DOI: 10.31577/ahs-2022-0023.02.0023

ACTA HYDROLOGICA SLOVACA

Volume 23, No. 2, 2022, 207–216

Impact of climate change and human factors on the water regime of the Danube Delta

Viktor VYSHNEVSKYI*, Serhii SHEVCHUK

Climate changes in the Danube Delta, as well as changes in water temperature, water runoff and sediment yield, have been identified on the basis of available observational data. It has been shown that the intra-annual distribution of water runoff has become more uniform in recent decades. It decreased in April-May and increased in February-March. At the same time, there has been a significant decrease in sediment transport. Changes due to anthropogenic impact were detected in water runoff in the largest river branches, in particular, the reduction of the share of the Kiliyskyi branch. Over the past 60 years, the water temperature in the Danube Delta has increased significantly, by more than 2°C. In general, the water temperature is higher than the air temperature, especially in autumn. Some features of the delta formation have been identified.

KEY WORDS: the Danube River; delta, water discharge, sediment yield, air and water temperature

Introduction

The Danube is the second largest river in Europe in terms of catchment area, length and water runoff. At the same time, the Danube River is the most international river in the world, with a catchment area of 19 countries. 10 of these countries have direct access to the Danube River. An important feature of the Danube River is the presence of the large delta, which is the second largest in Europe after the Volga Delta (Olson and Krug, 2020).

It is concidered (Panin and Jipa, 2002; Olson and Krug, 2020; The Lower Danube River..., 2022) that the catchment area of the Danube River is 817,000 km^2 and the length is 2860 km. There are also slightly different data (Habersack et al., 2013; Stagl and Hattermann, 2015; Romanova et al., 2019), but the difference is small.

The water regime of the Danube River and, in particular its delta, largely depends on climate, which is unstable. Many papers (Webb and Nobilis, 2007; Pekarova et al., 2008; Marin et al., 2014; Vyshnevskyi and Donich, 2021) contain information on air temperature increase within the Danube River catchment area. At the same time, the results of studies on precipitation show that there are no significant changes (Marin et al., 2014; Vyshnevskyi and Donich, 2021).

There are many scientific works devoted to the Danube Delta itself (Panin and Jipa, 2002; Hydrology..., 2004; Gastescu, 2009; Gatejel, 2018; Tanasescu and Constantinescu, 2020; Covaliov et al., 2022).

One of the most important issues is the delta size. According to the data (Hydrology..., 2004), its area is estimated at 4200 km^2, including the Ukrainian part – 830 km^2, the Romanian one – 3370 km^2. Some other data about the delta area (4152 km^2) and its Romanian part (3446 km^2) are given in the paper (Olson and Krug, 2020). If we consider the Razim-Sinoe lagoon as part of the Danube Delta, its total area reaches 5165 km^2 (Olson and Krug, 2020). In general, the boundaries of the delta and, accordingly, its area are somewhat debatable.

The important issue of the lower course of the Danube River is water runoff and its distribution by the delta branches. This issue is considered in the works (Mikhailova et al., 2002; Hydrology..., 2004; Gastescu, 2009; Romanova et al., 2019). However, the distribution of runoff is unstable – it changes due to natural and anthropogenic factors.

An important feature of the river is the sediment yield, which significantly affects the delta size. According to the studies (Mikhailova et al., 2002; Panin and Jipa, 2002; Levashova, 2004, Gastescu, 2009; Habersack et al., 2013) the sediment yield has the tendency to significant decrease. The creation of reservoirs upstream the Djerdap-I HPP and Djerdap-II HPP is considered to be an important factor of this tendency (Mikhailova et al., 2002; Panin and Jipa, 2002; Gastescu, 2009).

The issues related to the Danube Delta, are the water temperature, water quality etc. These issues are studied in the works (Hydrology..., 2004; Gastescu, 2009; Covaliov et al., 2022; The Lower Danube River …, 2022).

It is important that part of the delta is a protected area. The Danube Delta Biosphere Reserve was created in the Romanian part of the delta, and the Danube

Biosphere Reserve in the Ukrainian part. At the same time, there are various economic activities in the delta: crop production, fisheries, reed harvesting, tourism. Some areas which were previously transformed, have regained their natural status (Gastescu, 2009; Tanasescu and Constantinescu, 2020; Covaliov et al., 2022).

In general, not all issues related to the Danube Delta are properly studied, some results are outdated. This is partly due to the fact that recent years have been very warm and low water. This affected both water temperature and the ecological state of the delta. In this regard, the main purpose of this study is to identify the impact of climate change and human activity on the water regime of the Danube Delta.

Material and methods

The Danube Delta is generally located in the south of Europe, on the border of two countries: Romania and Ukraine. As it was mentioned, most of the Danube Delta belongs to Romania, less – to Ukraine. Near the delta there are several large lakes, that connected with the Danube River (Fig. 1).

The Danube Delta begins some upstream the city of Izmail, where the river for the first time is divided into two branches: the left – Kiliyskyi, the right – Tulchynskyi. This place is called the Izmail Chatal. 17 km downstream from this place the Tulchynskyi branch is again divided into two: the left – Sulinskyi, the right – Georgievskyi. The width of these branches is less than the width of the river upstream of its branching. Thus, the width of the Kiliyskyi branch is about 400–450 m. As we approach the sea, the main branches are divided several more times, which determines the existence of a large number of watercourses and islands. In particular, the Kiliyskyi branch in the delta is divided into the Ochakivske (in the northeasten direction), the Bystre (in the eastern), the Starostambulskyi (in the southeastern) branches. In addition, there are many lakes within the delta (Fig. 2)

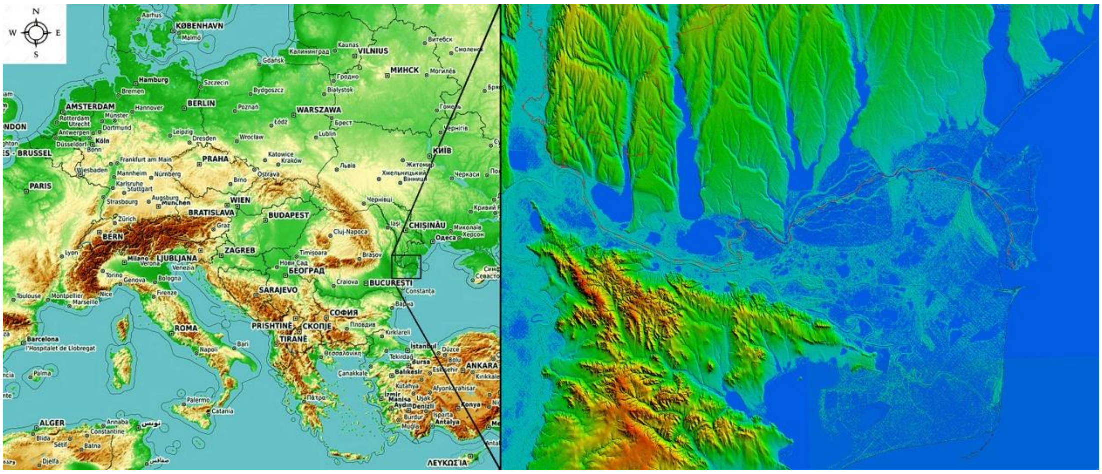


Fig. 1. The location of the Danube Delta and its volumetric image.

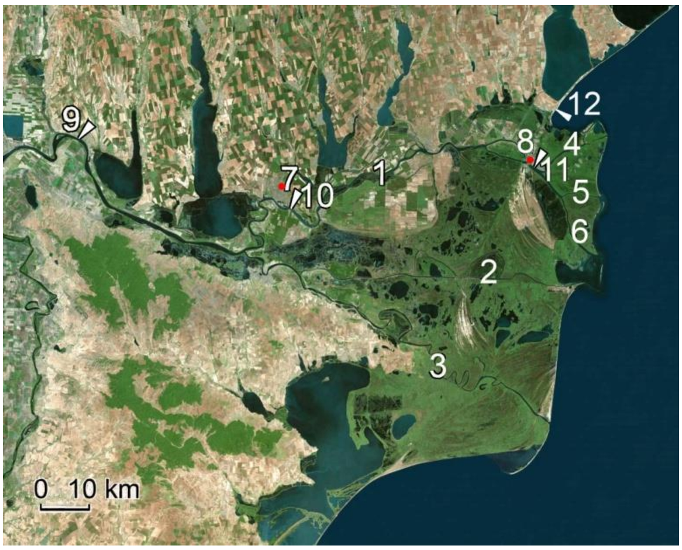


Fig. 2. The main water bodies in the Danube Delta and the available network of observations. The river branches: 1– Kiliyskyi, 2– Sulinskyi, 3 – Georgievskyi, 4 – Ochakivskyi, 5 – Bystre, 6 – Starostambulskyi. Meteorological stations: 7 – Izmail, 8 – Vylkove. Hydrological stations: 9 – Reni, 10 – Izmail, 11 – Vylkove, 12– Prymorske.

The length of the delta from its top to the sea edge in a straight line is 80 km. Approximately the same is the length from the north to the south.
The paper used the data from observations at meteorological and hydrological stations of Ukraine, which are summarized in the Danube Hydro-meteorological Observatory (Izmail).
In addition to regular monitoring data remote sensing data were also used in the paper. Most attention was paid to the data of Landsat 8 and Sentinel 2 satellites, which are available at https://earthexplorer.usgs.gov and https://scihub.copernicus.eu. The volumetric image of the Danube Delta was created on the basis of SRTM and GlobalMapper program.

Results and discussion

The air temperature and its changes

The climatic conditions of the Ukrainian part of the Danube Delta were studied on the basis of data meteorological stations Izmail and Vylkove. Meteorological station Izmail is located on the northern outskirts of Izmail city, 4.7 km from the Danube River, meteorological station Vylkove – almost on the river bank (see Fig. 2).
The mean annual air temperature at Izmail meteorological station during 1991–2020 was 11.7°C, and at Vylkove station – 12.2°C. The mean air temperature in January is minus 0.5°C and plus 0.4°C, respectively, the mean air temperature in July – respectively 23.6°C and 24.1°C.
Over the past 60 years, namely 1961–2020, mean air temperature in the studied area has increased significantly. Its changes during this period are 0.36–0.38°C per decade. The highest air temperature for the entire observation period was in recent years, namely in 2019 and 2020 (Fig. 3).
The air temperature in 2021 was smaller than in two previous years (Izmail station –11.9°C, Vylkove station – 12.4°C), but higher than mean value in 1991–2020.

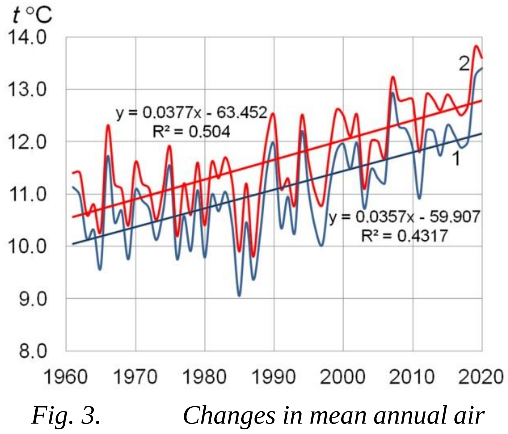


Fig. 3. Changes in mean annual air temperature at Izmail (1) and Vylkove (2) meteorological stations during 1961–2020.

Precipitation

Another important factor influencing the Danube Delta state is the amount of precipitation. Mean annual precipitation during 1991–2020 at Izmail meteorological station was 449, at Vylkove station – 463 mm. In the previous 30 years (1961–1990) the precipitation was some larger – 490 and 481 mm, respectively.
As the precipitation is characterized by considerable spatial and temporal variability, averaging was carried out at two mentioned meteorological stations to assess the changes. It turned out that the smallest precipitation was in 2019 (Fig. 4).
The intra-annual distribution of precipitation is rather even. However, the largest precipitation is observed in June: at Izmail station – 59 mm, at Vylkove station – 44 mm.

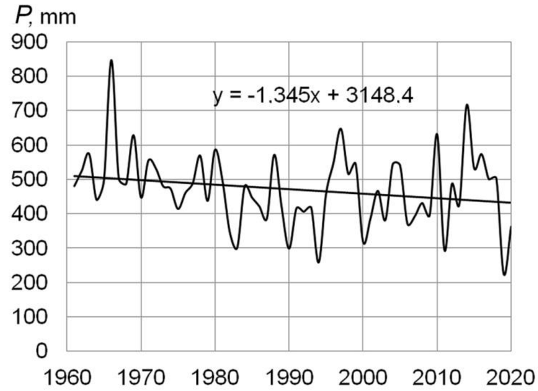


Fig. 4. Changes in averaged annual precipitation at Izmail and Vylkove meteorological stations during 1961–2020.

Evaporation from the water surface

Evaporation from the water surface in the Danube Delta was estimated on the basis of data from meteorological station Vylkove, where the observations are carried out using GGI-3000 evaporator, the water surface of which is 3000 cm^2.
According to the available observations the daily evaporation layer in summer days can reach 6.0–7.0 mm and the monthly evaporation can exceed 200 mm. It was identified that evaporation from the water surface is highly dependent on air temperature. It is important, that this dependence is nonlinear. The same results were obtained for many meteorologicas stations and for the different conditions (Vyshnevskyi, 2022) (Fig. 5).
Based on the obtained dependence shown in Fig. 5 it is possible to determine the changes in evaporation from the water surface over a long period (Fig. 6).
These data show that in recent decades, evaporation from the water surface has increased significantly – from about 900 mm to 1080 mm. The obtained result is similar to those given for the adjacent territory of Romania (Neculau and Stan, 2016), where the fact of evaporation over 1000 mm was determined as well.

The largest increase in evaporation is observed in July and August. While in 1961–1990 the mean daily values were close to 5.0 mm, now they are close to 6.0 mm (Fig. 7).

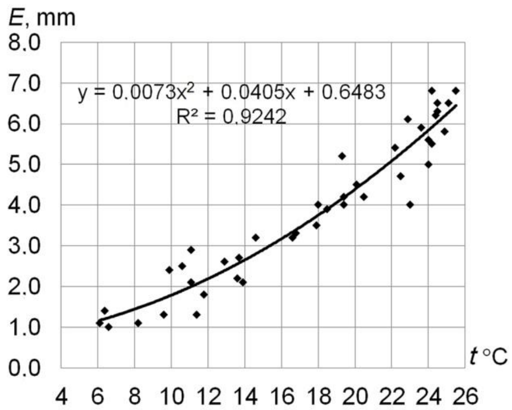


Fig. 5. The dependence of water surface evaporation on air temperature at Vylkove meteorological station.

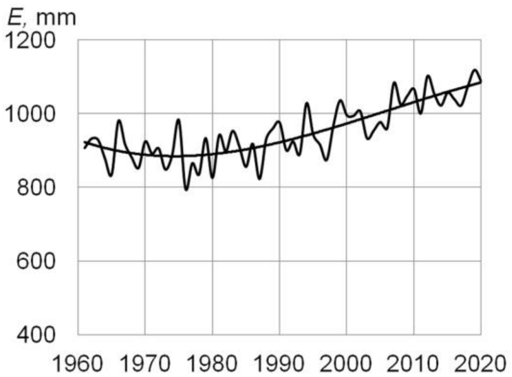


Fig. 6. The long-term changes of calculated annual evaporation from the water surface at Vylkove meteorological station.

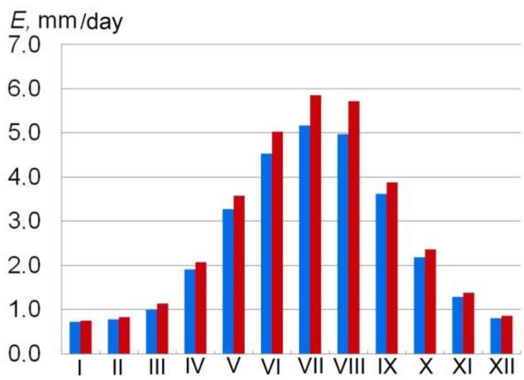


Fig. 7. The long-term changes in mean daily evaporation from the water surface at Vylkove meteorological station by months: left columns – 1961–1990, right columns – 1991–2020.

The results of studies presented in the paper (Vyshnevskyi, 2022), show that the evaporation from the evaporation basins (and, accordingly, from natural reservoirs) is slightly smaller than from the evaporator GGI-3000 due to less water heating. It makes approximately 0.9 from the data of evaporator GGI-3000. With this in mind, we obtained the next mean annual evaporation from the water surface for the different periods: 1991–2000 – 853 mm, 2001–2010 – 905 mm, 2011–2020 – 952 mm.

These data suggest that part of the river flow in the Danube Delta is lost as a result of evaporation, as it is twice larger than precipitation. In summer period mean evaporation layer exceeds precipitation by about four times.

It should be borne in mind that most of the delta is not a water space. The main territory is shallow water covered with air-water vegetation, which is dominated by reed (Covaliov et al., 2022). According to the studies (Stan et al., 2016) carried out in Romania, evaporation from such reservoirs is about twice as much as evaporation from the water surface. It means that evaporation from such water bodies can reach 1900 mm and additional evaporation 1450 mm. According to these data, it is possible to estimate the loss of water in the Danube Delta due to evaporation. Taking into account the delta area of 4200 km^2, the additional evaporation from natural landscapes can be estimated as 4–5 km^3. This is quite a noticeable value even for such a large river as the Danube.

Economic activity in the delta

The economic activity in the Danube Delta is long-term and varied. Some of its kinds have almost no effect on the water regime of the river, others affect – and quite noticeable. One of the first measures that significantly affected the Danube Delta was the construction in the early XX century the directing flow dam (training dike) at the place of Izmail Chatal. This dam was constructed from the stone and it is periodically repaired. Currently it reaches almost the middle of the Danube River width, which significantly affects the redistribution of the river flow in favor of the Tulchynskyi branch (Fig. 8).

To a large extent, the construction of this directing flow dam was associated with measures to improve navigation – especially in the Sulinskyi branch, which is the middle one of the three largest delta branches. This branch was straightened and deepened in some places. In addition, in order to reduce the sedimentation in the river mouth two parallel dams were built in the direction of the sea (Gatejel, 2018). Due to this, the Sulinskyi branch became the most important navigable route in the delta.

Measures to improve navigation in the Ukrainian part of the delta at the mouth of the Bystre branch were similar. The bar at the mouth of this branch was deepened. In addition, to the north of the mouth of this branch was built a dam in order to minimize the sedimentation by the coastal flow of sediments which moves from the north.

Fig. 8. The directing flow dam (shown by the arrow) at the division of the Danube River into Kiliyskyi and Tulchynskyi branches.

Another important measure that affected the delta was the construction of dikes on the river banks in order to use the adjacent territory in the economic sphere – primarily for agriculture. Such measures were carried out in both the Ukrainian and Romanian parts of the delta. In particular, on the left bank of the Danube River in the late 1950s and early 1960s was built a dike about 200 km long, which protected the adjacent lands from the flooding. At the same time, 21 sluice-gates were built on the watercourses connecting the Danube River with the lakes. As a result, these lakes were partly transformed into reservoirs.

In 1979–1980, another project was implemented, namely the construction of the Danube-Sasyk canal. The purpose of this project was to transform Lake Sasyk in fresh water body and to use it for irrigation. In the early 1980s, this canal supplied 0.5–1 km^3 of water. However, the water in the lake still remained brackish and therefore the water intake from it was stopped. Currently, only a small volume of water is taken from the canal itself for irrigation and fish farming.

A small volume of water is taken from the Danube River as well. In particular, the Danube water is used for the cities of Kilija and Vylkove.

Water runoff

Long-term observations of the Danube River runoff at Reni station, which started 100 years ago, make it possible to study the most important features of the river water regime. The mean long-term runoff of the Danube River at the top of the delta during 1921–2020 is 6510 $m^3 s^{-1}$, or 205 km^3 per year. Almost the same value is given in other works (Levashova et al., 2004; Gastescu, 2009; Stagl and Hattermann, 2015). The largest mean annual water discharge (9950 $m^3 s^{-1}$) over the past 100 years was observed in 1941, the lowest one (3920 $m^3 s^{-1}$) – in 1921 (Fig. 9).

As can be seen in Fig. 9, over the past 100 years there have been no significant changes in the water runoff of the Danube River. At the same time, the river is characterized by redistribution of runoff by separate branches. On the one hand, they are due to natural factors, on the other – human impact. In the latter case, the greatest impact was caused by the above-mentioned directing flow dam at the site of the first division of the Danube River into two branches. As a result, the share of the Kiliyskyi branch river flow has significantly decreased. While in the early XX century this share reached 70%, in recent decades it has significantly decreased. Thus, in 1991–2000, the share of the Kiliyskyi branch was 58.1% of the total runoff of the Danube River, in 2001–2010 – 53.4%, in 2011–2020 – 49.8%.

The share of the Kiliyskyi branch runoff slightly increases in case of large river flow and decreases at low water. Thus, in 2010, when the river flow was large, the share of this branch was 53.5% of the total. Next year, when the river flow was small, this share was only 49.7%.

Significant redistribution of water runoff occurred and continues to occur between the branches located downstream of Vylkove. To some extent, this is due to human activities, including dredging to improve shipping conditions. In particular, the deepening of the Bystre branch and removing the shallow at its mouth caused the increase of its share. In 2000, this branch accounted for 17.9% of total runoff, in 2020 – 19.2%. In turn, this led to a reduction of the river flow in the adjacent branches.

As it was already mentioned, evaporation, as well as water intake for economic needs, have a certain influence on water runoff at the mouth of the river. Thus, the mean discharge of the Kiliyskyi branch in recent years at Izmail station is larger than at Vylkovo station by 70–80 $m^3 s^{-1}$ or 2.2–2.5 km^3 per year. The main part of this volume is losed for evaporation.

During the year, the largest water runoff of the lower Danube River is observed in April, slightly less – in May. The lowest discharges are observed in September. It is important that over the past decades the intra-annual distribution of river flow has become more even, in particular, the maximum runoff in April–May has become lower. The discharges also decreased in the summer. Meanwhile, the flow increased in February and March (Fig. 11).

As a result of climate change, there was some approach of flood peak to the beginning of year. Currently, this peak at Reni station is observed closer to May 1. A similar result regarding the reduction of flood discharges and the approach of the flood peak to the beginning of the year was obtained in the works (Stagl and Hattermann, 2015; Blöschl, et al., 2017; Vyshnevskyi and Donich, 2021). For the future there is a forecast of runoff increase in winter and decrese for summer (Stagl and Hattermann, 2015).

Water turbidity and transport of sediment

The Danube River is one of the rivers with a fairly high water turbidity, and in terms of sediment yield, it ranks the first in Europe. Ultimately, this determines the existence of large delta, the size of which is growing. The average long-term transport of sediment at Reni station during 1978–2020 was 30 million tons, at Izmail station – 15 million tons. However, during this period transport of sediment decreased significantly and now it is two to three times smaller than the mean value for period from 1978 (Fig. 12).

The mean water turbidity during 1978–2020 at Reni station was 145 g m^{-3}, at Izmail station – 131 g m^{-3}. In recent years, under conditions of relatively small water runoff of the Danube River, the water turbidity has essentially decreased. In particular, in 2020 at Reni station it was 57 g m^{-3}, at Izmail station – 56 g m^{-3}, at Vylkove station – 50 g m^{-3}.

Reduction of water turbidity and sediment yield in the Danube River has been recorded in other works as well. In particular, in the paper (Mikhailova et al., 2002), it was noted that in natural conditions (1840–1920), the transport of sediment was 62.7 million t/year. The volume for the period 1921–2000, given in the paper (Gastescu, 2009), is slightly smaller – 58.75 million tons. However, the difference between these data is small. According to the paper (Gastescu, 2009), the modern transport of sediment is 25–35 million t/year.

As can be seen, during 1978–2020, compared to natural conditions, transport of sediment decreased by half and continues to decrease markedly. One of the factors of this is considered (Panin and Jipa, 2002; Levashova et al., 2004) the creation of reservoirs upstream the Djerdap-I HPP and Djerdap-II HPP. However, these reservoirs were built 40–50 years ago (Djerdap-I – in 1972, Djerdap-II – in 1984), but the sediment yield decrease continues. According to (Habersack et al., 2013) one of

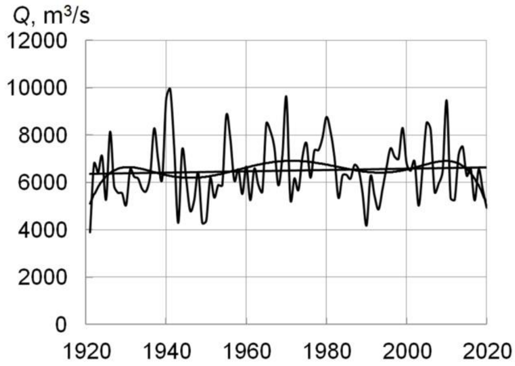


Fig. 9. Fluctuations of mean annual water runoff of the Danube River at Reni station during 1921–2020.

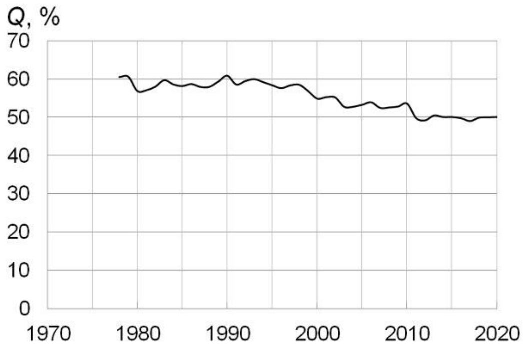


Fig. 10. Change in the share of Kiliyskyi branch runoff at Izmail station to the total at the top of the Danube Delta at Reni station.

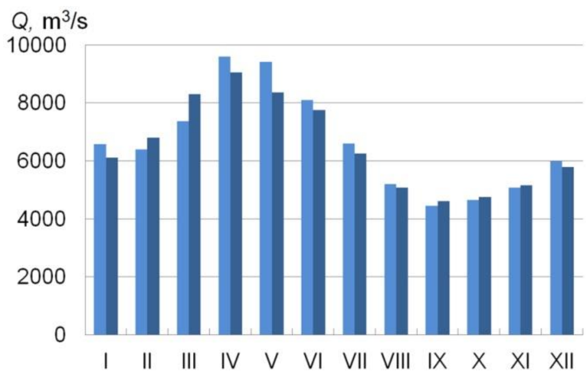


Fig. 11. Intra-annual distribution of the Danube River runoff at Reni station during 1981–2020. Left columns – 1981–2000, right columns – 2001–2020.

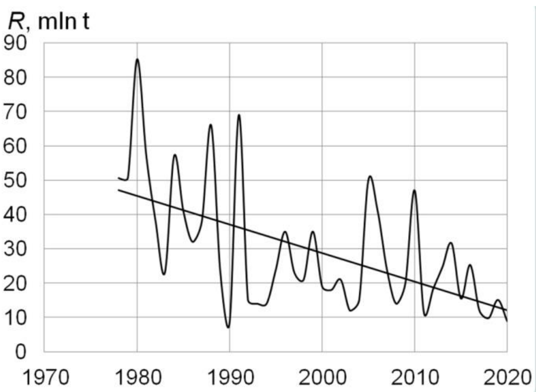


Fig. 12. The long-term changes of sediment yield at the top of the Danube Delta at Reni station.

the reasons of sediment yield decrease is the dredging to improve the navigation conditions. In our opinion, there are other factors related to climate change. Due to the increase of air temperature, in paricular in winter, soil freezing decreases and, accordingly, the share of surface runoff decreases as well. The second consequence of climate change is the reduction of maximum spring flood and flow velocity during this period. This trend of sediment yield decrease is observed in many regions of Europe, including the rivers that have not been regulated. A certain role in reducing of sediment trasport can be caused by environmental activities – increasing forest cover in the mountains and anti-erosion measures.

Water temperature

The location of the Danube Delta in the southern Europe determines a fairly high water temperature. It is important that in the Romanian section of more than 200 km the river flows from the south to the north. Being in this section the water temperature has time to rise. Another factor to consider is the location of places of water temperature observation. All hydrological stations within Ukraine are located on the left bank of the river, which is oriented to the south. This contributes to the fact that the water temperature here can be a few tenths of a degree higher than in the middle of the river.

These factors determine that the water temperature in the Danube Delta is high. In particular, at Izmail hydrological station, mean monthly water temperature in July and August during 1991–2020 was 25.4 and 25.7°C. It is important that the water temperature in the Danube Delta is essentially higher than the air temperature. In particular, the mean monthly water temperature at Izmail station during 1991–2020 in July is 1.8°C higher than air temperature. Excess of water temperature over air temperature is even greater in autumn and December. The largest difference is observed in October, when the mean air temperature is 11.9°C and the mean water temperature is 16.1°C. Even in March–April, when the rapid increase of air temperature is observed, water temperature is higher than air temperature (Fig. 13).

This rather significant excess of water temperature over air temperature is explained by the fact that the main absorption of solar energy occurs in the upper layer of water, where, in fact, the temperature is measured. Another probable factor in the excess of water temperature over air temperature is the above mentioned fact of water flow in the adjacent section from the south to the north. In addition, fresh water temperature has minimum 0°C, which air temperature does not have. Similar results showing an excess of water temperature over air temperature were obtained in many other works (Webb and Nobilis, 2007; Pekarova et al., 2008; Ptak et al., 2018; Vyshnevskyi, Shevchuk, 2021; Ptak et al., 2022), but the excess in the Danube Delta is larger than in many other rivers.

Importantly, water temperatures, like air temperatures, have risen essentially in recent decades. The increase is observed throughout the year (Fig. 14).

Fig. 14 shows that water temperature rose especially markedly in July and August, which corresponds to an increase of air temperature. At the same time, the increase in water temperature in April is small.

It is important, that observed increase of annual water temperature is a little bit larger, than the increase in air temperature. Over the past 60 years the increase in mean annual water temperature near Izmail is 0.38°C per decade and the increase of air temperature is 0.36°C per decade (Fig. 15).

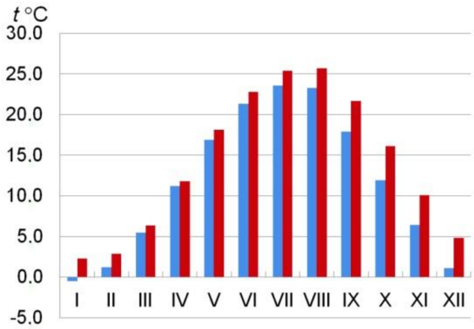


Fig. 13. Intra-annual distribution of air temperature (left columns) and water temperature (right columns) in Izmail during 1991–2020.

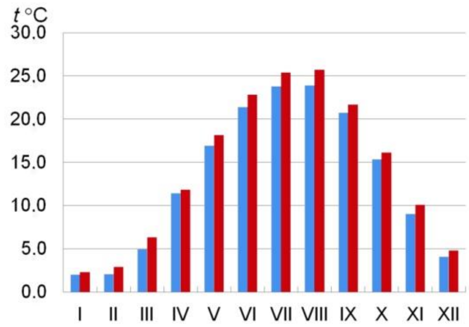


Fig. 14. Intra-annual distribution of water temperature at Danube–Izmail. Left columns – 1961–1990, right columns – 1991–2020.

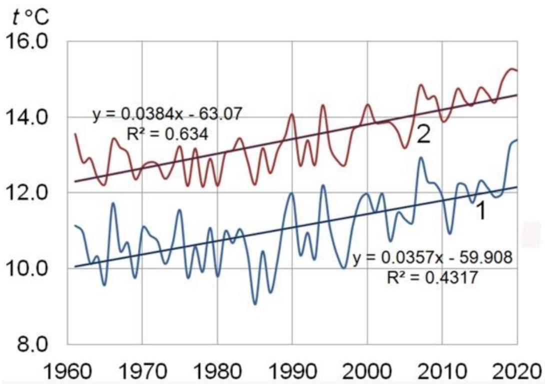


Fig. 15. The long-term changes in mean annual air (1) and water (2) temperature at Izmail meteorological and Izmail hydrological stations.

The conclusion about the increase in water temperature is contained in many other works (Webb and Nobilis, 2007; Basarin et al., 2016; Marszelewski and Pius, 2016; Czernecki and Ptak, 2018; Vyshnevskyi and Shevchuk, 2021; Ptak et al., 2022; Wrzesiński and Graf, 2022), but the excess of water temperature increas over air temperature increase is somewhat unusal. It can be assumed that the found feature on the Danube Delta is caused by the decrease of the river flow. But during long-time period the annual water runoff of the Danube River is practically stable. Another factor can be wastewater discharge, but the local cities are small without powerful enterprises. In fact, the main cause of the discovered feature is noticeable decrease of the Kiliyskyi branch river flow during observed period. Whereas in the early 1960's its share was about 60% of the total, by nowadays it is about 50%. It means that artifical decrease of the Kiliyskyi branch water runoff contributed to the increase in water temperature.

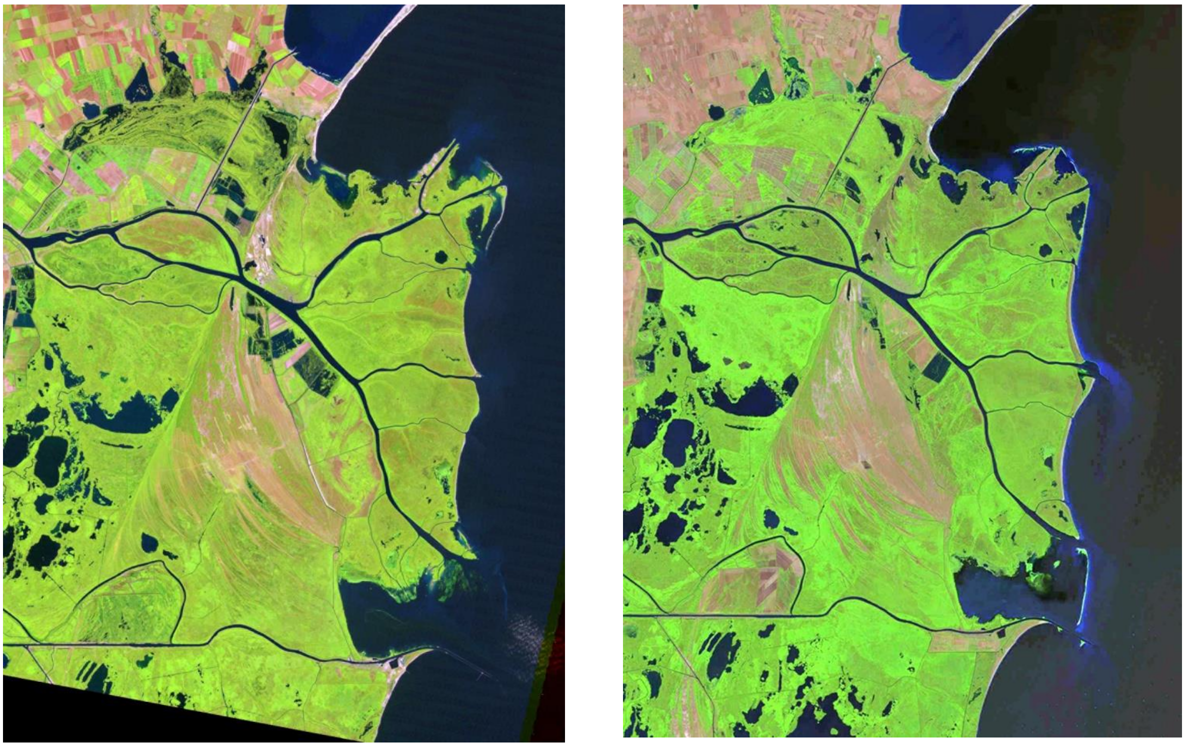
The available data show that water temperature depends on the water runoff of the Danube River. As river flow decreases, its heating in the warm period increases, in particular, due to the simultaneous reduction of mixing and depth. The opposite is observed at large discharges, when the water temperature may even be lower than the air temperature. Regression analysis also shows the inverse effect of the river flow on its temperature during main part of year except January–February. The most essential impact of water runoff on water temperature is observed in June. Taking into account two arguments (air temperature and water runoff) it is possible to obtain a close relationship between actual and calculated water temperature. A similar result was obtained in papers (Pekarova et al., 2008; Wrzesiński and Graf, 2022).

Delta size change

The change in delta size is primarily due to its advance towards the sea, because most of the sediment is deposited there. For a long period of time, the study can be carried out using Landsat satellite images. The first satellite images of the delta by Landsat 5 satellite were obtained in 1984. In particular, the image dated September 7, 1984 is of high quality. The image of Landsat 9 satellite dated August 07, 2022 is also of high quality. According to these data, it is possible to determine the changes which have occured over the past 38 years (Fig. 16).

A comparison of these images shows some differences between them. First of all, the appearance of an elongated island between the Starostambulskyi and the Sulinskyi branches is noteworthy. Its northern part belongs to Ukraine, the southern part – to Romania. Currently, in this island is the only land border between these states. Another place where the delta has moved towards the sea is located at the exit from the Ochakivskyi branch, which is oriented to the northeast. In this place several elongated islands were created.

In general, the changes in the size of the delta during the last decades are small. This is primarily due to the decrease of the Danube River sediment yield, as it was mentioned above. There is also another factor namely sea level rise. At Prymorske station, located near



a *b*

Fig. 16. Satellite images of the Danube Delta obtained by Landsat 5 on 07.09.1984 (a) and Landsat 9 on 07.08.2022 (b).

the mouth of the river, the mean sea level in 1981–1985 was minus 0.17 m, in 2017–2021 – minus 0.05 m. This means that the water level rose by about 12 cm, which also affected the delta.

Conclusions

The water regime of the Danube Delta is influenced by natural and human factors. Over the past 60 years, air temperature in the area of the Danube Delta has risen. This caused the essential increase in water temperature which is slightly larger than the increase of air temperature. The highest increase of water temperature is observed in summer period. The water temperature in the Danube Delta is higher than the air temperature. In spring this excess is about 1°C, in autumn – it reaches 4°C.

Despite climate change, the mean water runoff at the top of the Danube Delta remains stable at about 205 km^3. Meanwhile, intra-annual river flow distribution has become more even than it was some decades ago. In particular, the maximum runoff in April–May have become less. At the same time, it increased in February and March. The changes of flow regime has affected the sediment yield, which tends to essential decrease. In turn, the reduction of sediment yield has led to the fact that the movement of the delta towards the sea has slowed. Another factor, which impacted the delta, is the sea level rise.

One of the most important factors of human influence on the delta was the construction in the early twentieth directing flow dam at the site of the first division of the Danube River into two branches. As a result, the share of the Kiliyskyi branch has decreased from 60% to 50% in the last 40 years alone. It has some impact on the water temperature in this river branch.

References

Basarin, B., Lukić, T., Pavić, D., Wilby, R. L. (2016): Trends and multi-annual variability of water temperatures in the river Danube, Serbia. Hydrological Processes, 30, 18, 3315.

Blöschl, G., Hall, J., Parajka, J. et al. (2017): Changing climate shifts timing of European floods. Science 357, 588–590.

Czernecki, B., Ptak, M. (2018): The impact of global warming on lake surface water temperature in Poland – the application of empirical-statistical downscaling, 1971–2100. Journal of Limnology. 77 (2). 340–348.

Covaliov, S., Doroftei, M., Mierla, M., Trifanov, C. (2022): Natural vegetal resources of the Danube Delta territory – present status and trends. Scientific Annals of the Danube Delta Institute. 27. 25–33.

Gastescu, P. (2009): The Danube Delta Biosphere Reserve. Geography, biodiversity, protection, management. Rom. Journal Geogr. 53, (2), 139–152.

Gatejel, L. (2018): Building a better passage to the sea: engineering and river management at the mouth of the Danube, 1829–61. Technol. Cult. 59, 925–953.

Habersack, H., Jäger, E., Hauer, C. (2013): The status of the Danube River sediment regime and morphology as a basis for future basin management. International Journal of River Basin Management, 11: 2, 153–166.

Hydrology of the Danube Delta. Under editorship of Mikhajlov V.N. (2004): Moscow: GEOS, 448 p. (in Russian).

Levashova, E. A., Mikhailov, V. N., Mikhailova, M. V., Morozov, V.N. (2004): Natural and anthropogenic changes in water and sediment runoff at the mouth of the Danube River. Water resources. Volume 31. N. 3. 261–272 (in Russian).

Marin, L., Birsan, M.-V., Bojaru, R., Dumitrescu, A. et al. (2014): An overview of annual climatic changes in Romania: trends in air temperature, precipitation, sunshine hours, cloud cover, relative humidity and wind speed during the 1961–2013 period. Carpathian Journal of Earth and Environmental Sciences, November, 9, 4, 253–258.

Marszelewski, W., Pius, B. (2016): Long-term changes in temperature of river waters in the transitional zone of the temperate climate: A case study of Polish rivers. Hydrol. Sci. J. 61, 1430–1442.

Mikhailova, M. V., Mikhailov, V. N., Levashova, E. A., Morozov, V. N. (2002): Natural and anthropogenic changes in water and sediment runoff of the Danube at the delta head (1840–2000). Proc. XXIth Conference of the Danubian countries on hydrological forecasting and hydrological bases of water management, Bucharest, 1–7.

Neculau, G., Stan, F.-I. (2016): Evaporation and evapotranspiration in Romania. Forum geografic. Studii și cercetări de geografie și protecția mediului. Volume XV, Supplementary Issue (December 2016). 39–48.

Olson, K. R., Krug, E. (2020): The Danube, an Empire Boundary River: Settlements, Invasions, Navigation, and Trade Pathway Journal of Water Resource and Protection. 12, 10, 884–897.

Panin, N., Jipa, D. (2002): Danube River Sediment Input and its Interaction with the North-western Black Sea Estuarine, Coastal and Shelf Science. 54, 551–562.

Pekarova, P., Halmova, D., Miklanek, P., Onderka, M., Pekar, J., Skoda, P. (2008): Is the water temperature of the Danube River at Bratislava, Slovakia, rising? Journal of Hydrometeorology, 9, 5, 1115–1122.

Ptak, M., Sojka, M., Choiński, A., Nowak, B. (2018): Effect of environmental conditions and morphometric parameters on surface water temperature in Polish lakes. Water, 2018, 10, 580.

Ptak, M., Sojka, M., Graf, R., Choiński, A., Zhu, S., Nowak, B. (2022): Warming Vistula River – the effects of climate and local conditions on water temperature in one of the largest rivers in Europe. J. Hydrol. Hydromech., 70, 1, 1–11.

Romanova, Y., Shakirzanova, Zh., Ovcharuk, V. et al. (2019): Temporal variation of water discharges in the lower course of the Danube River across the area from Reni to Izmail under the influence of natural and anthropogenic factors. Energetika. 65 (2–3). 144–160.

Stagl, J. C., Hattermann, F. F. (2015): Impacts of climate change on the hydrological regime of the Danube River and its tributaries using an ensemble of climate scenarios. Water. 7, 6139–6172.

Stan, F.-I., Neculaub, G., Zaharia, L. et al. (2016): Study on the evaporation and evapotranspiration measured on the Căldărușani Lake (Romania). Procedia Environmental Sciences, 32, 281–289.

Tanasescu, M., Constantinescu, S. (2020): The human ecology of the Danube Delta: A historical and cartographic perspective. Journal of Environmental Management. 262.

The Lower Danube River: Hydro-Environmental Issues and Sustainability (2022): Editors Abdelazim Negm, Liliana Zaharia, Gabriela Ioana-Toroimac. 582 p.

Vyshnevskyi, V. I. (2022): The impact of climate change on evaporation from the water surface in Ukraine. Journal of Geology, Geography and Geoecology. Vol. 31. N 1. 163–170.

Vyshnevskyi, V. I., Donich, O. A. (2021): Climate change in the Ukrainian Carpathians and its possible impact on river runoff. Acta Hydrologica Slovaca. Vol. 22, № 1, 3–14.

Vyshnevskyi, V., Shevchuk, S. (2021): Thermal regime of the Dnipro Reservoirs. J. Hydrol. Hydromech., 69, 3, 300–310.

Webb, B. W., Nobilis, F. (2007): Long-term changes in river temperature and the influence of climatic and hydrological factors. Hydrolog. Sci. J., 52, 74–85.

Wrzesiński, D., Graf, R. (2022): Temporal and spatial patterns of the river flow and water temperature relations in Poland. J. Hydrol. Hydromech., 70, 2022, 1, 12–29.

Prof. Viktor Vyshnevskyi (*corresponding author, e-mail: vishnev.v@gmail.com)
National Aviation University
Liubomyra Huzara Ave, 1
Kyiv, 03058
Ukraine

Serhii Shevchuk, seniour researcher
Central Geophysical Observatory
Nauky Ave., 39/2
Kyiv, 03028
Ukraine