

Automatic processing of Sentinel-2 image for Kerch peninsula lake areas extraction using QGIS and Python

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Abstract. Climatic changes that have occurred over the past decades, with an acceleration of urbanization of territories and technological development, leads to the significant changes not only in the atmosphere, but also in the Earth's surface. Surface water bodies are one of these components. Today there are 3 main methods of monitoring water bodies - field, remote and combined. In this paper, we show the possibility of automating remote monitoring of water bodies using QGIS, Python and Sentinel-2 data of the main and largest lakes of the Kerch Peninsula. Having analysed both the available satellite data and the features of the study area, we came to the conclusion that it is advisable to use the NDWI index instead of the mNDWI. After processing and analysing the Sentinel-2 data for 2018 using the data processing model presented in the work, we obtained time series of changes in the areas of the studied lakes of the Kerch Peninsula.

1 Introduction

Mapping natural resources, like water objects, is becoming very important due to development of remote sensing products and technologies [1,2].

In recent years, historical data obtained from Landsat satellites have been used for water bodies monitoring [3,4]. The main disadvantage of using Landsat data is a relatively low spatial resolution which is about 30 m.

an alternative of Landsat data using is data from the Sentinel-2 satellite, launched by the European Space Agency (ESA) in 2016 [5,6]. Their main advantage over Landsat data is a higher spatial resolution (10 m) and a higher level of survey frequency, which is about 5 days (while for Landsat it could go up to 15-16 days) [7].

However, it should be noted that the accuracy of water surfaces, that're extracting using satellite images depends not only on the spatial resolution of the used data, but on the algorithm, that is used for determining water areas.

At the moment, two main indices are used to distinguish water areas - NDWI and MNDWI [7].

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Over the past decades, it can be seen noticeable signs of the transformation of water bodies on the Russian Federation's territory. The most striking example of such changes is the problem of the Aral Sea. Increasing in level of anthropogenic impact led not only to a water areas decreasing, but also to significant landscape and climatic transformations [8].

One of the important features of the lakes of the Kerch Peninsula is their balneological properties, but gradually changing climatic conditions, as well as a constantly increasing anthropogenic impact, lead to significant changes in their water regime, thereby leading to a significant decrease in their water level and, consequently, to their drying[2].

Despite the important both recreational and economic importance in the sustainable development of the Kerch Peninsula, the knowledge of its lakes conditions is rather weak. Basically, previous studies were aimed at studying oil extraction in some lakes, the mineralogical composition of waters, the species composition of bottom vegetation and phototrophs, and the geoecological features of balneological resources.

2 Research area

2.1 Geographical conditions

The Kerch Peninsula is located in the eastern part of the Crimean Peninsula from which it is separated by the Akmonai Isthmus and is washed by the Black Sea and Sea of Azov, as well as the Kerch Strait (Figure 1). The biggest distance from east to west, from the Akmonai Isthmus to the waters of the Kerch Strait, is about 90 km, and from south to north - up to 54 km. The total area of the peninsula is approximately 3 thousand km² [9,10].

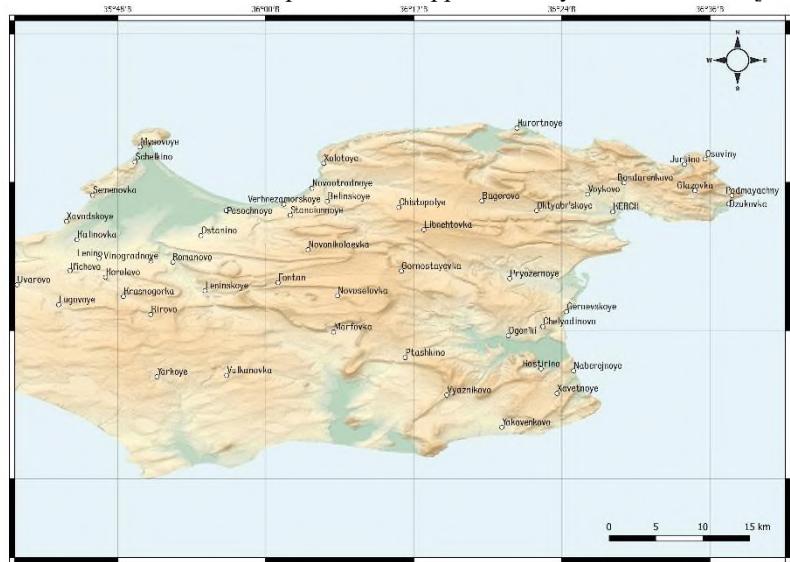


Fig. 1. Physical map of the Kerch peninsula.

The relief of the peninsula can be described as the steppe hills with a division into 2 parts - a gentle southern and western part and hilly northern and eastern [11]. Geologically, the Kerch Peninsula belongs to the Kerch-Taman folding, where prevail only sedimentary rocks, the thickness of which reaches more than 5 km [8].

The Kerch Peninsula is a seismically active zone, the level of which is largely similar to the mountain systems of the Caucasus and the Crimean Mountains [9]. Basically, a high level of seismic activity is observed in the deformations of young geological formations,

areas of mud volcanoes and movements of the Earth's surface. But according to recent studies, at this moment, it's in a stage of seismic lull.

The climate of the peninsula can be described as dry, moderately hot, continental type. The average annual air temperature is 11 °C [12]. The average temperature of the warmest month - July is -26 °C, the coldest - February - 4 °C. Winters are mild, but with rare short-term temperature drops. The absolute minimum is about 25-27 °C below zero. In summer, the air temperature can reach 35-40 °C [13]. The average annual amount of rainfall on the peninsula is 459 mm. Their highest level occurs in the winter months and early spring [14]. The spatial distribution of precipitation is approximately the same throughout. There is a slight tendency to decrease from east to west. Most precipitation falls in the area of Kerch (about 435 mm per year).

The surface waters of the peninsula are represented by rivers and streams, which are rather low-watered, which is caused by an insignificant level of precipitation here. Autumn-winter floods are weak, sometimes in December – January [15]. The average intensity of rising water levels in rivers in the spring is 0.1 ... 0.2 m/day, the maximum is 0.5 m/day, which is most often observed in the spring (March - April), or at the beginning of summer (June) and in some cases in July-August.

Economic activity on the Kerch Peninsula is mainly focused on the agricultural sector, which employs about a third part of the population. The main crops grown here are wheat, barley and peas. The largest enterprises in this area are "Vostok" and "Zolotoy Kolos"

2.2 Lakes of the Kerch Peninsula

Lakes of the Kerch peninsula has a marine origin and located on the shores of the Black Sea, the Sea of Azov and the Kerch Strait. The main sources of water incoming here are played by surface waters from snowmelt and downpours [16].

The most famous Lake Chokrakskoye is located in a hollow among mountains, 16 km from Kerch and is separated from the Sea of Azov by a 320 m wide embankment. Its banks are steep and cut by streams, flowing into it. The lake is replenished with waters flowing down from the slopes of the mountains. The water of the lakes, usually have high levels of salinity, that's why they are much heavier than sea waters [15].

The lakes of the Kerch Peninsula contain about 21 million m³ of high-quality therapeutic mud reserves. However, over the last 20 years their ecosystem was completely transformed due to the pollution and desalination of the Tobechikskoye and Uzunlarskoye lakes, which led to a significant reduction (approximately 16 million m³) of standard amount of their mud.

3 Materials and methods

3.1 Data

In this paper, we used the satellite data of the Sentinel-2 satellite mission for the period of 2018 year. All satellite images used in this study were preprocessed with radiometric and atmospheric corrections. We used only the third (560 nm) and eleventh (842 nm) channels with a spectral resolution of 10 meters per pixel.

In addition to remote sensing data, we used data about temperature and precipitation on the peninsula for 2018. We used climate data from the National Center for Environmental Information (NCEI CDO) at Kerch station (WMO code - 33983).

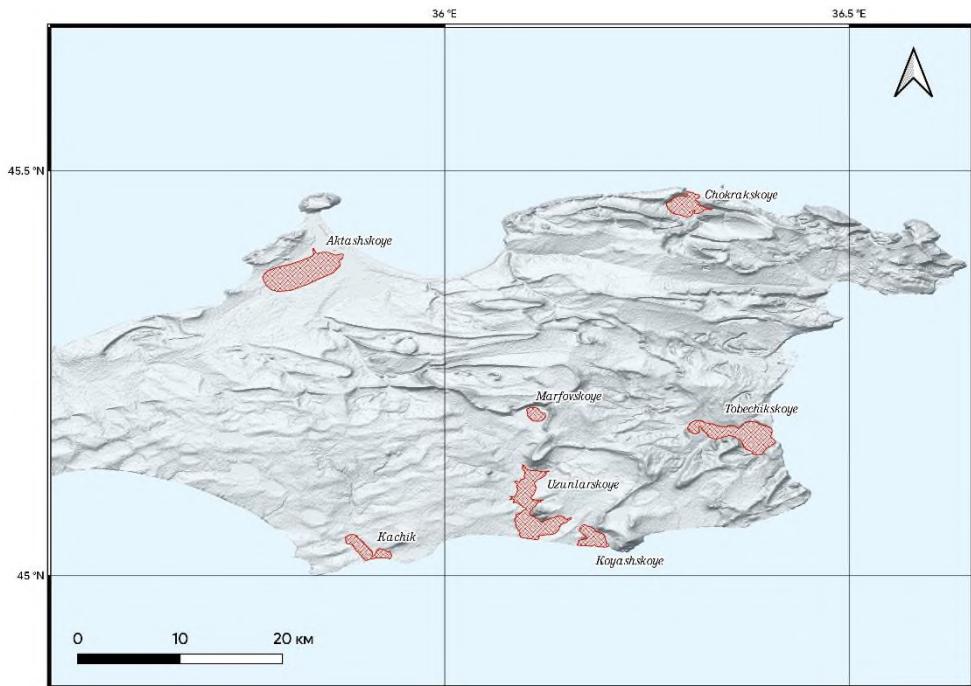


Fig. 2. Map of the research area.

We've chosen 7 lakes on the Kerch peninsula for our research - Aktashskoye, Chokrakskoye, Marfovskoye, Tobechikskoye, Kachik, Uzuntarskoye and Koyashskoye, as they are main water resources and recreation sources of the peninsula (Figure 2).

3.2 Water indices

In his work [17] McFeeters purposed using the NDWI (Normalized Difference Water Index) index for differentiating water from the land surface by using Green and NIR bands. It is based on fact, that water bodies have the maximum reflectivity in the green spectrum and the minimum reflectance in the near infra-red. Calculation of the NDWI based on the formula:

$$\text{NDWI} = \frac{\text{Green}-\text{NIR}}{\text{Green}+\text{NIR}} \quad (1)$$

where Green is a B03 channel of Sentinel-2 images, NIR is B08 channel of Sentinel-2.

Water bodies are characterized by values ranging from 0.3 to 1 of the NDWI index. Vegetation is in range from 0.2 to 0.3, and artificial structures are 0 to 0.2. Values lower than 0 are typical mainly belongs to open soils, agricultural lands, etc. One of the most important drawbacks of this index is the poor differentiation in the near infrared spectrum of water bodies and artificial structures, which can lead to errors in the classification of water bodies located near settlements and other buildings and structures.

To solve this problem, Xu in his work [18] modified the NDWI water index by replacing the near infrared channel with a short-wave infrared channel (SWIR). When calculating this index, water bodies have values greater than 1, while values of the land area are values less than 1.

$$\text{MNDWI} = \frac{\text{Green}-\text{SWIR}}{\text{Green}+\text{SWIR}} \quad (2)$$

where Green is channel B03 of Sentinel-2, SWIR is channel B11 of Sentinel-2.

The disadvantage of this index is the low spatial resolution of the SWIR channel (20 m) compared to NIR (10 m), which leads to a decrease in the granularity of the results.

Thus, in spite of the slightly less inferior possibilities in separating water bodies from land using the NDWI index, we choose it, because from the one hand the spatial resolution of the extracted water bodies plays a big role here, due to a small areas of some lakes here, and from the other hand Kerch peninsula is more agricultural area, with only one big settlement. That's why using NDWI index for this territory is more appropriate, than MNDWI.

3.3 Water extraction algorithm

Using the QGIS Model Builder, we've created an algorithm that allows us to automatically process the satellite images and obtain data that displays lakes of the Kerch Peninsula and their characteristics - area and perimeter (Figure 3).

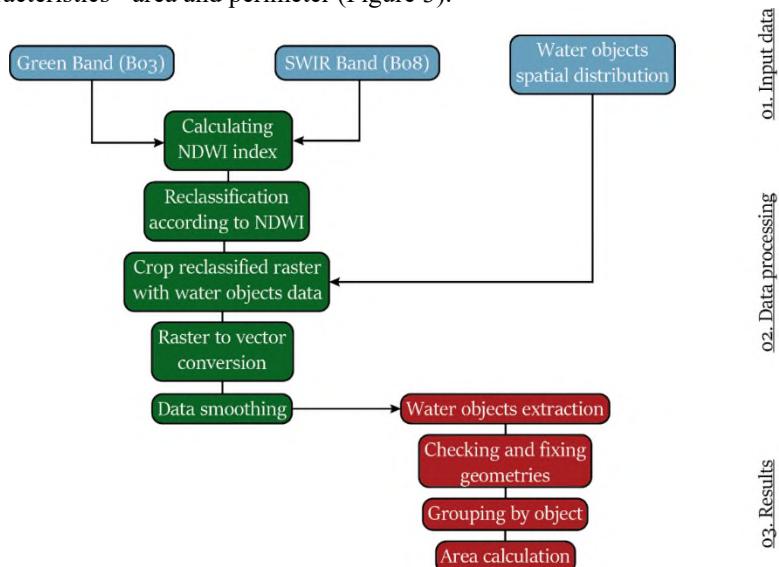


Fig. 3. Scheme of Sentinel-2 data processing model for automatic water extraction.

Inputs of this algorithm are green and NIR bands, and vector data with our area of interest. The output of this algorithm is a vector file, that contain all of the data of studied waterbodies at appropriate time.

4 Results and discussion

According to the analysis, the water area of all 7 lakes during the year has a tendency to annual changing. Often this range reaches 100%, from full filling with water to absolute drying out. For most lakes on the peninsula, a decrease water level began in March-April, sometimes in February. In the summer period, increase in air temperature and the intensity of water evaporation leads to a significant decrease in its level, up to complete drying out. Since almost all of the analysed lakes are mud - their drying out is manifested in a significant decrease in the water component in the mud solution, leading it to a more viscous or sometimes solid state.

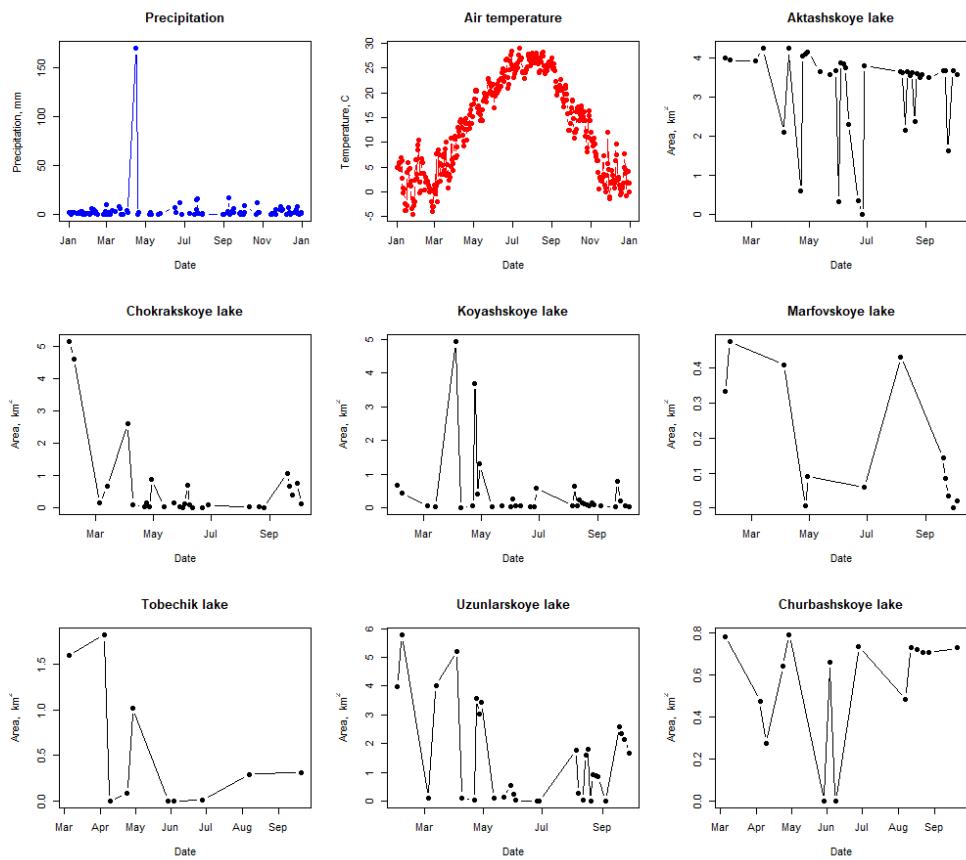


Fig. 4. Time difference in amount of precipitation, air temperature and lakes areas in 2018.

Based on analysed precipitation data on Kerch station can be seen, that their level was significantly low during all 2018 year. An exception only can be an amount of precipitation in April (Figure 4).

The most significant was the fluctuations in water level of Uzunlarskoye and Churbashskoye lakes. Distinctive features of these two lakes is a high level of anthropogenic impact. Area, near lake Uzunlarskoe was a part of a military training ground located near Opuk mount, which led to significant deformation of the coast and bottom of the lake, to contamination by used shells, fuel residues, etc. Unlike Uzunlarskoye, Churbashskoye lake is not affecting by active anthropogenic impact, but it owes its level of pollution to the now inactive Kerch iron ore plant, which some time ago actively dumped its wastes into lake waters. This led to extremely severe pollution of the lake, as well as to the loss of balneological status.

In general, as can be seen from the analysis, the lake areas weakly correlates with the amount of precipitation, although in some cases there is a characteristic increase in area in early April, which is definitely associated with a significant level of precipitation. On the other hand, the most significant sources of water supply to the lakes of the Kerch peninsula are likely to be groundwater and the infiltration interactions with the Black Sea and Sea of Azov.

Unlike precipitation, the annual variation in air temperature has a more noticeable effect on the area of the lakes of the Kerch peninsula. So, almost all lakes are characterized by a decrease in area with increasing air temperature in the summer, and a gradual area

increasing in the autumn-winter period. Frequent fluctuations in the lake's areas can be correlated with both natural causes and excessive anthropogenic removal of mud from lakes for cosmetic and balneological purposes, which leads to an imbalance in the percentage of therapeutic mud from the Kerch lakes and leads to a change in the level of the water component.

5 Conclusion

The results of the research show that the use of methods based on the calculation of vegetation indices for monitoring and automatic extraction of water bodies from satellite images is very promising. The disadvantage here can be attribution to the class of water bodies of any anthropogenic structures. We also suggest adjusting the algorithm and changing the used vegetation index depending on the characteristics of the territory. In more populated or built-up areas it should be used the MNDWI index, and in areas dominated by natural areas - NDWI.

The developed technique fully allows to process a large amount of remote sensing data for extracting areas of water bodies according to spatiotemporal conditions.

The surface areas of lakes, which largely determine the volume of water contained in it, change significantly during the year under the influence of various factors.

The change in the area of lakes on the Kerch peninsula correlated with the annual course of temperature, groundwater, as well as infiltration from the Black Sea and Sea of Azov.

The impact of precipitation is not significant, and in the vast majority of cases it is practically absent.

References

1. S. Latu, EJISDC 38, 1 (2009)
2. D. O. Krivoguz and D. N. Burtnik, Nauchno-Tekhnicheskiy Vestn. Bryanskogo Gos. Univ. 4, 113 (2018)
3. O. H. Adedeji, C. O. Adeofun, O. H. Adedeji, and C. O. Adeofun, J. Geogr. Inf. Syst. J. Geo-Graphic Inf. Syst. 6, 375 (1986)
4. L. Hung Trinh and D. Tuyen Vu, Russ. J. Earth Sci. 19, ES2003 (2019)
5. E. S. A. (ESA), Sentin. User Handb. (2015)
6. Q. Wang and P. M. Atkinson, Remote Sens. Environ. 204, (2018)
7. G. Kaplan and U. Avdan, Eur. J. Remote Sens., 50, (2017)
8. D. Krivoguz and L. Bespalova, Int. J. Prof. Sci., 19 (2017)
9. D. Krivoguz and L. Bespalova, Russ. J. Earth Sci., 20, 1 (2020)
10. D. Krivoguz, Russ. J. Earth Sci., 20, 1 (2020)
11. V. M. Peshkov, Ecol. Saf. Coast. Shelf Zo. Sea 1, 12 (2015)
12. D. Krivoguz and L. Bespalova, Vestn. Kerchenskogo Gos. Morskogo Tehnol. Univ. 5 (2018)
13. V. V. Korzhenevsky, Y. V. Korzhenevskaya, and A. A. Kvitnitskaya, Tambov Univ. Reports. Ser. Nat. Tech. Sci. 22, 930 (2017)
14. P. A. Balykin, D. N. Kutsyn, and A. M. Orlov, Oceanology 59, 358 (2019)
15. N. V. Shadrin, E. V. Anufrieva, and S. N. Shadrina, Mar. Biol. J. 2, 80 (2017)

16. G. G. Matishov, L. A. Bespalova, O. V. Ivlieva, A. E. Tsygankova, and L. V. Kropyanko, *Dokl. Earth Sci.* **471**, 1269 (2016)
17. S. K. McFeeters, *Int. J. Remote Sens.* **17**, (1996)
18. H. Xu, *Int. J. Remote Sens.* **27**, (2006)