Report on Geological and Bathymetry survey of glacial lake at Baspa Upstream of Sangla [Lake ID - NDMA081]

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BY

CENTRE FOR DEVELOPMENT OF ADVANCED COMPUTING

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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 09 scientists and engineers from C-DAC reached Shimla on September 04, 2024, from Pune and Thiruvananthapuram to assess a glacial lake situated at Baspa Upstream of Sangla on the Left Bank (Lake ID—NDMA081), with geo-coordinates 33.3386N, 78.2531E, and a mean elevation of 4710m in Sangla Tehsil of District Kinnaur, Himachal Pradesh. The lake, formed by the accumulation of meltwater from surrounding glaciers, is primarily influenced by climate conditions. It plays a critical role in the hydrology of the Baspa River system. The lake supports unique flora and fauna, providing a habitat for various species. It is a critical component of the local ecosystem, contributing to biodiversity.

The Indian Himalayan Region is grappling with the growing impacts of climate change. Notably, glacial retreat and the emergence of large glacial lakes are key indicators of this crisis. These changes increase the risk of Glacial Lake Outburst Floods (GLOFs), highlighting the need for proactive hazard assessment and risk management. In response, the Himachal Pradesh State Disaster Management Agency (HP-SDMA) and District Disaster Management Agency, Kinnaur (DDMA-Kinnaur), have come up with a strategy to conduct a bathymetric survey on this glacier lake, marking an important step toward thorough hazard evaluation and risk reduction. Like many glacial lakes, NDMA081 is vulnerable to climate change, which affects glacial melt rates and lake stability. Research on these changes is essential for understanding broader environmental impacts.

The District Disaster Management Authority (DDMA) Kinnaur organized an expedition to the glacial lake at Baspa Upstream, near Sangla in Kinnaur, Himachal Pradesh, from September 7 to 10, 2024. The expedition aimed to study and analyze the glacial lake, designated as NDMA081, situated on the left bank of the Baspa River with geo-coordinates 33.3386N, 78.2531E, at a mean elevation of 4710 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 from Sangla CHC, DDMA Kinnaur, and several porters. A DDMA-appointed mountaineer led the expedition. With proper planning and with the help of multiple mountaineers (Mr Padam, Mr Amit Negi), this time, the team reached the lake site and carried out a bathymetry survey and drone imaging.

2. Objectives

The C-DAC team was mandated to carry out the physical assessment of the lake, its outlet, slope condition, lake condition, moraine dam condition, visual evaluation of moraine dam stability, and other criteria, along with lake bathymetry assessment using an Autonomous Bathymetry Survey Vessel (ABSV) for glacial lake profiling and volume of water computation. 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 of 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

As part of the geological survey, we conducted field observations in the study area to visually interpret geological features. This involved examining rock outcrops, identifying faults, folds, and other structures, and collecting rock samples . The visual interpretation provided valuable insights into the subsurface geology of the region. The team observed the rapid melting of the moraine dam wall. The perimeter of the lake is 2226 m. The maximum depth was recorded as 28 m, and the depth is 13 m near the dam wall. The length of the moraine dam wall is around

150 m, and its height is around 15 m. There is dead ice at the base of the wall. Over period of time, the moraine dam wall is collapsing, and the lake area is increasing (Fig. 1).

3.2 Bathymetric Survey

A bathymetric survey of a glacial lake involves mapping the underwater topography to understand its depth, shape, and sediment distribution. This survey utilizes techniques like sonar and GPS to collect data, revealing features such as submerged valleys and potential hazards. By analyzing these bathymetric maps, researchers can assess the impacts of glacial melt, track ecological changes, and inform conservation efforts. Such studies are crucial for understanding the dynamics of glacial systems and their influence on surrounding ecosystems and water resources.

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.

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

4. Results

4.1 Geological Findings

- ✓ The Baspa river is the main river of the area having significant water flow from glacial melt.
- ✓ The lake under study has no overtopping and no major significant water flows out of the lake in form of piping.
- ✓ The lake is located on left Bank side of Devar Nallah at altitude of 4700+ meter.
- ✓ The origin point of Devar Nallah appears from different glaciers as there is a high ridge between the lake and the Glacier.
- ✓ The lake water forms a small rivulet and meets the Devar Nallah as its tributary.
- ✓ Devar Nallah is one the main tributaries of Baspa River.
- ✓ The general slope of the Baspa 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 rock types are a mix of granite gneiss, micaceous schists, amphibolite, granodiorites and meta-sediments. Occasionally pegmatite veins are also seen.
- ✓ The area may be prone to cloud burst but the chances of heavy rainfall in higher altitude is less.
- ✓ 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 9 km from the lake till Sangla Bridge which is the last motorable point.
- ✓ JSW Baspa Hydel Power Stations may get affected due to lake burst and GLOF.
- ✓ Population at Sangla may be affected but not to a major extent as elevation of Sangla Bazar and other localities are more than 10 mtrs (apprx) from the river channels.

4.1.1 Geology of the lake:

The Baspa Valley and Kinnar Kailash Ranges are primarily composed of metamorphic rocks, such as gneiss and schist. However, the region also contain some igneous rocks, including mafic and ultramafic rocks. Mafic rocks in the region include basalt and gabbro Whereas Ultramafic rocks which are denser than mafic rocks, include peridotite and dunite. The presence of mafic and ultramafic rocks in the Baspa Valley and Kinnar Kailash Ranges suggests that the region has a complex geological history, involving the intrusion of magma from the Earth's mantle. These igneous rocks can provide valuable insights into the region's tectonic evolution and mineral resource potential.

Overall, the geological diversity of the Baspa Valley and Kinnar Kailash Ranges is a testament to the region's rich and complex geological history. The presence of metamorphic, mafic, and ultramafic rocks, along with other geological features, contributes to the unique landscape and biodiversity of this area.

4.1.2 Observations :

1. The lake is not connected to an active glacier. The glacier has retreated and only a remnant glacier is left behind.
2. During winter or snow fall seasons, some snow deposition is possible on the higher part. Shortly after the snowfall, the entire snow appears to get melted and drained in the lake.
3. There is piping and water is flowing down the moraine.
4. Southern and western slopes are steep with loose rock fragments.
5. New cracks are getting developed in the moraine dam wall (Fig. 1)
6. Moraine dam wall collapsing in shorter span (Fig. 2, Fig. 3, Fig. 4)
7. Dead ice core upto 2 m is seen on the southern side.
8. The moraine dam is vulnerable and in due course of time may fully collapse leading to release of water downstream

4.2 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.

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 1. Survey data plotted in the background of Bapsa lake

4.2.1 Area & Volume Calculation

Due to the short window period and adverse weather conditions that prevailed at Lake Face, the survey was conducted haphazardly, covering almost the entire lake area. 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 2, 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.

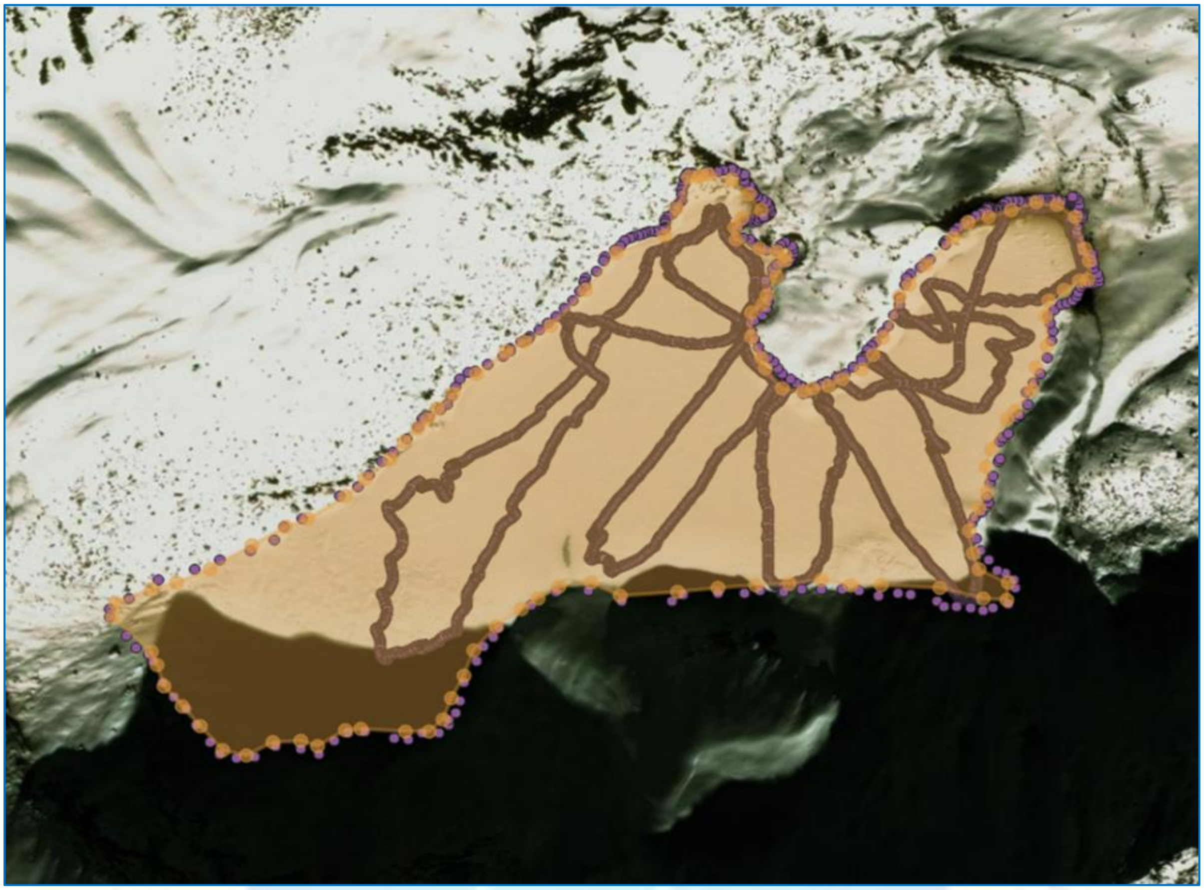


Fig 2. Manually marked lake boundary

Now, the bathymetric data contains the actual survey data points with depth values and data points marked in the lake's boundary with 'zero' depth values. However, for effective data analysis and lake profiling, the data corresponding to unsurveyed areas are to be incorporated. In this need, pseudo-survey data with interpolated depth values was generated to fill the area where the survey was not done.

Thereafter, the interpolated data, along with bathymetric data, were 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 used. Fig 3 (a) shows the comparison between the areas calculated by AGLPS and through QGIS. The lake's water volume was also calculated based on the depth data surveyed for the lake.

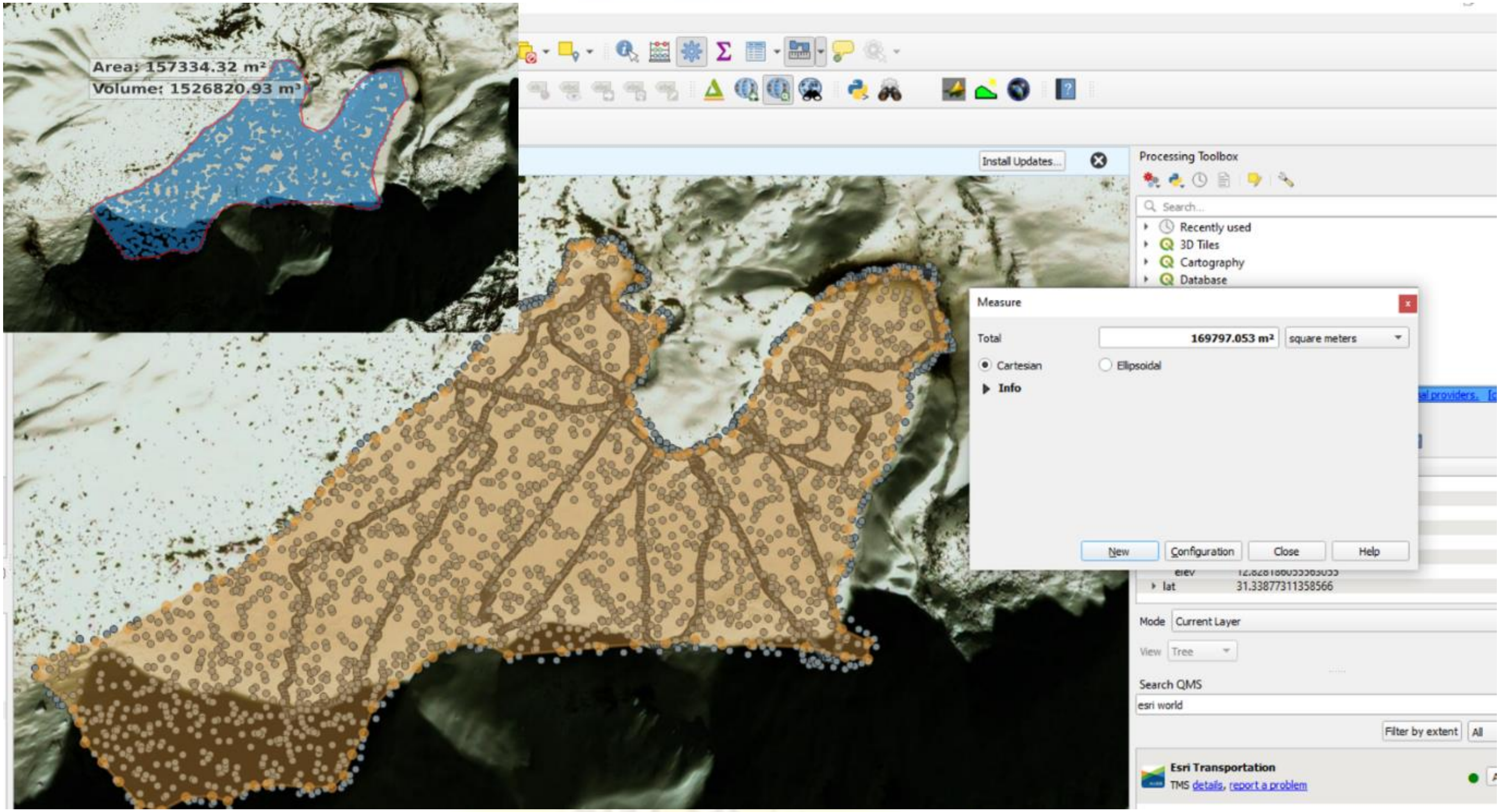


Fig 3(a). Calculated Area and volume of Baspa lake

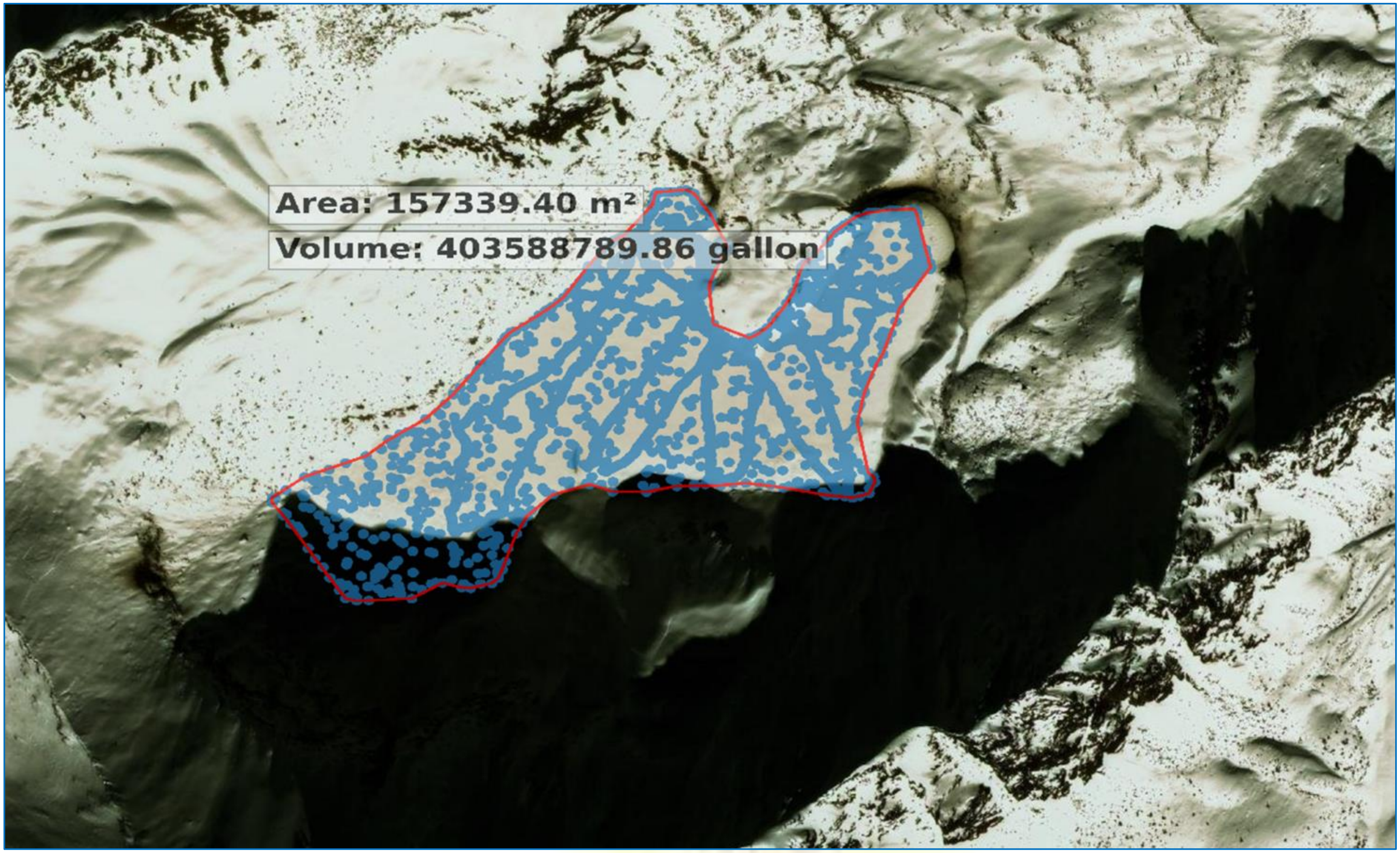


Fig3(b). Lake Area & volume

Lake inference

- ✓ **Area of the lake** : **0.15734 km^2**

  : **15.73 Hectare**

- ✓ **Depth data**
  - **Maximum Depth** : **28.75 m**
  - **Average Depth** : **9.75 m**

- ✓ **Volume of water in the lake : 1527583566.365 Lts = 1.52758 million cubic meters**

<u>Contour/Depth Profiling</u>

The depth contour is generated using the survey data where the 'JET' colour scheme has been adopted for presenting the depth of the lake. The highest depth value was measured at the lake's centre (indicated in maroon colour). The lake has a profile of decreasing depth towards its shores in all directions.

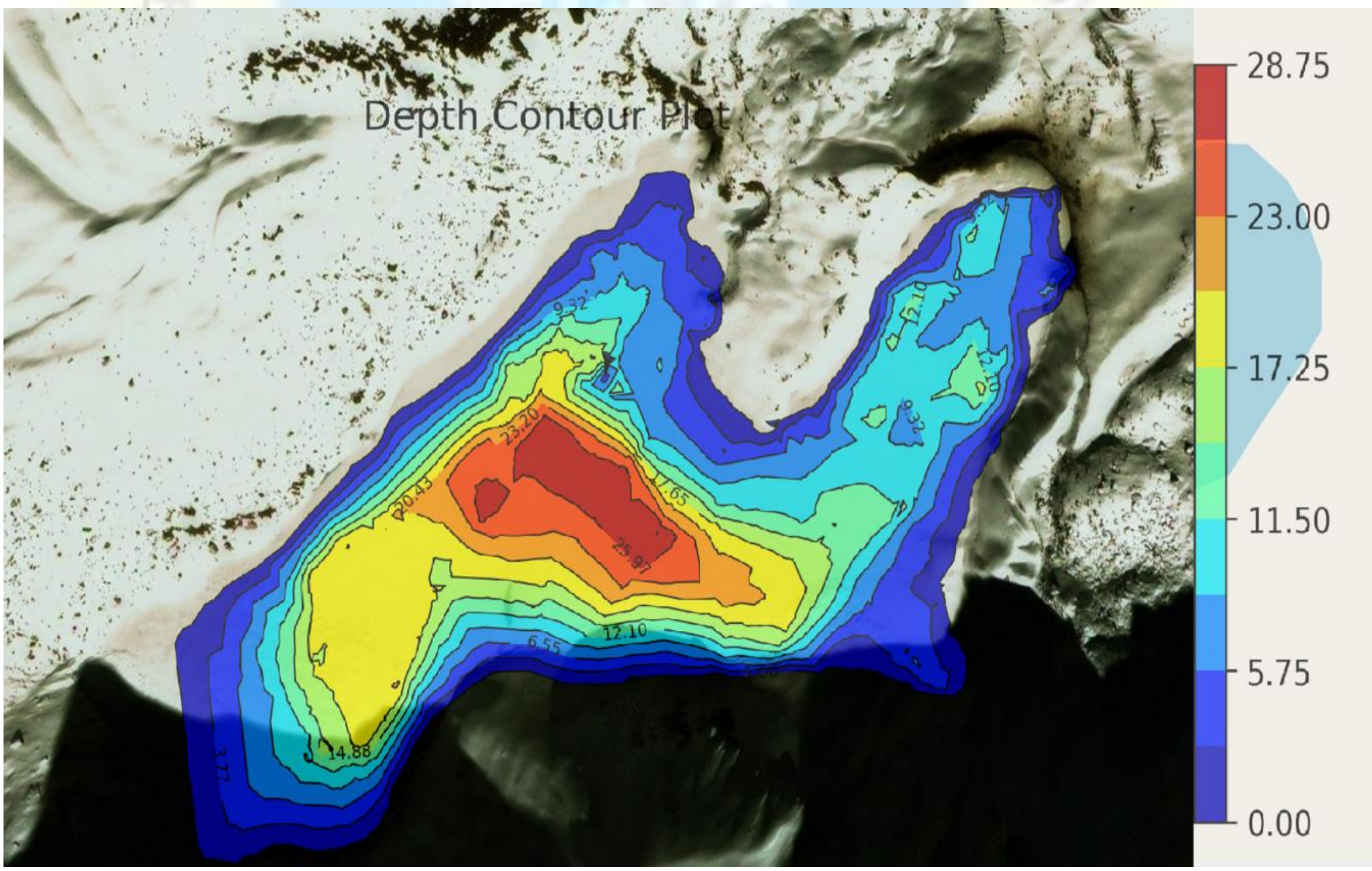


Fig 4. Depth contour

Presentation of Digital Elevation Model

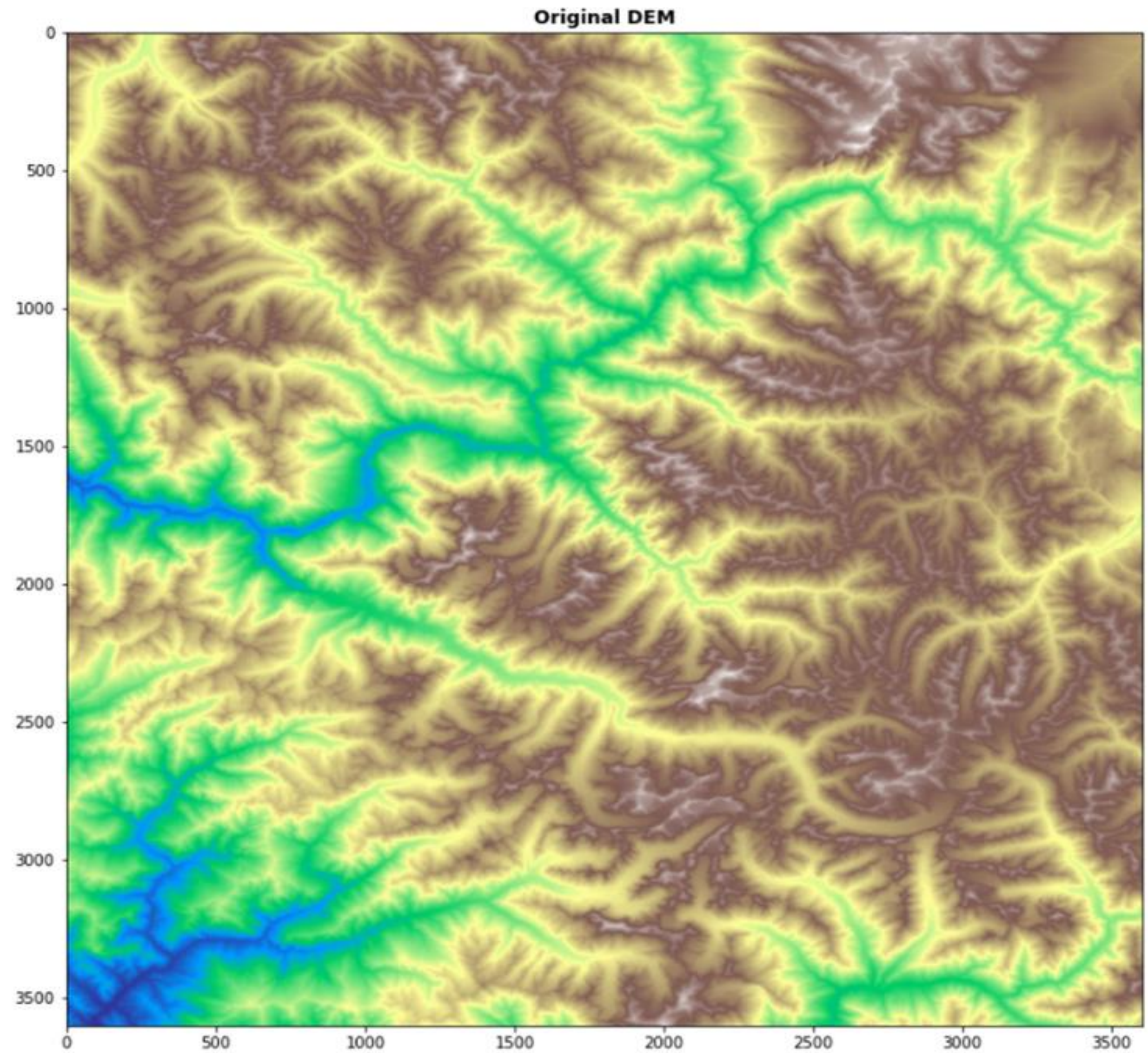


Fig 5. Digital elevation Model from USGS world map

3-D model

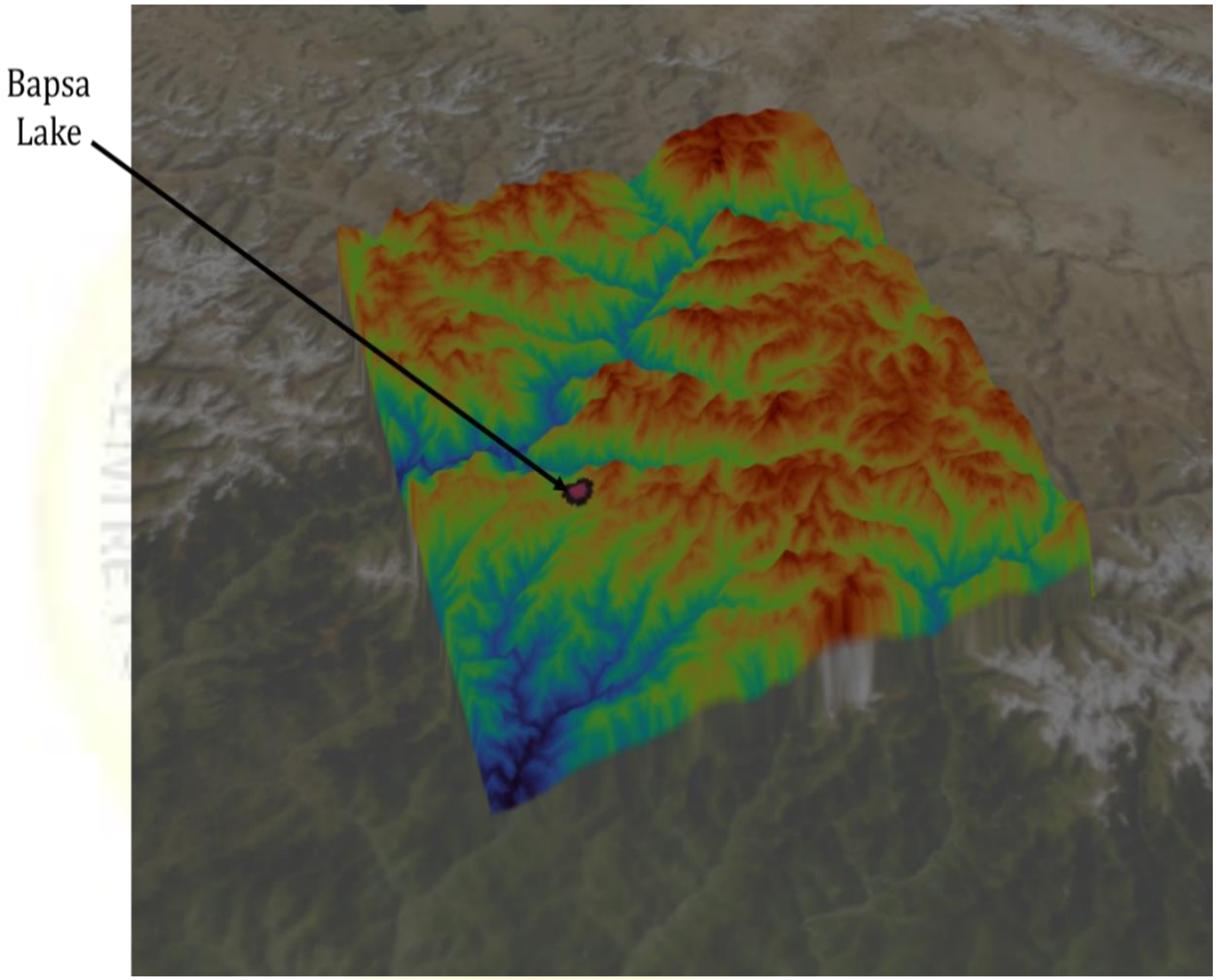


Fig6. 3D elevation model

5. Discussion

- Area of lake in year 2017 was 13.4 ha (Based on Sentinel 2 data of October 2017)
- Area of lake in year 2024 is 14.29 ha (Based on Sentinel 2 data of August 2024)
- Change in lake area from 2017 to 2024 is 0.87 ha
- The area of the lake in September 2024 is 15.73 ha (Based on bathymetry data)

6. Conclusion

Lake inference

✓ Area of the lake : 0.15734 km^2

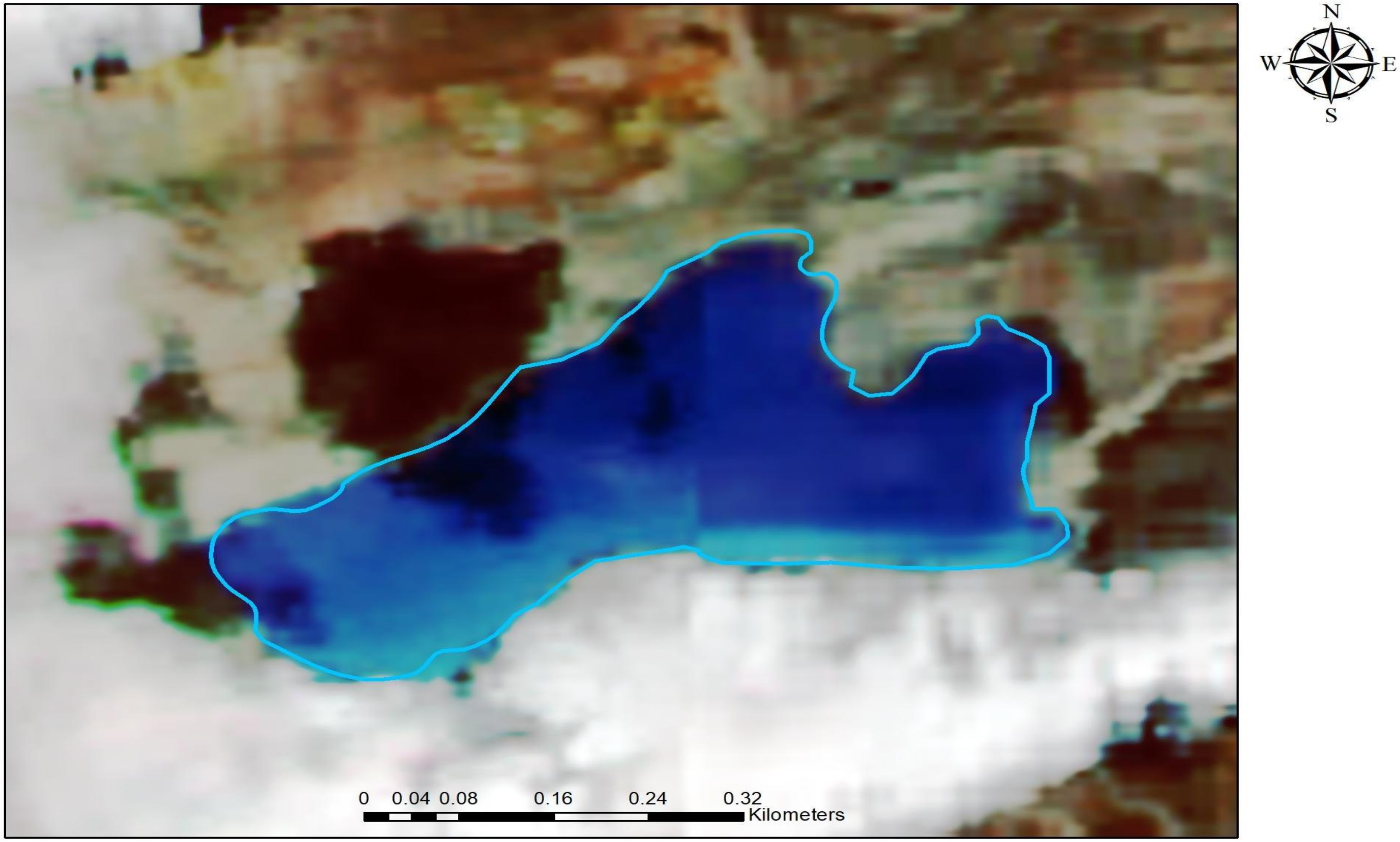
: 15.73 Hectare

✓ Depth data

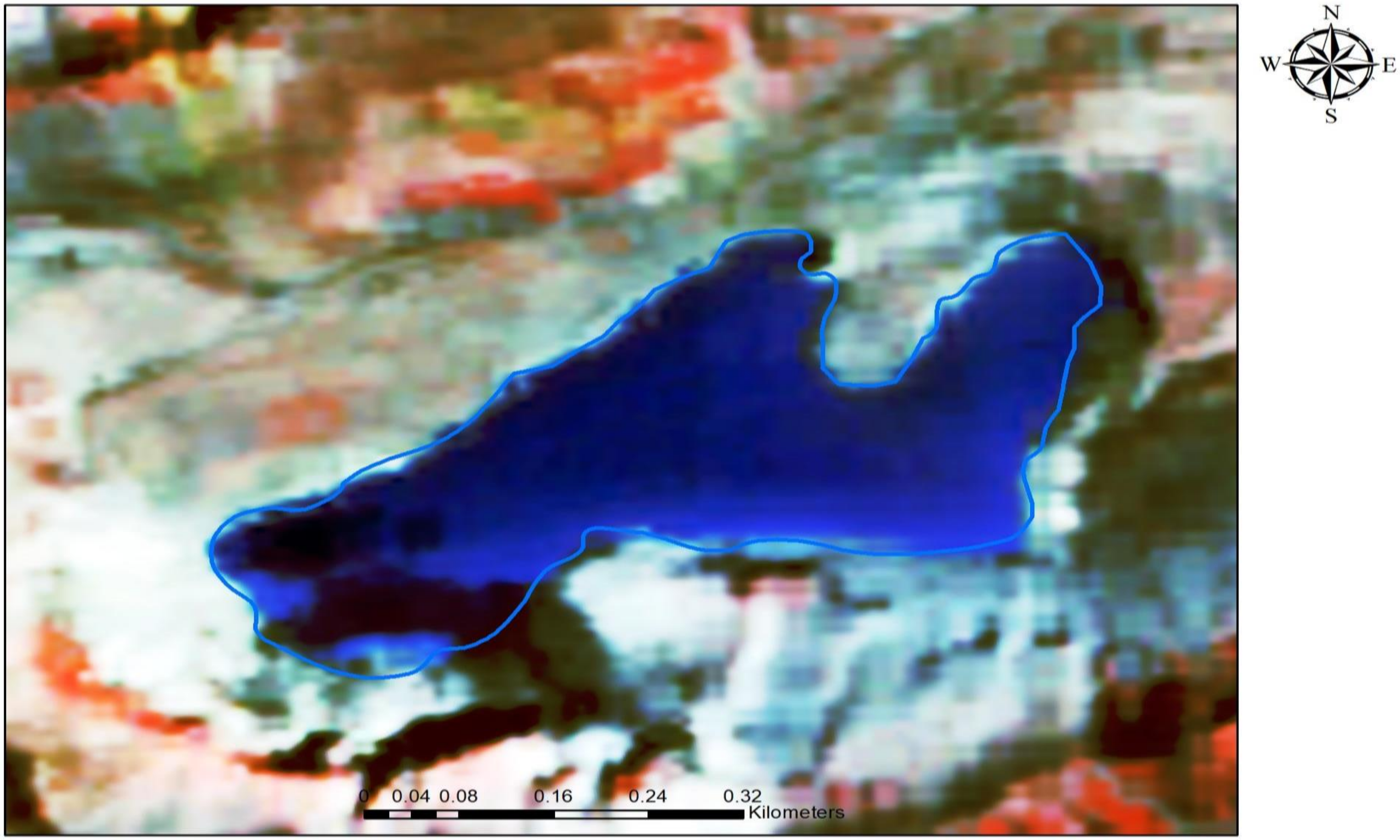
- Maximum Depth : 28.75 m
- Average Depth : 9.75m

✓ Volume of water in the lake : 1527583566.365 Lts

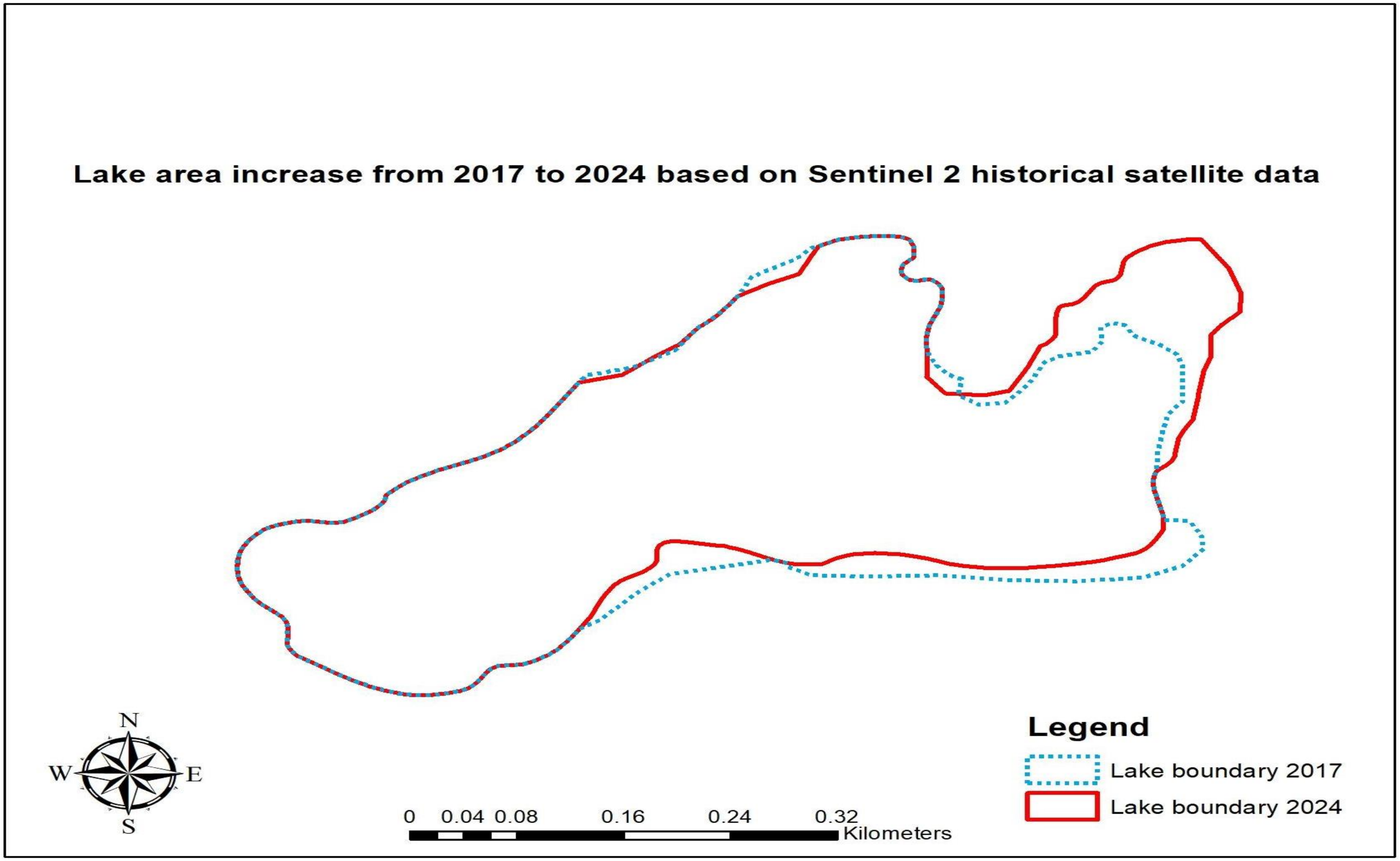
= 1.52758 million cubic meters (MCM)



Lake size in October 2017 (based on Sentinel 2 FCC of same month)



Lake size in August 2024 (based on Sentinel 2 FCC of same month)



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

7. Recommendations

- Suggestions for further studies.
  - ✓ Frequent 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
  - ✓ The Moraine dam width is decreased drastically over the last 10 Years
  - ✓ The Fischer formation above the Moraine Dam is to be closely observed

9. Appendices

Annexure-1

Fig 1: Crack seen on the moraine wall (Photo captured using drone)

Fig 2: The moraine dam wall on 9th September 2024

Fig 3: The moraine dam wall in August 2024

Fig 4: The moraine dam wall in July 2024

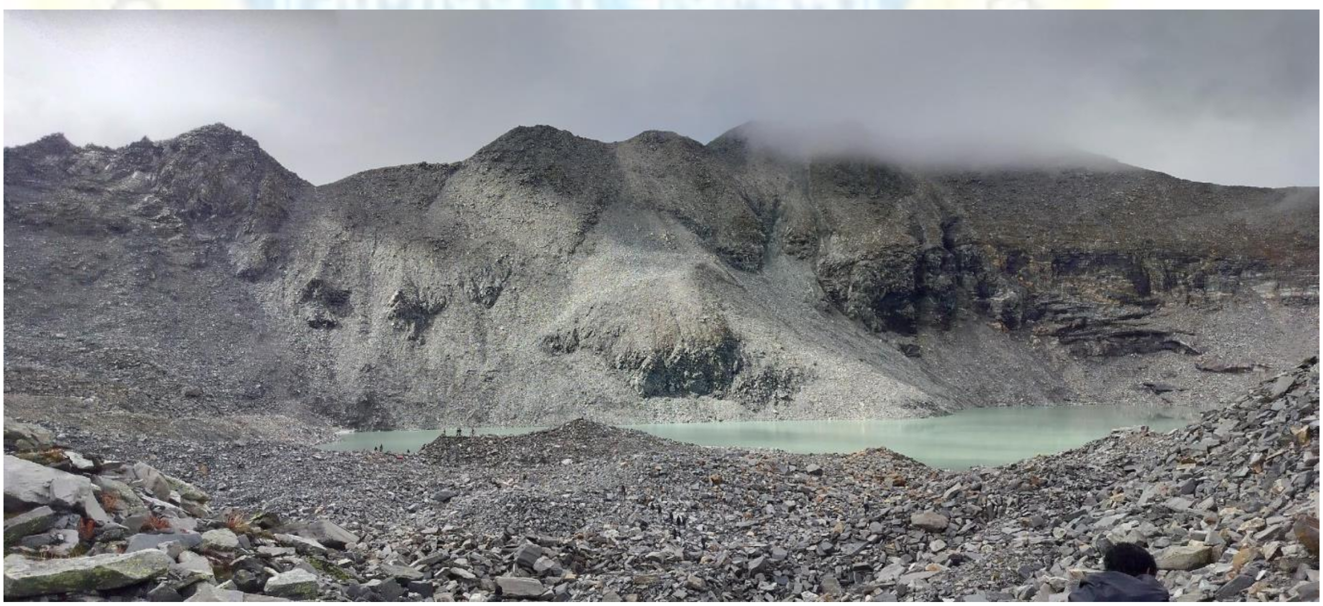


Fig 5: Lake view

Expedition Photographs shared by various Participants

Briefing to the Expedition Team by DDMA officials

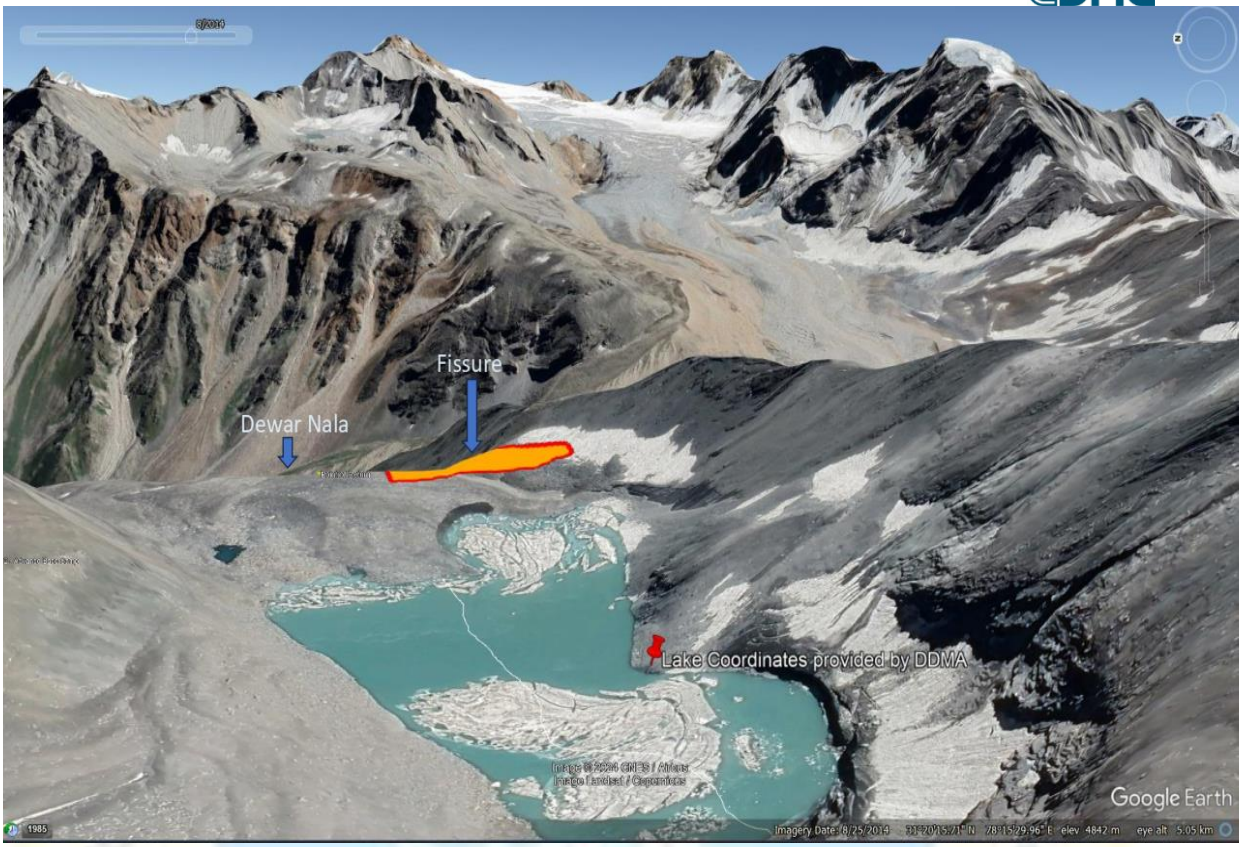
Base Camp Setup in progress


Second base camp setup in progress


Instruments setup in progress and ABSV assembling

ABSV survey starting on the lake

Southern slopes of the lake


Fissure
Dewar Nala
Lake Coordinates provided by DDMA
Google Earth