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Water Reservoirs Bathymetric Mapping Using A GIS-Based Distance Method

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Abstract: Accurate knowledge of reservoir bathymetry is fundamental for quantifying water storage, managing irrigation resources, and assessing the long-term impacts of sedimentation. This study presents firstly the results of the bathymetric mapping of the Karkidon Reservoir, located in the Fergana region of Uzbekistan and fed by the Isfaramsay River and other main water reservoirs of Ferghana Valley of Central Asia, using a GIS-based distance method. The approach, originally developed within the framework of the GLOBathy global dataset (Khazaei et al., 2022), translates Euclidean distances from reservoir shoreline pixels to a continuous depth surface without requiring in-situ echo-sounding surveys. Input data comprised the maximum depth value from official reservoirs' records and the waterbody polygons from the HydroLAKES dataset. Analysis was performed in Python (GDAL/NumPy) and the resulting bathymetric raster was visualised in ArcGIS software. Results indicate that the water surface area of the Karkidon Reservoir as of March, 2022 covers approximately 4.41 km², with an estimated maximum depth of about 30 m and a total water volume of roughly 50 million m³—representing approximately 24% of the reservoir's original design capacity of 211 million m³. The findings underscore the need for systematic monitoring of reservoir morphology in the region and demonstrate the utility of open-source, remotely sensed data products for water resource management in data-scarce environments.

Keywords: Bathymetric mapping; GIS; distance method; Karkidon Reservoir; water volume; sedimentation; Uzbekistan; HydroLAKES; GLOBathy.

INTRODUCTION:

Freshwater reservoirs are critical infrastructure in arid and semi-arid regions, where they serve as primary sources for irrigation, municipal water supply, and in some cases, hydropower generation. In Central Asia—and particularly in Uzbekistan—man-made reservoirs form the backbone of agricultural water management, supporting the irrigation of millions of hectares of cropland dependent on the Amu Darya, Syr Darya, and their tributaries (Rakhmatullaev et al., 2013). The Karkidon Reservoir, constructed in 1967 on the Isfaramsay River in the Fergana Valley, is one such strategic water body, with an original design capacity of 211 million m³ and a maximum depth of 64–66 m. However, like many

reservoirs across the region, its operational capacity has been progressively diminished by lack of water resources and partly by sedimentation.

Bathymetry - the scientific measurement of the depth and topography of the underwater floor - is the primary tool for characterizing reservoir morphology and deriving stage-area-volume relationships essential for water balance modelling (Khazaei et al., 2022). Traditionally, bathymetric surveys rely on acoustic echo sounding conducted from survey vessels, a method that is both time-consuming and financially costly. These limitations become particularly acute in developing-country contexts and for the large number of smaller reservoirs that remain unmapped globally (Messager et al., 2016). Remote sensing and GIS-based methods have emerged as cost-effective alternatives, making large-scale or repeat surveys tractable without in-situ instrumentation.

Conventional methods for reservoir bathymetry rely on single- or multi-beam echo sounders deployed from survey vessels. While highly accurate, such surveys are expensive, logistically demanding, and represent point-in-time snapshots that rapidly become outdated as sedimentation progresses (Gao, 2009, cited in Khazaei et al., 2022). The need for more efficient, scalable approaches has driven significant methodological innovation over the past two decades.

Remote sensing has emerged as a dominant paradigm for bathymetric mapping. Wang (2024) reviewed methods and applications for coastal bathymetry using remote sensing, cataloguing spectral, photogrammetric, lidar, and wave-derived approaches. Similarly, a systematic review by the International Society for Photogrammetry and Remote Sensing (ISPRS, 2023) found that satellite-derived bathymetry has become the current focus of shallow water mapping research, with emerging unmanned aerial vehicle (drone) platforms providing higher-resolution data for localized surveys. For inland water bodies, Liu et al. (2020) proposed the ADBAR approach, which uses freely available digital elevation models and satellite imagery to reconstruct the bathymetry of channel-type reservoirs based on the geomorphological similarity between the inundated area and its surrounding valleys. This method requires only open-access data and is particularly suitable for large-scale applications.

An important development for freshwater bodies specifically was the introduction of the GIS-based distance method, which forms the basis of the GLOBathy dataset (Khazaei et al., 2022). The method derives depth by converting the Euclidean distance of each raster cell from the waterbody shoreline into a depth estimate, scaled by the maximum distance across the waterbody and the known or estimated maximum depth. The GLOBathy maximum depth estimates were validated against observed data at 1,503 waterbodies globally, and the resulting dataset is freely accessible via figshare and the Google Earth Engine community catalog. This methodological approach has been directly adopted in the present study.

Reservoirs and natural lakes together store the vast majority of Earth's accessible liquid freshwater, and their morphological characterization is a prerequisite for sound hydrological modelling and water resource management. Messager et al. (2016) provided a foundational global database (HydroLAKES) cataloguing over 1.4 million lakes and reservoirs, together with geostatistical estimates of average depth, water volume, and hydraulic residence time. Their work demonstrated that global inland water storage amounts to approximately 181,900 km³ yet also highlighted the considerable uncertainty in depth estimates for individual water bodies where direct measurements are absent.

Investigating waterbody dynamics relies primarily on understanding the morphology and geophysical characteristics defined by bathymetry. As Khazaei et al. (2022) noted, bathymetric conditions define stage-storage relationships and circulation and transport processes in waterbodies, yet many studies oversimplify these mechanisms due to unavailability of bathymetric data. This data gap motivated the development of GLOBathy, which provides validated maximum depth estimates and bathymetric rasters at 1 arc-second resolution for all HydroLAKES waterbodies, including essential head-area-volume (h-A-V) relationships for water balance studies.

This study applies the distance method of Khazaei et al. (2022) to derive a bathymetric map of the Karkidon

reservoir and estimate its current water volume. Firstly, bathymetric maps of Karkidon reservoir is generated and estimated water storage. After that, current water volume is estimated based on the area-volume relationship and current surface water area of the reservoir. Current water reservoir is calculated using Landat-8 OLI Surface Reflectance satellite images based on Normalized Difference Water Index (NDWI) (Equation-2).

Study Area

The Karkidon Reservoir is located in the Fergana region of eastern Uzbekistan (approximately 40.3°N, 71.1°E) and was commissioned in 1967 (Figure-1). It is an in-stream reservoir on the Isfaramsay River, a tributary of the Syr Darya basin. At full design capacity, the reservoir spans a surface area of 9.5 km² with a maximum depth of 64 m, a total storage capacity of 218.4 million m³, and an active storage capacity of 211.4 million m³ and it serves primarily as an irrigation supply source for the agricultural fields of Fergana region.

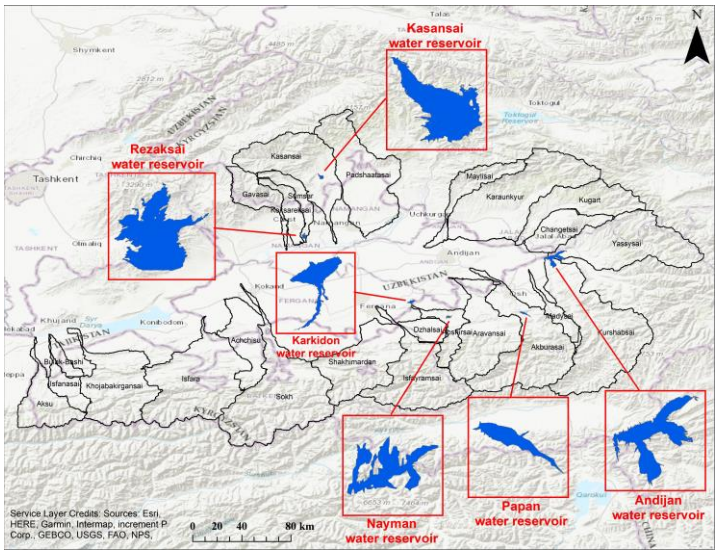


Figure-1: Location of main water reservoirs Ferghana valley.

Data Sources and Methods

1. Data

Three primary datasets were used in this study. First, the maximum depth of the water reservoirs was obtained from published reservoir inventory data. This parameter is essential for scaling the depth surface derived from the distance method. Second, the waterbody shoreline polygon was extracted from the HydroLAKES global database (Messager et al., 2016). HydroLAKES provides shoreline polygons for over 1.4 million lakes and reservoirs globally with surface areas above 10 ha, compiled from topographic maps, optical remote sensing imagery, and radar instruments. The polygon of Karkidon water reservoir used in this study corresponds to a current surface area of 4.41 km², which is notably smaller than the design surface area of 9.5 km², reflecting the current operational state of the reservoir under reduced storage conditions. Also, Landsat-8 OLI surface reflectance satellite images in the period of 2008-2022 were used for surface water analysis.

2. Methodology: GIS-Based Distance Method and Surface Water Area

The bathymetric mapping methodology follows the distance method described in detail by Khazaei et al. (2022) in the context of the GLOBathy dataset. The method consists of three sequential steps:

(1) Rasterisation of the Waterbody Polygon. The shoreline polygon from HydroLAKES was rasterised to a regular grid at a spatial resolution of approximately 27.94 m per pixel (consistent with the spatial extent of the polygon), producing a binary raster distinguishing waterbody cells from land cells.

(2) Euclidean Distance Calculation. For each cell classified as waterbody, the Euclidean (straight-line) distance to the nearest shoreline cell was calculated. This produced a distance raster ℓ, where values range from near-zero at the shoreline to a maximum value

L at the most interior point of the waterbody. The maximum distance L corresponds to the location farthest from any shoreline pixel.

$$D = \frac{l * D_{max}}{L} \quad (1)$$

where ℓ is the Euclidean distance of the corresponding waterbody cell from the shoreline, D□ax is the maximum depth of the waterbody, and L is the maximum distance of any waterbody cell from the shoreline. This formulation assumes a bowl-shaped bathymetric profile in which depth increases proportionally with distance from the shoreline—a simplification that has been shown to provide reasonable estimates of volume for a wide range of lake and reservoir shapes (Khazaei et al., 2022).

(3) Depth Derivation. Depth D for each waterbody cell was computed using the following equation from Khazaei et al. (2022):

For surface water identification in this study, NDWI by (McFeeters, 1996) was used to delineate open water bodies and their areas in time series for the study area. Open water bodies was delineated based on Equation 1 and threshold suggested by (Özelkan, 2020).

$$\mathbf{NDWI} = \frac{\mathbf{Green} - \mathbf{NIR}}{\mathbf{Green} + \mathbf{NIR}} \quad (2)$$

3. Software and Programming Tools

All geospatial processing steps were implemented in Python using open-source libraries. The GDAL (Geospatial Data Abstraction Library) library was used for reading and writing raster data, coordinate reference system management, and rasterization of the polygon input. NumPy provided array operations for the distance-to-depth conversion, and Rasterio was used for writing the final depth raster to a GeoTIFF output file. The Euclidean distance transform was computed using the scipy.ndimage.distance_transform_edt function, which efficiently calculates per-pixel distances to the nearest background (shoreline) cell.

Volume estimation is simply a matter of calculation the volume (i.e., cell area (27.94 m × 27.94 m ≈ 780.6 m²) * depth) and summing across all cells to obtain the total volume in cubic meters. Visualization of the resulting bathymetric raster - including contour generation and color-coded depth maps - was carried out in ArcGIS desktop GIS application. The combination of Python for processing and ArcGIS for visualization represents an entirely open-source workflow that can be readily replicated and applied to other reservoirs.

RESULTS AND DISCUSSION

1. Surface water of Karkidon water reservoir

The strong statistical relationship ($R^2 = 0.91$) between NDWI-derived surface water area and observed water volume (obtained from official records) confirms the robustness of remote sensing techniques for reservoir monitoring. However, the observed declining trend in surface water area highlights emerging water resource challenges, potentially driven by climatic and anthropogenic factors, necessitating integrated water management strategies in the basin.

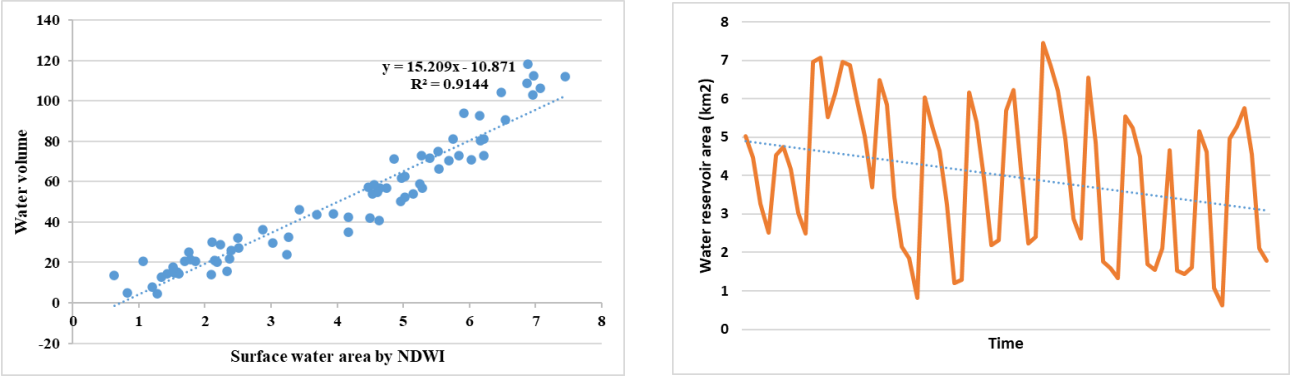


Figure-2: Relationship of NDWI-derived surface area (left) and temporal change of surface area derive by NDWI (right)

2. Bathymetric Map

The application of the GIS-based distance method yielded a continuous bathymetric depth raster for the main water reservoirs at a spatial resolution of approximately 27.94 m. The depth surface shows a characteristic bowl-shaped profile, with the deepest areas concentrated in the central portion of the reservoir and depth values decreasing smoothly toward the shoreline (Figure-3).

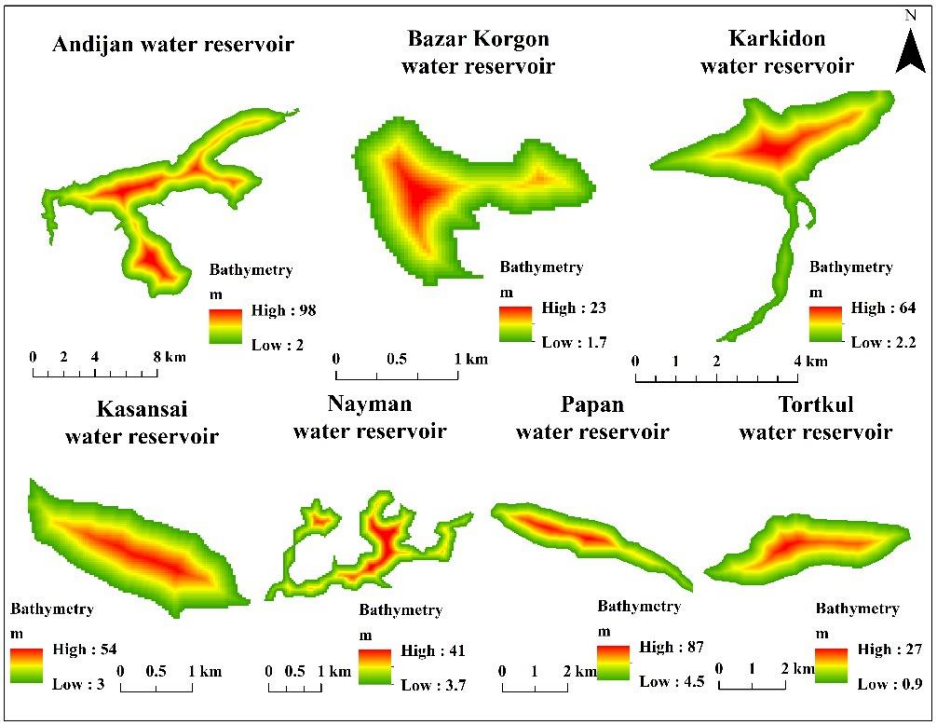


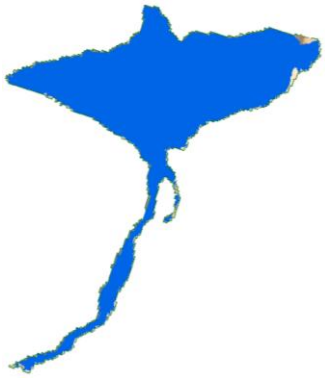
Figure-3. Bathymetric maps of main Fergana Valley reservoirs derived using the GIS-based distance method. Note: It shows estimated depth distribution. Deeper zones (reddish) are concentrated in the central body; shallow zones (greenish) fringe the shoreline.

3. Volume Estimation and Comparison with Design Capacity in case of Karkidon water reservoir

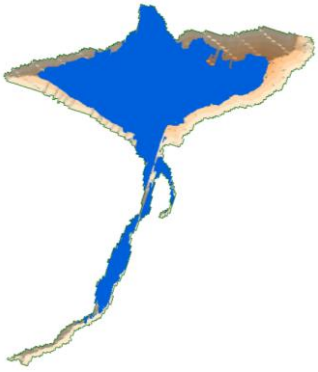
The total water volume of Karkidon water reservoir estimated from the bathymetric raster is approximately 50 million m³ and it correlates well with the official records on measured water volume on that day. Comparing this figure with the reservoir's original active capacity of 211 million m³, the current estimated storage represents approximately 24% of the designed operational volume—a reduction of roughly 161 million m³, or approximately 76% and main reason can be significant reduction of water resources in the region due to climate change. The surface area of the mapped waterbody polygon (4.41 km²) also represents a significant reduction from the design surface area of 9.5 km² at full operating level (a decrease of approximately 54%), further confirming the substantially degraded state of the

reservoir (Figure-4).

The spatial characteristics of the mapped reservoir are summarized as follows: a water surface area of 4.41 km², a pixel size of 27.94 m, a grid of 173 × 228 cells, and an estimated maximum depth of approximately 30 m (Figure-4). These parameters are consistent with a reservoir operating well below its design level, with substantial portions of the original reservoir floor exposed or infilled by sediment.



HydroLAKES waterbody polygon of the Karkidon Reservoir



Current extent, 4.41 km. Satellite image as of March, 2022 was used as input for the distance-based bathymetric model.

Figure-4: Full capacity (left) and extent of the area as of March, 2022 (right) of Karkidon water reservoir

These findings are broadly consistent with trends reported for other reservoirs in Uzbekistan. Studies of the Akhangaran Reservoir documented a total volume reduction of approximately 14.4% over 50 years of operation (Khasanov, 2025), while the Hisorak Reservoir experienced a 23.2% capacity loss over 42 years (Khasanov & Bakiev, 2025). However, the estimated water volume reduction at Karkidon is considerably more severe than these documented cases. Because in recent times, Karkidon water reservoir has been functioning as a flood-regulating reservoir during high-flow (flood) events. Moreover, several factors may contribute to this reduction: (1) significant decreasing water resources trends in the region; (2) Isfaramsai Small Transboundary Tributary drains a mountainous catchment with potentially high sediment yields and Karkidon Reservoir has been in operation since 1967, giving over 55 years for sediment accumulation and others.

4. Methodological Evaluation

The GIS-based distance method offers several advantages for reservoir monitoring in data-scarce environments. It requires only two input parameters - the waterbody polygon and the maximum depth - both of which are available globally through open-access datasets. The workflow is fully reproducible and computationally efficient. Validation of the GLOBathy distance method by Khazaei et al. (2022) across 1,503 waterbodies globally demonstrated acceptable accuracy for basin-scale hydrological applications, though individual reservoir estimates may deviate substantially from true values depending on the actual shape of the reservoir floor.

Limitations of the current study should be acknowledged. The distance method assumes a symmetric, bowl-shaped bathymetric profile, which may not accurately represent the more complex floor topography of a valley-fill reservoirs. Additionally, the HydroLAKES polygon used as input represents the contemporary water surface extent, which may differ from the full-supply-level extent used in the original design specifications. A comparison with acoustic survey data or high-resolution satellite altimetry (such as ICESat-2) would provide important validation for this estimate.

Despite these limitations, the current findings provide actionable information for reservoir managers and regional water authorities. Regional studies such as that of (Perera et al., 2023) project continued global storage losses from sedimentation through 2050, reinforcing the need for systematic reservoir monitoring programmes across Central Asia.

CONCLUSION

This study applied a GIS-based Euclidean distance method, following the approach of Khazaei et al. (2022), to derive a bathymetric maps of the main water reservoirs in Fergana Valley of Uzbekistan. Using the HydroLAKES waterbody polygon and the reservoir's published maximum depth as inputs, a continuous depth surface was generated through open-source Python processing and visualised in ArcGIS desktop software. The results indicate a current water surface area of approximately 4.41 km², an estimated maximum depth of about 30 m, and a total water volume of approximately 50 million m³ and the results well correlated with official records.

The study demonstrates the utility of freely available global datasets and open-source GIS tools for bathymetric assessment in data-scarce environments, and highlights the urgent need for systematic bathymetric monitoring of Uzbekistan's reservoir infrastructure.

Future work should integrate ICESat-2 or similar satellite altimetry data to constrain the water surface elevation and improve volume estimates and should compare the distance-method results with field-based acoustic surveys to quantify method uncertainty for this specific reservoir type and region.

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