INDIAN INSTITUTE OF TECHNOLOGY, ROORKEE

Department of Civil Engineering

Geospatial Engineering

Project-1 Report:

Glacial Lake area changes in the eastern Ladakh region between year 2014-2022

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Subject: CEN-612

Introduction

An attempt is made here to study the spatio-temporal changes in the lakes of eastern Ladakh region. These glacial lakes are mostly endorheic in nature and have elevation of over 3000m on average. Glacial lakes in Ladakh are of importance because of the benefits they provide, as well as the hazard they pose in the region. Ladakh being a cold-arid region has scarce water availability and these lakes could be a good source of water. There are both freshwater and saltwater lakes present in the region. Saltwater lakes could help provide the salt and other minerals, also they act as a retreat for many bird species and as well as home to other organisms. Despite the benefits and the tourism they provide for in the region, these lakes also pose a much bigger threat which have been sporadic cause of disasters in the region. This threat is the glacial lake outbursts floods (GLOF), the cause is of course the climate change, with the change in temperature, receding glaciers, increase in rainfall or summer precipitation, this hazard is only increasing.

The lake area change detection exercise here is performed to study the changes in area of the lakes to understand how remote sensing data can be used to perform lake change detection and to understand the significance of these changes on the surrounding region.

Study area

The study are as mentioned before is the eastern Ladakh region. Some of the lakes here extend to further into the territory of China so the study area also consists of some region from China as lake is studied as one geographical body as a whole rather than in parts. The Figure 1 shows the extents of study area extracted using Google Map Terrain and SOI datasets.

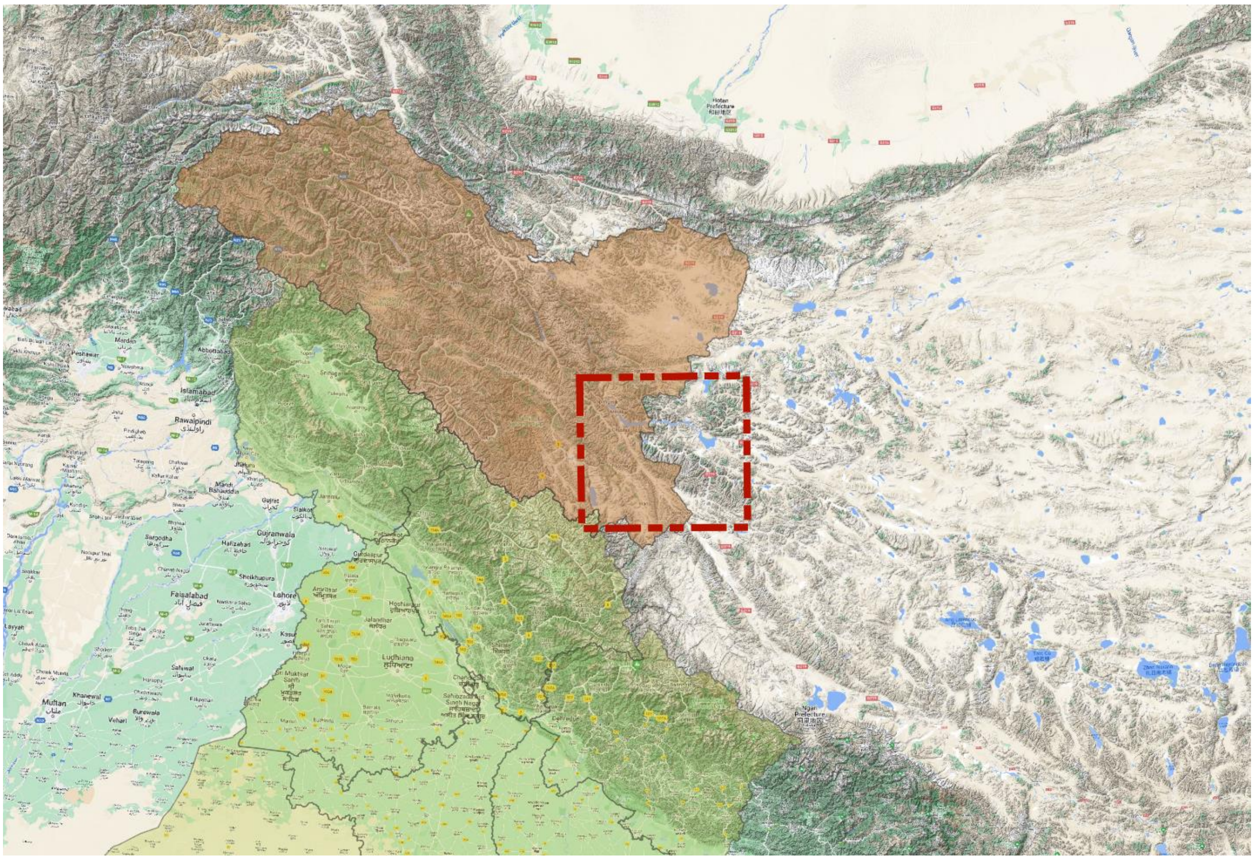

Figure 1 Study area

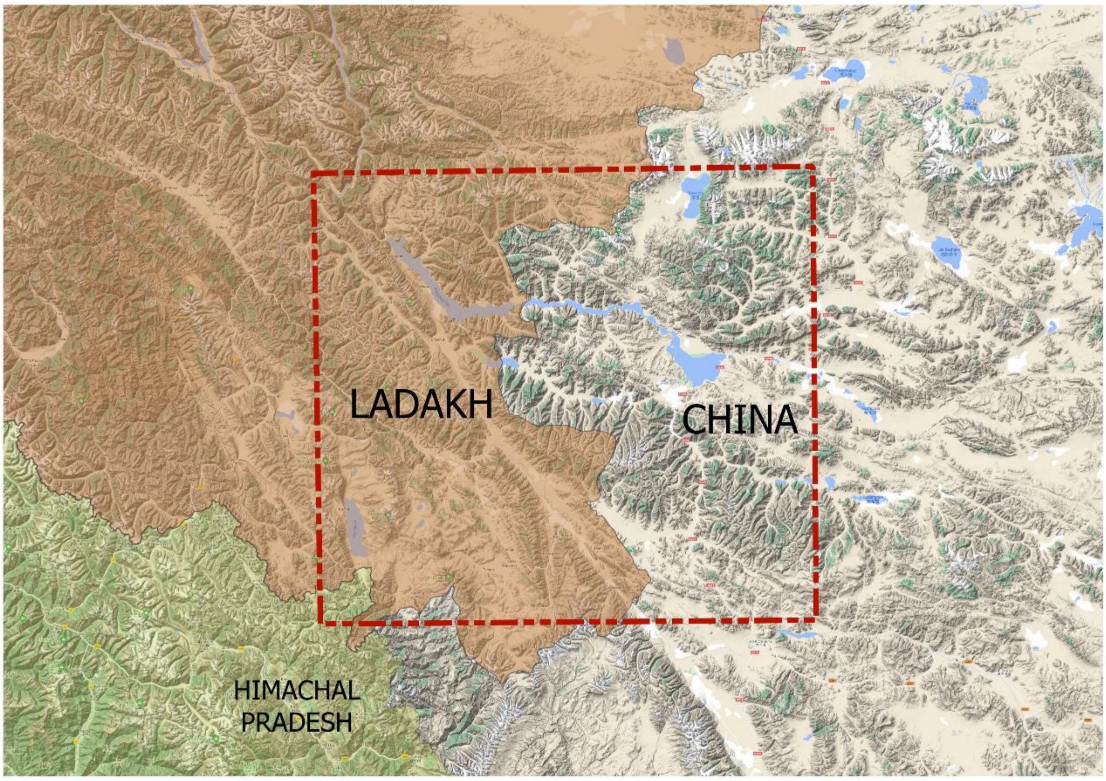

Figure 2 Study area with international and state boundary

Eight lakes have been selected for the study as shown in the figure 3. These lakes are – Pangong Tso, Mirpal Tso, Ryul Tso, Chilling Tso, Tso Moriri, Kyagar Tso, Lake A and Lake B. The last two lakes didn't have any established names, so they have been assigned the names "Lake A and Lake B" for the sake of the analysis and henceforth would be addressed the same throughout the study.

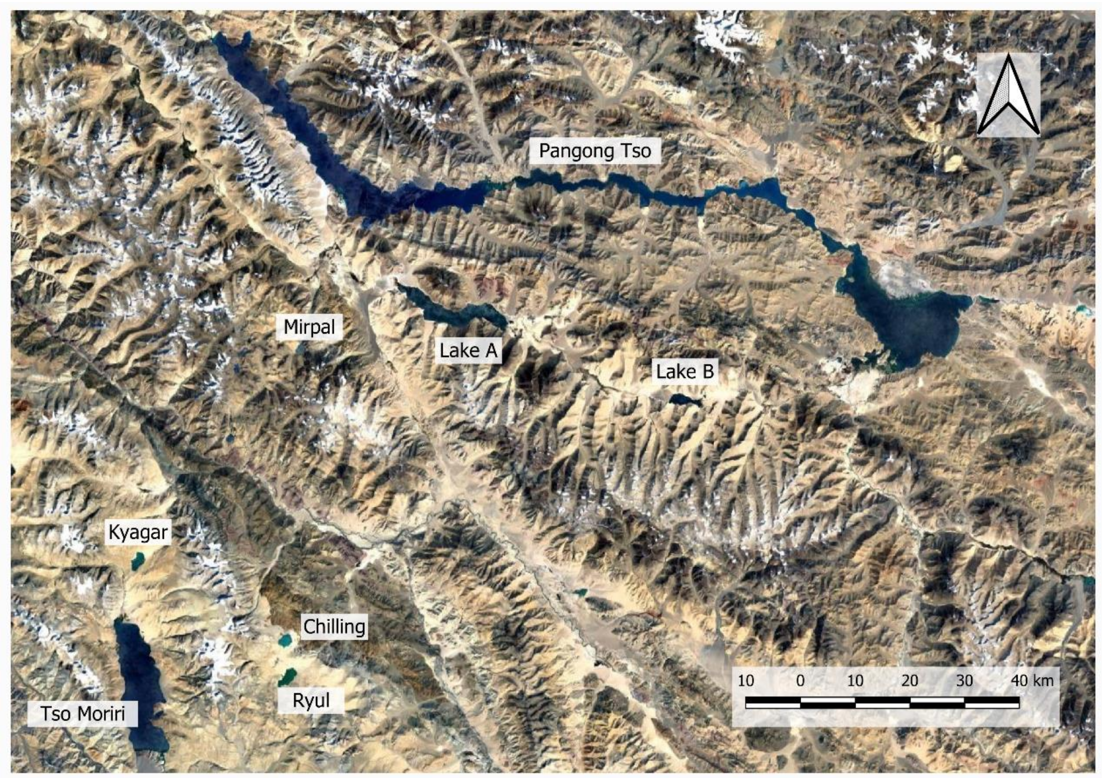

Figure 3 Topography of the study area

Datasets and Methodology used

Landsat 8 Collection 2 Level 2 datasets were used from year 2014 to 2022. Only the best scenes from June and July month were used having minimal cloud cover for the analysis.

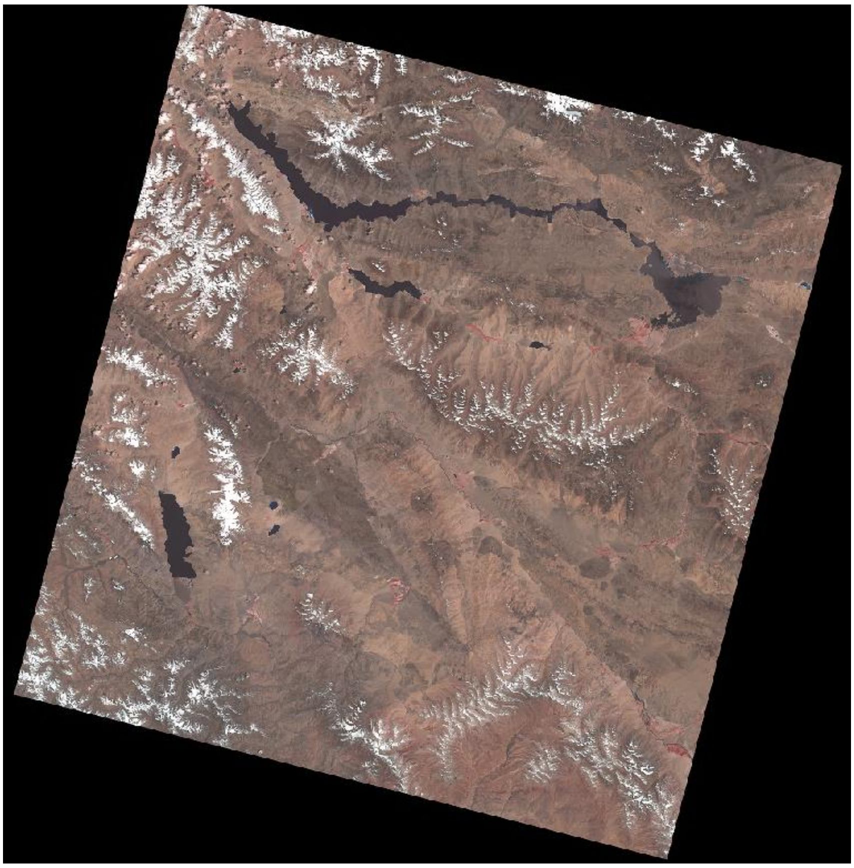

Figure 4 Landsat 8 RGB image from July 2022; Path = 146, Row = 37

The Landsat 8 scene size is 185 km(cross-track) by180 km(along-track). The nominal spacecraft altitude is 705 km. The bands used for analysis were band 2, 3, 4 and 5 which are blue, green, red and NIR respectively as the optimization of processing and memory power was of concern considering the timeframe and the storage size of each scene. So, the data acquired was the four bands along with the metadata and quality assessment band file.

The spatial resolution for each band is 30m. The reason behind choosing the Landsat 8 dataset over Sentinel 2 despite Sentinel 2 having 10m resolution scenes for the same bands is the availability of dataset, and requirement of a greater number of scenes due to the difference in the scene coverage. Therefore, the Landsat 8 dataset was preferred over the Sentinel 2, as it was providing data from year 2014 and was also covering the study area extent in a single scene.

The software and tools used to perform the analysis are Python, QGIS, ERDAS Imagine, SNAP and Sublime Editor. While most of the work of data acquisition, processing and representation is done using python, but bulk jobs which required visualizing, optimization of results and preparation of maps have been done using QGIS, and it graphical modeler and layout manager.

Methodology

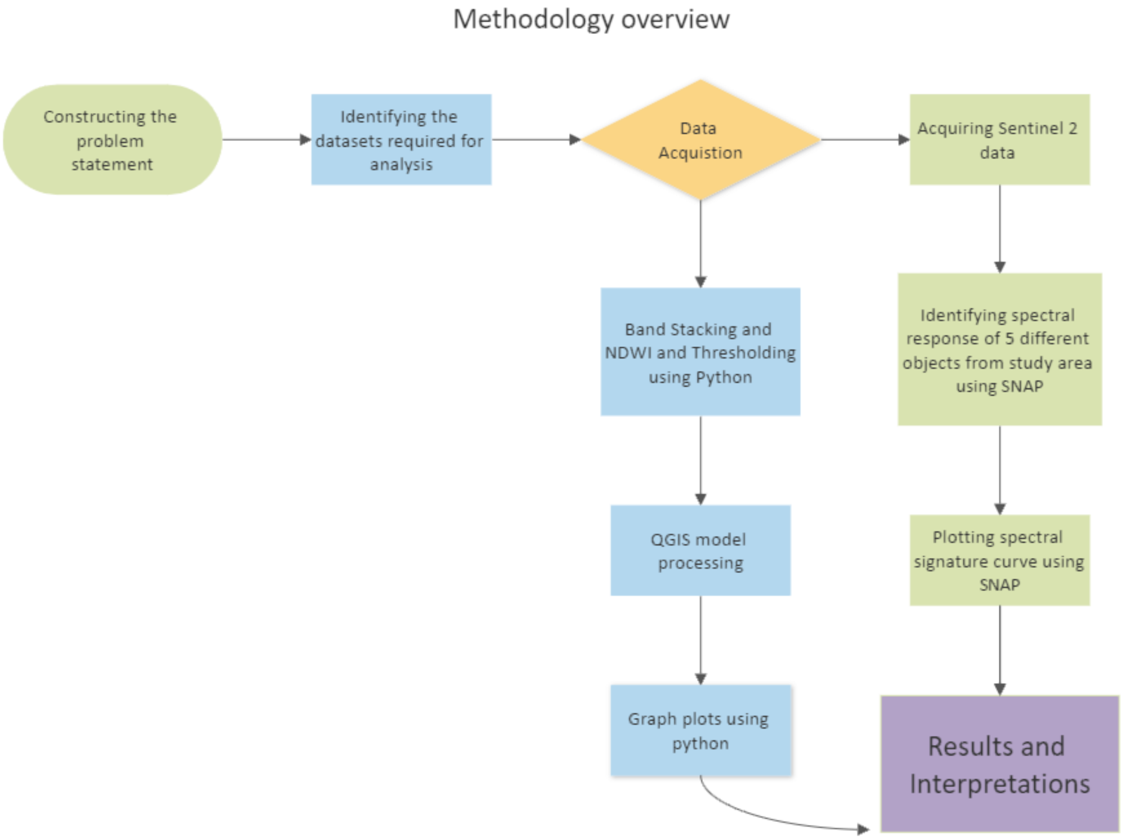

Figure 5 General methodology overview

A) Python code for NDWI and Thresholding

```python
import rasterio
import numpy

# Define the input file path
input_img = 'C:\\Users\\warde\\OneDrive\\Desktop\\PCEN-612\\test_env\\Data\\stack18.img'

# Define the output file path
output_img = 'C:\\Users\\warde\\OneDrive\\Desktop\\PCEN-612\\test_env\\Data\\NDWI\\ndwi18.tif'

# Open the input image
with rasterio.open(input_img) as src:
    # Read the bands for NDWI calculation
    green_band = src.read(2)
    nir_band = src.read(4)

    numpy.seterr(divide='ignore', invalid='ignore')

    # Calculate NDWI
    ndwi = (green_band.astype(float) - nir_band.astype(float)) / (green_band + nir_band)

    # Update the metadata for the output image
    kwargs = src.meta.copy()
    kwargs.update({
        'count': 1,
        'dtype': 'float32'
    })

    # Save the NDWI image
    with rasterio.open(output_img, 'w', **kwargs) as dst:
        dst.write(ndwi.astype(rasterio.float32), 1)

print(numpy.nanmin(ndwi))
print(numpy.nanmax(ndwi))
```

Figure 6 Code for NDWI calculation

```python
import rasterio
import numpy as np

# Define the input file path
input_fp = 'C:\\Users\\warde\\OneDrive\\Desktop\\PCEN-612\\test_env\\Data\\NDWI\\ndwi18.tif'

# Define the output file path
output_fp = 'C:\\Users\\warde\\OneDrive\\Desktop\\PCEN-612\\test_env\\Data\\threshold\\threshold_ndwi18.tif'

# Define the threshold value
threshold = 0

# Open the input image
with rasterio.open(input_fp) as src:
    # Read the image data
    img_data = src.read()

    # Classify the image into 2 classes
    img_data = np.where(img_data > threshold, 1, 0)

    # Update the metadata for the output image
    kwargs = src.meta.copy()
    kwargs.update({
        'count': 1,
        'dtype': 'uint8'
    })

    # Save the classified image
    with rasterio.open(output_fp, 'w', **kwargs) as dst:
        dst.write(img_data.astype(rasterio.uint8))
```

Figure 7 Code for Thresholding and creating binary classes.

After acquiring the Landsat 8 data, stacked image was created using ERDAS Imagine with bands 2, 3, 4 and 5. The first program in Figure 6, uses the following formula to calculate the NDWI:

NDWI = (GREEN-NIR)/(GREEN+NIR)

After preparing the NDWI image, the thresholding was applied to create a image with just two classes representing "water" or "not water".

B) Preparing the final image products using QGIS model builder

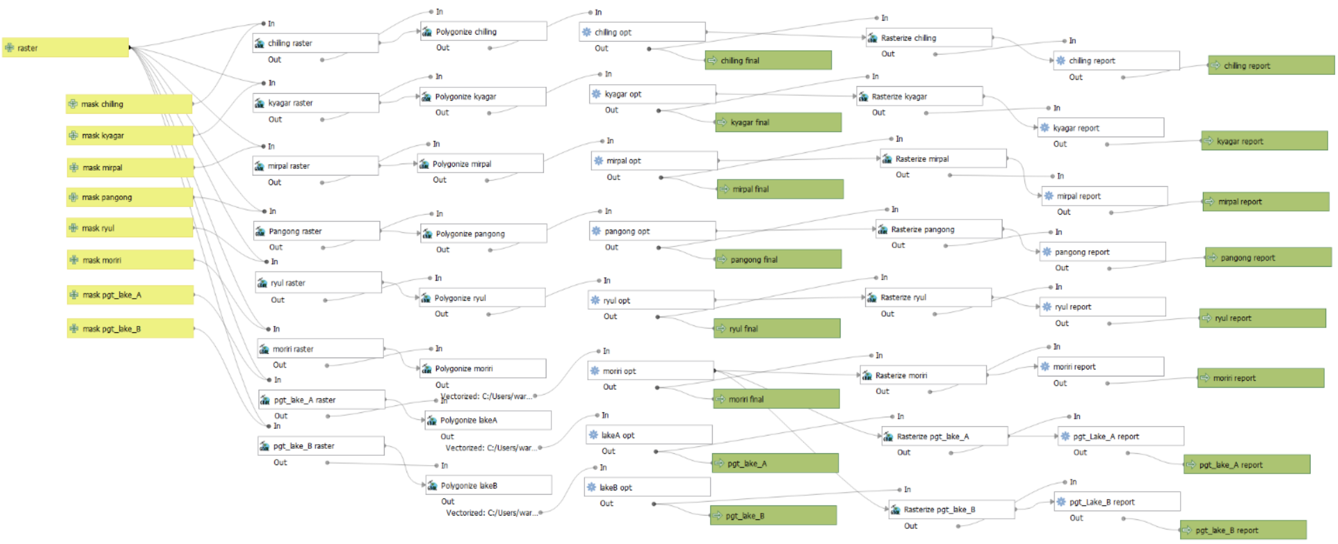

Figure 8 QGIS model

QGIS model builder was used to create a model for extracting each lake feature from the Threshold image, and to account for the cloud cover covering some small parts of few of the lakes in some scenes. It also helped batch process most of the redundant tasks that required certain level of human intervention using GUI.

C) Code for creating plots.

```python
import csv

import matplotlib.pyplot as plt
from matplotlib.ticker import NullFormatter

def formatter(x, pos):
    return str(round(x / 1e6, 1)) + " million"

filename = "C:\\Users\\warde\\OneDrive\\Desktop\\PCEN-612\\Output\\report\\csv\\ryul.csv"

with open(filename) as file_object:
    reader = csv.reader(file_object)
    header_row = next(reader)
    print(header_row)

    years, area_square_meter = [], []
    for row in reader:

        year = int(row[0])
        area = int(row[1])
        years.append(year)
        area_square_meter.append(area)

print(years, area_square_meter)
fig, ax = plt.subplots()

ax.scatter(years, area_square_meter, c=area_square_meter, cmap='plasma_r', s=10)
ax.plot(years, area_square_meter)

# to display all digits on yaxis values
# ax.yaxis.get_major_formatter().set_scientific(False)
# ax.yaxis.get_major_formatter().set_useOffset(False)

# to display all digits on yaxis values with a million
ax.yaxis.set_major_formatter(formatter)
ax.yaxis.set_major_formatter(formatter)
# plt.fill_between(area_square_meter, years, facecolor='green', alpha=0.31)
# Format plot
plt.title("Area Change in Lake", fontsize=18)
plt.xlabel("Year", fontsize=14)
plt.ylabel("Area of Lake(square meter)", fontsize=14)
plt.tick_params(axis='both', which='minor', labelsize=10)

# Set the range for each axis
# ax.axis([2013, 2023])
# limy_min
# limy_max
# Plot graph
plt.savefig('C:\\Users\\warde\\OneDrive\\Desktop\\PCEN-612\\Output\\plots\\ryul.png', dpi=300, bbox_inches='tight')
plt.ylim(min(area_square_meter)*0.997, max(area_square_meter)*1.003)
plt.show()
```

Figure 9 Code for plotting graphs using Python.

Above code was used to plot bar charts and graphs to show the changes in lake area graphically. The area calculations obtained from the QGIS model were used as the input data for the above code.

Results and Interpretation

A) Chilling Lake

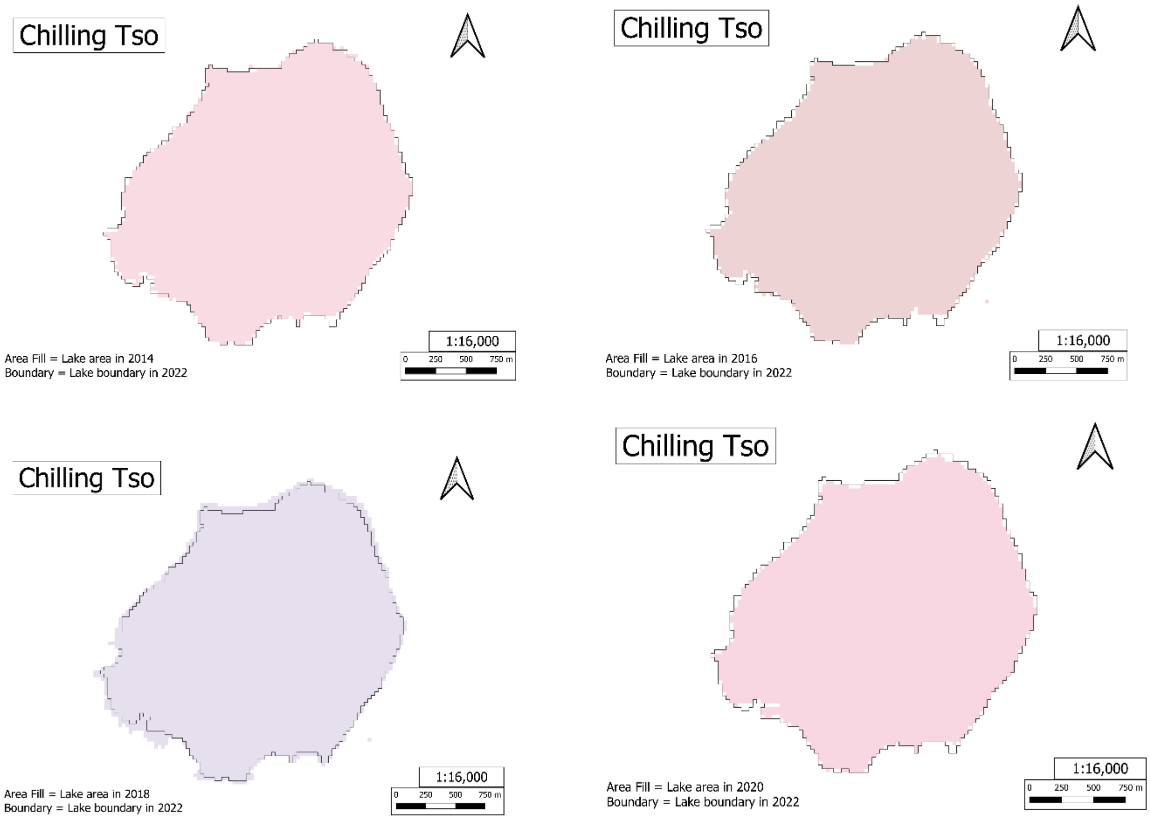

Figure 10 Chilling Tso change in lake area

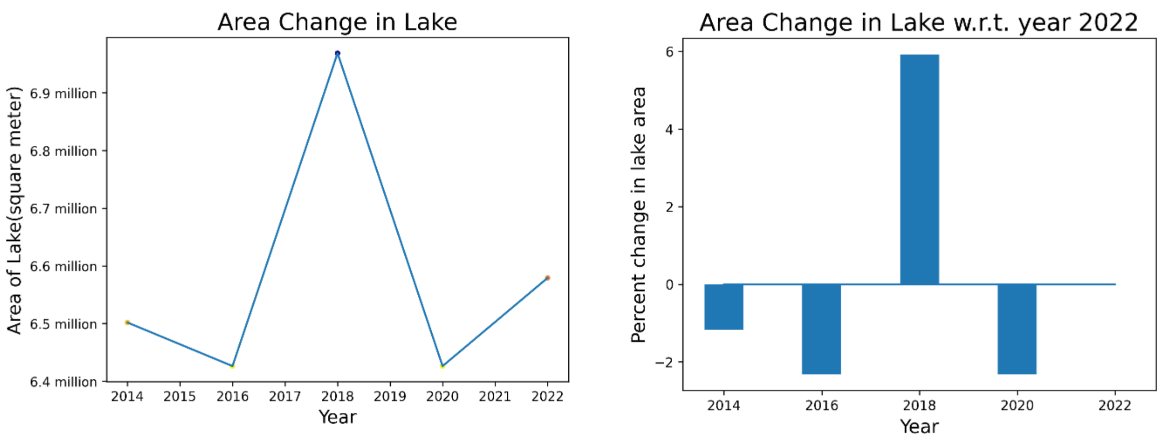

Figure 11 Plots depicting area change in Chilling Lake

- It can be inferred that only in 2018 that lake area increased by 6% compared to the lake area in year 2022 and it was lowest in the year 2016 and 2020.

B) Kyagar Tso

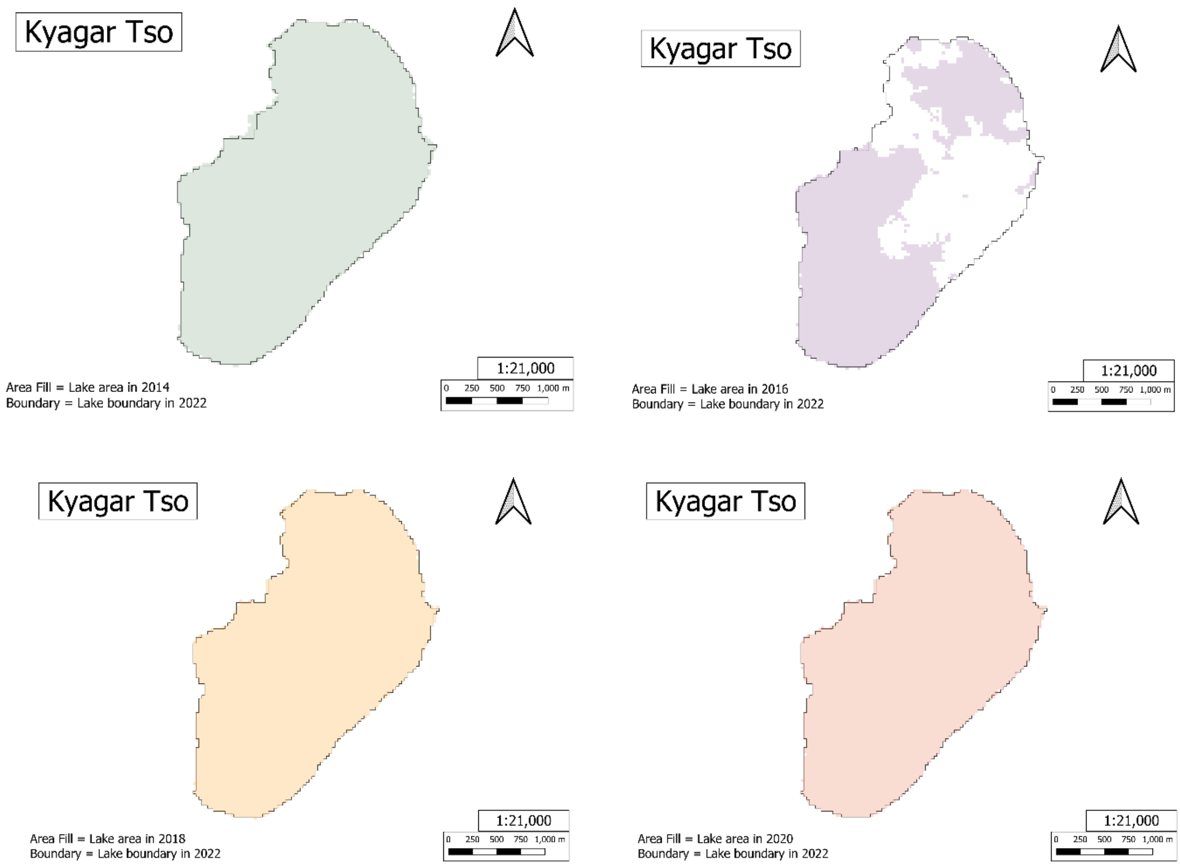

Figure 12 Kyagar Tso change in lake area

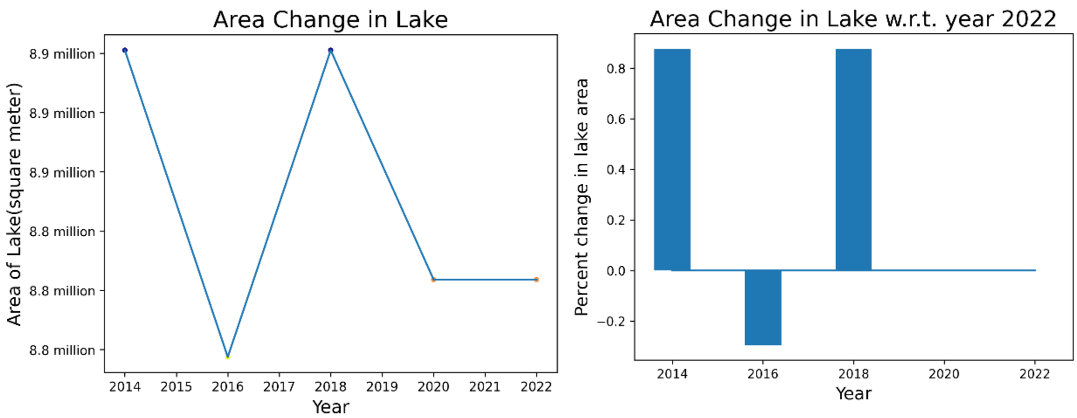

Figure 13 Plots depicting area change in Kyagar Tso

- Kayagr Tso hasn't seen any change in the lake area between 2020 and 2022. Only time the lake area was found to be shrunk was in 2016 as per in graph. But actually, the data for year 2016 is unfit for further analysis as the lake had cloud cover during study period affecting the analysis.
- Year 2018 and 2014 observed the maximum lake area.

C) Mirpal Tso

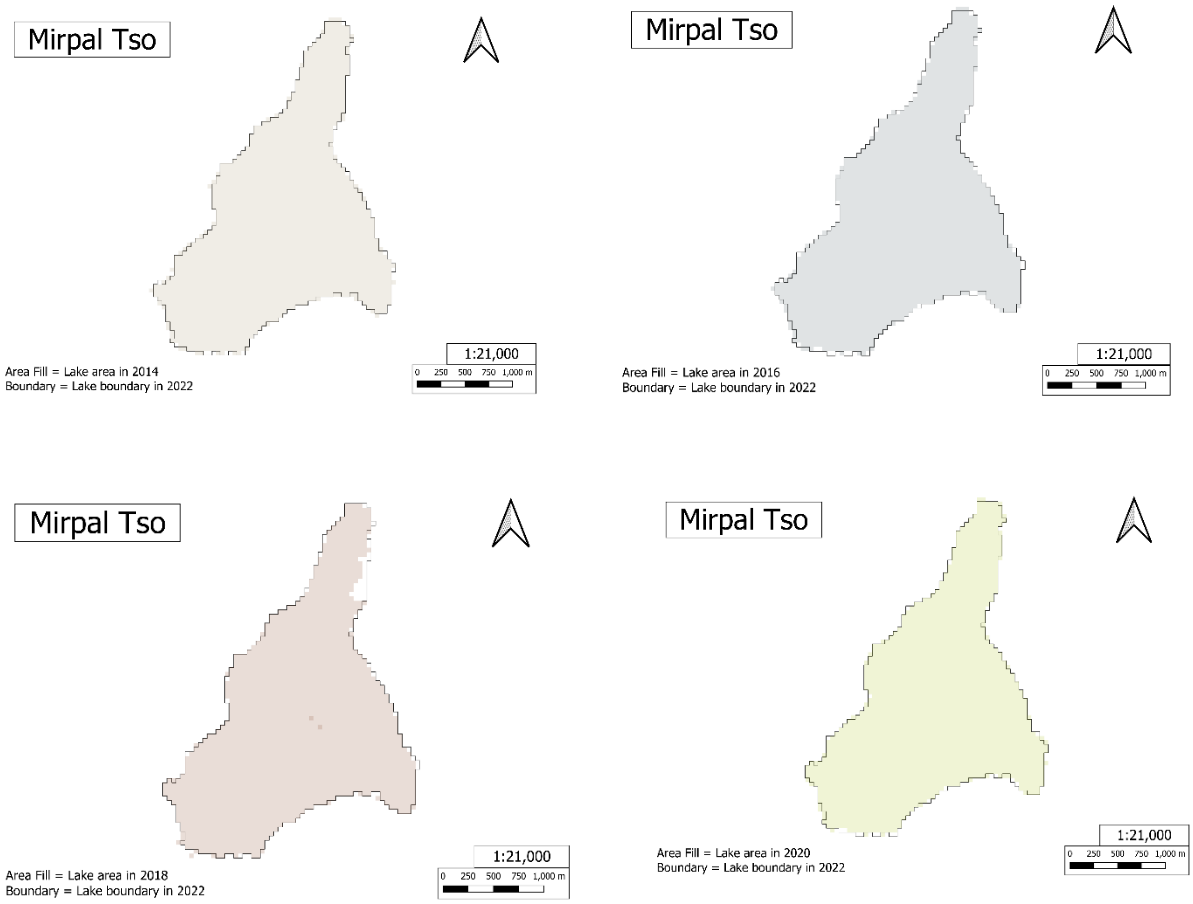

Figure 14 Lake area change in Mirpal Tso

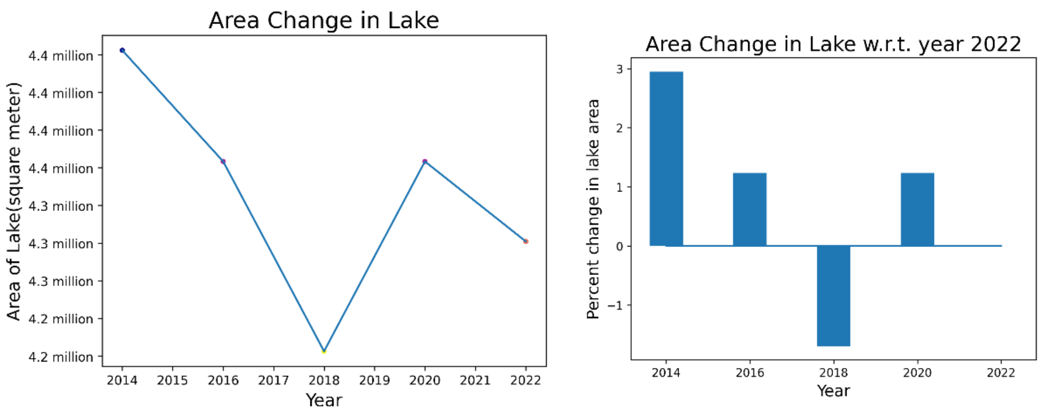

Figure 15 Plots depicting area change in Mirpal Tso

- Mirpal Tso's Lake area had been shrinking since 2014 till 2018. It went down till 2018 then rose to 1% in the next year then shrunk back again by 1% in 2022

D) Tso Moriri

Figure 16 Lake area change in Tso Moriri

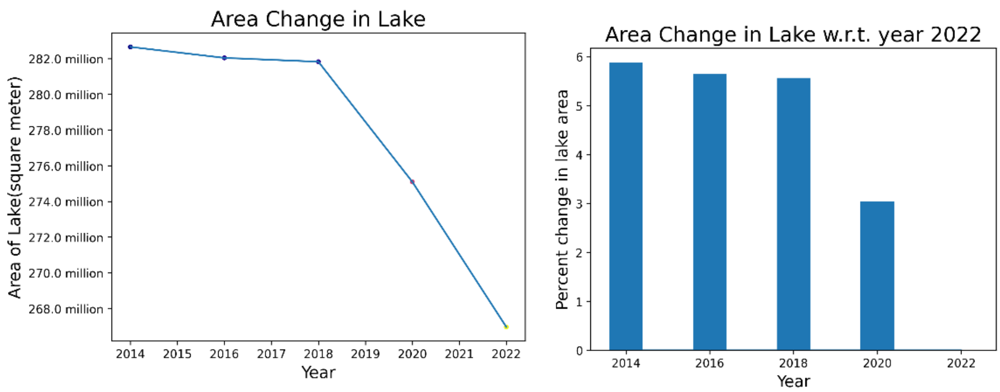

Figure 17 Plots depicting lake area change in Tso Moriri

- Tso Moriri's had been increasing at a slow pace until 2018, after which it suddenly started shrinking with 3% rate every year.

E) Pangong Tso

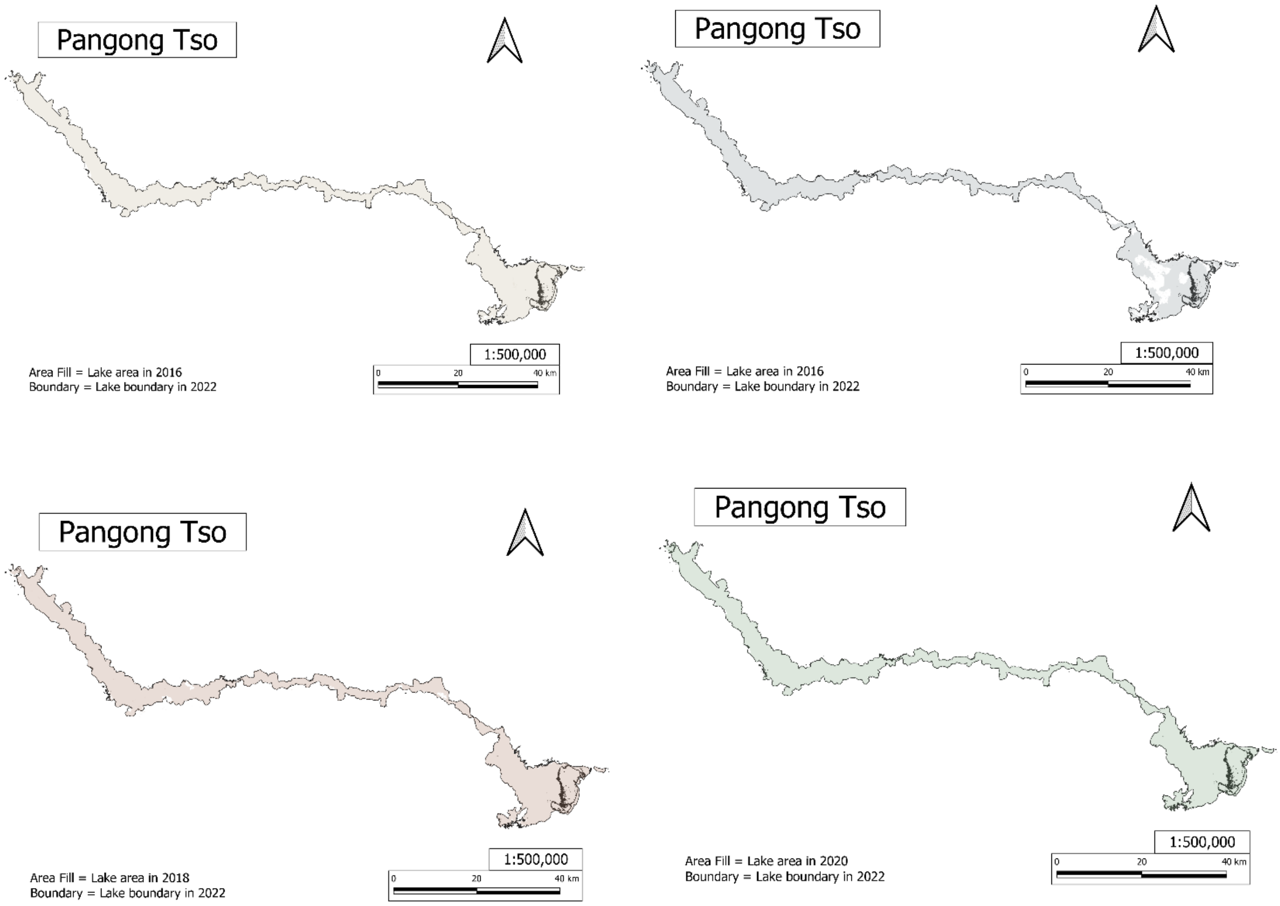

Figure 18 Lake area change in Pangong Tso

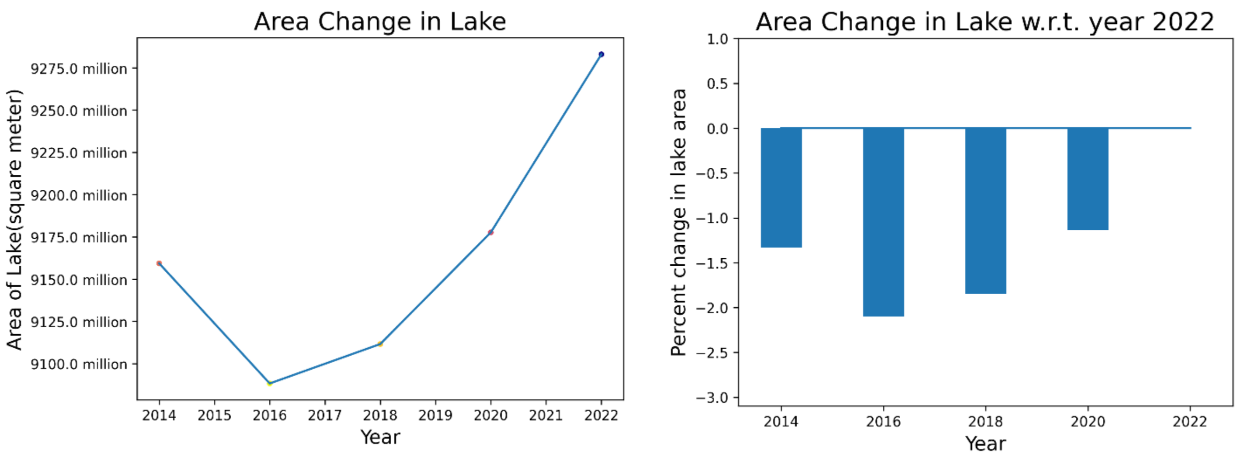

Figure 19 Plots depicting area change in Pangong Tso

- Only time the lake area shrunk its lowest was in 2016. However, the data for 2016 had cloud cover affecting the accurate analysis. So, the actual area maybe a bit higher than the observed for the year.
- After 2016, though, the lake area had been increasing steadily till 2020 and then suddenly increased in 2022.

F) Ryul Tso

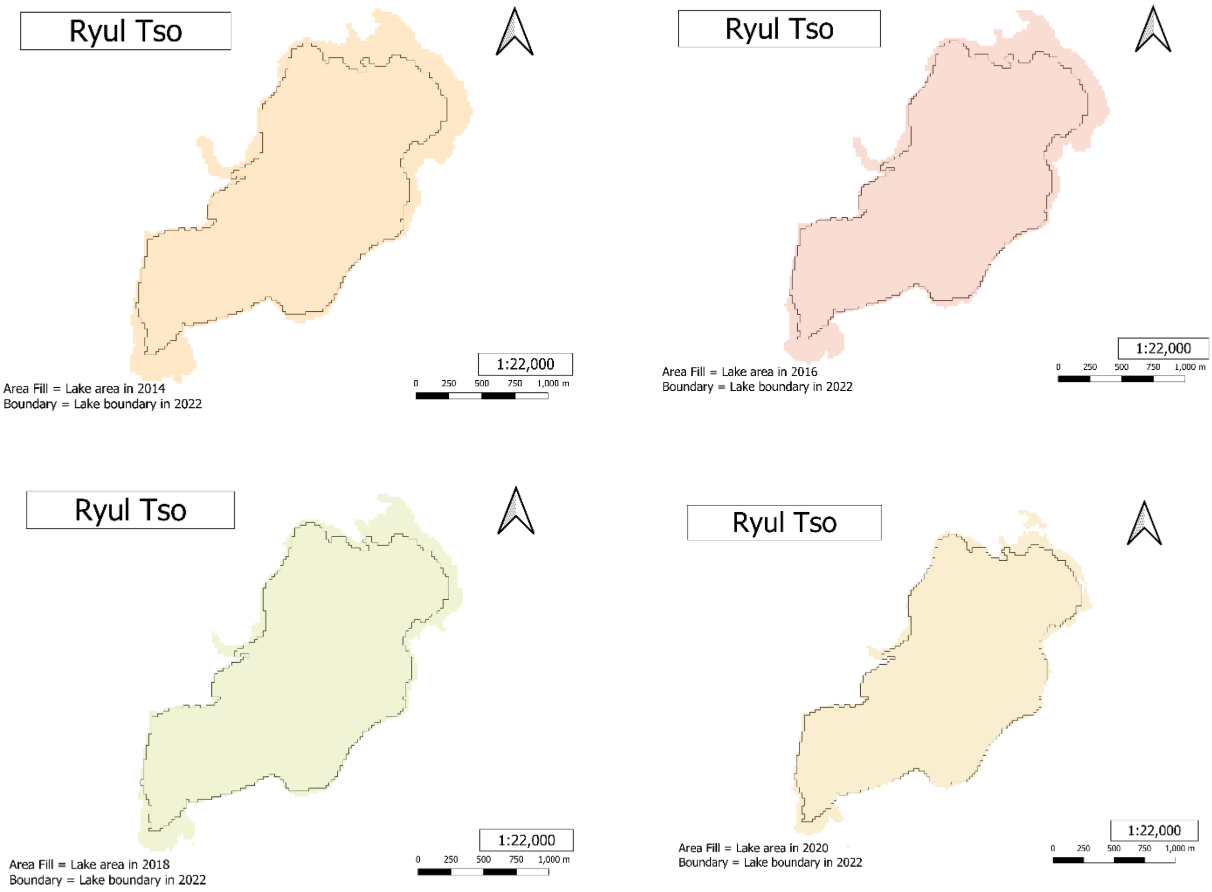

Figure 20 Lake area change in Ryul Tso

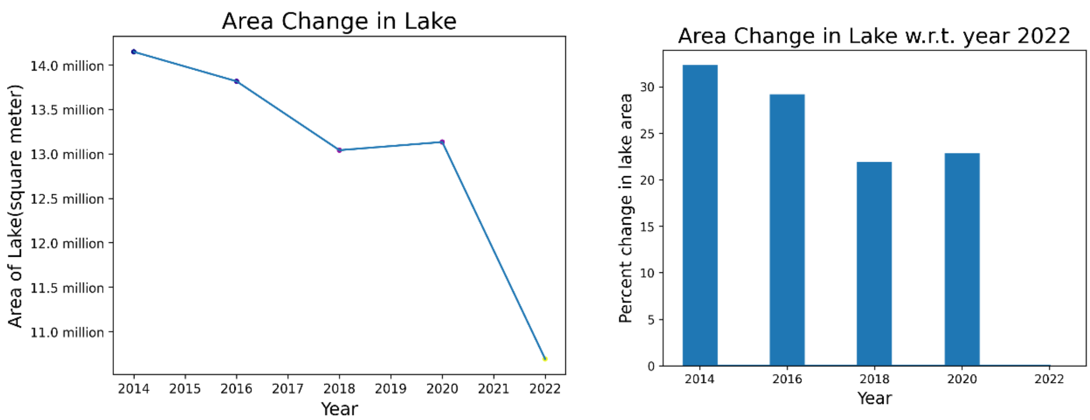

Figure 21 Plots depicting area change in Ryul Tso

- Lake area saw huge fall after 2020, a total of 20%. This is the highest fall in lake area observed for the duration in the study region.
- Largest area was observed in year 2014.

G) Lake A

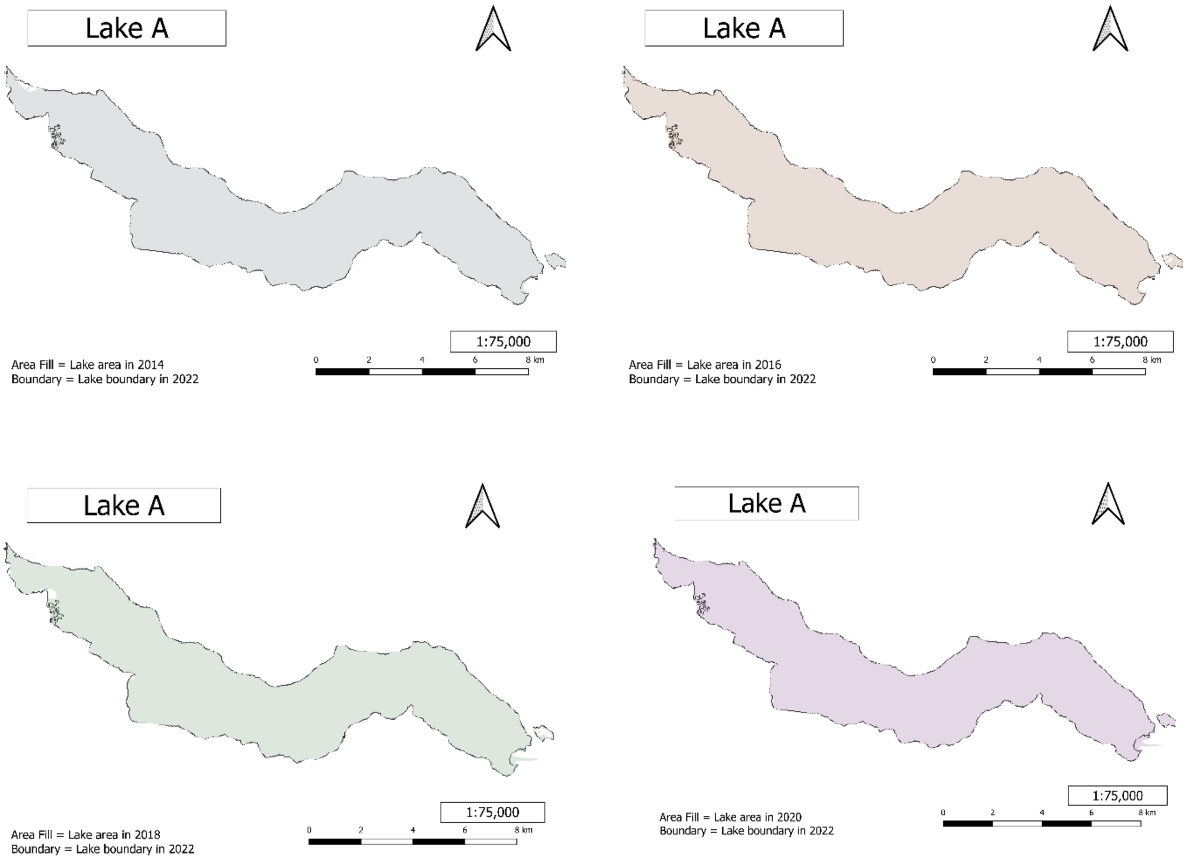

Figure 23 Lake area change in Lake A

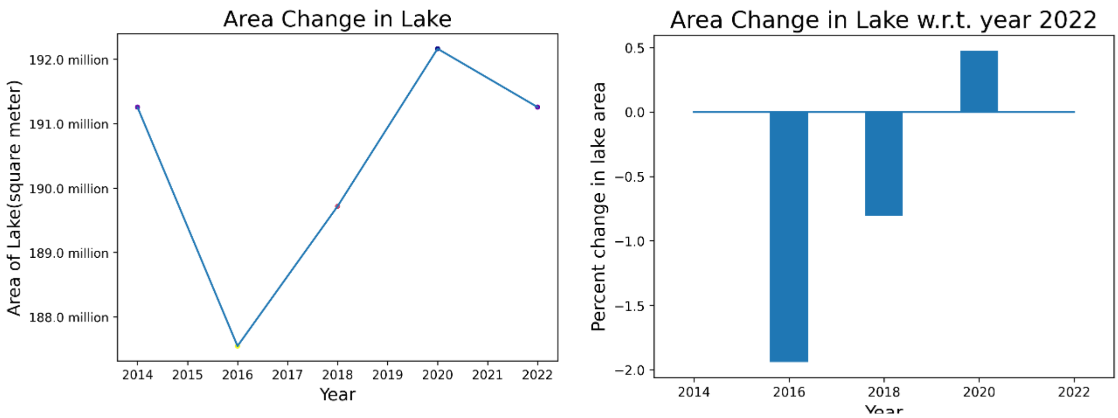

Figure 22 Plots depicting area change in lake A

- Same lake area was observed in year 2014 and 2022.
- It sharply fell in the year 2016, then gradually rose and increased back to same area to year 2014 in 2022
- Largest lake area was observed in the year 2020

F) Lake B

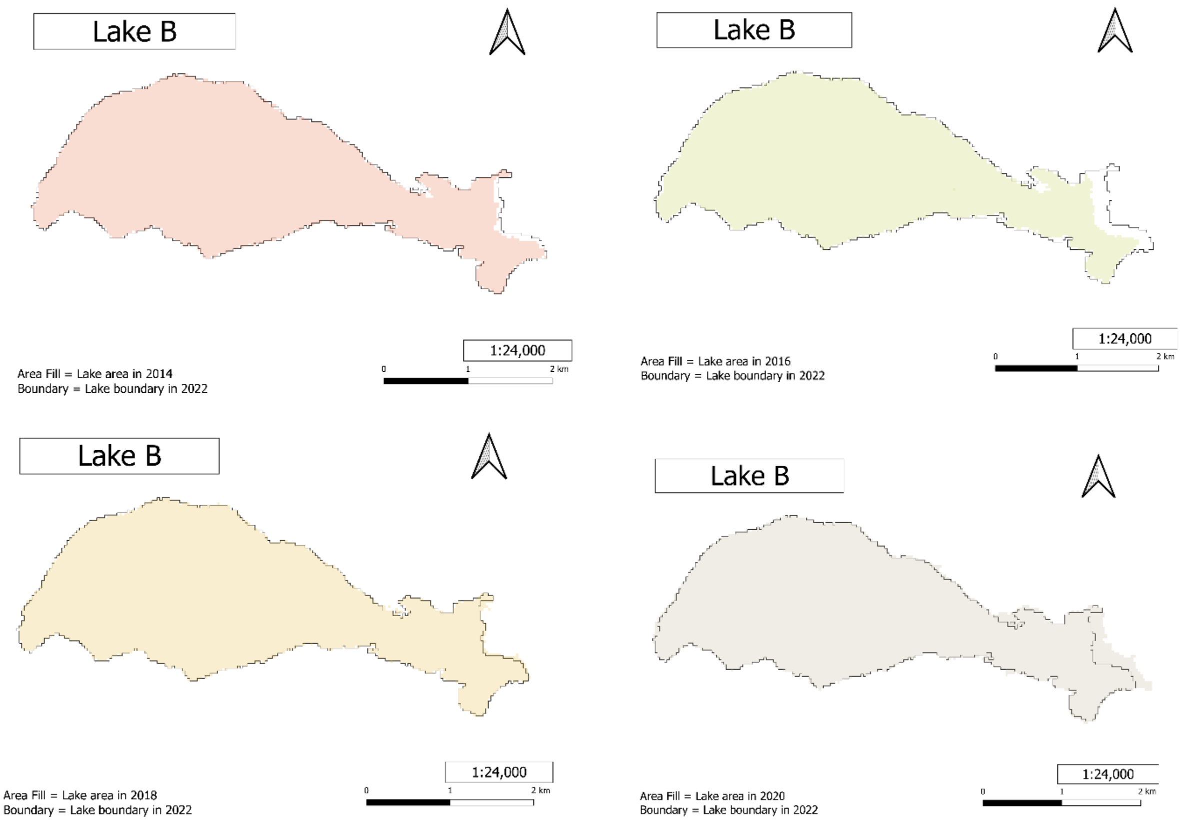

Figure 24 Lake are change in Lake B

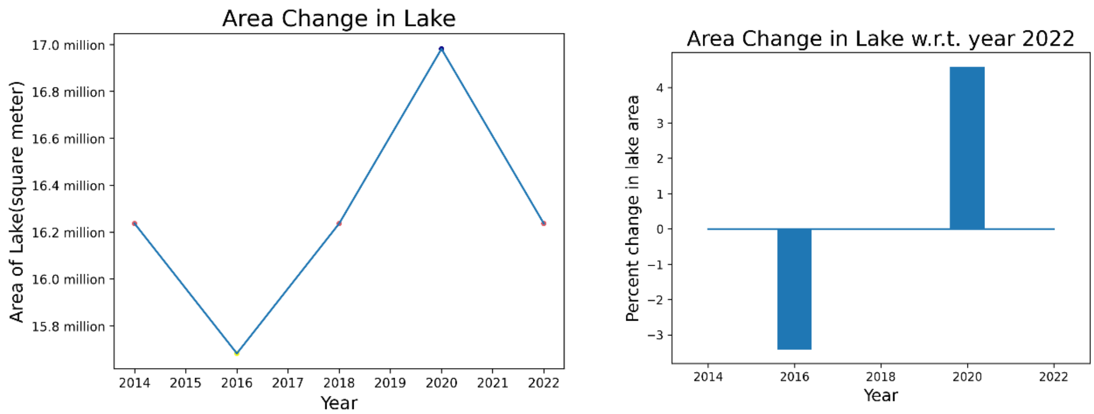

Figure 25 Plots depicting lake area change in Lake B

- Above lake shows an interesting pattern where the lake area only saw one peak and low during the whole study interval.
- Highest was observed in 2020 whereas lowest lake area was observed in 2016.
- It can also be said the area was gradually increasing since 2016 till 2020.

Comparison of spectral responses of five objects with their spectral signatures in the study area using sentinel-2 imagery

Western end of the Pangong lake was chosen for selecting the five objects for studying their spectral responses. Five objects are:

- Road
- Snow cover
- Water
- Sand/sediments
- Building

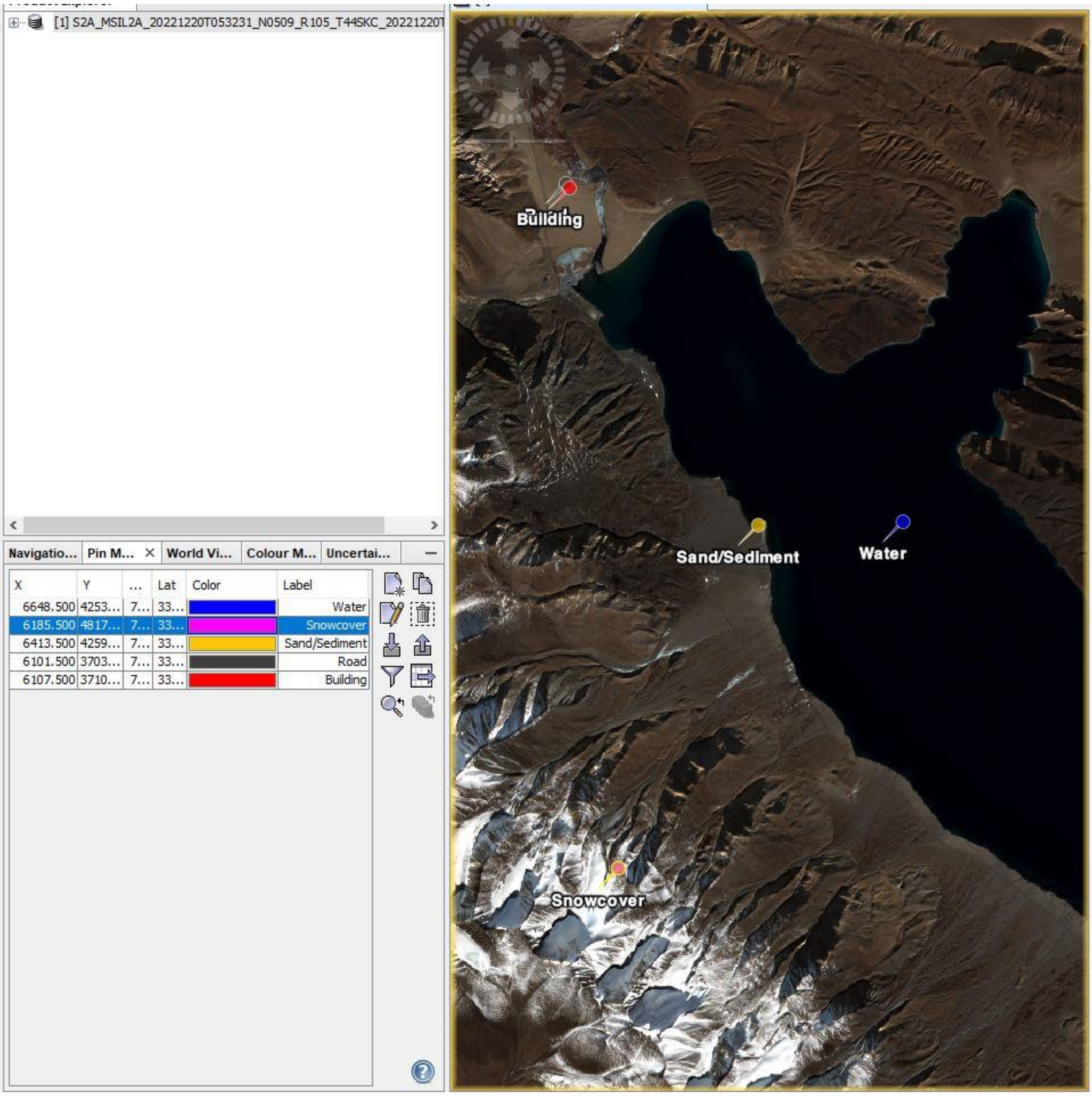

Figure 26 ROI with five objects marked for studying their spectral responses

The Figure 26 below shows the spectral responses of the above five objects

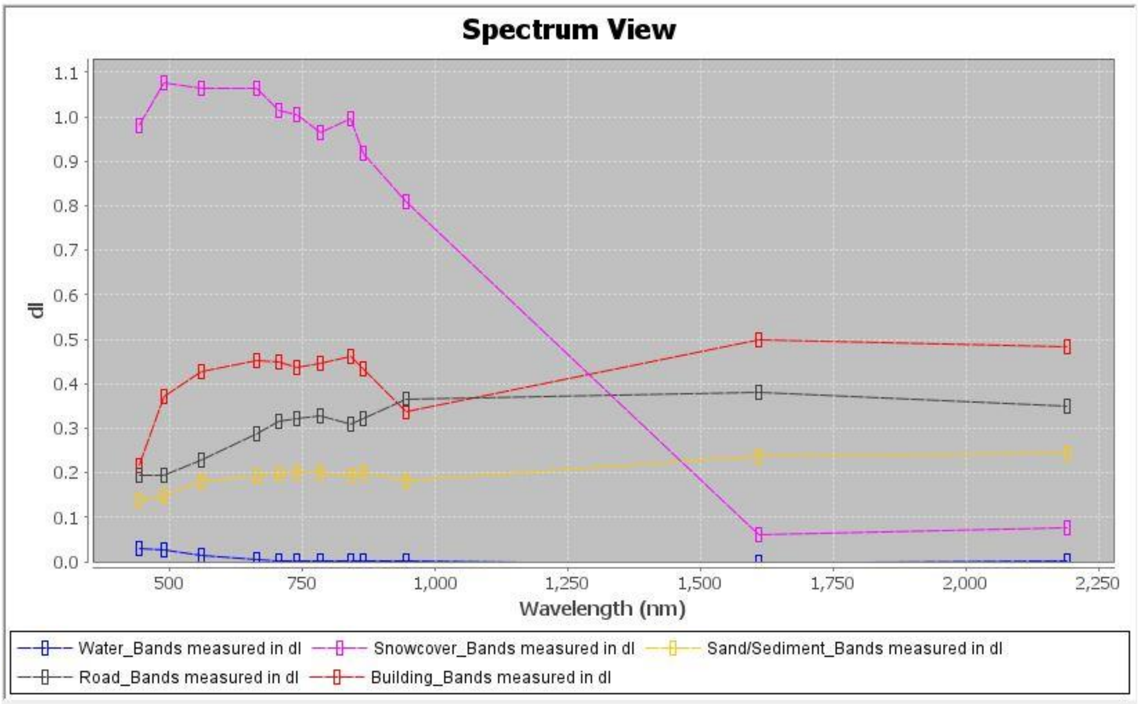

Figure 27 Spectral responses of five selected objects

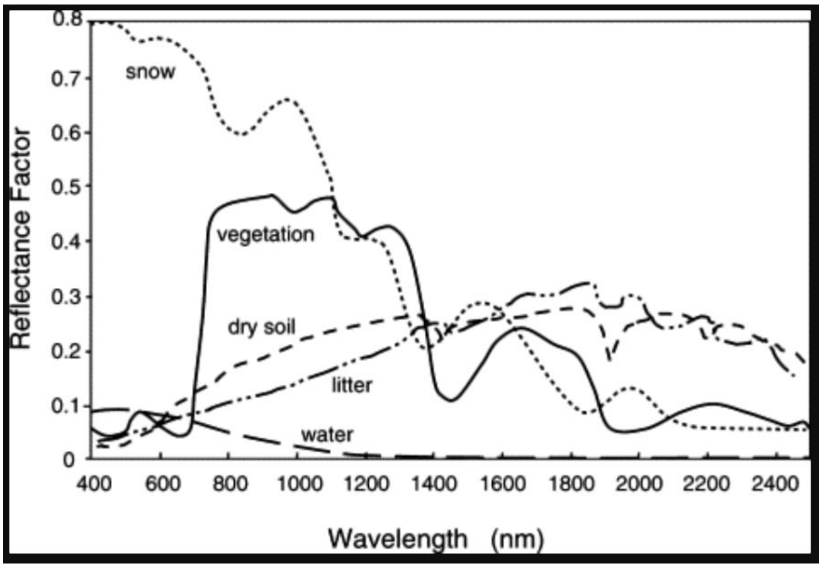

Figure 28 Spectral reflectance signatures of healthy vegetation, dry soil, gray grass litter, water, and snow; Source: https://ars.els-cdn.com/content/image/3-s2.0-B9780120644773500138-f11-04-9780120644773.gif

- Comparing figure 27 and figure 26, we can find snow and water showing almost similar curves. Higher reflectance factor for snow in our spectral response compared to its spectral signature could be due to some residual radiance in the atmosphere, increasing the magnitude of reflectance factor. Water's spectral response being lower than its spectral signature could be due to the presence of salts in the lake as Pangong lake is a saltwater lake.
- Now comparing sand/sediments and road's spectral response we can see that both are comparable to the spectral signature of dry soil. Lower magnitude of spectral response for sand/sediments could be due to the presence of minerals in the sand as the sand/sediment point

location appears to be near a receding glacier, accumulating sediments with the water seepage from glacier. Roads too are mostly covered with sand most of the time in summers in Ladakh region, moreover many places don't even have proper bituminous roads. That explains why road's spectral response is like that of spectral signature of dry soil.

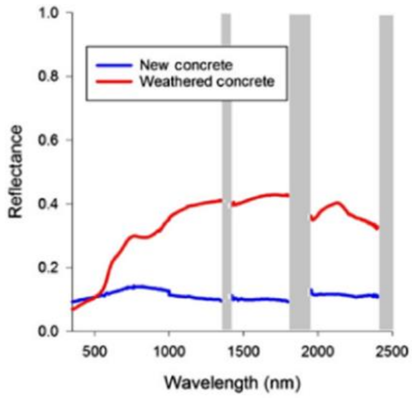

Figure 29 Spectral signature of concrete; Source: https://www.researchgate.net/figure/Mean-spectra-for-a-asbestos-b-clay-c-concrete-and-d-metal_fig3_277340159

- From figure 28, It is clear that our building shows similarity to the weathered concrete in terms of spectral response. Again, the deviations from the ideal character could be due to many reasons such as atmospheric radiance, materials used in construction, sands accumulated due to wind currents.

Conclusion and Learnings:

Glacial lakes are as hazardous as they are an excellent source of resources. Glacial lake outburst Floods (GLOF) are one such disastrous phenomenon. Also many of these lakes form an important ecosystem in the Himalayan region for migrating birds species and for the native wildlife present there. Hence, it becomes necessary to monitor the Himalayan glacial lakes and lake area change detection is one such technique which facilitates monitoring of these lakes using remote sensing.

Learning of practical- 1, 2, 3, 6 and 8:

- Here, we had to select one among the two datasets - Landsat 8 and sentinel 2 as per our needs and requirements. This helped us understand about the difference in the two datasets and their uses, as well as their significance.
- The hardware/software modules used in image processing operations are collectively called Image Processing Modules. Depending on the kind of processing to be performed there could be different resource requirements for different processing operations. For instance, dealing with large chunks of data require a lot of memory, some functions require the use of GUI while some does not, etc.
- Data can be visualized in three ways- image space, spectral space and feature space. Each have their own importance, and the purpose determines the use of suitable space.
- Data dimensionality reduction is performed when there are large number of bands, and we must reduce the redundant information and increase the separability of features, to uniquely identify them. In this exercise, we didn't use any data dimensionality reduction techniques.

- Biophysical parameters can be derived from the multi and hyperspectral data similar to how we study the spectral signatures of objects. Since spectral signatures are unique to every material and derive from how some material, for instance leaves interact with EM radiations and by studying that particular phenomenon we can determine the similar patterns in leaves anywhere on the Earth. By comparing these biophysical parameters we can study the changes in the phenomenon or in the material itself. How we acquired and compared the spectral responses of certain objects to their established spectral signatures in the second objective above describes this very process.

References

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- https://scihub.copernicus.eu/dhus/#/home
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