Assessing inland water resources variability by using satellite data: Case study of the Serra del Corvo artificial Lake in Italy

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Short Note

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ABSTRACT

Satellite data provide valuable information on the variations in the surface area of inland waters. These observations are crucial for monitoring remote or poorly instrumented regions and offer complementary insights to in situ measurements. To further assess this capability, we analyzed the temporal variations of Serra del Corvo Lake – located at the border between the Basilicata and Puglia regions in southern Italy – using cloud-free Sentinel-2 imagery acquired from 2015 to 2025. The satellite-derived surface water extent time series were compared with daily in situ measurements of water volume and level, achieving very high correlation (R > 0.98). This strong correlation supported the development of two predictive models, based on both linear and exponential regression method, which demonstrated satisfactory accuracy (R^2 consistently above 0.8 in both calibration and validation phases). These results highlight the high potential of satellite-based approaches to provide almost independent and reliable information on inland water dynamics.

KEYWORDS: remote sensing, Sentinel-2, inland water, water resources management, Basilicata region.

INTRODUCTION

Satellite imagery acquired from sensors working in the optical and microwave wavelengths of the electromagnetic spectrum can recognize with a high level of accuracy the presence of permanent inland waters, such as rivers, lakes and artificial reservoirs (Nagaraj & Kumar 2024; Che et al., 2025). Optical sensors are preferred when long-term continuous monitoring is required, especially when organised in satellite constellations, because they tend to have a higher temporal frequency than microwave sensors, overcoming issues related to cloud cover (Lacava et al., 2010, Liang & Liu 2020).

The Sentinel-2 (S2) mission, developed in the framework of the European Copernicus program (European Union, 2014), is an example of an optical-based satellite constellation that has been operating since 2015 when the first satellite of the mission, S2A, was launched (European Space Agency, 2025). Subsequently, S2B was launched in 2017, and S2C was launched in 2024, both of which carry the Multispectral Imager (MSI). Using this instrument, imagery of the surface in the visible to short-wave infrared spectral region can be obtained at a spatial resolution of up to 10 m and a temporal resolution of up to 2 days when all three sensors are orbiting together. Otherwise, the nominal temporal resolution of each satellite is 10 days and 5 days in combination. Sentinel-2 data have already been used to identify the presence of inland water by using several indices exploiting the different spectral response of the water in the acquired spectral range (e.g., Al-Ali et al., 2024). Among these, the Normalized Difference Water Index (NDWI;

McFeeters, 1996) remains one of the most widely adopted metrics, particularly in recent multi-sensor water-mapping products (Miura et al., 2025). Several studies have further demonstrated the robustness of NDWI-based methods for water extraction from Sentinel-2 data across diverse environmental settings (Kumar, 2024; Girma et al., 2025).

In this study, we analyzed the S2-derived NDWI to characterize the water surface variability of the Serra del Corvo Lake, an artificial reservoir built at the border between the Basilicata and Puglia regions (southern Italy), to store and supply water for irrigation (EIPLI, 2025). By exploiting a multi-year time series of NDWI maps, complemented by in situ measurements, the main objective of this work was to develop and validate satellite-based models capable of estimating water storage variability of the lake in terms of both water volume and water level. Although aligned with the overall approach proposed by Pham-Duc et al. (2022), the present study advances that work by providing a clear and methodologically significant incremental contribution, as detailed below. First, the Serra del Corvo Lake is a relatively small reservoir situated in an area already experiencing significant water stress (Albano et al., 2025), whereas the Thac Mo reservoir examined in the earlier study is much larger and less sensitive to climatological fluctuations. Second, the Sentinel-2 temporal series analyzed here (2015–2025; 323 scenes in total) is substantially longer than the dataset used in the previous work (2016–2021; 22 scenes), enabling a full calibration-and-validation analysis of the developed models, an aspect that could not be implemented in the earlier study. Finally, the results obtained for Serra del Corvo Lake, when considered together with those already available for larger reservoirs, contribute to providing a more comprehensive understanding of inland-water variability in regions increasingly affected by climate-change impacts (Albano et al., 2025).

THE STUDY AREA

The Serra del Corvo Lake, also named as the Basentello dam, was generated in 1974 by building a dam along the Basentello River (Fig. 1), which flows from the northern area of the Basilicata region toward the Bradano River. The dam has a maximum water capacity of 41 million cubic meters (Mm^3) at a water level of 269 m above the sea surface, supplying water to an agricultural area of approximately 267 km^2 in the Basilicata region (EIPLI, 2025). About 5 Mm^3 of water are released downstream every year (ABDAMSB, 2025a). In recent years, however, this outflow has generated a pronounced water deficit, as the released volumes have not been compensated by precipitation, particularly during the summer months. This hydrological imbalance makes the Serra del Corvo reservoir markedly different from the other major reservoirs in Basilicata, where water levels typically show a quicker recovery following seasonal rainfall events. Such a distinctive behavior strengthens the relevance of analyzing its water-storage dynamics through satellite-based approaches, as carried out in this research.

DATASET

Sentinel-2 observations were processed and analyzed directly within the Google Earth Engine (GEE) cloud computing platform (Gorelick et al., 2017), exploiting the “S2_SR_HAMONIZED” dataset, which consists of Sentinel-2 Level-2A Bottom-Of-Atmosphere (BOA) imagery. In more detail, cloud-free Sentinel-2 imagery available between July 2015 and July 2025 over the analyzed dam was considered for a total of 323 images. To avoid any contamination in the temporal series, we adopted a strict 1% cloud-probability threshold based on the Sentinel-2 Cloud

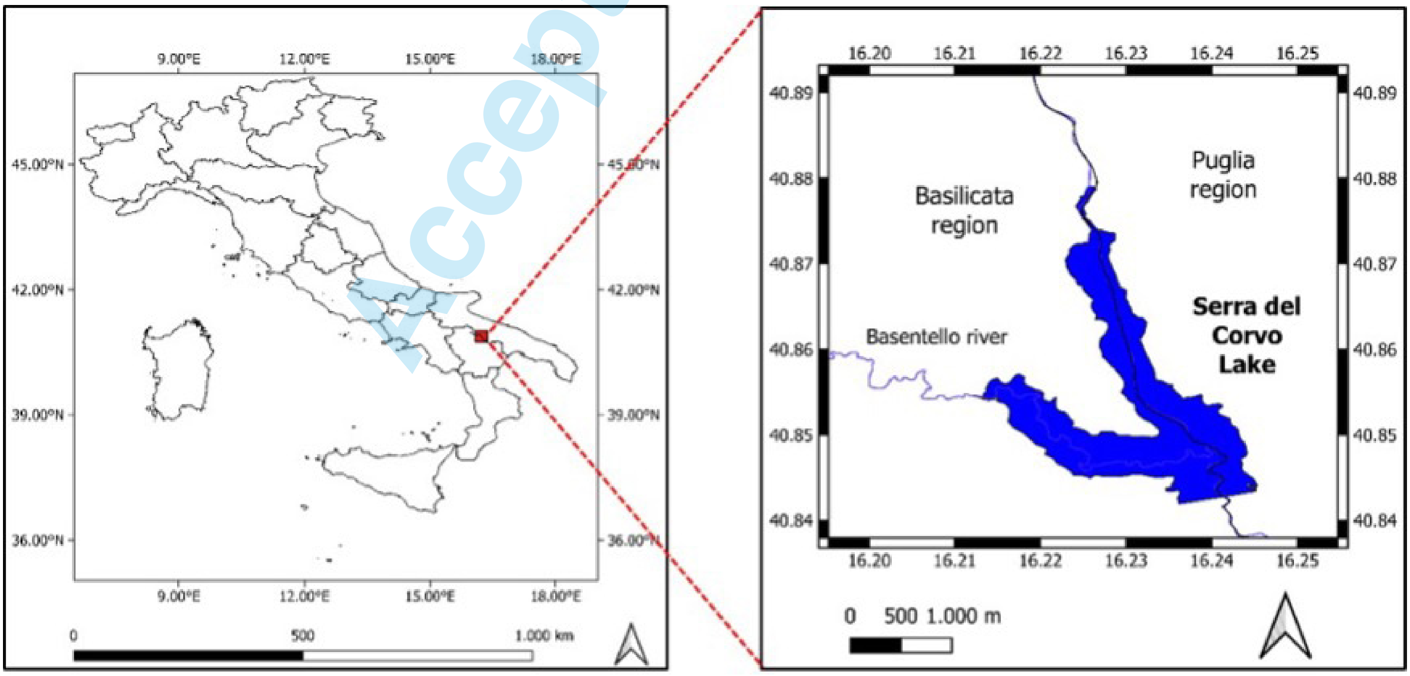

Fig. 1 - Serra del Corvo Lake location.

Probability product available in GEE, retaining only images that were both cloud-free and provided full coverage of the lake. This criterion ensured the selection of high-quality observations, typically yielding approximately one valid scene per month. No additional filtering for snow or ice presence was applied, and no temporal interpolation was used to fill eventual gaps in the series. For each date corresponding to a Sentinel-2 acquisition, in situ measurements of net water volume and water level were manually downloaded from the website of the competent water-basin authority (ABDAMSB 2025b), which provides daily information for the main reservoirs of the Basilicata region. In total, the in-situ dataset includes 323 pairs of water-volume and water-level measurements collected over the 11-year period.

METHOD

Figure 2 presents the flowchart of the proposed methodology, which is structured around two main components: 1) Processing Sentinel-2 imagery to extract the temporal dynamics of water extent at the Serra del Corvo Lake; and 2) Developing and validating both linear and exponential regression models to characterize the relationship between satellite-derived water extent and in situ measurements of water volume and level, using data spanning from 2015 to 2025. The processing steps highlighted in green were executed directly on the GEE platform, while those in orange were performed on local workstations.

In the first phase, cloud-free S2 images were employed to map and monitor the temporal variability of the water surface of Serra del Corvo Lake over the 2015–2025 period, following the methodology outlined by Pham-Duc et al. (2022). In addition to investigating reservoirs with different morphological and climatological characteristics, the main improvement over the that work concerns the use of a substantially longer Sentinel-2 time series and the implementation of a full calibration-and-validation assessment, both of which were not achievable in the previous study. These two aspects significantly enhance the robustness and generalizability of the proposed approach. For the data processing, each S2 image was first spatially subset using a predefined mask encompassing the entire reservoir area (see Fig. 3). Surface reflectance values from the green (band 3) and near-infrared (NIR, band 8) wavelengths were then extracted to compute the NDWI [*NDWI = ((B3-B8)/(B3+B8))*] across this spatial domain. Subsequently, the Otsu thresholding algorithm (Otsu, 1979) was applied to the NDWI histograms to determine an optimal threshold (T) for each individual image, enabling pixel classification into two categories: water (NDWI > T) and non-water (NDWI ≤ T). This process yielded binary maps at a spatial resolution of 10 meters, with water pixels assigned a value of 1 and non-water pixels a value of 0. A water mask was then applied to exclude non-relevant water bodies, ensuring that only surface water associated with the reservoir was retained. This mask corresponds to the inundation-frequency layer (Figure 3d) and was generated by combining all pixels classified as water using the selected threshold on the NDWI maps. The final

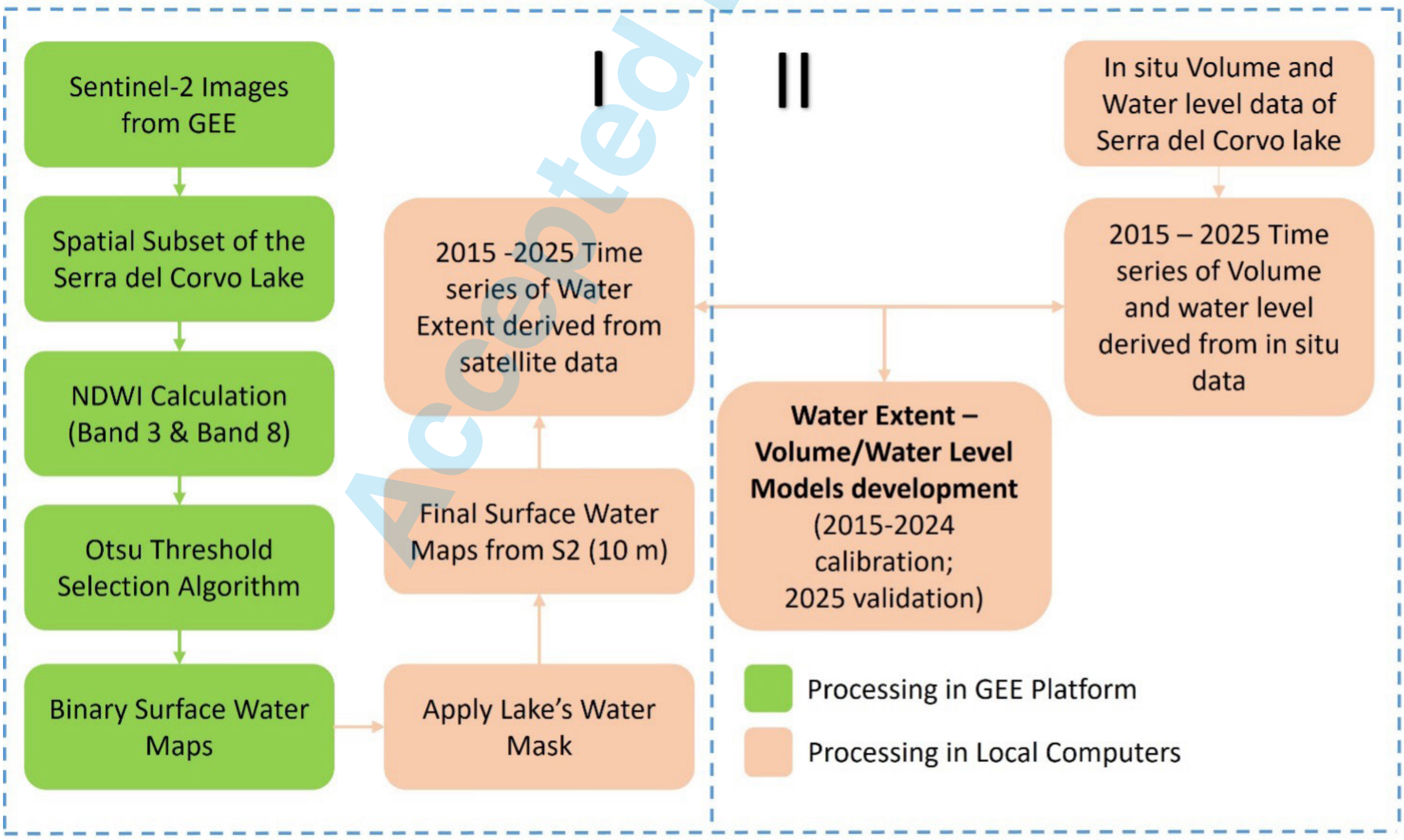

Fig. 2 - Flowchart of the proposed approach (Green boxes indicate the steps executed in GEE, while orange ones represent those processed on local computers).

time series of water extent for the 2015–2025 period was derived by aggregating the results from all processed Sentinel-2 scenes.

In the second phase, daily water volume and level data corresponding to the Sentinel-2 acquisition dates were retrieved from the ABDAMSB database, generating time series for the 2015–2025 period. These series were compared with the satellite-derived surface area maps using the Pearson correlation coefficient (R). Two regression models were then developed to relate surface water area to both volume and water level, using linear and exponential functions. Model calibration was performed using data from 2015 to 2024, and validation was conducted with data of 2025 only. Model performance was assessed using the coefficient of determination (R^2), Root Mean Square Error (RMSE), and Mean Absolute Error (MAE).

RESULTS

The variation in the surface water extent of the Serra del Lago Lake during the study period was assessed using S2-derived NDWI imagery. In Figure 3, an example of the generated maps is shown together with the inundation frequency map achieved during the investigated period. The three maps refer to: a) April 18, 2018, when the highest water level during the 2015-2025 period was recorded; b) April 13, 2024; and c) October 13, 2024. The latter two dates highlight both the high differences with respect to 2018 and 2024, with a clear reduction in the area covered by water. The water frequency (Fig. 3d) confirms the direction of surface reduction, with the southern sector, namely the one closest to the dam, characterised by the presence of permanent water.

The comparison of the variability of the NDWI-based surface water area with in situ measurements — both in terms of volume and water level — for the dam during the 2015–2025 period is shown in Figure 4. The generally good agreement between the analyzed signals is confirmed by the Pearson correlation coefficient, which ranges from 0.990 for water volume to 0.994 for water level. Each graph shows a clear seasonal trend, with higher values of surface area, volume, and water level typically recorded from November to March, coinciding with periods of increased precipitation. The entire period can be divided into two intervals, with a breakpoint at the end of 2021. Prior to this breakpoint, the mean water volume was 15.78 Mm^3, whereas in the subsequent period it decreased sharply to 4.53 Mm^3. A similar pattern emerged for water level, whose

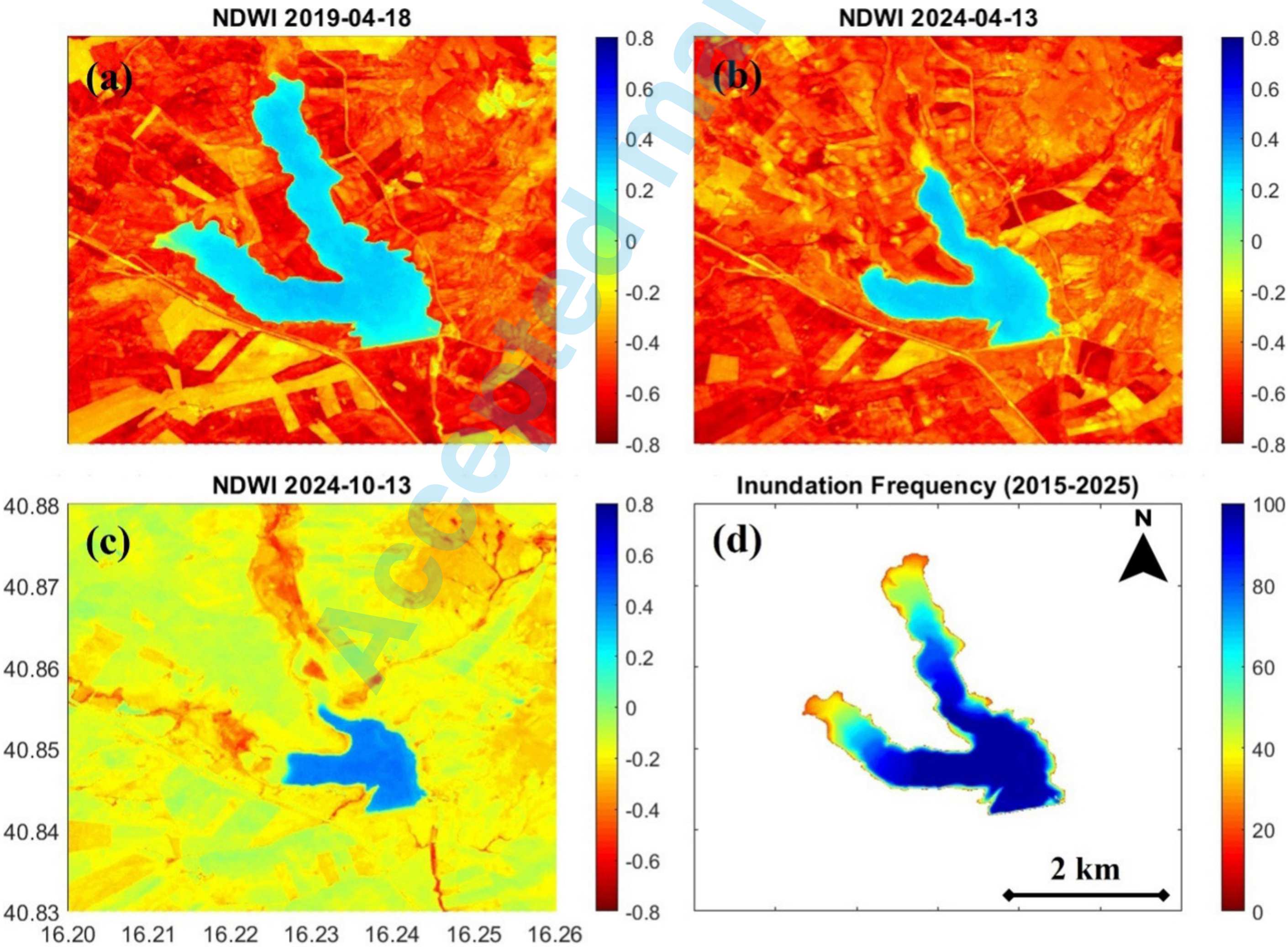

Fig. 3 - NDWI maps of the Serra del Corvo Lake derived from Sentinel-2 imagery on: a) April 18, 2019; b) April 13, 2024, and c) October 13, 2024; and d) Inundation frequency of the dam during the 2015-2025 period which is used as the water mask of the lake.

mean value declined from 265.08 m to 259.79 m. No increase in either water volume or water level was observed after the winter of 2021, indicating a continuous release of water until the end of that year. Conditions improved slightly in 2023 before a complete water drawdown in late 2024, followed by a minor recovery in 2025. The sharp increase observed between 2018 and 2019 was due to the availability of only one cloud-free image, acquired on 9 December 2018, between 9 November 2018 and 19 February 2019, during which water volume varied by more than 10 Mm^3 (corresponding to a 4 m change in water level) over four months. Focusing on surface area variability, a "saturation" effect can be noted around 3.9 km^2, corresponding to a water level of approximately 267 m. Due to the dam's steep-sloped morphology, at this threshold, an increase in water level of almost half a meter (relatively small) results in a water volume increase of less than 2 Mm^3, while the surface area remains nearly unchanged. This is also influenced by the spatial resolution of the satellite data used. This effect is evident between March and July 2019, when the highest water volume was recorded: 22.5 Mm^3, with a water level of 267.5 m on 18 April 2019 (Fig. 3a).

Following the analysis of the temporal variability of surface area, water volume, and water level, we proceeded with the development of regression models aimed at establishing robust relationships between the NDWI-derived surface water area and in situ measurements. Two functional forms were tested: a linear model and an exponential model. Both models were calibrated using the complete dataset acquired over the 2015–2024 period, ensuring that the full range of hydrological conditions was represented in the analysis. The performance of the two models is illustrated in Figure 5. Overall, the linear model (represented by the red dashed line) demonstrated superior predictive capability compared to the exponential model (black dashed line) across all datasets. Specifically, the linear regression achieved coefficients of determination (R^2) ranging from 0.978 for water volume to 0.990 for water level, indicating an almost perfect fit and confirming the strong linear dependency between the NDWI-based surface water area and the corresponding in situ observations. These results highlight the reliability of the linear approach for estimating key hydrological parameters from remotely sensed data, suggesting that the inclusion of more complex non-linear functions does not significantly improve model accuracy in this context. Consequently, the linear model was selected as the preferred method for subsequent analyses and applications.

The developed linear models were applied to the 2025 dataset, considering all data available from the beginning of January 2025 up to the end of August 2025, and results are shown in Figure 6. These linear models demonstrated satisfactory performance, with a coefficient of determination (R^2) exceeding 0.85. The observed RMSE values were 0.35 Mm^3 and 0.09 m, respectively, while the MAE values were 0.33 Mm^3 and 0.07 m, confirming the high accuracy and reliability of the developed linear models.

DISCUSSION

The results presented in the previous section highlight the strong potential of the proposed approach to accurately reproduce water volume and water level of the dam based on optical satellite

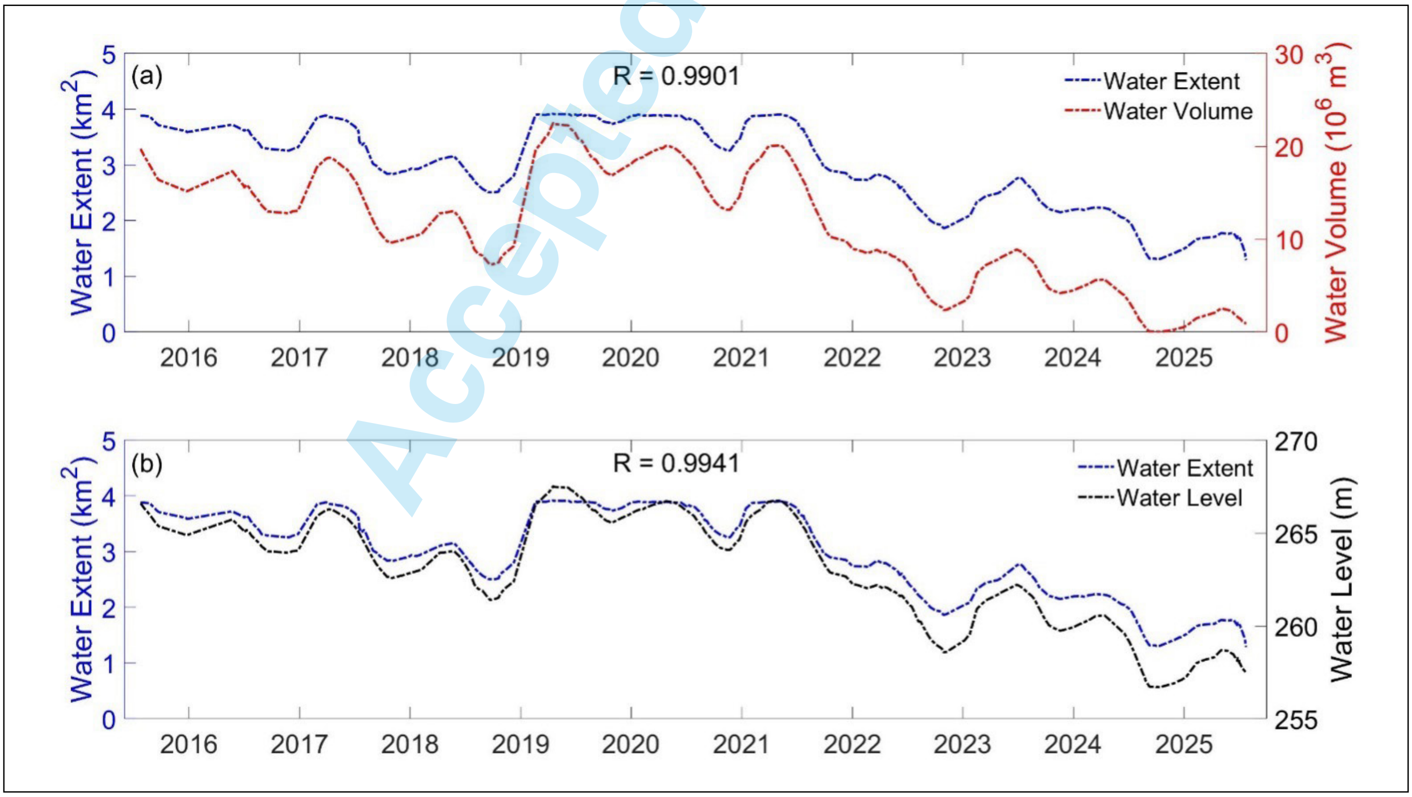

Fig. 4 - Comparison between the surface water extents derived from Sentinel-2 imagery (blue dashed line) and in situ measurements for the Serra del Corvo Lake during the period 2015-2025 and: a) net volume (red dashed line); b) water level (black dashed line).

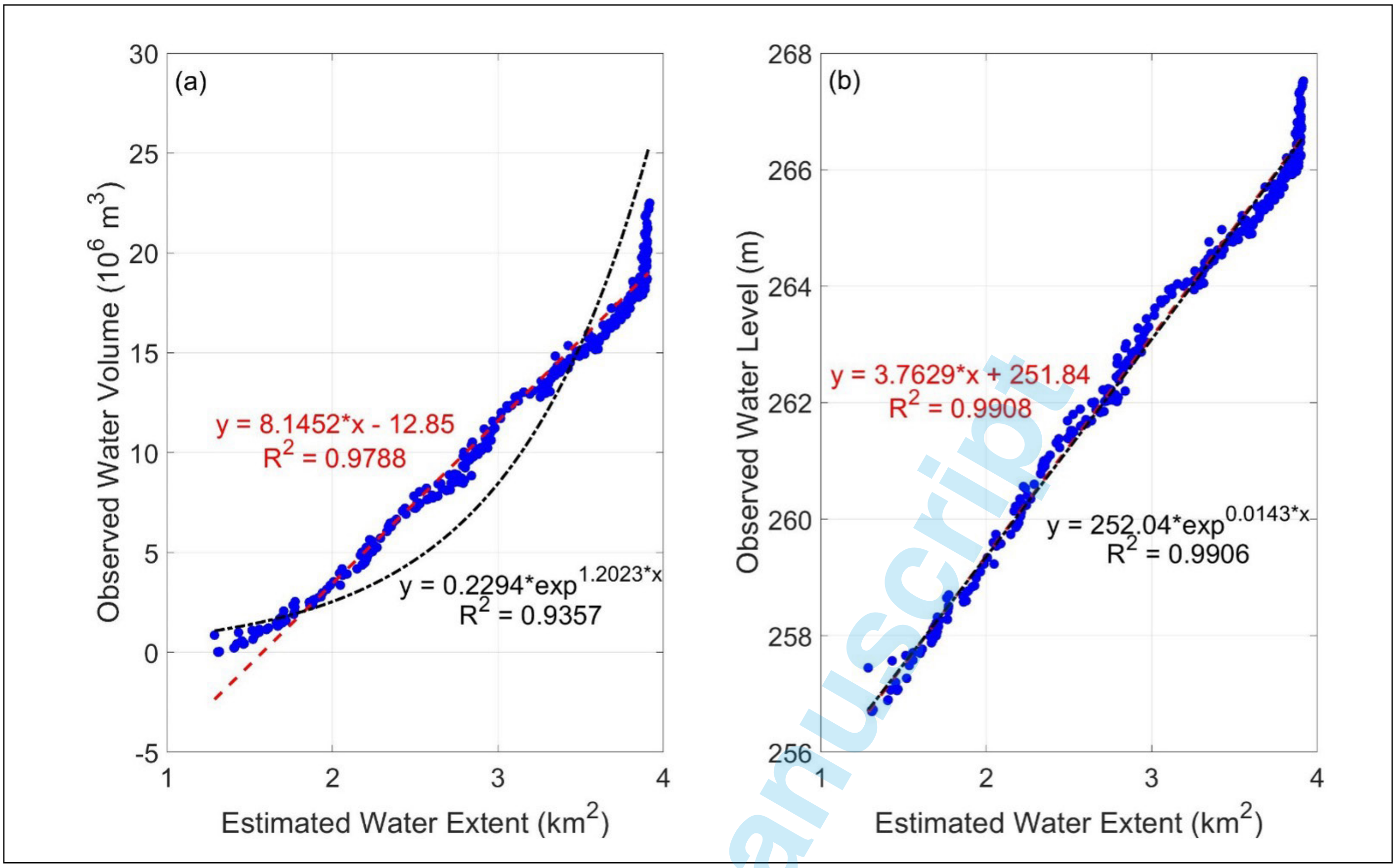

Fig. 5 - Linear (red dashed line) and exponential (black dashed line) regression models between surface water area and in situ water volume (a) and level (b) during the period 2015-2024.

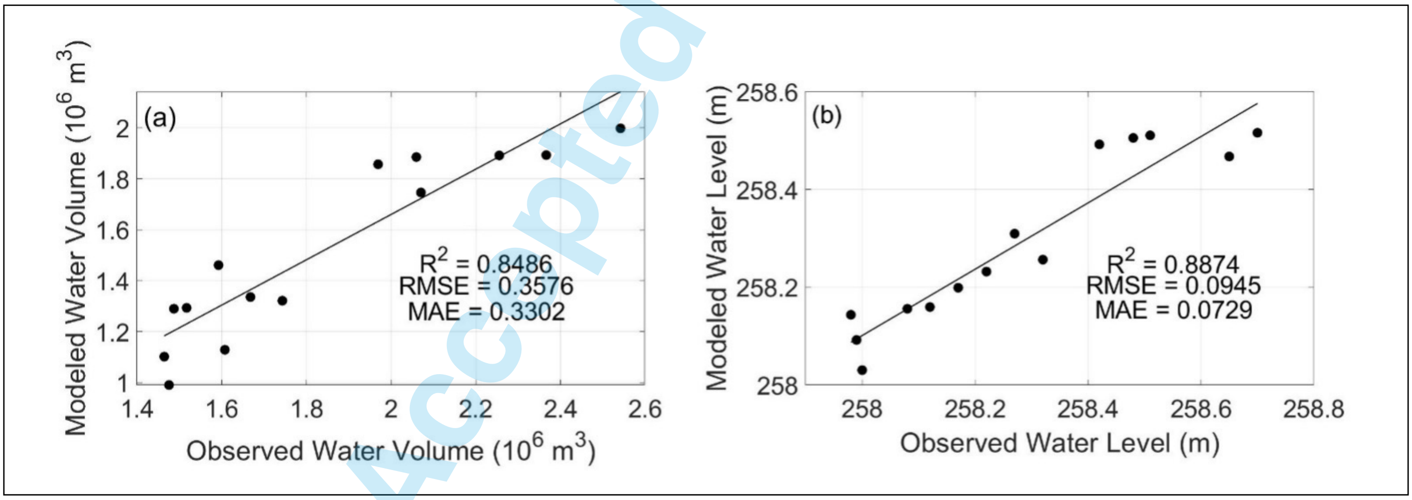

Fig. 6 - Validation of the developed linear models shown in Figure 5 considering only data acquired in 2025 (N=14).

observations of surface water extent of the dam. This capability is particularly valuable for monitoring remote and/or poorly instrumented areas (Avisse et. al, 2017), as well as for integrating in situ information when such data are not publicly available. More broadly, the empirical area–level–volume relationships derived in this study are consistent with those reported in recent multi-sensor reservoir applications (Gui et al., 2025). The strong linear correlations observed between satellite-derived surface water area and in-situ water volume/level also align with previous reservoir assessments conducted in Vietnam and Greece using similar optical–altimetric approaches (Pham Duc et al., 2022; Gourgouletis et al., 2022), as well as with earlier global studies combining surface-area dynamics with water-level datasets (Gao et al., 2012). In particular, when considering the findings by Pham Duc et al. (2022), comparable correlation coefficients were observed between water-surface maps derived from 151 Sentinel-1 and 22 cloud-free Sentinel-2 acquisitions and concurrent altimetry data. In the present study, we confirm the capability of Sentinel-2 to provide accurate surface-extent maps and demonstrate the strong linear relationship between these estimates and in-situ measurements of water volume and water level. The performance of the empirical area–storage relationships developed here further supports the applicability of NDWI-based monitoring techniques for operational reservoir management, consistent with recent lake–area–storage reconstructions (Gourgouletis et al., 2022; Yao et al., 2023) and global surface-water datasets (Miura et al., 2025).

From a climatological perspective, our findings agree with previous studies indicating that southern Italy is experiencing severe water stress (Albano et al., 2025; Lacava et al., 2025), along with a substantial decline in inland water resources. Major reservoirs in the Basilicata Region, including Camastra, San Giuliano, Pertusillo, and Monte Cotugno, have exhibited similar trends to the Serra del Corvo Lake, particularly in recent years, with a pronounced reduction in available water. Among these, the Camastra reservoir has been the most critically affected (Faggella & Barbosa, 2025).

To further investigate this aspect, we collected monthly in-situ temperature and precipitation measurements from the Irsina rain gauge station, which is part of the "Centro Funzionale Decentrato" network of the Basilicata Region Civil Protection Office (CFD Basilicata, 2025) and is the closest station to Serra del Corvo Lake (Fig. 1). The resulting 2015–2025 time series (Figure 7) reveals a marked decrease in annual precipitation (-1.51 mm yr^{-1}) combined with a significant increase in temperature ($+2.35$ °C decade^{-1}). These trends indicate the occurrence of a prolonged dry period, previously documented by Albano et al. (2025) and Lacava et al. (2025), which resulted in a persistently negative water balance and, consequently, a notable reduction in lake-water availability.

In addition to climatic drivers, water-resource management practices must also be considered, as they may be influenced by regulatory or structural constraints. (Faggella & Barbosa, 2025). For example, the substantial drop in water level observed at the end of 2021 was due to a directive from the Italian Ministry of Infrastructure and Transport's Ufficio Tecnico Dighe (Naples), which required lowering the reservoir to enable inspection of the dam's structural conditions (Regione Basilicata, 2022). A distinctive characteristic of the Serra del Corvo Lake is that, following the 2021 drawdown, water levels failed to return to previous values due to the extremely negative hydrological balance between water demand and precipitation, particularly during summer months. Nevertheless, the proposed approach proved effective in monitoring water-dynamics variations using optical satellite data, regardless of the underlying causes, whether climatic, operational, or regulatory, contributing to water-level fluctuations.

Some methodological limitations must, however, be acknowledged. The most critical issue concerns cloud cover in optical imagery, which limits the temporal density of observations, as occurred between November 2018 and February 2019. Additionally, the 10 m spatial resolution of Sentinel-2 imagery may introduce uncertainties along the land–water transition zones, where mixed pixels and spectral heterogeneity are more common. This effect becomes more pronounced during periods of rapid water-level change. Although in-situ data from 2025 span a wide range of volume and level conditions, relying on a single year for model validation may have affected the accuracy of the evaluation. Finally, the reliability of the proposed approach ultimately depends on the quality and completeness of in-situ data used during the calibration phase, and this aspect should be carefully considered when applying the method operationally or transferring it to other reservoirs.

CONCLUSION

In this study, we evaluated the capability of optical satellite imagery to infer inland water resource variability. The Serra del Corvo Lake, located in southern Italy, was analyzed over the 2015–2025 period by integrating Sentinel-2 observations with ground-based measurements of daily water volume and level. The developed linear models yielded very good results, with R^2 values exceeding 0.98 during the calibration phase, and 0.85 during the validation phase, respectively. The proposed approach, being primarily based on satellite data, is easily exportable and could be further enhanced by integrating additional optical datasets, such as Landsat-8/9, and PlanetScope, to increase temporal frequency and mitigate the effects of cloud contamination. Sentinel-1 data could be also integrated for the same scope, while altimetry data, such as those provided by the

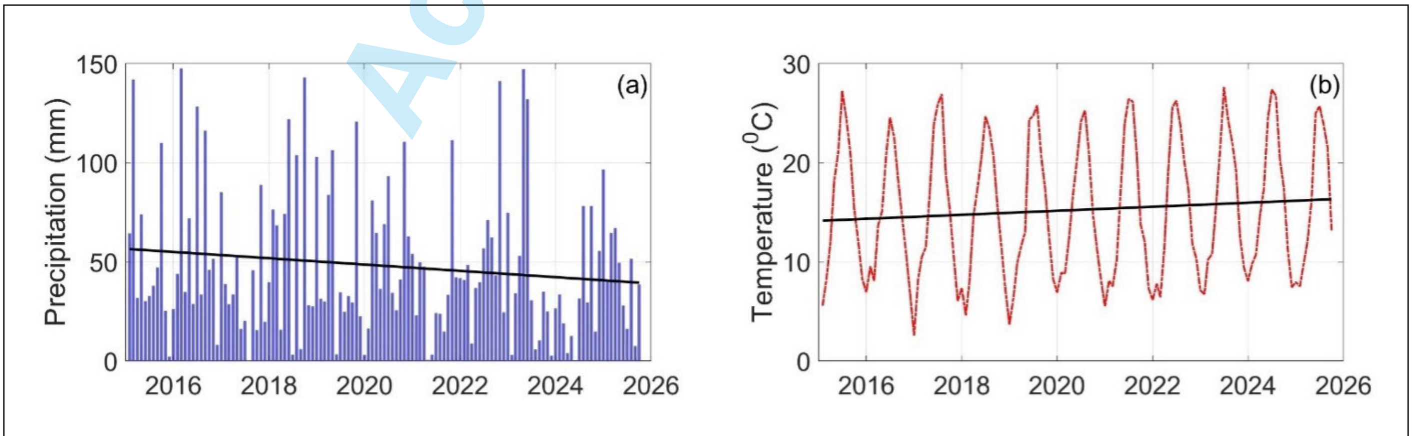

Fig. 7 - 2015-2025 monthly precipitation (a) and temperature (b) time series as recorded at the Irsina rain gauge station.

Surface Water and Ocean Topography (SWOT) mission, can be used to reduce dependence on in-situ data during calibration. Overall, the results confirm the potential of optical satellite-based methods to provide reliable and quasi-independent information, particularly during the operational stage, on water-volume and water-level dynamics in artificial lakes. Such information is essential for supporting decision-makers involved in water-resource management. Moreover, the high accuracy achieved in this study suggests that the full dataset employed here (i.e., high-frequency and high-quality in-situ measurements combined with Sentinel-2 NDWI-derived surface water-extent maps) represents a valuable benchmark for testing and validating satellite-based retrieval algorithms. Taken together, these findings underline the relevance of satellite-based monitoring frameworks for supporting sustainable water-resource management and highlight the importance of continuing to develop robust, transferable, and data-efficient methodologies for future hydrological applications.

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