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Remote Sensing Upon Tracking Changes in the Water Sufrace Area of Belmeken Dam

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Abstract: Determining the characteristic volumes in a water reservoir contributes to the correct use of its water potential, nevertheless it is used for irrigation, water supply or for power generation. The introduction of new technologies and methods for tracking changes in water areas during the operation of hydrotechnical facilities has been a topical subject in recent decades. The present survey investigates the possibilities of using remote sensing data to track the changes of water areas in the reservoir lake of the Belmeken dam. We have applied a common remote sensing index (NDWI) for a five- year period (2018-2022) to analyze possible changes in water areas/water surface. The results show that the application of satellite data, specifically the NDWI index, that are compatible with the volumes measured for the same period in the dam, that are calculated by the balance method, could contributes to up-to-date information on the water volumes formed in the reservoir of Belmeken dam. The research can facilitate the process for determining the water volumes in Belmeken dam and support decision-makers and responsible institutions in the management of the water volumes during the dam's reservoir operation.

Keywords: Remote sensing, NDWI, Water balance method, Water volumes curve, Flooded areas curve

Introduction

Reservoirs, which are part of water energy systems, are an important component of water management and water resources management in the conditions of seasonal irregularity of precipitation and river inflow and of water use from the dam, especially in the conditions of climate change and anthropogenic impacts.Water resources are unevenly distributed on the territory of Bulgaria, both in perennial and seasonal aspects. According to Eng. Lyubenov (2009), in just 2-3 months in the spring, 60-70% of the high waters formed on the territory of the country drain away. Part of these water volumes are accumulated in the reservoirs for their distribution in the remaining months of the year for the respective consumers, and the remaining volumes flow into the riverbeds. The stored water volumes in the reservoirs of the large hydropower cascades maintained and managed by the "Dams and Cascades" enterprise of NEK-EAD(https://www.nek.bg/index.php/bg/) amount to 3.5x109.m^3, which is 50.1% of the total regulated volume of reservoirs in the Republic of Bulgaria.(River Basin East Aegean Directorate, 2016-2021)

Observations on the water levels in the artificial reservoirs are daily and based on them, monthly schedules of the inflow and outflow of water are drawn up, open data available on the website of the Ministry of Environment and Water (MOEW). In addition, the open-accessed data (with a resolution of 5x5 m) from Sentinel - 2 satellite have been used, which allows the calculation of the Normalized Difference Water Index (NDWI), distinguishing a given water body against the background of soils and vegetation. The water index generated from satellite images has been observed by McFeeters (1996), Rogers & Kearney (2004) and Xu (2006). The index was used to assess the hydrological drought in West Java during El Niño 2015 (Luisa et al., 2018). and in the Ravi basin (Taloor et al., 2021). A comparative analysis between NDWI and ground data can be found in the studies of Sawunyama et al. (2006) and Xu et al. (2006). Gao et al. (2012) and Yigzaw et al. (2018) reviewed the possibility of remote sensing methods to assess the morphometry of reservoirs and water storage ponds. Zhang et al. (2014) and Sekertekin et al. (2018) and Bhangale et al. (2019) considered the possibility of extracting water surface information from different satellite images.

The aim of the present invetsigation is to analyze the NDWI water index data generated from Sentinel -2 imagery and compare it with the hydrometric monitoring of “Belmeken” dam, the highest located in the Belmeken-Sestrimo-Chaira cascade in Bulgaria.

Study Area

The Belmeken Dam is an element of the Belmeken-Sestrimo-Chaira cascade, which is one of the four main hydropower complexes for the production of electricity in the country. The cascade was designed and built in stages from 1964 to 1996. The first stage covers the design and construction of the Belmeken Dam, the Stankovi Baraki Dam, the Belmeken hydropower plants-pumped-storage hydro facilities, the Sestrimo Hydroelectric Plant, the Momina Klisura Hydroelectric Plant", two gathering derivations and two equalizers, and the second stage with the construction of the Chaira dam and the Chaira PAVEC, which came into operation in 1996. The complex operates with a full capacity of 1599 MW, after 1997 (Nabatov, 2015) (Figure 1).

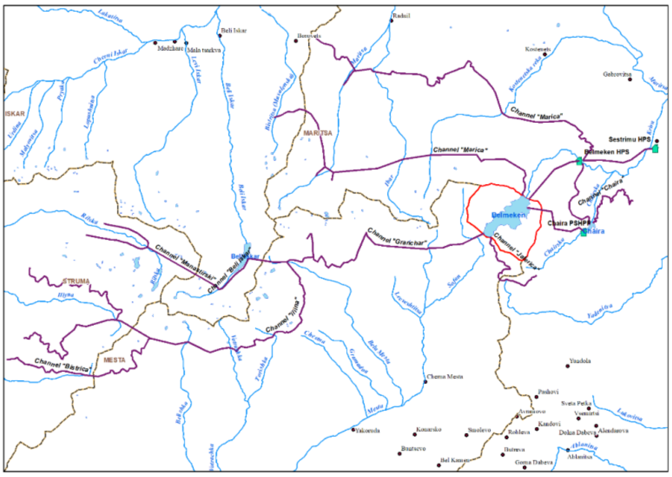

Figure 1. Location of "Belmeken-Sestrimo-Chaira" cascade

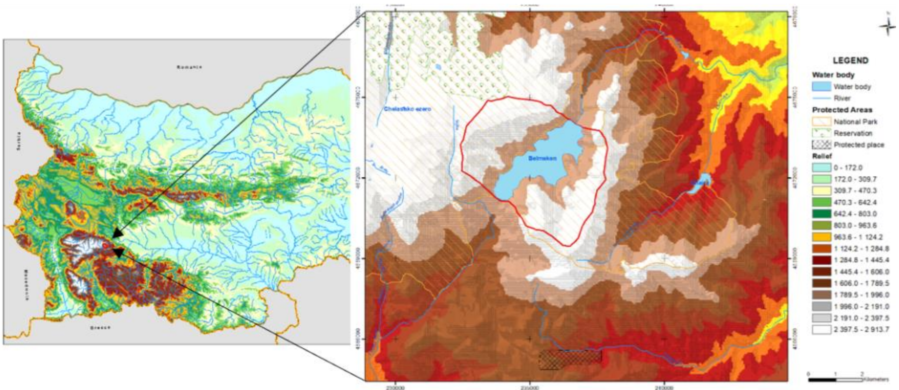

Figure 2. Location of "Belmeken" dam

The catchment area of "Belmeken" dam is developed in the highland part of the eastern part of the Rila mountain, within the borders of the "Rila" National Park, and within the borders of the East Agean River Basin Directorate, to the west with the river basin of the Sofanitsa River (Sofan Dere), and to the northeast and southeast with the river basins of the Kostenska River, the Chaiirska River, and the Yadenitsa River. The border of the watershed passes through the village of Belmeken (2626 m) and to the southeast through the village of Slavov vrah (2306 m). The "Belmeken" dam is 1923 m above sea level and was built on the Kriva River with a catchment area of 20 km^2.

The majority of the inflow into the dam comes from the collecting derivations "Granchar", "Dzaferitsa", "Manastirski" and "Iliina", built in the catchments of the Mesta River and the Struma River (Figure 1). "Belmeken" dam is built by two dam walls: a stone embankment with a height of 88.2 m, and a counter wall with a height of 23 m. The reservoir is annually leveled with a total pumped volume of 144.1.106.m^3 and a flooded area of 4.6 km^2. The delineation of the water surface was obtained from the developed geoinformation system for water management, available on the website of MoEW.

Materials and Methods

Data from Sentinel-2 satellite images within a period 2018- 2022 has been used in the survey- Level-2A orthorectified atmospherically corrected surface reflectance, available since 2017, and Level-1C orthorectified top-of-atmosphere reflectance, available since 2015. We have selected days in the abovementioned period with cloud cover below 40%. (Table 1).

Table 1. Input satellite data

Year	Date	Satellite	Year	Date	Спътник	Year	Date	Satellite
2018	19.01.	Sentinel 2 L2A	**2020**	24.01.	Sentinel 2 L1C	**2021**	25.09.	Sentinel 2 L1C
	29.04.	Sentinel 2 L1C		08.02.	Sentinel 2 L1C		25.10.	Sentinel 2 L1C
	08.06.	Sentinel 2 L1C		19.03.	Sentinel 2 L1C		14.11.	Sentinel 2 L1C
	07.08.	Sentinel 2 L1C		23.04.	Sentinel 2 L1C		24.12.	Sentinel 2 L1C
	11.09.	Sentinel 2 L1C		08.05	Sentinel 2 L1C	**2022**	18.01.	Sentinel 2 L2A
	16.10.	Sentinel 2 L1C		27.06.	Sentinel 2 L1C		12.02.	Sentinel 2 L2A
	10.11.	Sentinel 2 L1C		31.08	Sentinel 2 L1C		8.04.	Sentinel 2 L2A
	20.12.	Sentinel 2 L1C		20.10.	Sentinel 2 L1C		13.05	Sentinel 2 L2A
2019	25.03.	Sentinel 2 L1C		14.11.	Sentinel 2 L1C		02.06.	Sentinel 2 L2A
	19.04.	Sentinel 2 L1C		19.12.	Sentinel 2 L1C		22.07	Sentinel 2 L2A
	09.05.	Sentinel 2 L1C	**2021**	18.01.	Sentinel 2 L1C		26.08.	Sentinel 2 L2A
	18.06.	Sentinel 2 L1C		12.02.	Sentinel 2 L1C		05.09.	Sentinel 2 L2A
	12.08.	Sentinel 2 L1C		04.03.	Sentinel 2 L1C		20.10.	Sentinel 2 L2A
	16.09.	Sentinel 2 L1C		23.05.	Sentinel 2 L1C		14.11.	Sentinel 2 L2A
	16.10.	Sentinel 2 L1C		17.07.	Sentinel 2 L1C		29.12.	Sentinel 2 L2A
	20.12.	Sentinel 2 L1C		16.08.	Sentinel 2 L1C			

The multispectral satellites provide 13 spectra in the green (B3), red (B4) and near-infrared (B8) ranges with a high resolution of 10×10 m. For the studied territory with an area of 4.6 km^2, satellite images with a resolution of 5×5 m are used, on which primary and secondary data processing was done. Primary processing includes channel selection to create composite water index (NDWI) images. NDWI extracts water body by utilizing Green (G) and Near Infrared (NIR) bands defined in the formula below. Vegetation and soil in NDWI image are presented in the low reflectance values, whereas the water body is presented in high reflectance values (Sekertekin,2018).

$$NDWI = (G - NIR)/(G + NIR)$$

Secondary processing includes the generation of areas from the created composite images with the ArcMAP tools. The data on the monthly volumes of water stored in the reservoir of the “Belmeken” Dam for the studied period were provided by "Dams and Cascades". Information for the water use from the complex and significant dams have been taken from the monthly schedules which is available in open data sources (webpage of MOEW). Table 2 presents the monthly volumes of water stored in the "Belmeken" dam for the accepted calculation period (2018-2022).

Table 2. Monthly water volumes W [10^6 m^3]

Years	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
2018	120.1	103.1	85.0	109.5	131.0	140.0	138.4	127.0	108.7	108.7	66.2	37.7
2019	33.2	30.1	34.3	44.7	98.5	119.3	109.2	99.5	93.0	89.7	88.5	84.9
2020	81.1	81.5	89.0	96.0	127.2	137.7	132.5	127.5	116.2	110.2	105.9	96.7
2021	93.3	84.5	67.7	52.4	101.0	92.2	141.1	120.0	108.1	110.6	101.2	89.9
2022	80.6	69.7	52.7	54.4	115.6	129.6	133.0	121.0	114.7	104.3	97.4	93.9

To determine the relationship between the water surface area and the depth in the reservoir, a graphic dependence was made based on data for specific elevations by dam depth and the corresponding water surface areas obtained by the stored water volumes in the dam lake over the years. Figure 3 shows the graphical relationship between the elevation of the water level Z[m] and the water volume W [$10^6.m^3$] with the derived polynomial dependence of the second degree with coefficients of determination, R-squared = 0.999935.

$$(1)\ \ Z = -\ 0{,}00199.\ W^2 + 0{,}7272.W + 1857{,}073$$

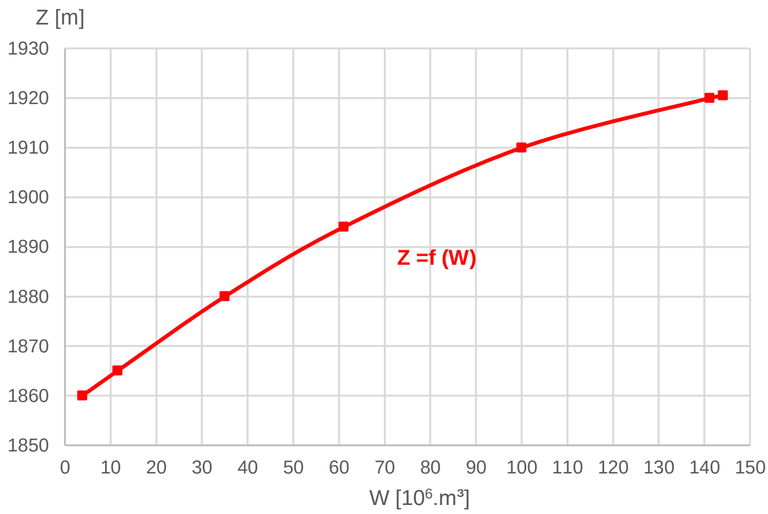

Figure 3. Dependence of water level elevation(Z) and water volume (W)

Figure 4 presents the measured ground data for water level elevation Z[m], water volume W [$10^6.m^3$] and water surface area A [km^2] in the reservoir of the "Belmeken" dam. Through the mathematical analysis between the water volume and the elevation of the water level W = f(Z) and the area of water and the elevation of the water level A = f(Z), polynomial dependences of the second degree with coefficients of determination, R-squared = 0.999976 (formula 2) and R-squared = 0.999958 (formula 3). The graphically constructed curves and derived polynomial dependences refer only to "Belmeken" dam and cannot be applied to other dams due to the difference in morphometry and natural factors.

$$(2)\ W = 0{,}023635.\ Z^2 - 87{,}107.\ Z + 80257$$

$$(3)\ A = 0{,}000425.\ Z^2 - 1{,}53823.\ Z + 1390{,}1628362$$

The approach to tracking changes in the water surface area of the Belmeken Dam inludes the following steps

(1) Generate the water surface area of the reservoir based on 2A and 1C Sentinel -2 images by creating composite images of NDWI for the period 2018-2022;

(2) Calculate the Water surface elevations (Z) of Belmeken dam from the open data on water volume in the reservoir and through the obtained polynomial dependence (formula 1) for the water volume for each month during the year;

(3) Based on the obtained water level elevations (Z) for each month during the year, the water areas in the water reservoir to be calculated from ground data by dependence (formula 3);

(4) Compare the water areas derived from ground-based data with water area data derived from satellite data (NDWI values)

(5) Contour the water surface of Belmeken Dam using ArcMap tools at NDWI values above 0.2.

Results and Discussion

The results of the survey are reflected in Figure 4 for selected days within the period 2018–2022, and for water areas by months in Table 3. The blanks in the table indicate that no available Sentinel-2 raster image with cloud cover below 40% was found. The obtained water area data of "Belmeken" Dam from the satellite images by NDWI is comparable to the ground water area data, which is confirmed by the coefficient of determination R^2 = 0,85. (Figure 5).

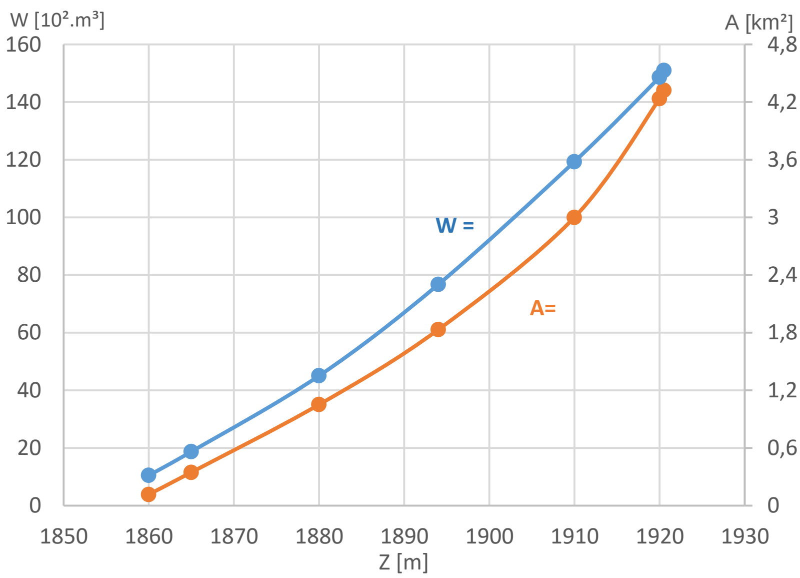

Figure 4. Graphical relationship between water level elevation (Z) – water volume (W) – water surface area (A)

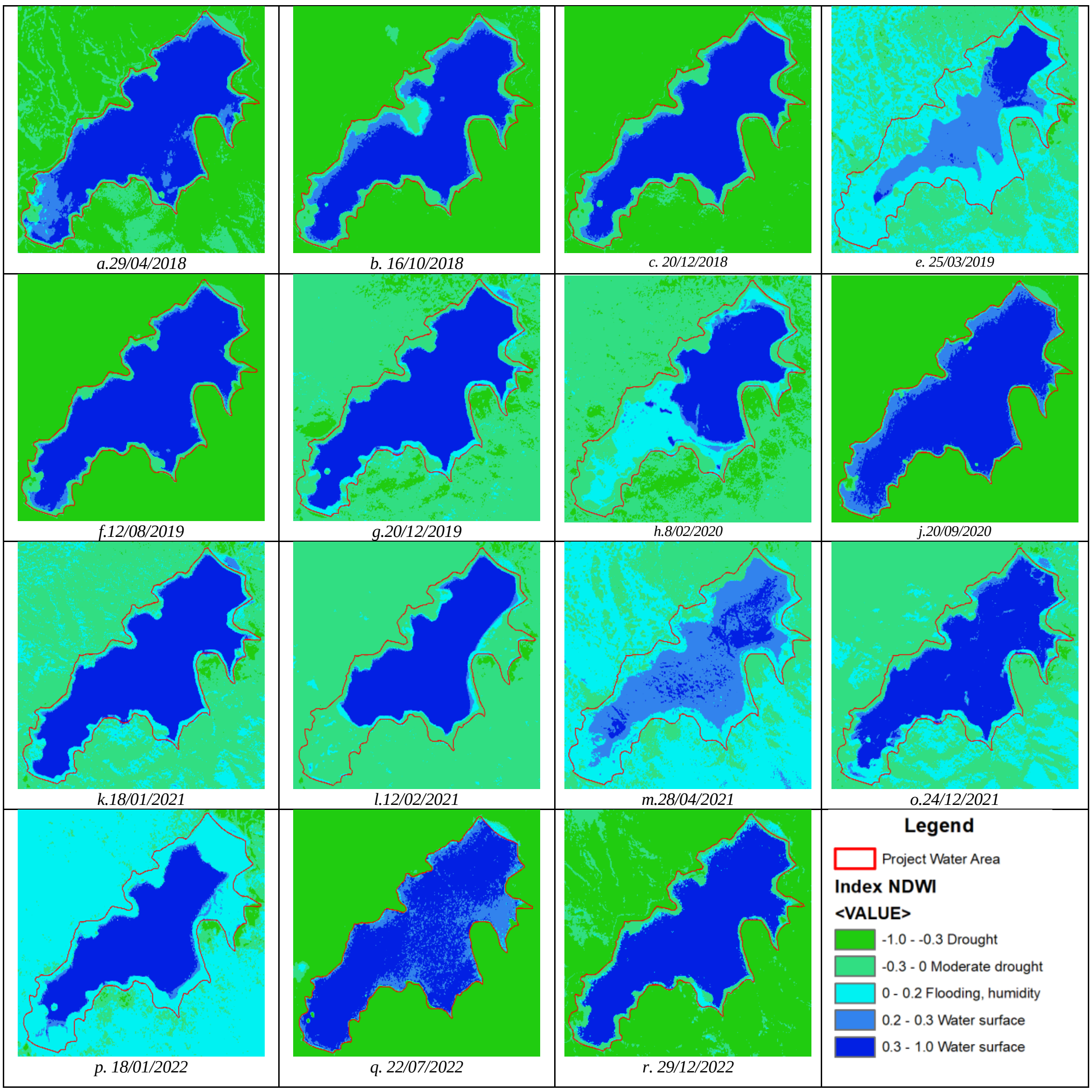

Figure 5. NDWI spatial distribution in Belmeken Dam reservoir for 2018-2022

Table 3. Water area (km^2) of “Belmeken” dam by months

Year	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
2018	4.01	-	-	3.83	-	4.18	-	4.17	3.97	3.55	3.20	1.28
2019	**-**	-	1.76	1.75	2.86	4.05	-	3.71	3.57	3.48	-	3.44
2020	2.92	1.70	3.1	3.67	3.75	4.2	4.1	-	4.03	3.86	3.70	3.65
2021	3.49	2.82	2.21	2.56	3.56	-	4.31	4.12	3.8	3.86	3.50	3.37
2022	2.70	1.95	-	2.14	3.38	4.15	4.27	4.01	3.86	3.57	3.49	3.55
Average	3.28	2.16	2.36	2.79	3.39	4.15	4.23	4.00	3.85	3.66	3.47	3.06

Analyzing the data by months we have detected a decrease in the water surface area calculated by NDWI in February and May (Figure 6). A possible reason for the difference found is the permanent snow cover during the winter months in the catchment area of the "Belmeken" dam and the icing of the water surface. For the spring months, there is a sudden change of days with cloudy to cloudless conditions, typical for areas with an altitude above 1900 m.

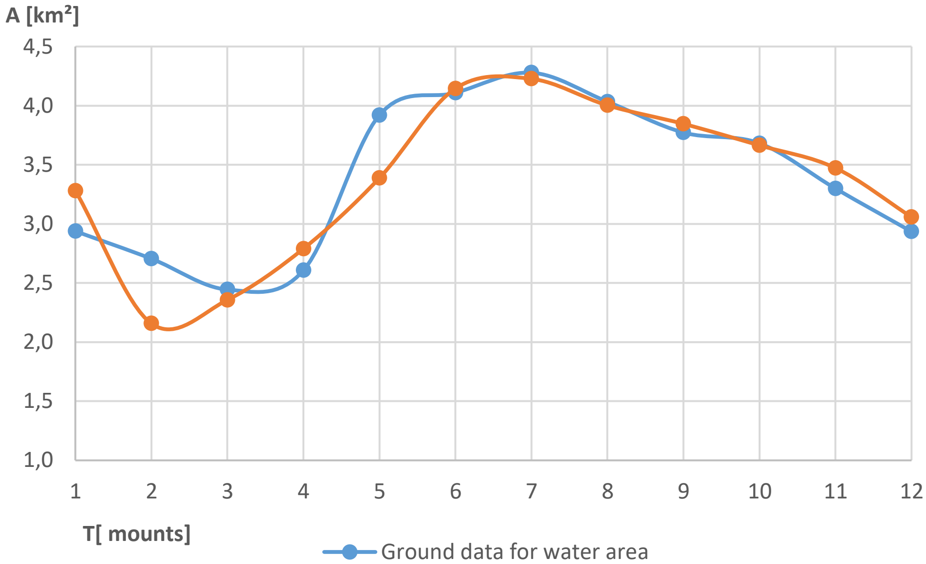

Figure 6. Water area satellite and ground data collation

Conclusion

The presented approach for the interpretation of satellite images data on water surface area of dams, lakes and wetlands verifies the objectivity of NDWI and expands the possibilities of analysis of water bodies for which there is no information from the reference hydrometric network. Tracking the fluctuations of water surface areas during the year through satellite-derived data by using NDWI is determined to be of great importance to survey the climate change influence in the hydrological regime. The application of remote sensing data for water surface area estimatation of water bodies can contribute to the process for determining the water volumes in dams and thus can be of support to the decision-makers. Integrating remotely-sensed data with ground data presents new methodological solutions for hydrological and engineering hydrological studies.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgements or Notes

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