 1020,4 | 1018,2 | 1016,4 | 1013,6 | 1013,8 | 1013,2 |

| Meteo station | Month | | | | | |
|---|---|---|---|---|---|---|
| | VII | VIII | IX | X | XI | XII |
| Novo selo | 1013,2 | 1013,6 | 1016,3 | 1020,1 | 1019,5 | 1020,7 |
| Lom | 1013,5 | 1014,2 | 1016,2 | 1020,2 | 1020,0 | 1021,0 |
| Oryahovo | 1011,7 | 1012,8 | 1015,2 | 1019,0 | 1019,2 | 1019,5 |
| Svishtov | 1011,7 | 1012,8 | 1015,2 | 1019,0 | 1019,2 | 1019,5 |
| Ruse | 1012,3 | 1013,1 | 1015,5 | 1019,2 | 1019,0 | 1020,1 |
| Silistra | 1011,9 | 1013,3 | 1015,5 | 1019,3 | 1018,9 | 1019,9 |

Based on the results in Table 3, the months of the year are differentiated into three groups with close atmospheric pressure values:

**Table 4** Groups of months with close atmospheric pressure values (P)

| Group | Months | Range of (P) |
|---|---|---|
| 1 | **October November December January** | 1019 hPa - 1021 hPa |
| 2 | **February March September** | 1015 hPa - 1019 hPa |
| 3 | **April, May June, July August** | 1011 hPa - 1015 hPa |

- **Distribution of relative air humidity**

**Table 5** Monthly average air humidity for the period 1994-2013 in the Bulgarian section of the Danube River, in (%)

| Meteo station | Month | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII |
| Novo selo | 81 | 76 | 67 | 68 | 68 | 67 | 64 | 64 | 69 | 73 | 81 | 79 |
| Lom | 82 | 77 | 68 | 68 | 70 | 69 | 67 | 69 | 72 | 78 | 81 | 79 |
| Oryahovo | 72 | 71 | 65 | 64 | 64 | 64 | 58 | 54 | 62 | 70 | 78 | 73 |
| Svishtov | 82 | 76 | 66 | 64 | 64 | 63 | 61 | 61 | 67 | 75 | 79 | 78 |
| Ruse | 82 | 75 | 65 | 62 | 62 | 62 | 59 | 58 | 64 | 72 | 78 | 78 |
| Silistra | 81 | 74 | 67 | 66 | 65 | 66 | 64 | 64 | 69 | 76 | 79 | 77 |

Based on the results in Table 5, the months of the year with few exceptions are differentiated into three groups with close relative air humidity values:

**Table 6** Groups of months with close values for relative air humidity

| Group | Months | Range of relative air humidity |
|---|---|---|
| 1 | **November, December January** | 77 % - 82 % |
| 2 | **February, March September, October** | 66 % - 77 % |

| | | |
|---|---|---|
| 3 | **April, May, June July, August** | 54 % - 66 % |

- **Distribution of wind**

**Table 7** Direction and rate of prevailing winds in the Bulgarian section of the Danube River for the period 1994-2013

| Month | Prevailing wind direction | | | Rate (m/s) |
|---|---|---|---|---|
| **I** | NE | W | SW | 2,9 |
| **II** | NE | W | SW | 3,4 |
| **III** | NE | W | - | 3,5 |
| **IV** | NE | W | - | 3,1 |
| **V** | NE | W | - | 2,9 |
| **VI** | NE | W | SW | 2,6 |
| **VII** | NE | W | SW | 2,7 |
| **VIII** | NE | W | NW | 2,5 |
| **IX** | NE | W | NW | 2,6 |
| **X** | NE | W | - | 2,5 |
| **XI** | NE | W | SW | 2,5 |
| **XII** | NE | W | SW | 2,5 |

Based on the results in Table 7, the months of the year are differentiated into three groups with close values for direction and rate of the prevailing winds:

**Table 8** Groups of months with close values for direction and rate of the prevailing winds

| Group | Months | Wind direction and rate | |
|---|---|---|---|
| 1 | **March, April May, October** | NE W | 2,5 / 3,5 m/s |
| 2 | **January February June, July November December** | NE W SW | 2,5 / 3,0 m/s |
| 3 | **August September** | NE W NW | 2,5 / 3,5 m/s |

Calm weather in the Bulgarian section of the Danube River is a rare occurrence with no clear character. It is observed within no more than 25 days of the year. Due to this fact it can be stated that there are no periods of calm weather in the Bulgarian section of the river almost all year. In terms of the probability of ice formation and the occurrence of ice drift in the Bulgarian section of the river, the most critical are the months of December and January with prevailing northeasterly and westerly winds with an average rate of 2.5 to 2.9 m/s. They carry cold air masses increasing the probability of ice formation.

- **Precipitation**

There are two high periods and three low periods of the precipitation in the Bulgarian section of the river. The first maximum is in July and the second is in October. The minimums are in March, August and November. On average, in one year the number of days with rainfall fluctuates between 70 and 110, with snowfall between 34 and 46 days. In the western part of the Bulgarian section of the river the amount of precipitation is lower than in the eastern part.

In terms of the probability of ice formation and the occurrence of ice drift in the Bulgarian section of the river, the most critical are the months of December, January and February, where precipitation is around and above the average for the area. Due to the low temperatures there is snowfall. Snow cover lasts from 5 to 7 weeks, which is a prerequisite for the formation of sleet and ice patches that make shipping difficult.

- **River level**

From the summarized data in Table 9 for the average monthly river level in the Bulgarian section, one maximum and one minimum are observed. The maximum of the water level is in April after the snowmelt and the minimum is in the months of August, September and October.

In terms of the probability of ice formation and the occurrence of ice drift in the Bulgarian section of the river, the most critical months are December and January. Then there is a decrease in the level below the "average", which in combination with the low air temperatures and the prevailing northeasterly and westerly winds, as well as snowfall, favor the formation of ice and ice drift on the river.

**Table 9** Average monthly water level for the period 1994-2013 in the Bulgarian section of the Danube River, in (cm)

| Meteo station | Month | | | | | |
|---|---|---|---|---|---|---|
| | **I** | **II** | **III** | **IV** | **V** | **VI** |
| **Novo selo** | 349 | 340 | 439 | 517 | 452 | 376 |
| **Lom** | 407 | 397 | 496 | 573 | 515 | 436 |
| **Oryahovo** | 289 | 281 | 375 | 451 | 399 | 322 |
| **Svishtov** | 301 | 296 | 389 | 470 | 422 | 343 |
| **Ruse** | 313 | 314 | 407 | 512 | 444 | 358 |
| **Silistra** | 336 | 343 | 420 | 499 | 458 | 376 |
| **Meteo station** | **Month** | | | | | |
| | **VII** | **VIII** | **IX** | **X** | **XI** | **XII** |
| **Novo selo** | 286 | 219 | 220 | 223 | 267 | 325 |
| **Lom** | 346 | 274 | 271 | 280 | 321 | 372 |
| **Oryahovo** | 237 | 169 | 163 | 172 | 208 | 257 |
| **Svishtov** | 258 | 192 | 180 | 190 | 221 | 270 |
| **Ruse** | 265 | 192 | 176 | 190 | 222 | 278 |
| **Silistra** | 288 | 217 | 194 | 214 | 222 | 299 |

- **Water temperature**

**Table 10** Average monthly water temperature for the period 1994-2013 in the Bulgarian section of the Danube River, in ($^{o}$C)

| Meteo station | Month | | | | | |
|---|---|---|---|---|---|---|
| | **I** | **II** | **III** | **IV** | **V** | **VI** |
| **Novo selo** | 2.5 | 3.1 | 6.4 | 11.2 | 17.1 | 21.0 |
| **Lom** | 2.6 | 2.9 | 6.5 | 11.5 | 17.4 | 21.5 |
| **Oryahovo** | 4.4 | 4.7 | 7.8 | 12.7 | 18.5 | 22.5 |
| **Svishtov** | 3.1 | 3.5 | 7.0 | 12.5 | 18.2 | 22.3 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Ruse** | 2.9 | 3.3 | 6.9 | 12.1 | 18.1 | 22.3 |
| **Silistra** | 2.7 | 3.1 | 6.7 | 12.0 | 18.1 | 22.4 |

| **Meteo station** | **Month** | | | | | |
|---|---|---|---|---|---|---|
| | **VII** | **VIII** | **IX** | **X** | **XI** | **XII** |
| **Novo selo** | 23.4 | 23.7 | 20.0 | 15.0 | 9.5 | 4.8 |
| **Lom** | 24.0 | 24.3 | 20.3 | 15.3 | 9.7 | 4.8 |
| **Oryahovo** | 25.3 | 25.6 | 21.6 | 16.6 | 11.2 | 6.4 |
| **Svishtov** | 25.0 | 25.3 | 21.0 | 25.8 | 10.2 | 5.2 |
| **Ruse** | 24.9 | 25.2 | 20.9 | 15.7 | 10.1 | 5.1 |
| **Silistra** | 25.0 | 25.3 | 20.9 | 15.7 | 10.1 | 5.0 |

From the summarized data in Table 10, one maximum and one minimum are observed. The maximum water temperature is in the months of July and August and the minimum is in the months of January and February.

***Fig. 4*** *Hydro-meteorological station in Ruse*

Low water temperatures in January and February combined with low air temperatures and prevailing northeasterly and westerly winds, as well as snowfall, contribute to the formation of ice and ice drift on the river.

In 2014, automatic hydro-meteorological stations were installed on depth-gauges in nine settlements along the river - Novo selo, Vidin, Lom, Oryahovo, Nikopol, Svishtov, Ruse, Tutrakan and Silistra.

Every minute the stations report the level of the river, the temperature and turbidity of the water, the humidity of the air, the rate and the direction of the wind, the amount of precipitation, the atmospheric pressure and other parameters. The data is displayed on an electronic dashboard. (Fig. 4)

Hydro-meteorological information from the stations is also available online on the website of the Executive Agency for Exploration and Maintenance of the Danube - http://www.appd-bg.org.

## 3 ANALYSIS OF ICE DRIFTS FORMED IN THE BULGARIAN SECTION OF THE DANUBE RIVER

Analyzes of hydro-meteorological data for the river show that the causes that led to the formation of ice drifts in the region of Ruse on 04.01.2008 and 15.02.2012 are a combination of two events:

- continuous negative daily average air temperature leading to a sharp drop in water temperature;

- low water level in the water areas of the ports of Svishtov, Ruse and Silistra.

The steady downward trend in the river level in the regions of Svishtov, Ruse and Silistra leads to a decrease in its water volume which accelerates its cooling process and promotes ice formation and ice drift.

It can be summarized that conditions for ice formation on the Danube River are created when there is a continuous period of at least 5 days in which the air temperature is below minus 5°C and the river level is low. This causes ice to form.

Initially, it is off the banks and not dangerous for shipping. If these factors continue to last for more than a week, the ice drift will increase. The surface is covered with ice patches which consequently begin to get thicker until huge floating ice blocks of over 100 $m^2$ are obtained with a thickness of 10 cm or more. Thus, gradually the river is ice filled.

Ice drift does not present danger to shipping until the coverage of 50% of the water area but above this percentage it becomes dangerous to navigation. Freezing of the river occurs when the ice drift stops moving. The process is preceded by ice blockages occurring in the vicinity of islands or where the section is narrow.

## 4 FORECASTING THE PROBABILITY OF ICE DRIFT IN THE BULGARIAN SECTION OF THE DANUBE RIVER

An empirical dependence is derived to calculate the probability (P) for the occurrence of ice drift on the Danube River (formula 1):

$$P = [k \,.\, n \,.\, (t_P)] \,/\, h_P \qquad (1)$$

where:
*k* - is the empirical coefficient determined from Table 11;
*n* - number of days for the period;
$t_p$ - average air temperature over the period, in (°C);
$h_p$ - average water level for the period, in cm.

If the final probability (P) result is negative, then there is a probability of ice formation and ice drift.

For example, if P = - 0.65, this means a 65% probability of ice formation and ice drift. If the final probability (P) is a positive value, then there is no probability of ice formation and ice drift.

The values of the coefficient *k* were determined over a period of 5 days at an average air temperature of 3°C to -20°C and an average river level of 200 cm to 11 cm. The results are listed in Table 11.

**Table 11** Values of the coefficient *k* for a period of 5 consecutive days

| ***k*** | $t_p$, **[°C]** | $h_p$, **[cm]** |
|---|---|---|
| **3** | от 3 до -4 | от 200.0 до 61.0 |
| **2** | от -4 до -5 | от 60.9 до 51.0 |
| **1** | от -5 до -8 | от 50.9 до 41.0 |

| | | |
|---|---|---|
| **0.1** | от -8 до -20 | от 39.9 до 11 |

Based on the empirical dependence derived to calculate the probability of an ice drift occurrence, the probability of an ice drift occurrence was calculated in 2017 at Silistra.

**Table 12** Calculating the probability (P) of an ice drift occurrence at the port of Silistra on 07.01.2017

| Date | Air temperature, [$^o$C] | River level, [cm] |
|---|---|---|
| 02.01.2017 | 0.7 | 107.0 |
| 03.01.2017 | 1.2 | 100.0 |
| 04.01.2017 | 0.0 | 96.0 |
| 05.01.2017 | 1.3 | 93.0 |
| 06.01.2017 | - 7.3 | 84.0 |
| Average value | - 0.82 | 96.0 |

$$P = [3\,.\,5\,.\,(-0{,}82)]\,/\,96{,}0 = -0{,}13 \qquad (2)$$

Formula 2 shows that the probability (P) for the formation of ice drift in the Silistra area on 07.01.2017 is 13%.

**Table 13** Calculating the probability (P) of an ice drift occurrence at the port of Silistra on 08.01.2017

| Date | Air temperature, [$^o$C] | River level, [cm] |
|---|---|---|
| 03.01.2017 | 1.2 | 100.0 |
| 04.01.2017 | 0.0 | 96.0 |
| 05.01.2017 | 1.3 | 93.0 |
| 06.01.2017 | - 7.3 | 84.0 |
| 07.01.2017 | - 9.5 | 80.0 |
| Average value | - 2.86 | 90.6 |

$$P = [3\,.\,5\,.\,(-2{,}86)]\,/\,90{,}6 = -0{,}47 \qquad (3)$$

Formula 3 shows that the probability (P) for the formation of ice drift in the Silistra area on 08.01.2017 is 47%.

**Table 14** Calculating the probability (P) of an ice drift occurrence at the port of Silistra on 09.01.2017

| Date | Air temperature, [$^o$C] | River level, [cm] |
|---|---|---|
| 04.01.2017 | 0.0 | 96.0 |
| 05.01.2017 | 1.3 | 93.0 |
| 06.01.2017 | - 7.3 | 84.0 |
| 07.01.2017 | - 9.5 | 80.0 |
| 08.01.2017 | - 9.3 | 74.0 |
| Average value | - 4.96 | 85.4 |

$$P = [3\,.\,5\,.\,(-4{,}96)]\,/\,85{,}4 = -0{,}87 \qquad (4)$$

Formula 4 shows that the probability (P) for the formation of ice drift in the Silistra area on 09.01.2017 is 87%. This high probability is confirmed by a photo of the water area of the port of Silistra taken on 09.01.2017 and published in the local press. (Fig. 5)

***Fig. 5*** *Freezing of the Danube at the port of Silistra on 09.01.2017*

Source:http://offnews.bg/obshtestvo/dunav-krasiv-i-zamraznal-snimki-643892.html

The calculations and forecasts made are also evidenced by images of the river route made by space based systems for remote monitoring of the Earth. Space photos from 09.01.2017 taken by a satellite of the European Space Agency (ESA) Sentinel-2 system are combined with fairway data and current electronic navigational charts of the Danube. (Fig. 6 and 7)

Due to the low air temperatures and the low river level sleet starts to occur above Svishtov. Due to the sharp turns and narrowed navigation areas the ice drift begins to accumulate not only off the bank but also in the shipping channel. In the area of Vetren and Silistra the river is completely frozen. (Fig. 6 and 7)

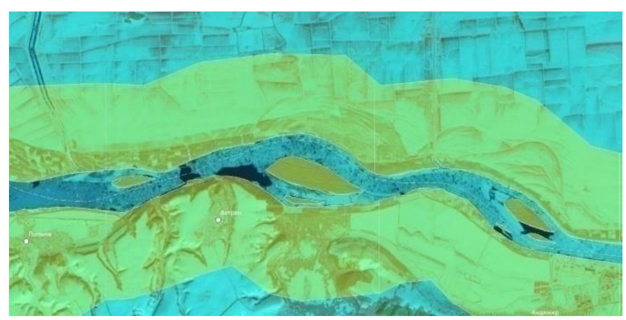

***Fig. 6*** *Freezing of the Danube in the area of Vetren on 09 January 2017*

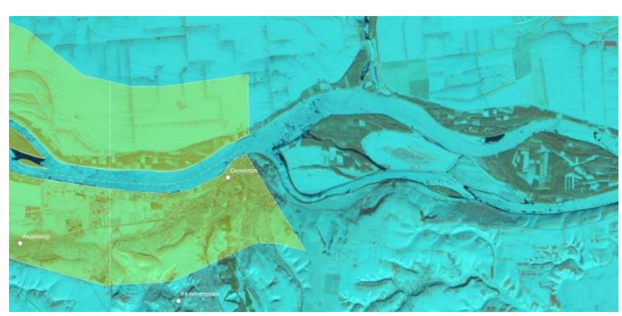

***Fig. 7*** *Freezing of the Danube at the port of Silistra on 09 January 2017*

## 5 CONCLUSION

On the basis of the models for the distribution of hydro-meteorological elements and phenomena and the analysis of the formed ice drifts in 2008 and 2012 in the Bulgarian section of the Danube River, the factors influencing the formation of ice drift are determined:

- the average air temperature over five days is lower than -5°C;

- the river level is below 200 cm.

The methodology for calculating the probability of ice drift occurrence can be successfully used to predict the formation of ice drift in the Bulgarian section of the river.

Models for the distribution of hydro-meteorological elements and phenomena can be integrated into navigation simulators for training inland ship's personnel to recreate actual hydro-meteorological conditions when navigating on the river any time.

## REFERENCES

[1] Hristov Hr., Hydrological State of the Danube River and Activities for Increasing the Safety of Navigation in the Bulgarian Section, Dissertation, Nikola Vaptsarov VVMU, Varna, 2017, 180 p.
[2] Doykov V., Geography of transport. Bulgarian Danube Shipping, Ruse, 2002.
[3] Pilot of Danube River, Budapest, 1989.
[4] Convention regarding the regime of navigation on the Danube, Belgrade, 1949.
[5] Catalogue of Publications, Danube commission, Budapest, 2019
[6] Rules for navigation on the Danube, Danube commission, Budapest, 2010.
[7] Directive (EU) 2017/2397 on the recognition of professional qualifications for inland navigation, European Parliament, Brussels, 2017.
[8] Konakov L., A brief analysis of the adaptive systems for automatic ship course management, Marine Scientific Forum, Nikola Vaptsarov Naval Academy, 2013, v.1 , p. 143-150, ISSN 1310-9278.
[9] Dimitrakiev D., Maritime Transport Management, Monograph, Largo City, Varna, 2016, ISBN 978-619-7026-15-3.
[10] Dimitrakiev, D., Molodchik, A.V., Digital Platforms as Factor Transforming Management Models in Businesses and Industries. Journal of Physics: Conference Series. International Conference Information Technologies in Business and Industry 2018 IOP Publishing IOP Conf. Series: Journal of Physics: Conf. Series 1015 (2018) 042040 DOI:10.1088/1742-6596/1015/4/042040.
[11] Yotsov, I.V., Dimitrakiev, D.Y., Zaburtov, A., Koritarov, T.D., Analysis of the logistics transport corridors i black sea region based on the short sea shipping concept. 2017 18 th Annual General Assembly of the International Association of Maritime Universities – Global Perspectives in MET: Towards Sustainable, Green and Integrated Maritime Transport, IAMU 2017, ISBN-978-954-8991-95-7.