Morphometric and Hydrological Dynamics of Lonar Crater Lake, India: A Temporal Assessment Based on Remote Sensing and Rainfall Variability (2019–2024)

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ABSTRACT

Lonar Crater Lake (19°58′N, 76°31′E) is a ~52 ka meteorite impact structure developed within the Deccan Traps basaltic province and represents an important natural archive for understanding crater-lake hydrology and geomorphic evolution. This study investigates short-term morphometric and hydrological variations in Lonar Crater Lake during the period 2019–2024, with particular emphasis on the role of rainfall variability and groundwater dynamics. Lake boundaries and morphometric parameters were extracted using high-resolution Google Earth Pro satellite imagery, while rainfall data for 2018 and 2023 were obtained from the Maharashtra Rainfall Monitoring Portal. Standard limnological indices, including Depth Ratio (Rz), Relative Depth (Zr), Shoreline Development Index (DSI), and Index of Basin Permanence (IBP), were calculated following established morphometric methodologies.

The analysis indicates a marked increase in lake surface area from 0.80 km² to 1.28 km² and shoreline length from 3.33 km to 4.21 km, corresponding to an approximately 36% increase in rainfall. A reduction in Relative Depth (0.62 to 0.49) reflects lateral expansion of the lake basin and suggests progressive sediment accumulation along the margins. In contrast, the observed increase in IBP signifies enhanced basin stability and improved water-retention capacity, likely resulting from increased surface runoff and groundwater recharge. The results confirm that the hydrological behaviour of Lonar Crater Lake is primarily controlled by the combined influence of rainfall-driven surface inflow and lithologically governed groundwater flow through fractured basalt. This study provides quantitative evidence of recent morphometric adjustments in Lonar Crater Lake and highlights the effectiveness of integrated remote-sensing and hydrometeorological approaches for monitoring hydrogeomorphic responses in basaltic impact-crater lake systems.

Keywords: Lonar Crater Lake; morphometric analysis; rainfall variability; groundwater recharge; remote sensing.

INTRODUCTION

Lonar Crater Lake (19°58′N; 76°31′E) is a rare astrobleme formed by a hypervelocity impact within basaltic terrain approximately 52,000 years ago. The crater’s geomorphology, hydrology, and geochemistry have made it a unique terrestrial analogue for Martian impact basins (Komatsu et al., 2014; Singh et al., 2023). Its closed drainage system, coupled with periodic rainfall variation, provides an exceptional natural laboratory for studying basin morphometry, sedimentation, and hydrological response.

Morphometric analysis quantitative measurement of lake geometry offers vital insights into hydrological functioning, sedimentation processes, and erosional dynamics (Håkanson, 1981; Stefanidis and Papastergiadou, 2012). The present study compares morphometric parameters of Lonar Lake between 2019 and 2024 to identify temporal variations in basin shape, shoreline configuration, and volume, and correlates these with rainfall trends and groundwater interactions.

Previous work by Komatsu et al. (2014) highlighted the critical role of drainage and groundwater flow in sustaining Lonar's hydrology, emphasizing the geological and structural controls on lake evolution. However, temporal morphometric changes in response to recent climatic variability have not been quantitatively evaluated.

Building upon the morphometric framework developed by Singh et al. (2023), this paper analyses short-term (2019–2024) morphometric changes and their hydrological significance using GIS and rainfall datasets.

Study Area

Lonar Crater (20° N, 76.5° E) is located in Buldhana District, Maharashtra, at an elevation of approximately 480 m above sea level. The crater has a diameter of 1.83 km and hosts a saline–alkaline lake occupying its centre. The catchment area comprises basaltic flows, thin soil cover, and sparsely vegetated slopes. The climate is semi-arid with mean annual rainfall between 700–900 mm, concentrated during June–September.

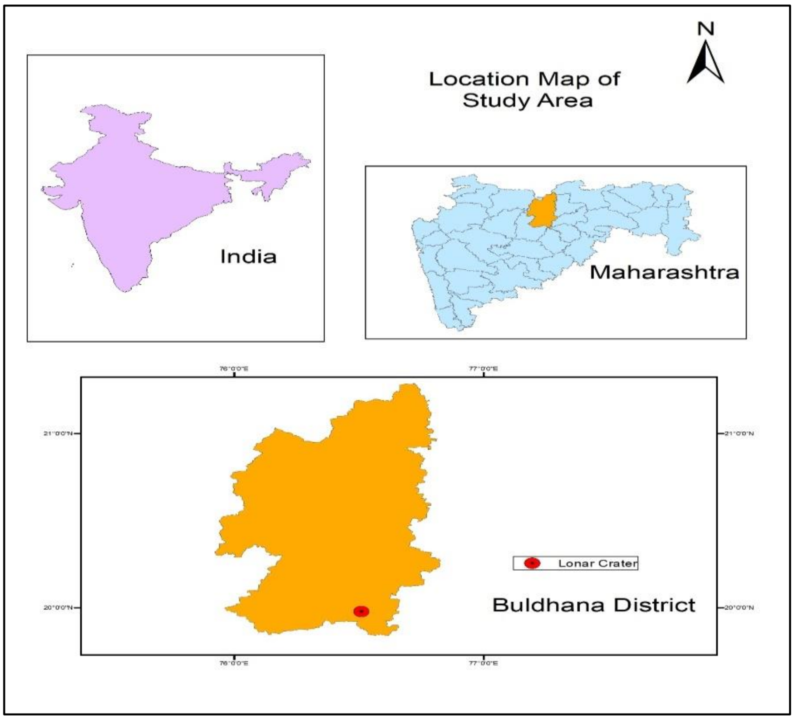

Fig. 1 Map of Study Area

DATA AND METHODOLOGY

Data Sources

High-resolution satellite imagery for 2019 and 2024 was obtained from Google Earth Pro to measure the lake's maximum length, width, and shoreline extent. Morphometric indices were computed using established formulas (Håkanson, 1981; Lakewatch, 2001). Rainfall data for 2018 and 2023 were retrieved from the Maharashtra Rainfall Monitoring Portal (https://maharain.maharashtra.gov.in) to evaluate climatic influence.

Tools and Software

All spatial analysis and mapping were performed using ArcGIS 10.2. The maximum and mean depth values were adopted from Singh et al. (2023), considering that the geological time span between 2019 and 2024 is insufficient for major depth alteration.

Morphometric indices such as Depth Ratio (Rz), Relative Depth (Zr), Shoreline Development Index (DSI), Development of Volume (Dv), and Index of Basin Permanence (IBP) were calculated following Håkanson (1981) and Stefanidis & Papastergiadou (2012).

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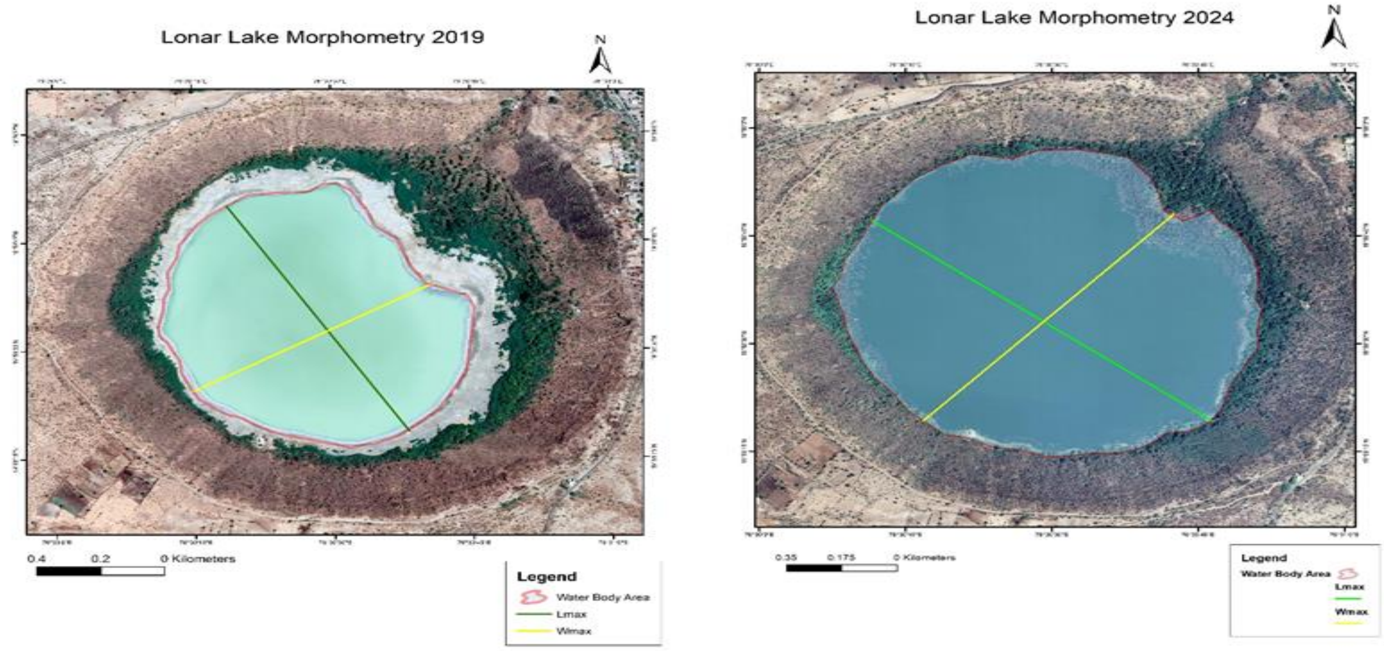

Fig. 2 Morphometric Parameter and change in area of lake water body (2019 & 2024)

RESULTS

Temporal Morphometric Parameters

Table 1 - Morphometric parameters of Lonar Lake for 2019 & 2024)

Parameter	Formula Description	Value April 2019	Value May 2024
Shoreline Elevation	H	0.496 km	0.508 km
Shoreline Length	SL	3.33 km	4.21 km
Surface Area	A	0.80 sq. km	1.28 sq. km
Maximum Length	L_{max}	1.11 km	1.33 km
Maximum Width	W_{max}	0.87 km	1.16 km
Maximum Depth	Z_{max}	0.0062 km	0.0062 km
Mean Depth	Z_{mean}	0.0022 km	0.0022 km
Depth Ratio	$R^z = Z_{mean} / Z_{max}$	0.3548	0.3548
Relative Depth	$Z_r = 50 \times (Z_{max} \times \sqrt{\pi}) / \sqrt{A_0}$	0.6165	0.4855
Shoreline Development Factor	$D_{sl} = SL / (2\sqrt{(\pi A_0)})$	1.0569	1.0524
Development of Volume	$D_v = 3 \times Z_{mean} / Z_{max}$	1.0645	1.0645
Volume	V	0.0017	0.0028
Index of Basin Permanence (IBP)	IBP = V / SL	0.0005	0.0006

DISCUSSION

Morphometric Changes and Significance

The morphometric analysis between 2019 and 2024 reveals a clear hydrological response to increasing rainfall. The lake's surface area expanded from 0.80 to 1.28 km² and shoreline length from 3.33 to 4.21 km, corresponding to a 36% rise in rainfall between 2018 and 2023. This demonstrates that precipitation-driven recharge dominated over evaporation loss. The Shoreline Development Index (≈1.05) indicates that the lake retains its circular crateral geometry, while a decline in Relative Depth (0.62 → 0.49) and a rise in the Index of Basin Permanence suggest lateral expansion and improved water retention due to enhanced subsurface inflow and reduced seepage.

Hydrological Controls

The results support previous findings that Lonar's hydrology is governed by the combined influence of surface runoff during monsoon and groundwater inflow through vesicular basalt and ejecta layers, which regulate recharge and maintain perennial water levels (Komatsu et al., 2014). Increased rainfall strengthens this dual recharge system.

Climatic and Geomorphic Implications

Rainfall variability is thus a major control on the lake's morphometry. The observed expansion and stable geometry indicate a climate-sensitive equilibrium state, consistent with hydrological parameters such as the energy factor (E = 0.165) and depth ratio (0.487) reported by Singh et al. (2023). These features affirm that rainfall and lithological factors jointly sustain Lonar's hydrogeomorphic stability.

Significance of the Study

This study provides valuable insights into the morphometric and hydrological evolution of Lonar Crater Lake, revealing its sensitivity to recent climatic variations. The observed expansion in lake area and volume from 2018 to 2023 demonstrates that rainfall intensity and groundwater inflow collectively regulate the lake's water balance within the basaltic crater system. The increase in the Index of Basin Permanence (IBP) and shoreline development suggests enhanced groundwater retention and improved hydrological stability. These findings emphasize that lithological permeability and structural controls are major factors influencing lake expansion and hydrodynamic behavior. Overall, this research contributes to a better understanding of crater-lake evolution in basaltic terrains and establishes a GIS-based framework for monitoring morphometric and hydrological changes in similar impact structures.

CONCLUSION

The morphometric evaluation of Lonar Crater Lake between 2019 and 2024 reveals distinct hydrogeomorphic adjustments driven by climatic and subsurface hydrological variability. Despite the relative stability in depth and basin morphology, the observed expansion in surface area and volume corresponds to increased precipitation and groundwater recharge. Integration with previous hydrogeological evidence indicates that the lake's hydrological regime is governed by the combined influence of surface runoff and lithologically controlled groundwater flow through basaltic strata. Overall, the study underscores the utility of morphometric monitoring as a reliable indicator of hydroclimatic variability and groundwater–surface water interactions in basaltic impact crater environments. Furthermore, these findings contribute to the broader understanding of crater lake evolution, offering valuable insights for comparative planetary studies and for developing long-term hydrological monitoring frameworks in similar geomorphic systems.

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