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Change in the Water Surface Area of Reservoir of the Crimean Peninsula According to Radar Satellite data Sentinel–1 for the Period from October 2014 to August 2022

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SUMMARY

According to Sentinel–1 radar satellite data, there is a tendency to reduce the area of the water mirror in all reservoirs of the Crimean Peninsula, analyzed in this study, compared to their water surface area in 2015. On average, the area of the water mirror decreased by 34% in 2021. In three reservoirs, the area of the water mirror decreased by more than 60% compared to 2015: Frontove, Taiganske, and Mizhhirske reservoirs. The tendency to reduce the water surface area begins to manifest clearly in mid–2019 and continues until 2021. Also, a retrospective analysis of satellite images for 2015–2021 showed that the Simferopol reservoir of water surface area had been reduced on average by ~ 20% compared to 2015. Changes in the Water Surface Area of Simferopol and Feodosiya Reservoir for the Period from October 2014 to August 2022 were presented. A retrospective analysis of satellite images for the period from March 2015 to August 2022 showed that the Simferopol and Feodosiya Reservoirs of water surface area had been reduced on average by ~20% and ~30% (according) compared to 2015.

Introduction

Changes in the water content of the Crimean reservoirs have been caused by climate change (aridification of climatic conditions), seasonal variations in runoff, intensive usage of water resources because of intensification militarization and tourism, and the termination of water supplies from mainland Ukraine (*Boychenko, Voloshyn, 2022*).

Water reservoirs in this region are referred to as natural runoff reservoirs and loading reservoirs (*Khilchevskyi, 2022*). The loading reservoirs have begun to decrease and are currently filled up to 20% and more (after the cessation of water supply from the Crimean canal in 2014). The reservoirs of natural runoff are characterized by a significant correlation between the surface water body and precipitation in the watersheds (so, in 2020, with low recorded water levels, the area of reservoirs reached only about 40% of the area). A periodic fluctuation of the water levels of reservoirs on the Crimean Peninsula during 1984–2020 was defined in (*Shinkarenko, 2021*) with the use of the medium– and high–resolution satellite images (Landsat and Sentinel). The assessment of the dynamics of the surface water body area of Crimean reservoirs 2015–2021 by using Sentinel–1 satellite data was discussed in (*Boychenko, 2022).*

Satellite high–resolution Sentinel–2 optical and Sentinel–1 radar imagery may provide essential information on spatial and temporal dynamics of the surface water body area. The water surface absorbs the energy in near and middle infrared bands and appears as the areas with lower reflection values on the images of those optical bands. At the same time radar signal, which is sensitive to the surface smoothness, may easily detect the water surface as the areas with low backscatter values (*Gao, 2012; Avisse, 2017*)

The study aims to analyze the change in the water surface area of the Crimean Peninsula reservoirs according to radar satellite data Sentinel–1 for the period from October 2014 to August 2022.

Method and Theory

Sentinel–1 satellite radar (microwave) sensor data was used for surface water area detection. Microwave sensors are sensitive to surface structure and roughness: the smoother the surface, the lower signal scattering. The smooth water surface acts as a mirror reflector, which makes radar sensing effective in detecting the boundaries of water bodies. The first Sentinel–1 satellite was launched in the summer of 2014. All available satellite images for the full–year period from 2015 to 2021 were analyzed in this study. Fifteen significant reservoirs of the Crimean Peninsula that provide water supply to the population were included in the assessment. For the imagery processing, we used Google Earth Engine platform to run the step–by–step procedures, so–called Recommended Practices, developed by UN–SPIDER (United Nations Platform for Space–based Information for Disaster Management and Emergency Response) to support emergency response rapid mapping in case of disaster event, such as flood (*UN–SPIDER, 2021*). In order to better identify trends in water surface area, we calculated the yearly averaged water mirror area between 2015 and 2021.

In this study, empirical data from the meteostations Simferopol and Feodosia for the period 1991–2021 were used (after 2014, empirical data were not received by the Central Geophysical Observatory of Ukraine (*CGO, 2021*), and therefore for the period 2014–2021, data by the resource (*Weather and climate, 2022*). Climatic parameters were presented as the anomaly of the monthly precipitation and the average monthly temperature (values of temperature were multiplied by 10 for clarity in the figures) and they were calculated from their average values for the period 1991–2020.

Results of investigations

Change in the Water Surface Area of Reservoir of the Crimean Peninsula According to Satellite data for the Period from October 2014 to August 2022. In the recent few years, the problem of water scarcity in Crimea has become extremely important, as water levels in several reservoirs approached critical levels *(Boychenko, Kuchma, 2022).* A comparison of the surface water body areas of the reservoirs in Crimea for the period 2015–2021 according to radar satellite data Sentinel–1 (*Google Earth Engine, 2022*) is presented in Table 1.

Table 1 *Comparison of the water mirror areas of the reservoirs in Crimea in 2015–2021 according to radar satellite data Sentinel–1*

Reservoir name	Yearly Averaged Water Mirror Area of Reservoir, (ha)													
	2015–2021	2015	2016		2017		2018		2019		2020		2021	
The loading reservoirs														
Feodosiya	153.5	177.0	164.5	–7%	159.7	–10%	157.9	–11%	150.8	–15%	150.6	–15%	113.9	–36%
Frontove	216.2	341.8	276.2	–19%	235.3	–31%	195.0	–43%	168.8	–51%	169.2	–51%	127.4	–63%
Yuzmak	111.5	124.0	111.0	–11%	105.0	–15%	105.4	–15%	111.3	–10%	117.3	–5%	106.4	–14%
Mizhhirske	60.5	116.2	73.7	–37%	49.2	–58%	52.5	–55%	35.0	–70%	76.1	–35%	21.1	–82%
Samarlinsk	97.8	109.6	99.4	–9%	97.9	–11%	95.9	–13%	96.4	–12%	96.4	–12%	89.0	–19%
The natural runoff reservoirs														
Chornorichensk	425.3	452.8	401.5	–11%	452.2	0%	473.2	+5%	466.6	+3%	349.3	–23%	381.7	–16%
Bilogirsk	119.0	142.6	106.6	–25%	137.5	–4%	108.7	–24%	145.0	+2%	86.2	–40%	106.5	–25%
Partyzansk	146.7	168.1	156.1	–7%	169.6	+1%	165.4	–2%	159.8	–5%	97.0	–42%	110.8	–34%
Zagorsk	119.1	137.2	129.5	–6%	130.0	–5%	127.3	–7%	123.8	–10%	84.5	–38%	101.2	–26%
Simferopol	236.3	282.4	261.0	–8%	269.3	–5%	253.5	–10%	244.6	–13%	175.5	–38%	168.0	–41%
Shchaslyve	42.6	48.1	40.0	–17%	44.5	–7%	43.6	–11%	42.6	–11%	37.4	–22%	42.0	–13%
Taiganske	76.8	116.7	63.3	–46%	55.0	–53%	37.0	–68%	143.4	+23%	85.0	–27%	36.9	–68%
Isobilnenske	50.0	52.5	55.0	+5%	54.8	+5%	53.4	+2%	53.1	+1%	43.6	–17%	37.3	–29%
Ayanske	25.2	28.2	24.1	–15%	26.8	–5%	25.4	–10%	24.3	–14	22.0	–22%	25.3	–10%
Starokrymske	23.0	20.8	17.4	–17%	28.1	+35%	24.7	+19%	31.9	+53%	24.7	+18%	13.2	–37%

Also, the values of deviations in (%) from their levels for 2015 are given. The most significant decrease in reservoir levels is typical for the loading reservoirs and the Taiganske reservoir due to the transfer of water from it to the Simferopol reservoir (*Resource, 2020*). While in some years for the natural runoff reservoirs, an increase in level has been shown (for example, Starokrymske, Isobilnenske, and Chornorichensk) (*Boychenko, Kuchma, 2022*). There is a tendency for the reduction of water surface areas in all reservoirs, analysed in this study, compared to their water surface area in 2015. The water mirror area decreased by 34% on average in 2021. In three reservoirs, the area of the water mirror decreased by more than 60% compared to 2015: Frontove, Taiganske, and Mizhhirske reservoirs. The tendency to reduce the water surface area begins to manifest clearly in mid–2019 and continues until 2021 (*Boychenko, Kuchma, 2022*).
The change in the water mirror area of the Simferopol and Feodosiya reservoir for the Period from October 2014 to August 2022 are described more precisely further in the article.

Change in the Water Surface Area of Simferopol and Feodosiya Reservoir for the Period from October 2014 to August 2022. Simferopol Reservoir was formed in 1954 on the Salgir River (water mirror area is about 317 ha, water volume is 36 million m^2). This reservoir is classified as with a natural runoff, and therefore the change in its level is due to seasonal changes in runoff, climatic conditions, and water use and consumption *(Lisovsky, 2011)*. Significant water use and consumption against the background of arid climatic conditions has caused a sharp decrease in the water level in the reservoir during 2015–2022 *(Boychenko, Kuchma, 2022*). The situation was especially critical in 2020–2021, while in the autumn–winter, the reservoir was filled due to the transfer of water from the Taiganske reservoir to the Simferopol reservoir *(Resource, 2020).*
Feodosiya Reservoir was formed in 1971 (water mirror area is about 317 ha, water volume is 8.5 million m^3) The main source of reservoir replenishment is the North Crimean Canal and it is classified as with a loading reservoir. Precipitation practically does not affect the inflow of water in the reservoir *(Lisovsky, 2011).* Due to the suspension of water supply to the reservoir from the Dnipro, water from the Taiganske reservoir began to be pumped into the reservoir in January 2015. The change of the water level in the reservoir during 2015–2022 was considered in (*Boychenko, Kuchma, 2022*).
A retrospective analysis of satellite images for the period from March 2015 to August 2022 showed that water surface area of Simferopol and Feodosiya Reservoirs of had been reduced on average by

~20% and by ~30% (according) compared to 2015. The seasonal changes in runoff are related to precipitation variations compared with the water surface area variations for the period January 2014 to August 2022. The anomaly of the monthly precipitation and the average monthly temperature was calculated from their average values for the period 1991–2020 (see Figure 1B).

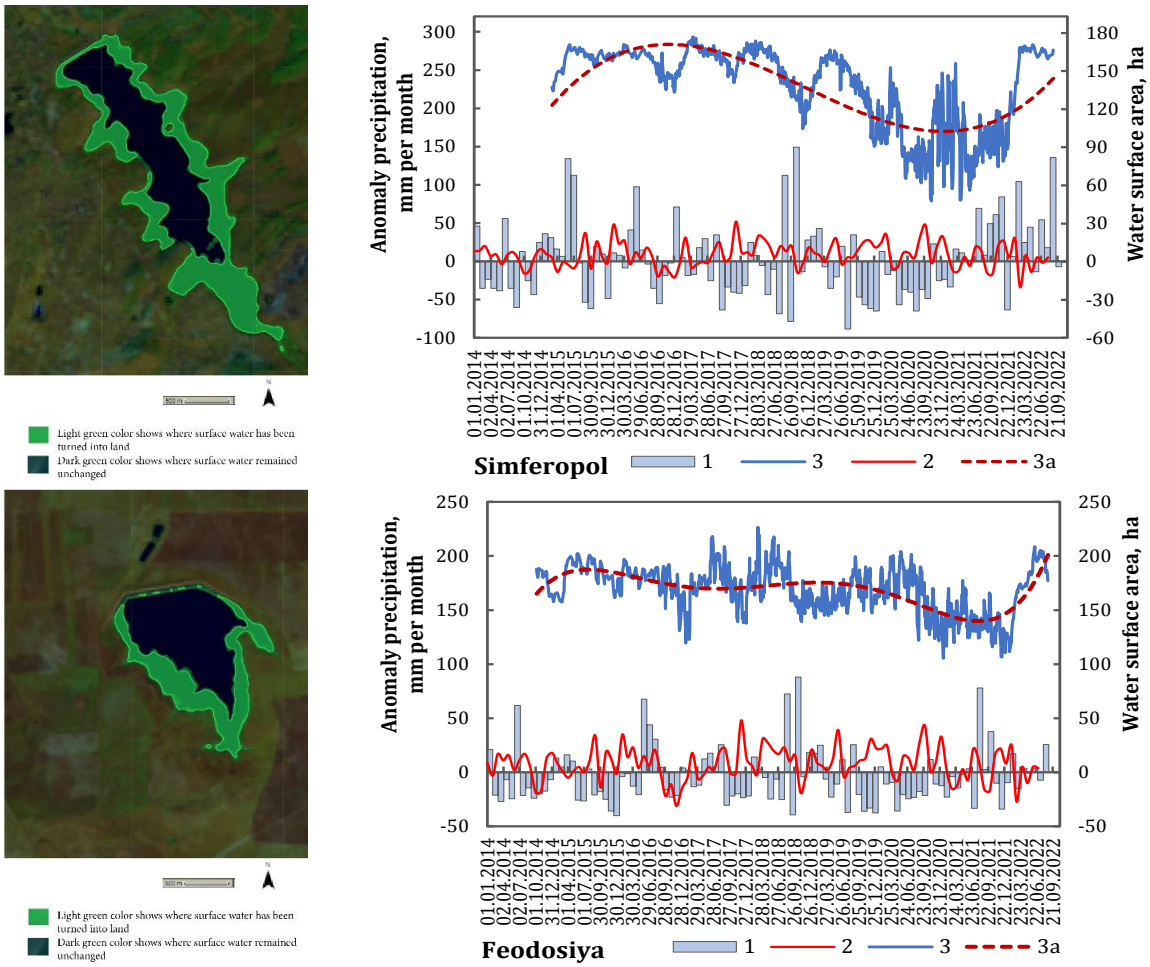

Figure 1 *Decrease in the water surface area of the Simferopol and Feodosiya Reservoirs in 2021 (dark green) compared to 2010 (light green) according to Landsat satellite imagery (**A**) and anomaly of monthly precipitation (**1**) and anomaly average monthly of temperature (**2**) for period from January, 2014 to August 2022 and dynamics of changes of water surface area (**3** and **3a** is polynomial spline) for the period from October, 2014 to August,2022 according to Sentinel–1 satellite data (**B**)*

According to Landsat satellite imagery, a comparison of the average water surface area of Simferopol and Feodosiya Reservoirs in 2020 with the area in 2010 is shown in Figure 1. The last few years, and especially 2020, were the hottest and driest in recent decades, and intensive water use led to a sharp drop in water levels in the Crimean reservoirs, as compared using Deltares Aqua Monitor planform (https://aqua–monitor.appspot.com). A decrease in the level of the reservoirs of peninsula, which was associated with the aridization of climatic conditions due climate change, was also observed in the past (for example, during 1993–1997, and 2011–2012) (*Popovych, 2018*).

Conclusions

According to Sentinel satellite imagery, there is a tendency to reduce the area of the water mirror in all reservoirs, analysed in this study, compared to their water surface area in 2015. On average, the area of the water mirror decreased by 34% in 2021. In three reservoirs, the area of the water mirror decreased by more than 60% compared to 2015: Frontove, Taiganske, and Mizhhirske reservoirs. The

tendency to reduce the water surface area begins to manifest clearly in mid–2019 and continues until 2021. Also, a retrospective analysis of satellite images for 2015–2021 showed that the Simferopol reservoir of water surface area had been reduced on average by ~ 20% compared to 2015.
Change in the Water Surface Area of Simferopol and Feodosiya Reservoir for the Period from October 2014 to August 2022 was presented. A retrospective analysis of satellite images for the period from March 2015 to August 2022 showed that the Simferopol and Feodosiya Reservoirs of water surface area had been reduced on average by ~20% and ~30% (accordingly) compared to 2015.

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