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Original article

The Danube River Water Discharge According to Satellite Optical Data of the Landsat Series

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Abstract
The paper aims to find the correlation relationship between the land–water area ratio for a fixed area of the Danube Delta and the total river discharge using Landsat series satellite products and SMHI Hypeweb hydrological model. The study period covered 1984–2010. We used a total of 132 satellite images in one band in the near-infrared spectral range with a spatial resolution of 30 m. Two study areas were selected: the delta area with channel and land (44.9–45.4°N, 29.55–29.60°E) and the control area of the mouth seashore (44.9–45.4°N and 29.80–29.85°E). For each of them a histogram was plotted which characterised the reflected light in relative units and their corresponding numbers of pixels. The signal from the first area was found to be in the range of 7000–26,000 r.u., whereas from the second one it was 7000–8000 r.u. This distinction allowed us to separate the delta areas occupied by river water from those of land. For this purpose, we calculated the ratio between the number of pixels corresponding to a value of 7000–8000 r.u. to all pixels in the area. Then we found the correlation between the river discharge from the SMHI Hypeweb hydrological model and the proportion of pixels corresponding to areas occupied by water. The regression $y = 7.78 \cdot 10^{-4} \cdot x^{0.09} - 5.98 \cdot 10^{-4}$ was obtained. The analysis of seasonal variability showed that in the studied delta area, the share of pixels related to water-occupied areas > 0.5 corresponds to the months from March to May, and the minimum values < 0.3 correspond to July–September. All this is consistent with the period of intensity of precipitation and snowmelt in the Danube River basin area. The data from this work may be useful to researchers assessing the impact of this river discharge on the hydrological regime and condition of the Black Sea.

Keywords: remote sensing, Danube River, river discharge, Landsat TM, SMHI Hypeweb, hydrological model, Black Sea

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Расход воды реки Дуная по оптическим спутниковым данным серии *Landsat*

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Аннотация
Цель работы – найти корреляционную связь между соотношением площадей суши и воды для фиксированного района дельты Дуная и суммарным расходом реки, используя спутниковые продукты серии *Landsat* и гидрологическую модель *SMHI Hypeweb*. Период исследования охватывал 1984–2010 гг. Всего было использовано 132 спутниковых снимка в одном спектральном канале в ближнем инфракрасном диапазоне спектра с пространственным разрешением 30 м. Выбрали два района исследования: участок дельты с руслом и сушей (44.9–45.4° с. ш., 29.55–29.60° в. д.), а также контрольный участок устьевого взморья (44.9–45.4° с. ш., 29.80–29.85° в. д.). Для каждого из них строили гистограмму, характеризующую отраженный свет в условных единицах и соответствующие им количества пикселов. Получено, что сигнал, исходящий от первого района, находится в диапазоне 7000–26 000 у. е., а от второго – 7000–8000 у. е. Данное различие позволило отделить участки дельты, занятые речной водой, от суши. Для этого вычисляли отношение между числом пикселов, соответствующих значению 7000–8000 у. е., ко всем пикселам в данном районе. Затем находили корреляцию между расходом реки по гидрологической модели *SMHI Hypeweb* и долей пикселов, соответствующих занятым водой участкам. Получена регрессия $y = 7.78 \cdot 10^{-4} \cdot x^{0.09} - 5.98 \cdot 10^{-4}$. Анализ сезонной изменчивости показал, что в исследуемом участке дельты доле пикселов, соответствующих занятым водой участкам, превышающим 0.5, соответствуют месяцы с марта по май, а минимальные значения (менее 0.3) характерны для июля – сентября. Все это согласуется с периодом интенсивности выпадения осадков и таяния снегов в ареале бассейна р. Дуная. Данные этой работы могут быть полезны исследователям, оценивающим влияние стока указанной реки на гидрологические режим и состояние Черного моря.

Ключевые слова: дистанционные методы исследований, Дунай, расход рек, *Landsat TM*, гидрологическая модель, Черное море

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Introduction

The Black Sea occupies a unique geographical position due to the system of the Bosphorus, Dardanelles and Gibraltar Straits, making it the most isolated water body in the Atlantic Ocean basin. Under such conditions, the water mass coming from the estuaries has a particularly pronounced effect on the dynamics as well as the optical and biochemical characteristics of waters at the mouths of marine areas. For the Black Sea, the Danube River runoff is a decisive factor in physico-chemical processes both in the north-western shelf area and in the whole sea in general [1, 2]. The contribution of the Danube to long-term and seasonal changes in sea level is also significant [3]. Therefore, quantification of the volume of water flowing from the Danube into the Black Sea is highly demanded in different fields of scientific knowledge.

With the development of the Earth surface remote sensing from artificial satellites, new opportunities arise for monitoring the areas of the river mouth interface with a lake or sea [1), 2)].

The problem of studying river discharge from satellite data in the optical spectral range is not new. For example, this problem is addressed in [4–6]. In these works, a two-band approach [5] or an automatic classification system (ISODATA) [4] are used to separate the surface occupied by water and land. Application of the obtained results with synchronous measurements of river discharge at gauging stations made it possible to construct a regression relationship between these parameters, which can be used for monitoring the river discharge based on satellite measurements only.

Altimetric methods [7–9] and estimation with high-resolution data from the Sentinel-2 satellite [10–13] are also known. However, it should be noted that the above methods, despite their advantages, are difficult to use by domestic researchers, as access to satellite products is currently limited. The use of these methods requires consideration of many factors (vegetation cover, water chromaticity, atmosphere aerosol component, spectral indices based on several bands, etc.), which complicates the estimation of river discharge.

The paper aims to find the correlation relationship between the land–water area ratio and the total water discharge of the Danube River from observations of a fixed area of the river delta using medium resolution second level satellite data (i.e. after atmospheric correction) in the near-infrared spectral range, using one band. The article uses materials of the report on the XII All-Russian Conference with international participation “Current Problems in Optics of Natural Waters (ONW’2023)” [14].

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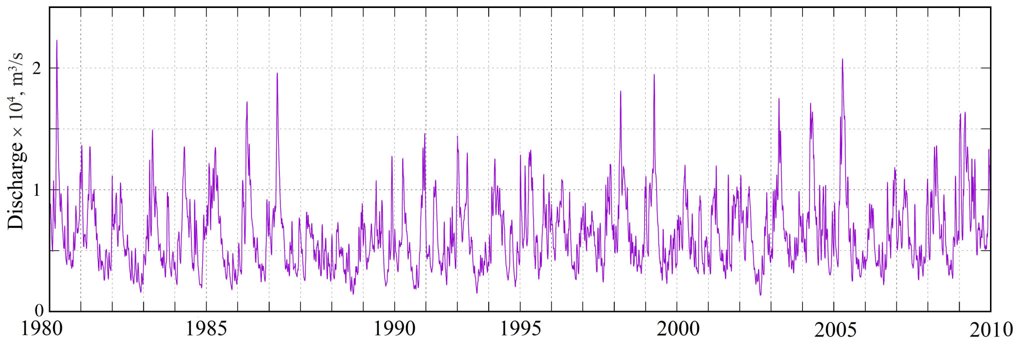
1) Scott, J.W., Moore, L., Harris, W.M. and Reed, M.D., 2003. *Using the Landsat Enhanced Thematic Mapper Tasseled Cap Transformation to Extract Shoreline*. U.S. Geological Survey Open File Report OF 03-272. 14 p. https://doi.org/10.3133/ofr2003272

2) NASA. *The Thematic Mapper*. 2025. [online] Available at: https://landsat.gsfc.nasa.gov/thematic-mapper/ [Accessed: 11 February 2025].

Materials and methods

Reanalysis data obtained from the SMHI Hypeweb website [3] were used as input data of the discharge at the Danube River mouth. The source provides information on daily water discharge (sector 9600704) from 1 January 1981 to 31 December 2010 (Fig. 1).

Landsat series satellite products (a joint project of the US Geological Survey and NASA) were obtained from the Landsat Missions website [4]. For the study, cloud-free images of the second level, i. e. after atmospheric correction, were selected from the entire available image array in band 5, wavelength range 1.55–1.75 μm with a spatial resolution of 30 m. This satellite product characterises the reflection coefficient of natural sunlight (in r. u.) of the study area of the Earth surface, taking into account atmospheric influence and observation geometry. For the water surface, the reflection coefficient values themselves and its variability associated with the observation geometry are minimal, as when selecting scenes, we excluded data with sea surface glare. The choice of band was stipulated by its lower sensitivity to errors associated with aerosol in the atmosphere and high content of mineral suspension in river waters, which determined a better separation of land and water surface.



F i g . 1 . Water discharge at the Danube River mouth (sector 9600704) according to reanalysis data from the SMHI Hypeweb website

[3] SMHI. *Europe Time Series*. 2025. [online] Available at: https://hypeweb.smhi.se/explore-water/historical-data/europe-time-series/ [Accessed: 11 February 2025].

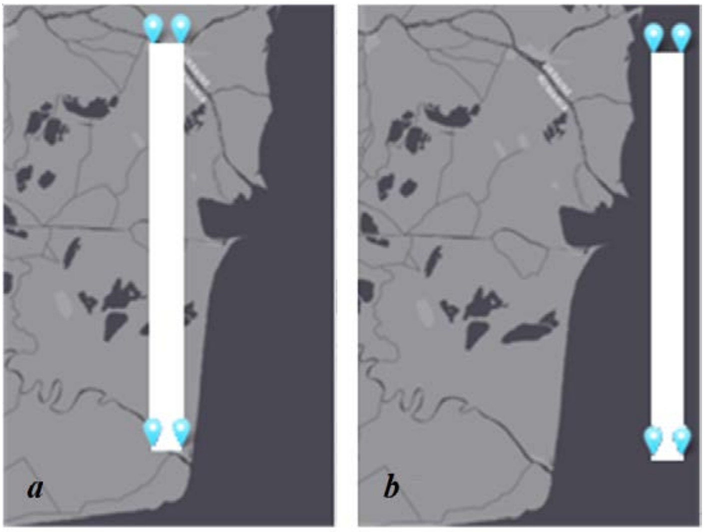
[4] U.S. Geological Survey. *Landsat Missions*. 2025. [online] Available at: https://www.usgs.gov/landsat-missions [Accessed: 11 February 2025].

A total of 132 images were selected for 1984–2010:

January	3	July	22
February	5	August	19
March	8	September	11
April	9	October	11
May	14	November	5
June	18	December	7

As would be anticipated, the largest number of suitable scenes is observed in the warm period of the year, a phenomenon primarily attributable to the frequency of cloud coverage throughout the year. The selected images are distributed uniformly over the years in the time interval under consideration, with an average of five months of the year being covered.

The study area (fixed delta area) coordinates are 44.9–45.4°N and 29.55–29.60°E (Fig. 2, *a*). In addition, a control area of the mouth seashore with coordinates 44.9–45.4°N and 29.80–29.85°E, located close to the study area, was selected (Fig. 2, *b*).



F i g . 2 . Study areas: *a* – the fixed section of the delta; *b* – the control area of the mouth seashore (adopted from: https://earthexplorer.usgs.gov/)

For Band 5, histograms (Fig. 3) were plotted for the two selected areas (Fig. 2). The control area of the mouth seashore (Fig. 3, *b*) exhibits variability in signal amplitude from the water surface, ranging from 7000 to 8000 r. u. Conversely, the entire range of variability for the fixed delta area (Fig. 3, *a*) extends from 7000 to 26,000 r.u. Fig. 3 demonstrates the obvious fact that the signal from the water surface (Fig. 2, *b*) is significantly weaker than that from land (Fig. 2, *a*) for the near-infrared range.

Thus, the share of water-occupied surface at the fixed delta area in Fig. 2, *a* (*weight water*) was found as the ratio of the number of pixels in the histogram from the range of 7000–8000 r. u. to all pixels in the area. The relationship between the discharge of the Danube River and the *weight water* was determined by the corresponding date of the survey, i. e. the same day. Since the cross-section of the channel (effluents) varies with depth, there must be a relationship between the width of the channel (effluents) and the water discharge. At the same time, the width of the channel (effluents) is obviously related to the area covered by water observed on the satellite scene.

Results and discussion

Fig. 4 shows the result of the relationship between the proportion of pixels (*weight water*) occupied by water at a fixed delta site and the Danube River discharge for 1984–2010. The correlation coefficient is 0.78 and the total number of points is 132.

The choice of individual effluents in the Danube River delta as a fixed delta area has little effect on the nature of the obtained relationship (Fig. 4). A similar observation can be made regarding the increase in the fixed area within the delta.

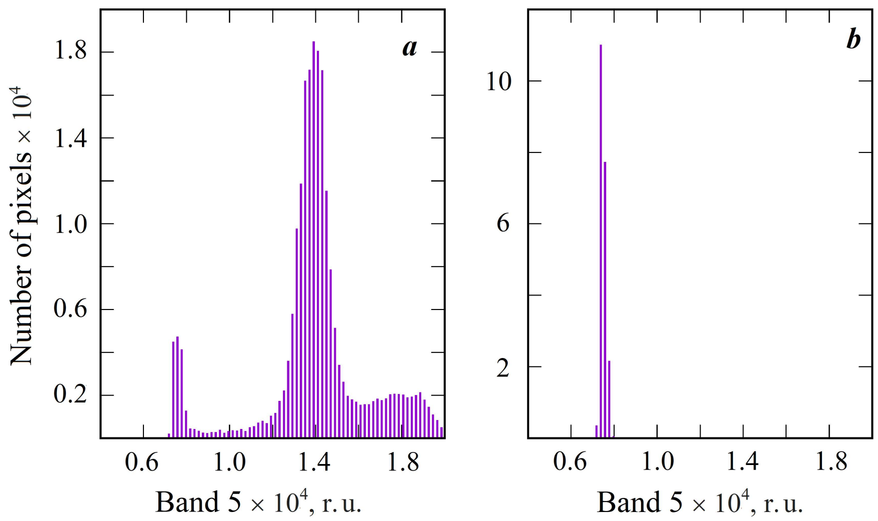
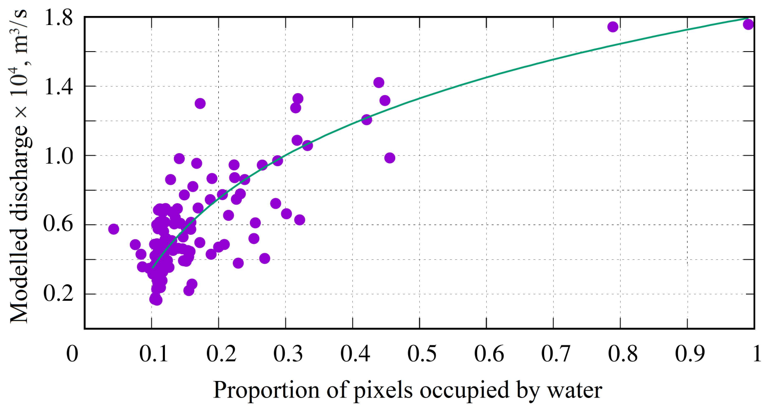


Fig. 3. An example of count in band 5 (1.55–1.75 μm) signal histograms for the fixed delta area (*a*) and the control area of the mouth sea-shore (*b*) for 5 September 2009



F i g . 4 . Relationship between the proportion of pixels (*weight water*) occupied by water for the fixed delta area and the Danube River discharge for 1984–2010: the dots denote separate scenes and the line is the general regression relationship: $y = 7.78 \cdot 10^{-4} \cdot x^{0.09} - 5.98 \cdot 10^{-4}$

The nature of the obtained functional relationship can be qualitatively explained within the framework of a simple hypothesis, for which it is sufficient to consider two trivial cases of river channel cross-sections: rectangular and triangular. In the first case, the channel width is fixed; hence, a change in discharge will not affect the increase in channel width or surface area occupied by water, i.e. it is a period of low discharge. In the second case, the relationship will be a quadratic function of channel width, and all other variants with less steep channel cross-sections will approach the relationship obtained.

The seasonal variability analysis shows that *weight water* over 0.5 corresponds to the months from March to May, whereas the minimum values of *weight water* under 0.3 correspond to July–September. All this is consistent with the period of intensity of precipitation and snowmelt in the Danube River water intake area [5)].

Conclusions

To solve the problem of determining the Danube River discharge using Landsat series satellite products, a simple one-band method was proposed, which is characterised by its accessibility to a wide range of users. The possibility of dividing the river delta area into land- and water-occupied zones based on their signal in the near-infrared spectral range is shown. It was found that the water surface corresponded to the range of 7000–8000 r.u. and the land to 7000–26,000 r.u.

[5)] Ivanov, V.A. and Minkovskaya, R.Ya., 2008. [*Sea Estuaries of Rivers of Ukraine and Estuarine Processes*]. Sevastopol: ECOSI-Gidrofizika, 448 p. (in Russian).

By calculating the ratio of the number of pixels corresponding to water-occupied areas to all pixels of the selected delta area and relating this share to the river discharge from the hydrological model reanalysis data for the same date, we obtained regression relationship $y = 7.78 \cdot 10^{-4} \cdot x^{0.09} - 5.98 \cdot 10^{-4}$. The above relationship can be applied to calculate the inflow of the Danube river water into the Black Sea. It was found that water–land pixel ratio exceeding 0.5 was typical for spring months and less than 0.3 corresponded to summer – early autumn, which coincides with the period of precipitation intensity and snowmelt in the Danube River basin.

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Evgeny A. Podgibailov – collection of study materials, primary processing and sorting of data, discussion of the results, article execution

Oleg V. Martynov – literature review on the study problem, discussion of the results, article execution

All the authors have read and approved the final manuscript.