



Report on Geological and Bathymetry Survey of Vasuki Glacial Lake [Lake ID – NDMAo77]

07.10.2024 TO 16.10.2024

BY



REPORT ON SURVEY CONDUCTED AT VASUKI LAKE, HP



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Abbreviations:

- i. GLOF : Glacier Lake Outburst Flood
- ii. ABSV : Autonomous Bathymetry Survey Vessel
- iii. DGPS : Differential GPS
- iv. GPS : Global Positioning System
- v. GNC : Guided Navigation and Control
- vi. IRNSS : Indian Regional Navigation Satellite System
- vii. AGLPS : Advanced Glacier Lake Profiling Software
- viii. DEM : Digital Elevation Model
- ix. MSL : Mean Sea Level
- x. GIS : Geographic Information System
- xi. MCM : Million cubic meters
- xii. FCC : False Colour Composite
- xiii. EWS : Early Warning System

1. Introduction

A team of 08 scientists and engineers from C-DAC reached Kasol on October 07, 2024, from Pune and Thiruvananthapuram for the assessment of Vasuki Glacial lake in Sosan, Kullu (Lake ID—NDMA077), with geo-coordinates 31.915N, 77.527E, and a mean elevation of 4500m in Sosan Tehsil of District Kullu, Himachal Pradesh. The lake, formed by the accumulation of meltwater from surrounding glaciers, is primarily influenced by climate conditions. It is a critical component of the local ecosystem, contributing to biodiversity.

The Indian Himalayan Region is increasingly facing the profound impacts of climate change, with glacial retreat and the expansion of large glacial lakes emerging as prominent indicators of this environmental crisis. These changes significantly heighten the risk of Glacial Lake Outburst Floods (GLOFs), which pose a serious threat to both human settlements and ecosystems downstream. Such events could lead to devastating floods, landslides, and infrastructure damage, underscoring the urgent need for proactive hazard assessment, risk monitoring, and disaster management strategies. In response to this growing threat, the Himachal Pradesh State Disaster Management Agency (HP-SDMA) and the District Disaster Management Agency, Kullu (DDMA-Kullu), have initiated a comprehensive strategy to conduct a bathymetric survey of a critical glacier lake. This survey marks a significant step toward improving hazard evaluation, early warning systems, and risk reduction measures for vulnerable communities. By assessing the depth, volume, and stability of the lake, experts will gain essential data to better predict potential GLOF events and design appropriate mitigation strategies.

Like many glacial lakes in the region, NDMA077 is highly susceptible to the impacts of climate change. Rising temperatures accelerate glacial melt, increasing the volume of water in these lakes, which in turn raises concerns about their stability. Additionally, shifting climatic conditions may alter precipitation patterns and the rate of ice and snow accumulation, further exacerbating the risks. Research into these changes is crucial not only for understanding the dynamics of glacial lakes but also for assessing the broader environmental consequences on water resources, biodiversity, and local livelihoods. Given the interconnectedness of these systems, such research is vital for informing policy decisions and ensuring sustainable management of the region's natural resources in the face of an uncertain climate future.

The District Disaster Management Authority (DDMA) Kullu organized an expedition to the Vasuki glacial lake at Sosan, Kullu, Himachal Pradesh, from October 7 to 15, 2024. The expedition aimed to study and analyze the glacial lake, designated as NDMA077, situated Sosan with geo-coordinates 31.915N, 77.527E, at a mean elevation of 4500 meters. The team comprised scientists and Engineers from Centre for Development of Advanced Computing (C-DAC) and the officials of Central Water Commission (CWC), along with personnel from the National Disaster Response Force (NDRF), Indo-Tibetan Border Police (ITBP), the Dogra Scout (Indian Army), the Himachal Pradesh Police, the Home Guard, Physician and Para-medical Staff, DDMA Kullu, and several porters. A DDMA-appointed mountaineer led the expedition. With proper planning and with the help of multiple mountaineers, the team reached the lake site on 12.10.2024 and carried out a bathymetry survey and drone imaging.

2. Objectives

The C-DAC team was entrusted with a detailed physical assessment of the lake, which included evaluating key factors such as the lake's outlet, slope stability, and overall condition. They were also tasked with inspecting the moraine dam, conducting a visual assessment of its stability, and assessing additional environmental criteria. Furthermore, the team was responsible for performing a bathymetric survey using an Autonomous Bathymetry Survey Vessel (ABSV), enabling precise profiling of the lake's depth and morphology. This survey would also support the calculation of the lake's water volume, which is crucial for understanding the potential flood risks and overall dynamics of the glacial system. The combined findings from these assessments will help inform risk management strategies and guide future mitigation efforts for the region.

The specific objectives of this expedition to make a report on the following points.

- i. Geology of the area, such as type/nature of rocks
- ii. Moraine /dam height and width its strength
- iii. Width and length of the lake
- iv. Slope of the valley near the lake and glacier

- v. Probability of landslide and avalanche affecting the lake
- vi. The Probability of rock falls due to frost activity in terms of the distance of the high mountain cliffs
- vii. Morphology of the downstream valley - type of soil, rock, vegetation
- viii. Downstream slope of the valley - gentle or steep — indicate in degree
- ix. Any hydropower station in the downstream area - approx. Distance, if any
- x. Depth of lake real-time or through visual observations
- xi. Water level of the lake
- xii. Volumetric Analysis of the glacier lake

3. Methodology

3.1 Geological Observations

The District Disaster Management Authority (DDMA) Kullu organized an expedition to the glacial lake Vasuki lake located in Sosan, Kullu, Himachal Pradesh, from October 8 to 15, 2024. The expedition aimed to study and analyze the Vasuki glacial lake, designated as NDMA077, with geo-coordinates 31.915N, 77.527E, at a mean elevation of 4500 meters. The team comprised scientists and Engineers from the Centre for Development of Advanced Computing (C-DAC) and the official of Jalshakti, along with personnel from the Indo-Tibetan Border Police (ITBP), Para-medical Staff from Kullu, staff from Atal Bihari Vajpayee Institute of Mountaineering and Allied Sports (ABVIMAS), Manali and several porters. The expedition was led by a DDMA appointed mountaineer with proper planning and with the help of multiple mountaineers (Mr. Shiva, Mr. Sunil, Mr. Sunil Tekchand)

The perimeter of the lake is 1.65km. The maximum depth was recorded as 36.91 m, and the average depth was 14.48 m. The length of the moraine dam wall is around 70 m and height is around 10 m. The glacier is found to be retreating and snout position is advancing towards the glacier. The Parvati Valley and its surrounding mountain ranges are primarily composed of metamorphic rocks, such as gneiss and schist, which form the backbone of the region's geology. Alongside these, there are also significant deposits of igneous rocks,

including both mafic and ultramafic types. Mafic rocks, such as basalt and gabbro, are abundant in the area, while the denser ultramafic rocks, like peridotite, are also present. This geological diversity, which includes a mix of metamorphic, mafic, and ultramafic rocks, contributes to the region's striking landscapes and plays a crucial role in supporting its varied ecosystems. The interaction between these different rock types also influences soil composition, hydrology, and vegetation, further enhancing the valley's rich biodiversity and ecological complexity.

As part of the geological survey, we carried out field observations in the study area to visually assess and interpret key geological features. This included examining rock outcrops, identifying faults, folds, and other structural formations, as well as collecting rock samples for further analysis. The visual interpretation of these features offered valuable insights into the region's subsurface geology. Regarding the lake, its perimeter was measured at 1.65 km. The maximum depth was recorded at 36.91 meters, with an average depth of 14.48 meters near the lake's center.

3.2 Bathymetric Survey

A bathymetric survey of a glacial lake involves mapping its underwater features to gain a comprehensive understanding of its depth, shape, and sediment distribution. Using advanced technologies such as sonar and GPS, the survey collects detailed data that reveals submerged features like valleys, channels, and potential hazards, such as unstable slopes or sediment buildup. By analyzing the bathymetric maps, researchers can assess the ongoing effects of glacial melt, track shifts in the lake's morphology, and monitor ecological changes in the surrounding environment. These studies are vital for understanding the behavior of glacial systems, evaluating their impact on downstream water resources, and supporting informed conservation and risk management efforts. Ultimately, bathymetric surveys play a critical role in enhancing our ability to predict and mitigate the environmental risks posed by rapidly changing glacial landscapes.

Autonomous Surface Vessel (ASV)

ASVs are battery operated, compact & stable, portable, crew-less surface vessels, having autonomous control and way point navigation with obstacle detection & collision avoidance feature. The vessel can be configured with multiple sensors/equipment as payloads depending on use case, as per customer requirements. This indigenous autonomous surface vessel has subsystems like the vessel hull and auxiliary structural elements, propulsion and power systems, GNC system, control & communication systems and bathymetry sensor suites including single beam echosounder and DGPS.

Depth Measurement and Geo tagging

Depth measurement and geo-tagging using echosounders and Differential GPS (DGPS) provide precise underwater mapping and positioning. An echosounder emits sound waves that bounce off the lake or seabed, allowing researchers to calculate depth based on the time it takes for the echoes to return. Simultaneously, DGPS enhances location accuracy by correcting satellite signals, ensuring that depth data is georeferenced with high precision. This combination enables detailed bathymetric surveys, helping to analyze underwater features and precise volumetric estimation, which is essential for effective scientific studies.



Fig 1: Autonomous bathymetric Survey Vessel for Glacial Lake Survey

Features:

- Autonomous control & way point navigation using GPS/IRNSS
- Echosounder with depth measurement up to 200m
- Collision avoidance & obstacle detection suite
- Battery operated– powered by high density battery pack
- Long endurance operation
- Remote Operation Mode
- High degree of Maneuverability
- Modular design, portable
- Autonomous Navigation, and Mission planning suite

3.3 Satellite data analysis

Sentinel 2 satellite data at 10 m spatial resolution was used for change detection analysis of the lake area. Temporal satellite images were downloaded for 12th Sept. 2017 and 20th Sept. 2024. False color composite (FCC) of band 8, 4 and 3 were used for visual interpretation of lake area. The lake area was digitized and vector datafiles were analysed.

4. Day wise summary of the expedition:

On October 9th, 2024, the team began their journey from Kasol and drove to Barshani, the last point accessible by vehicle. From there, the team completed a 4.5 km trek through rugged terrain to reach the first Base Camp (Khirganga base camp), which took approximately 4-5 hours. The team reached the base camp by the end of the day. ITBP, ABVIMAS, and Manali personnel accompanied the team and provided assistance whenever required.

On October 10th, 2024, the team started around 11:00 AM and reached the second base camp near the Tang nala around 5:00 PM. Due to uneven terrain, the camp arrangements were distributed.

On October 11th, 2024, The team started around 9:30 AM and reached the third base camp at Shepherd camp around 5:30 PM. En route lunch was provided. This camp was situated

above tree line. Kitchen staff watched a brown bear along the other side of the river in morning hours.

On October 12th, 2024, The team started around 10:00 AM and reached the Vasuki lake base camp at around 5:00 PM. En route lunch was provided. This camp was above tree line and temperatures were low at nights.

On October 13th, 2024, The team started around 8:30 am and reached Vasuki lake around 11 am. The ABSV was assembled and detailed bathymetry survey was carried out. Drone images were captured for the entire lake. The team started at 3 pm from the lake and reached the shepherd base camp around 7 pm, skipping the Vasuki lake base camp. The total walk for the day was more than 9 kms.

On October 14th, 2024, The team started around 9:30 AM and reached the Khirganga base camp at around 5:30 PM. En route lunch was provided. The total walk was more than 10 kms.

On October 15th, 2024, The team started around 10:00 AM and reached NHPC dam site near Barshani at around 5:30 PM. En route lunch was provided. While descending Nakhtan village route was avoided and Kulga village route was explored. From the dam site pick up vehicle dropped the team to Forest Guest house at Kasol marking the conclusion of the expedition.

5. Results

5.1 Geological Findings

- ✓ The Parvati river is the main river of the area having significant water flow from glacial melt.
- ✓ The river is very much vulnerable for flash floods due to unstable slopes and frequent heavy downpour in the valley.
- ✓ The lake under study has no overtopping and significant water flows out of the lake in form of piping and seepage.
- ✓ The general slope of the Parvati valley varies gradually between 10 to 45 degrees.

- ✓ The slope of the lake observed from satellite images and visualized in field varies between 30 to 60 degrees.
- ✓ The lithology of the area is mainly metamorphic rocks with igneous intrusions.
- ✓ The area is susceptible to landslide induced damming and landslide lake outburst flood (LLOF) and flashfloods.
- ✓ The rock types are a mix of granite gneiss, micaceous schists, amphibolite, granodiorites and meta-sediments. Occasionally pegmatite veins are also seen.
- ✓ Weathering – frost weaving has led to disintegration of rocks.
- ✓ No major settlement location is in the close vicinity of the lake up to a distance of approximately 15-20 km from the lake till Nakhtan village which is the last motorable point.
- ✓ NH PC dam at Barshani may get affected due to lake burst and GLOF.
- ✓ Population at Barshani may be affected.
- ✓ The soils are shallow and sandy derived from mechanical disintegration of rocks, due to, marked diurnal and seasonal fluctuation of temperature.

5.1.1 Geology of the lake:

The Parvati Valley and surrounding ranges are primarily composed of metamorphic rocks, such as gneiss and schist. However, the region also contains some igneous rocks, including mafic and ultramafic rocks. Mafic rocks in the region include basalt and gabbro, While Ultramafic rocks, which are denser than mafic rocks, include peridotite. The presence of metamorphic, mafic, and ultramafic rocks, along with other geological features, contributes to the unique landscape and biodiversity of this area.

5.1.2 Flora of the Valley:

The Parvati Valley has a diverse plant life, including alpine trees, shrubs, and medicinal herbs. Trees like Himalayan cedar (*Cedrus deodara*), juniper, birch, populus, and salix are encountered. Shrubs like *Myricaria*, *brutal* (*Juniperus macropods*), and *bhojpatra* (*Betula*

utilise) are found. Few herbs like Ephedra gerardiana, Ferula jaeschkeana and many others were found. Higher altitudes and extreme temperatures result in sparse vegetation density.

5.1.3 Observations

- The lake is connected to active glacier
- There is piping / seepage and water is flowing underneath the moraine dam.
- Southern and western slopes are steep with loose rock fragments.
- The perimeter of the lake is 1756 m based on 20th September 2024 satellite data (Sentinel 2 FCC)
- The area of the lake is 13.38 hectares based on 20th September 2024 satellite data (Sentinel 2 FCC)
- The area of the lake is 10.36 hectares based on 12th September 2017 satellite data (Sentinel 2 FCC).
- The lake area change from 2017 to 2024 is 3.02 hectares.
- Maximum width and length of the lake is 280 and 705 m respectively.

5.2 Bathymetric Findings

The ABSV was assembled and a detailed bathymetry survey was carried out. Drone images were captured for the entire lake. Due to high winds and adverse weather conditions that prevailed at Lake site on the day of survey, the survey was conducted rapidly, covering almost the entire lake area. The survey data is organized in three columns, with the latitude, longitude, and corresponding depth values of each surveyed point arranged in the same row.

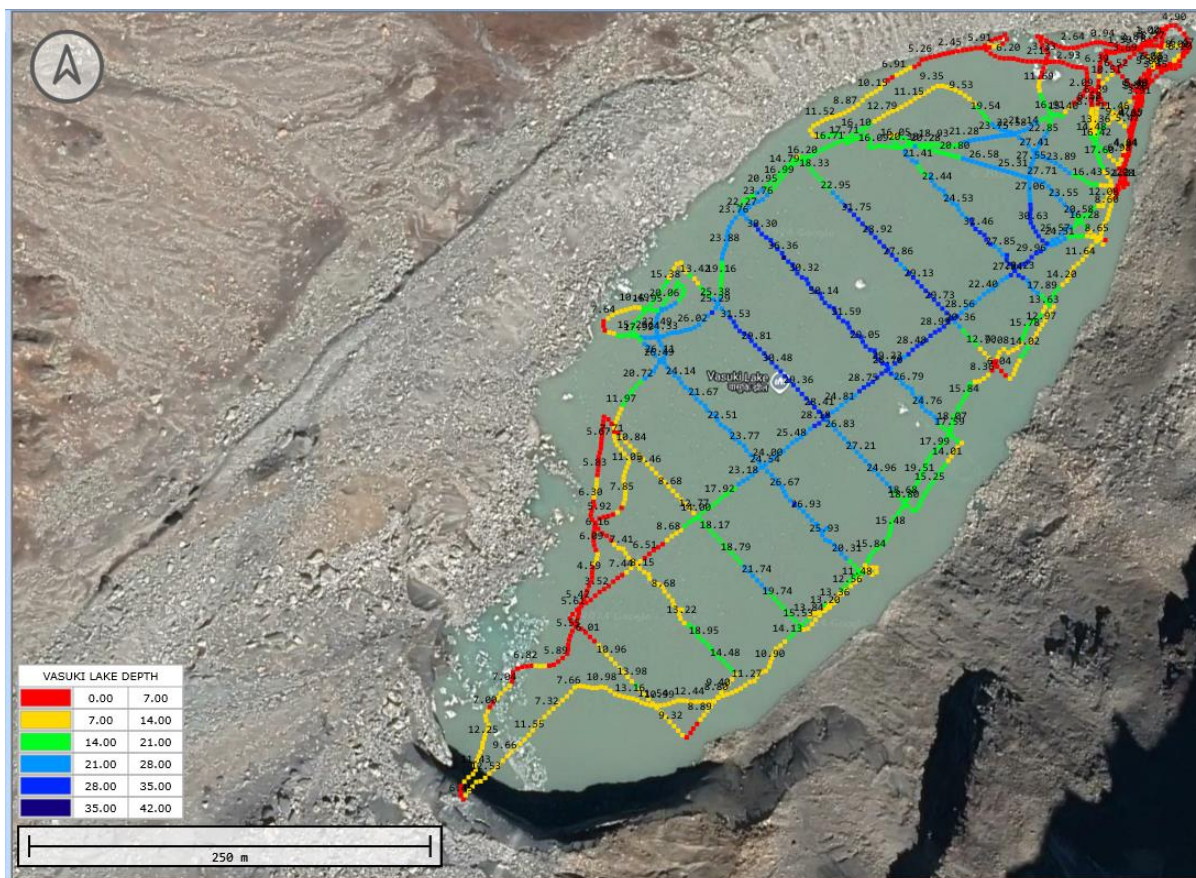


Fig 1:: Vessel Track and Depth Measurements

The Advanced Glacier Lake Profiling Software (AGLPS) was employed for carrying out the assessment of bathymetric data and further studies. Using the AGLPS, interpolation of depth values was carried out from the survey data to fill out the non-surveyed regions of the lake. The interpolated data along with the actual survey data forms the input for lake profiling and related inferencing.

In addition to the above, AGLPS also performs the following functions:

- ✓ Calculation of Area and Volume of lake
- ✓ Presentation of risky locations according to user-fed elevation levels
- ✓ 3-D view of the Digital Elevation Model (DEM)
- ✓ Depth Contour mapping

To carry out the above-mentioned functions, a high-resolution DEM corresponding to the location of the lake is required. C-DAC(T) has requested the Space Application Centre (SAC) to obtain a high-resolution DEM of the region of interest, which is yet to be received. In the interim report, a low-resolution DEM collected from 'USGS Earth Explorer', which is available for public use, has been utilized in the AGLPS for data processing.



Fig 3. Survey data plotted in the background of Vasuki lake

5.3 Area of Lake & Volume of water

The survey was conducted in autonomous mode with an offset of 50 m between the survey grids covering the entire area of the lake. Risky and narrow passages were surveyed separately in manual mode. Using the survey data, depth values were interpolated to fill out the non-surveyed regions of the lake. Therefore, the lake's boundary had to be manually marked using the base map as given

in Fig 4, and the data thus created has been utilized to automatically generate the envelope of the lake body. Drone images were captured of the entire lake to assist with this activity.

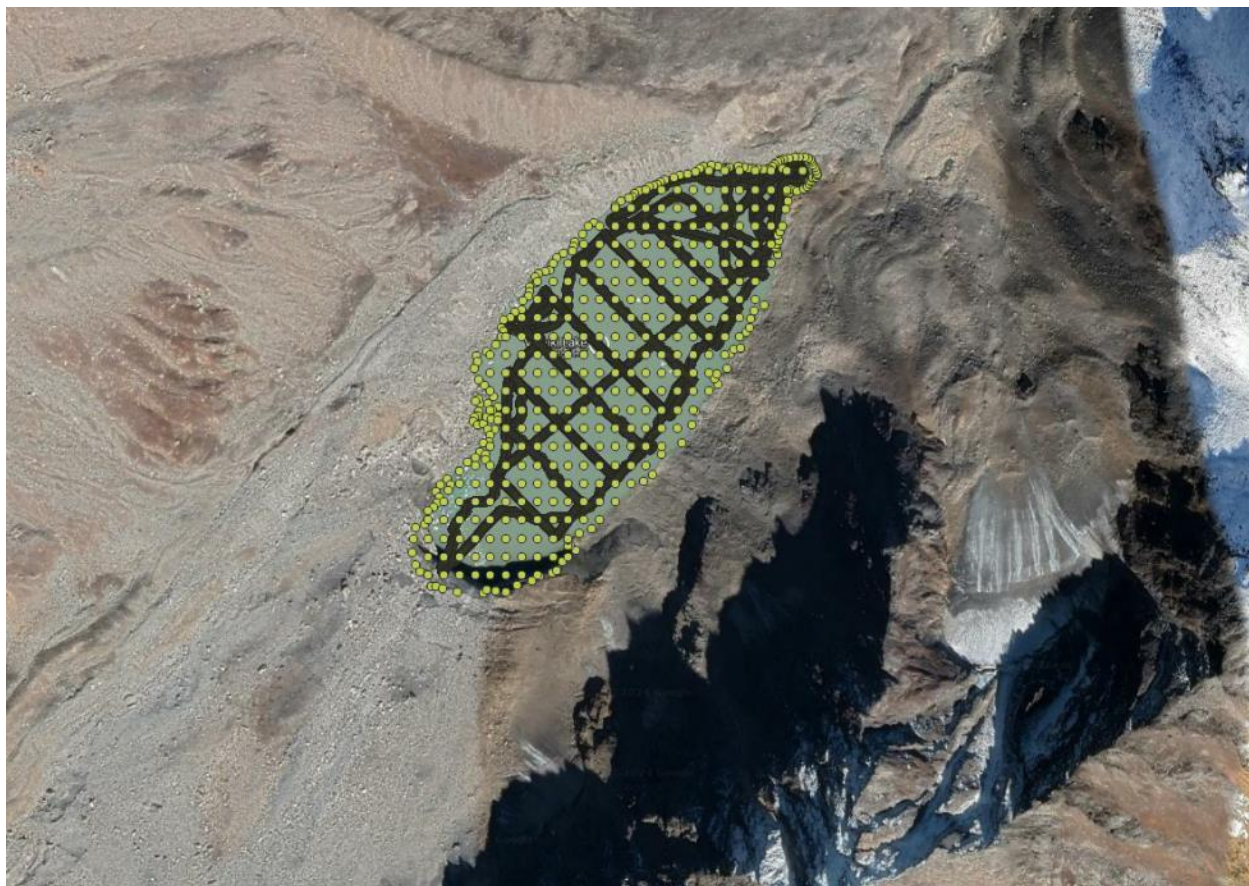


Fig 4(a). m arked lake boundary

The points marked manually are set with values of depth as zero which are added to the surveyed data. The next step is to fill out the areas which were not covered in the survey on the lake to provide comprehensive coverage for the data analysis and to derive a more realistic lake profiling. In this need, pseudo-survey data with interpolated depth values was generated to fill the unsurveyed area. The total data used for analysis, consisting of actual bathymetry data, manually added boundary points and the points with interpolated depth values is plotted in Fig 4(b).

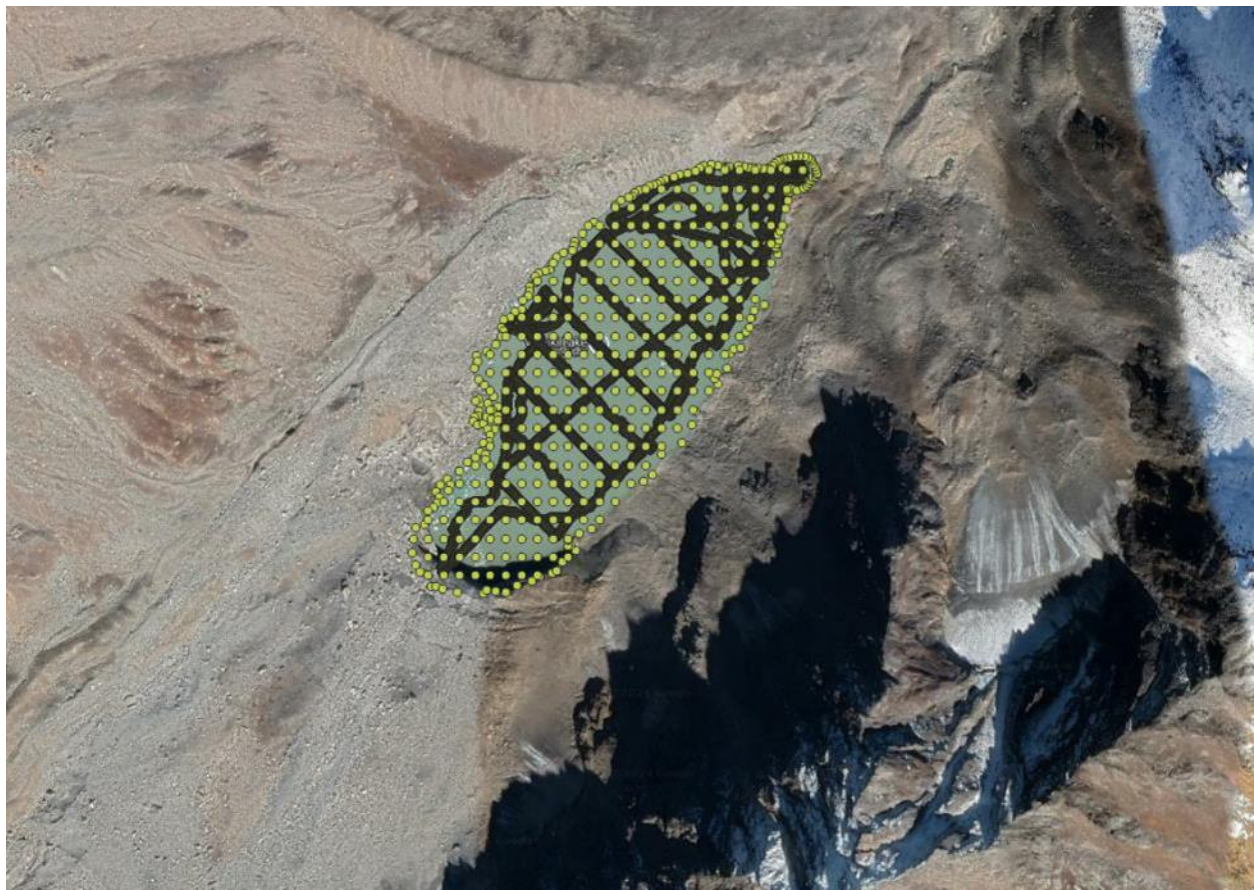


Fig 4(b). Data used for lake profiling

Thereafter, the interpolated data, along with bathymetric data, was used to calculate the total area of the lake through the Delaunay triangulation method. For validating the calculated area, a manually calculated area using QGIS software was also used. Fig 5(a) shows the comparison between the areas calculated by AGLPS and through QGIS. The volume of water in the lake was also calculated based on the depth data surveyed for the lake.

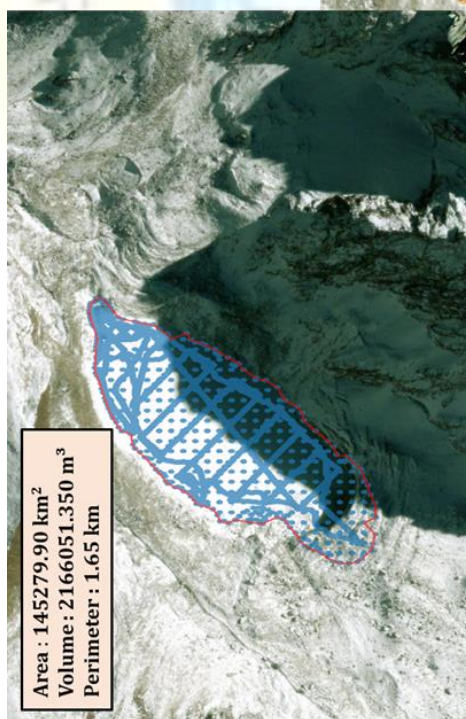


Fig 5(a). Calculated Area and volume of Vasuki lake

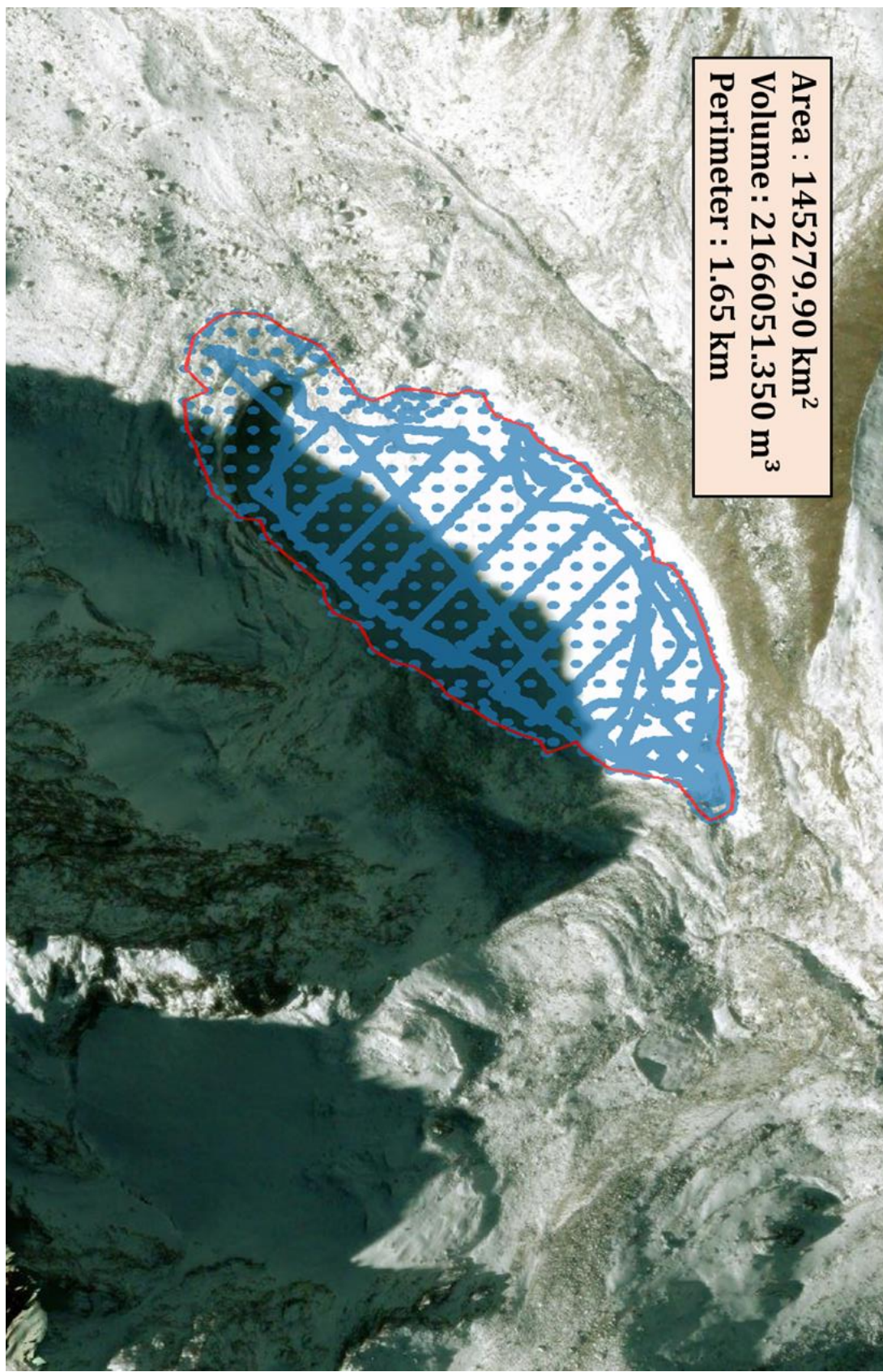


Fig5(b). Lake Area & volume

Lake inference

- ✓ Area of the lake : 0.1452799 km²
: 14.52799 Hectare
- ✓ Depth data
 - Maximum Depth : 36.91 m
 - Average Depth : 14.48 m
- ✓ Volume of water in the lake : 2166051350 L
: 2.16605135 million cubic meters (MCM)
- ✓ Perimeter of the lake : 1.65 km

Digital Elevation Model & 3D view of the area including lake

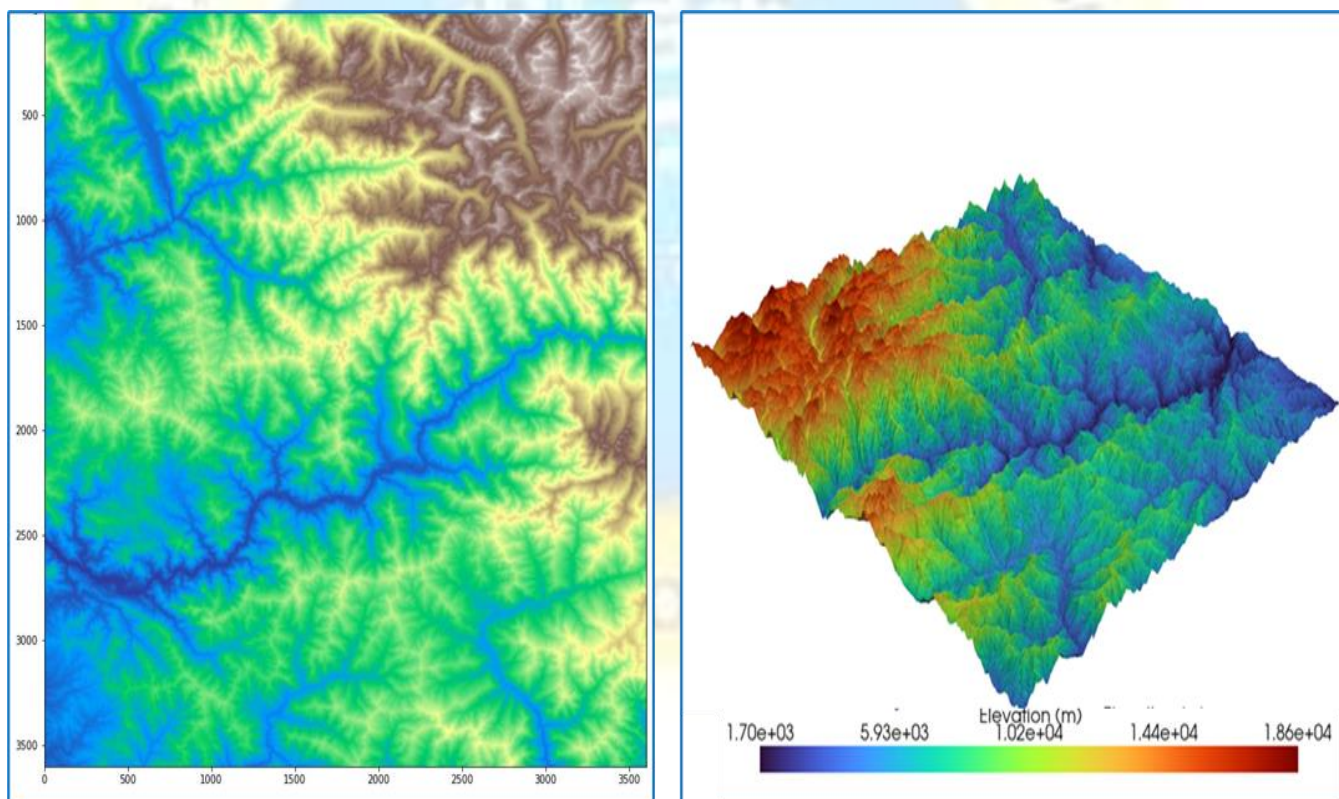


Fig6. DEM & 3D view of the location of lake from USGS Earth explorer

Depth contour map

The bathymetric map, also known as depth contour of the lake is presented in Fig 7 where lines connecting points of equal depths are plotted from the bathymetric survey data. The depth contour presented here is based on 'JET' colour scheme in which a spectrum of colours ranging from RED to BLUE is used for representing from deepest zone in the lake to the shallowest points in the boundary. The highest depth value was measured at the center of the lake and has a profile of decreasing depth towards its shores in all directions.

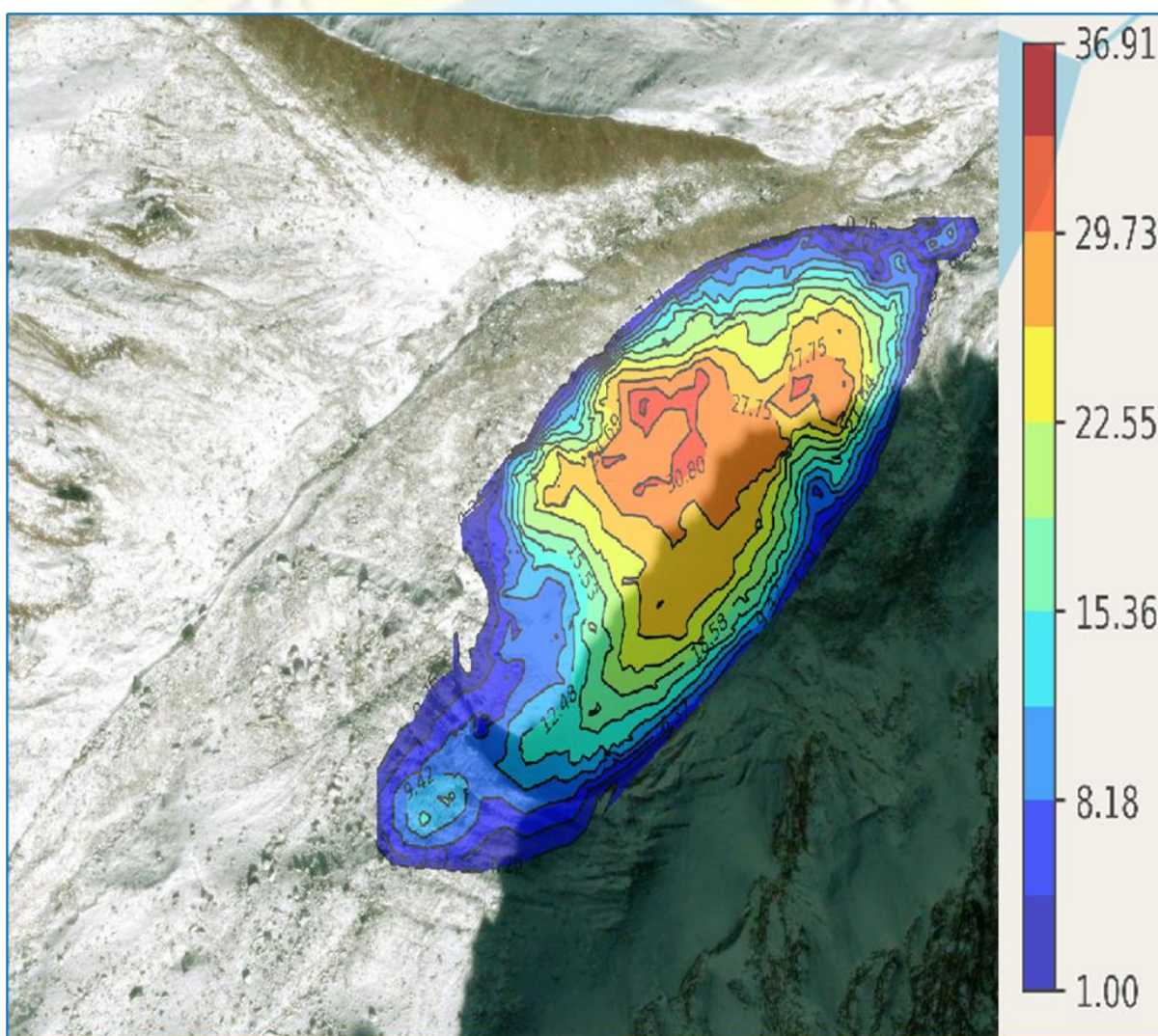
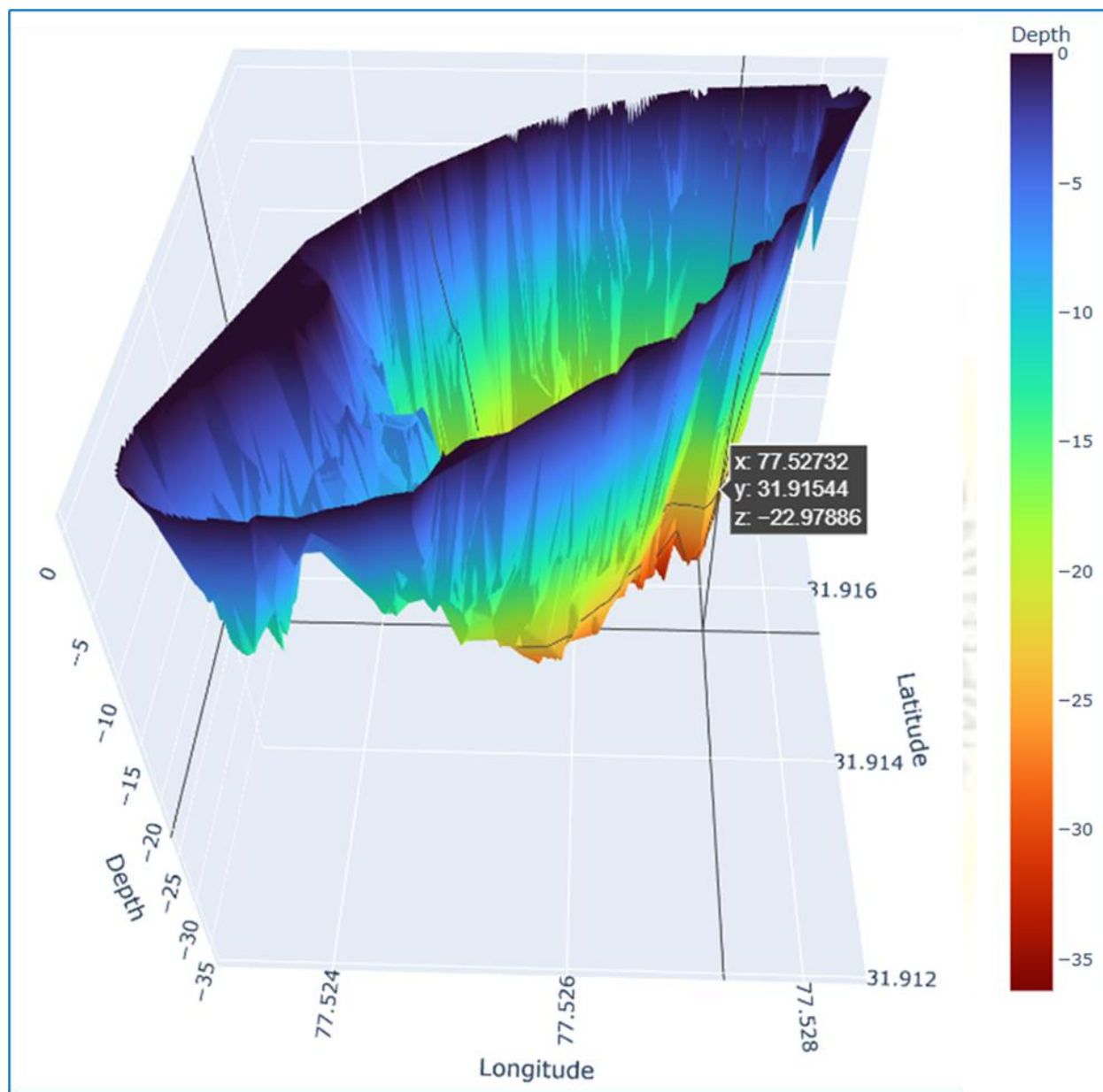


Fig 7. Depth contour map of Vasuki lake

3D Depth profile**Fig8(a). 3D map of Lake Vasuki**

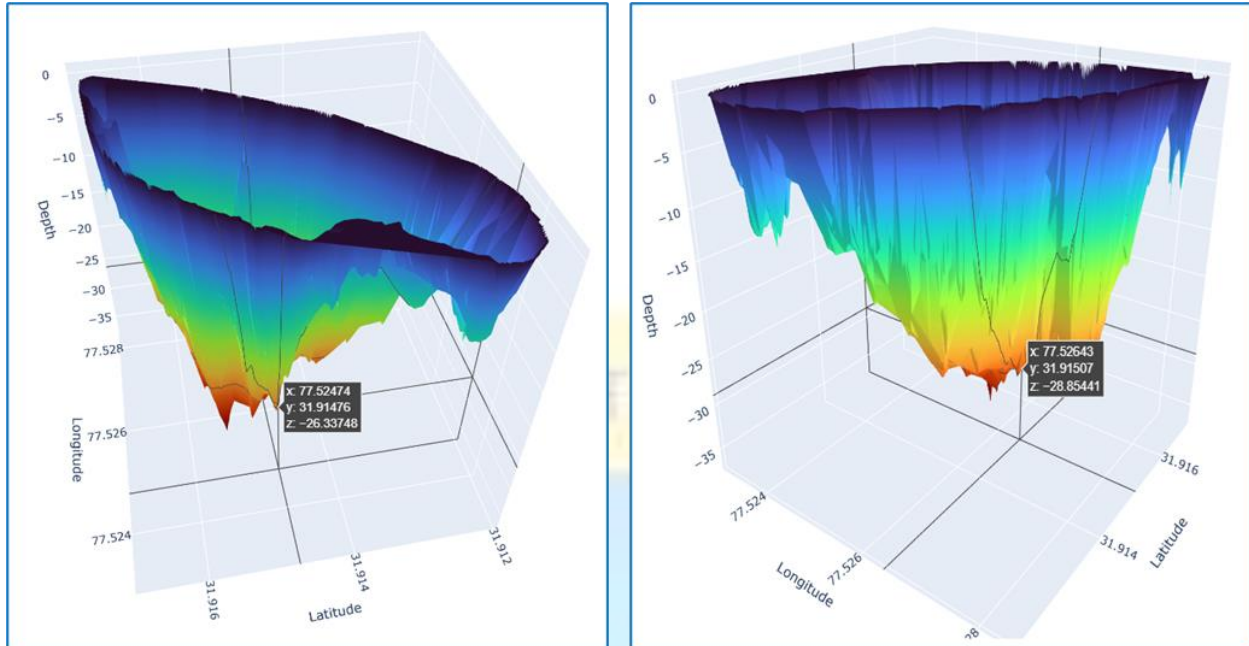


Fig8 (b). 3D map of Lake Vasuki

5.3 Water Quality Index

The Water Quality Index (WQI) is a numerical representation of the overall quality of water based on various water quality parameters. Here's a general step-by-step method to calculate the WQI:

Steps to Calculate WQI

- 1. Select Water Quality Parameters:** Common parameters include pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), total dissolved solids (TDS), nitrates, phosphates, and turbidity.
- 2. Measure the Parameters:** Obtain the measured values of these parameters from water samples.
- 3. Standardize the Parameters:** Convert the raw data into dimensionless sub-indices using standard curves or formulas specific to each parameter. This is usually done using a rating curve or a transformation function.
- 4. Assign Weights to Parameters:** Assign weights to each parameter based on their relative importance to overall water quality. The sum of the weights should be 1.

5. **Calculate Sub-Indices:** Multiply the standardized value of each parameter by its weight.

6. **Sum the Weighted Sub-Indices:** Sum the weighted sub-indices to get the overall WQI.

5.3.1 WQI CALCULATION (National sanitation Foundation WQI) NSF-WQI

The NSF WQI was developed by Brown in 1965 (Abrahão et al., 2007) as a modified version of the Horton model (Lumb et al., 2011). Like the Horton model, it has been used to evaluate surface water quality in various domains.

Measured Parameters of the Vasuki Glacial Lake water

- ✓ pH : 5.23 scale
- ✓ DO : 13.50 mg/L
- ✓ EC : 66.83 μ S/cm
- ✓ Turbidity : 0 NTU
- ✓ TDS : 36 mg/L

Using the formula:

$$WQI = \Sigma(Q_i \times W_i) / \Sigma W_i$$

$$WQI = \frac{(20 \times 0.11) + (90 \times 0.17) + (95 \times 0.16) + (100 \times 0.10) + (95 \times 0.07)}{0.11 + 0.17 + 0.16 + 0.10 + 0.07}$$

$$WQI = 3.6 + 25.2 + 24.7 + 16 + 10.45 = 79.95$$

- | | |
|----|-----------------------------|
| 1) | excellent (WQI=90–100) |
| 2) | good (WQI=70–89) |
| 3) | medium (WQI=50–69) |
| 4) | bad (WQI=25–49) |
| 5) | very bad quality (WQI=0–24) |

5. Discussion

- Area of lake in year 2017 was 10.36 ha (Based on Sentinel 2 data of Sept. 2017)
- Area of lake in year 2024 is 13.38 ha (Based on Sentinel 2 data of Sept. 2024)
- Change in lake area from 2017 to 2024 is 3.02 ha based on satellite data
- The area of the lake in September 2024 is 14.52799 ha (Based on bathymetry data)

6. Conclusion

Lake inference

- ✓ Perimeter Of the lake : 1.65 km
- ✓ \Area of the lake : 0.1452799 km²
: 14.52799 Hectare
- ✓ Depth data
 - Maximum Depth : 36.91 m
 - Average Depth : 14.48 m
- ✓ Volume of water in the lake : 2166051350 Lts
: 2.16605135 million cubic meters (MCM)
- ✓ WQI Value : 79.95

Satellite data analysis

Sentinel-2 satellite imagery with a spatial resolution of 10 meters was utilized to conduct a change detection analysis of the lake area. Temporal images were acquired for two dates: 12th September 2017 and 20th September 2024. To facilitate visual interpretation, a false color composite (FCC) using bands 8 (near-infrared), 4 (red), and 3 (green) was generated, highlighting differences in land and water features. The lake's boundary was manually digitized from the FCC images, and the resulting vector data was analyzed to assess changes in the lake's extent over the observed period. Figure 9-11 depicts the increase in Lake volume over a period of seven years.

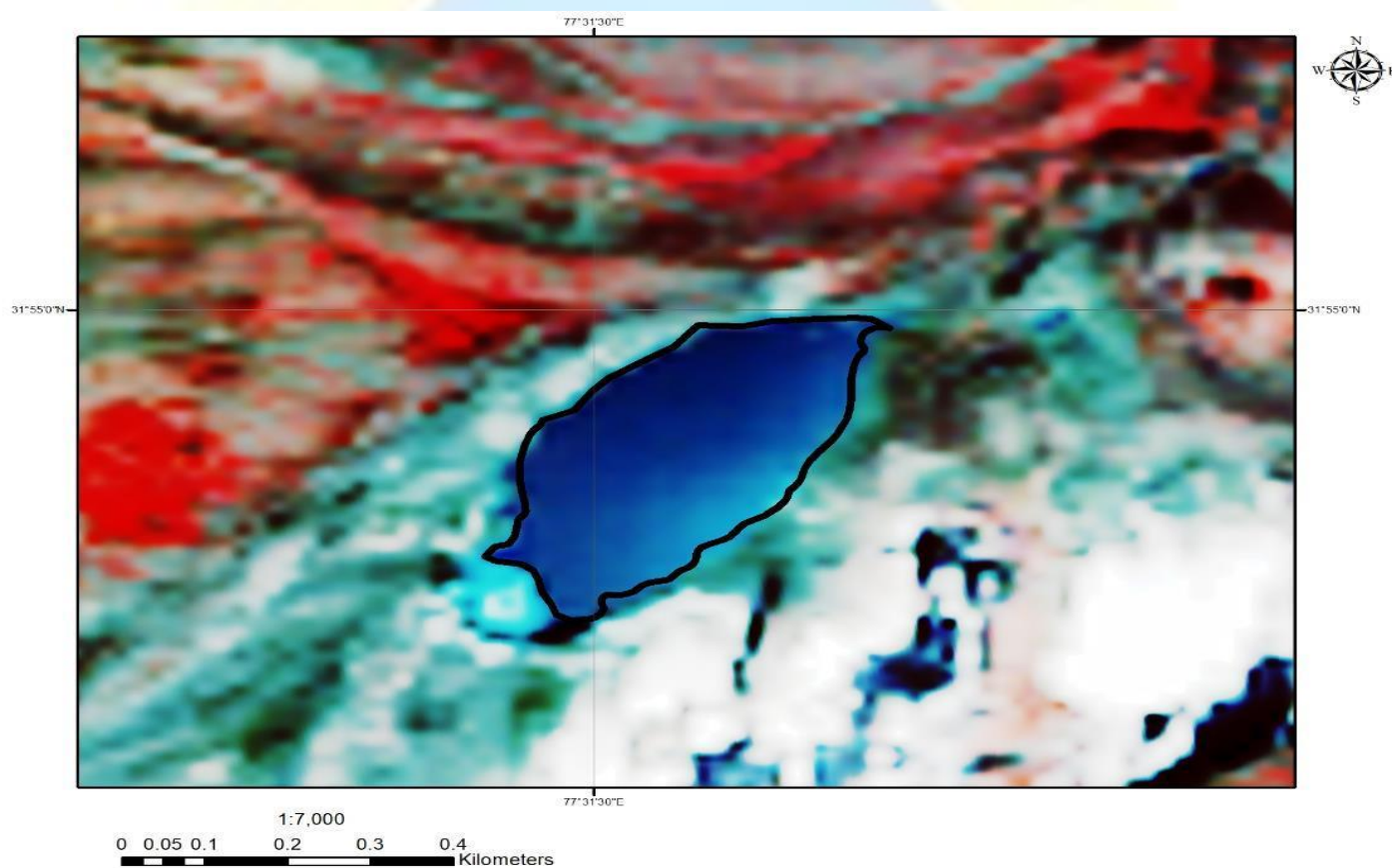


Fig9. Lake area based on Sentinel 2 FCC (843) acquired on 12th September 2017)

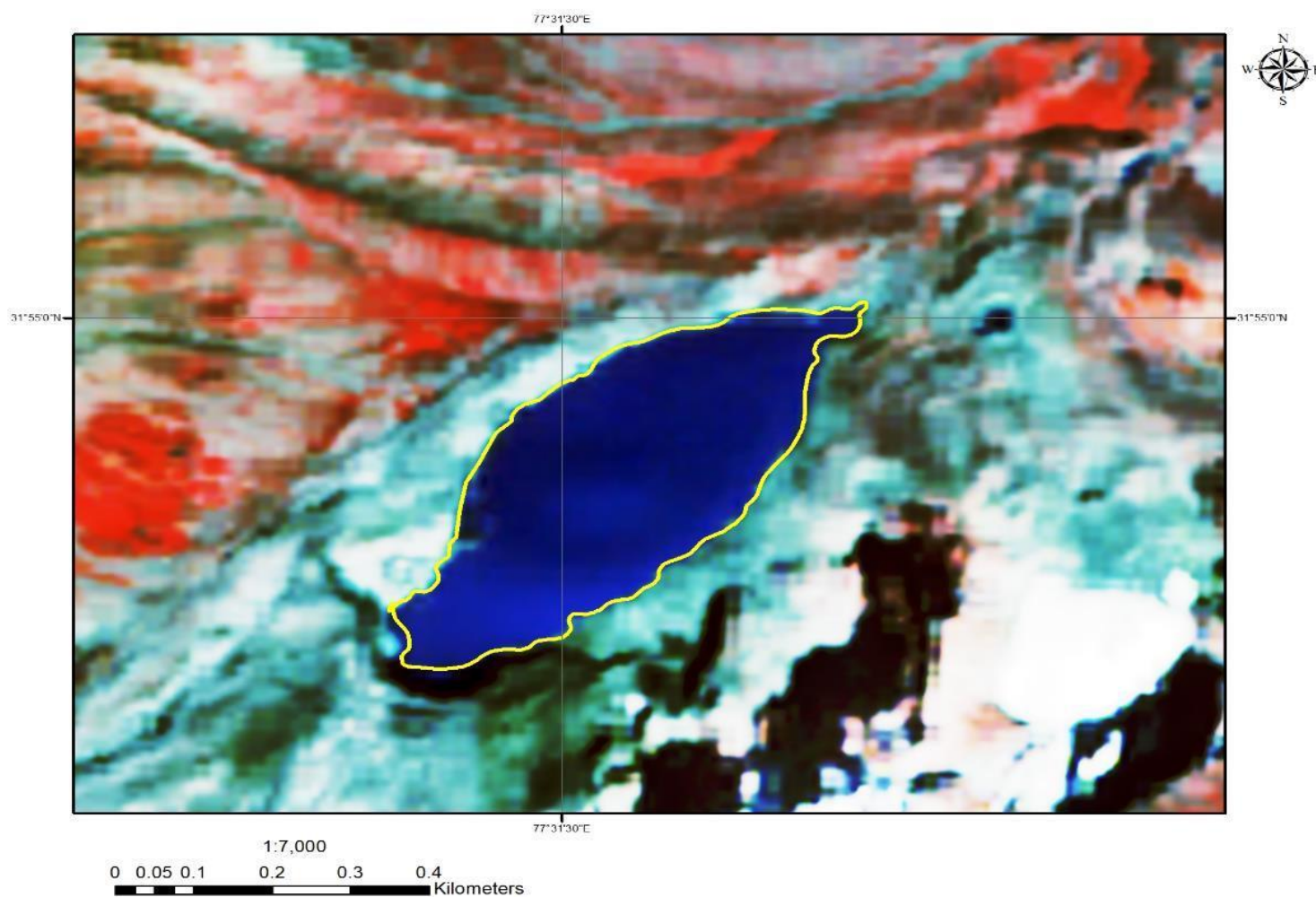


Fig10. Lake area based on Sentinel 2 FCC (843) acquired on 20th September 2024

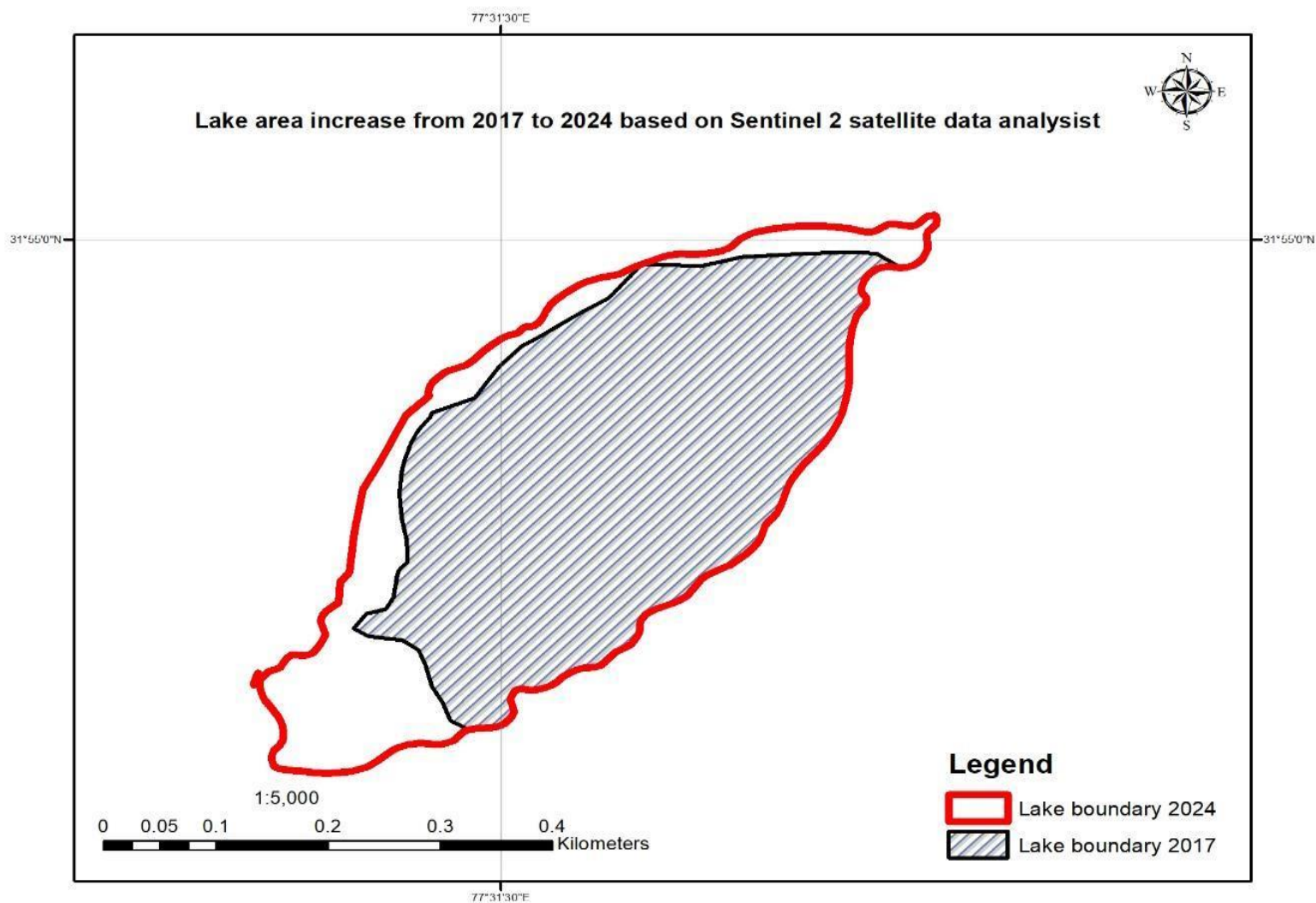


Fig11. Lake area increase from 2017 to 2024 based on Sentinel 2 satellite data analysis

7. Recommendations

- Suggestions for further studies.
 - ✓ Yearly field surveys are required to ascertain the moraine dam stability.
 - ✓ Time series analysis of lake using high satellite imageries is required
 - ✓ Installation of EWS
 - ✓ Water flow in the downstream of the lake needs to be monitored



9. Appendices

Annexure-1



VASUKI LAKE -DRONE IMAGES

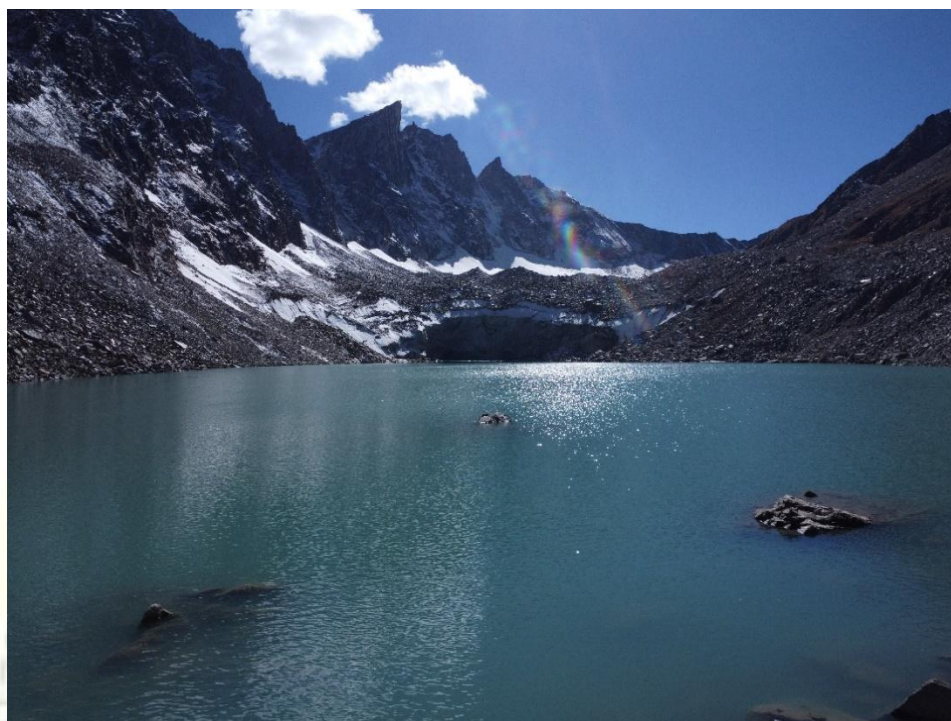


Figure 1: Vasuki Lake



Figure 2: Vasuki Lake : Wide angle



Figure 3: Mouth side : Top View



Figure 4: Glacier side : Front View



Figure 5: Glacier Side



Figure 6: Glacier Side : Closeup



Figure 7: Glacier side : top view (1)

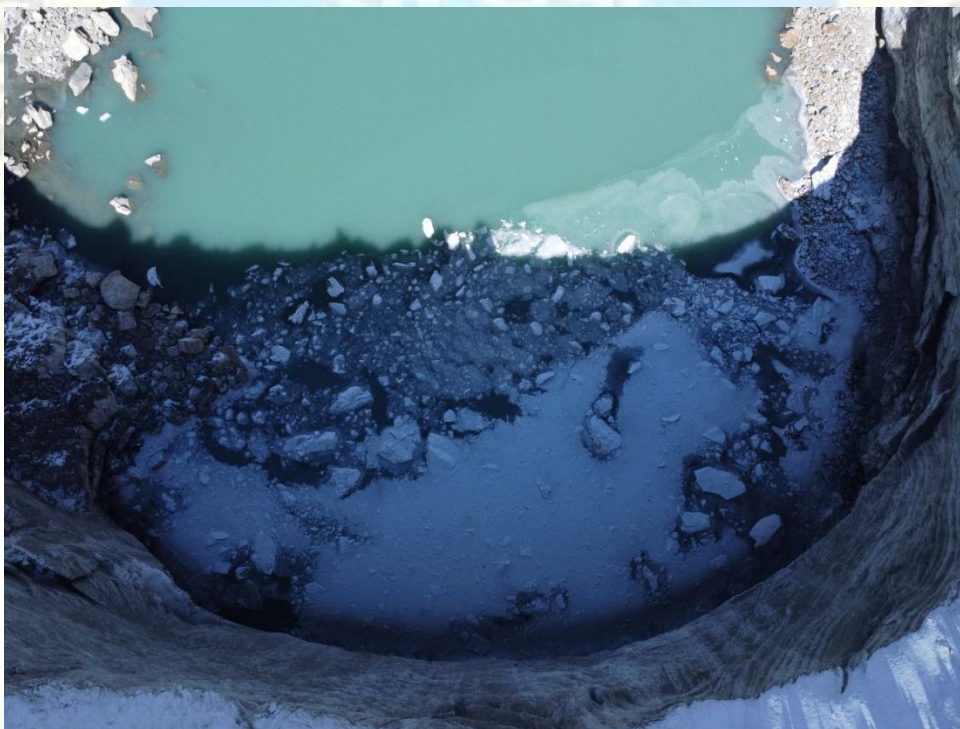


Figure 8: Glacier Side : Top View (2)



Figure 9: Control station side: operating ABSV for bathymetric survey at Vasuki lake.



Figure 10: Moraine

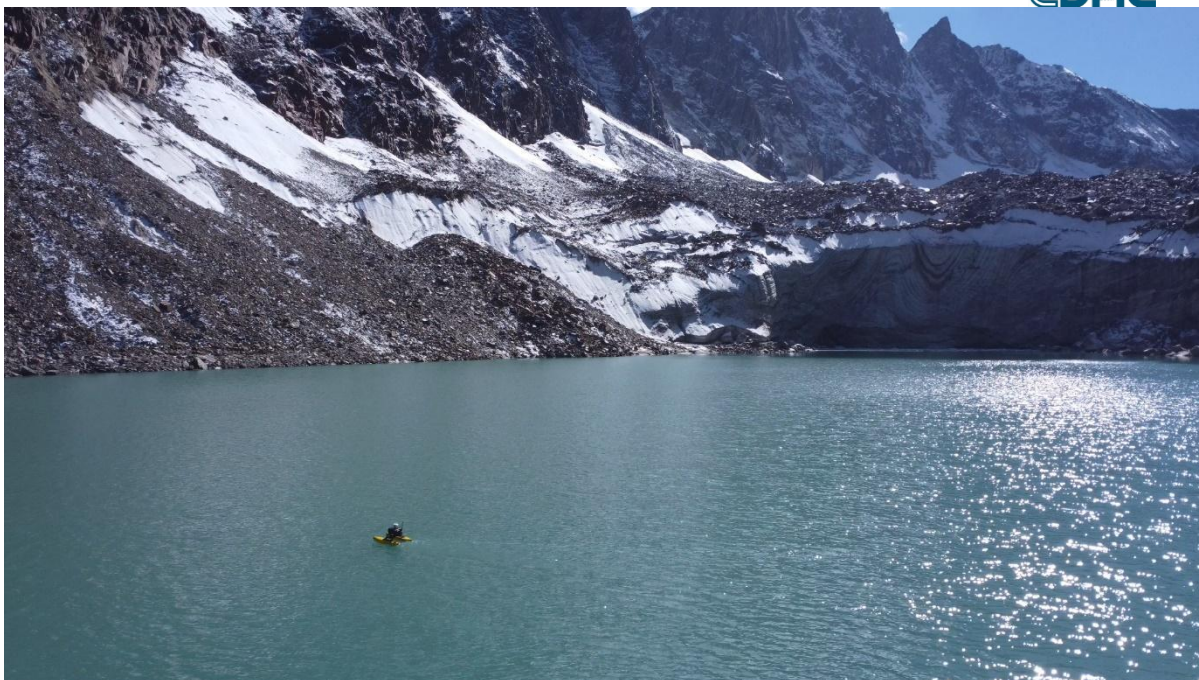


Figure 11: ABSV surveying the Vasuki Lake (1)

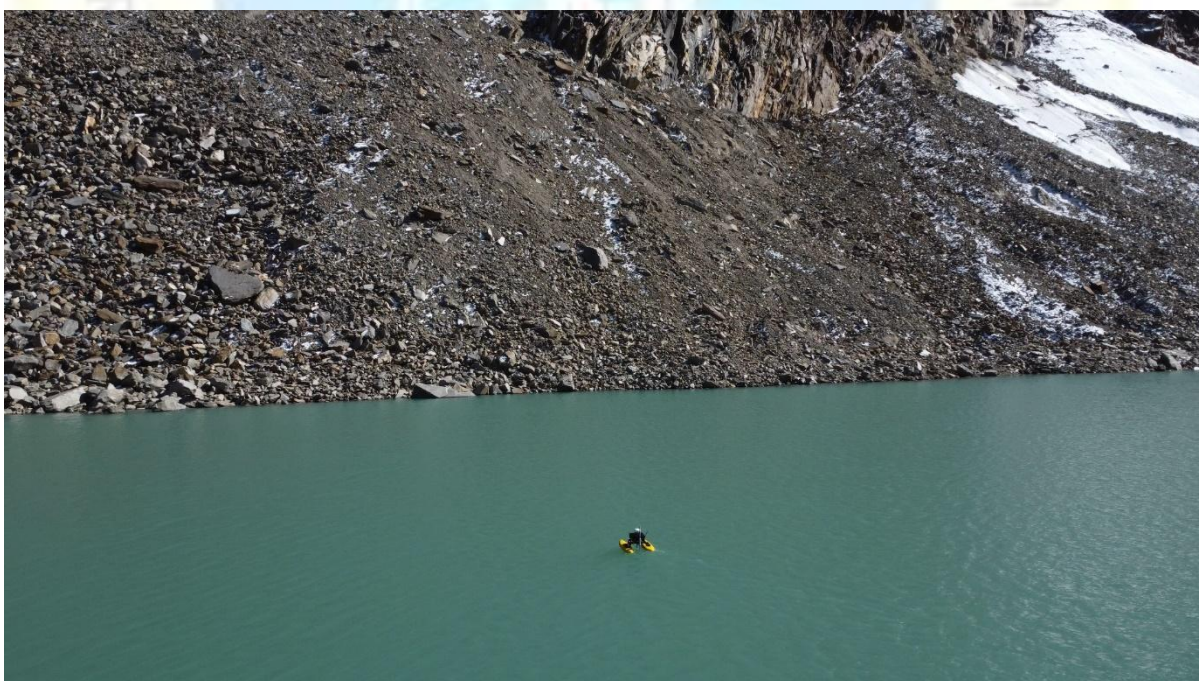


Figure 12: ABSV surveying the Vasuki Lake (2)



Figure 13: Glacier Side Outer Region (1)



Figure 14: Glacier Side Outer Region (2)



Figure 15: Mouth Side : Front View (1)



Figure 16: Mouth Side : Front View (2)



Figure 17: Mouth Side : Outer Side



Figure 19: Mouth Side : Outer Side (2)



Figure 18: POV from Glacier Side



Figure 20: POV from Mouth Side

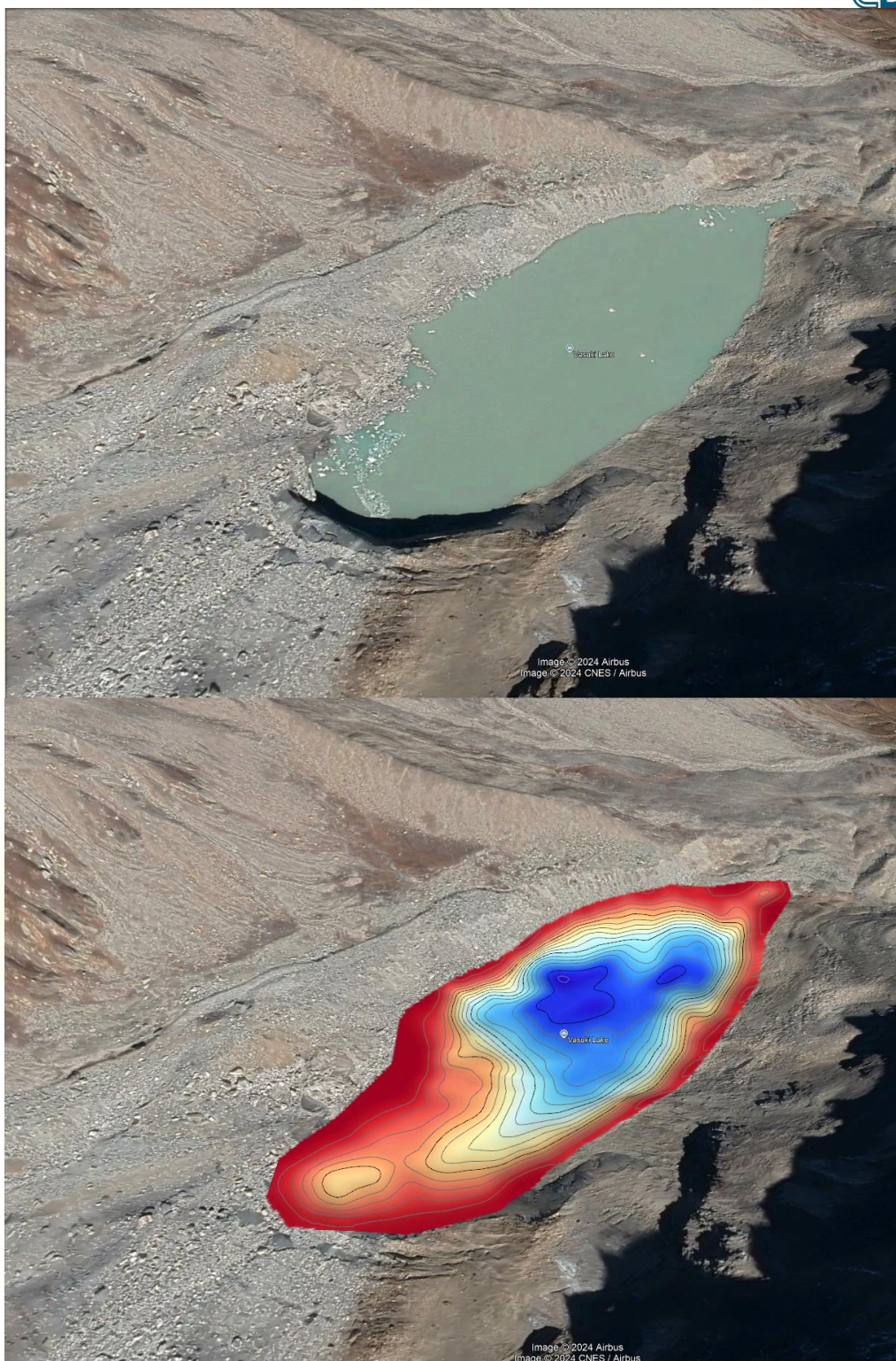


Figure 21: a. Google Earth Image of Vasuki Lake b. Superimposed Depth contours

