Analysis of SWOT Level 2 Data for Monitoring Mountain Lakes and Reservoirs

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In this study three distinct lakes and reservoirs were studied which includes Imja Lake, Kulekhani Reservoir and Phewa Lake. These water bodies are located across a wide elevation gradient, ranging from approximately 700 m to 5,000 m above mean sea level.

Analysis of SWOT Level 2 Lake Single-Pass Vector Data for Kulekhani Reservoir

1. **Study Overview:**

   Reservoir: Kulekhani Reservoir

   Coordinates: 27.59297°N, 85.15973°E

   Study Period: January 12, 2025 – December 12, 2025

   Data Product: SWOT Level 2 Lake Single-Pass Vector Data, Version D

   SWOT Passes: 551 and 008

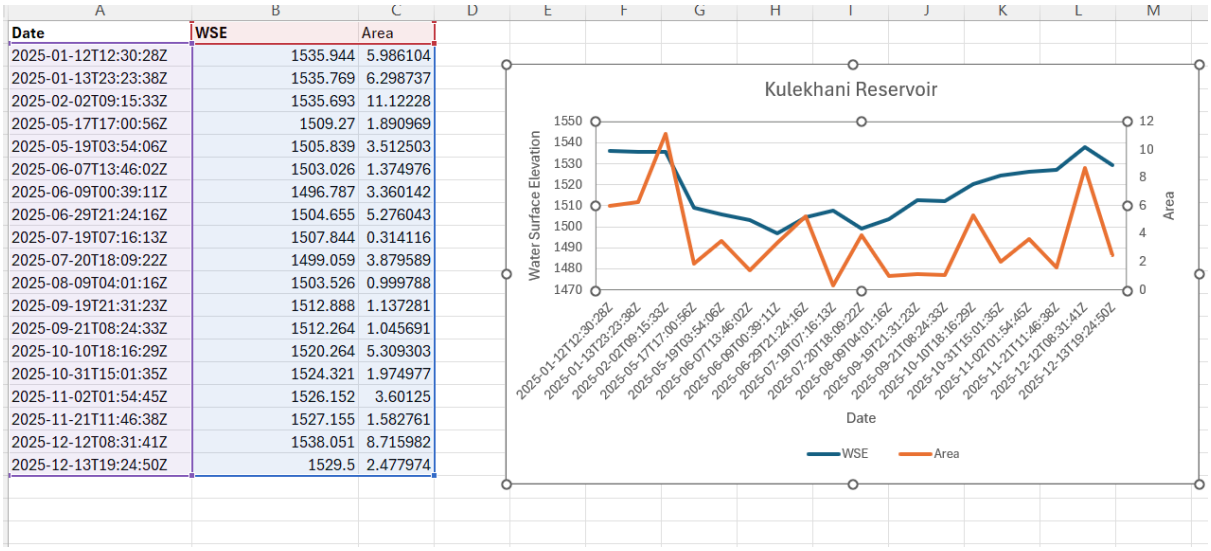
2. **Data Processing and Initial Findings**

   Initial inspection of the vector dataset revealed that multiple discrete water bodies were classified as lakes within the reservoir area. To ensure consistency, we selected the lake polygon representing the largest portion of the Kulekhani Reservoir for water surface elevation (WSE) extraction. On analysing the water surface elevation over the period, we found the following:

   Highest WSE: 1538.051 m (observed on December 12, 2025)

   Lowest WSE: 1496.787 m (observed on June 09, 2025)

   Total Range: 41.264 m



Date	WSE	Area
2025-01-12T12:30:28Z	1535.944	5.986104
2025-01-13T23:23:38Z	1535.769	6.298737
2025-02-02T09:15:33Z	1535.693	11.12228
2025-05-17T17:00:56Z	1509.27	1.890969
2025-05-19T03:54:06Z	1505.839	3.512503
2025-06-07T13:46:02Z	1503.026	1.374976
2025-06-09T00:39:11Z	1496.787	3.360142
2025-06-29T21:24:16Z	1504.655	5.276043
2025-07-19T07:16:13Z	1507.844	0.314116
2025-07-20T18:09:22Z	1499.059	3.879589
2025-08-09T04:01:16Z	1503.526	0.999788
2025-09-19T21:31:23Z	1512.888	1.137281
2025-09-21T08:24:33Z	1512.264	1.045691
2025-10-10T18:16:29Z	1520.264	5.309303
2025-10-31T15:01:35Z	1524.321	1.974977
2025-11-02T01:54:45Z	1526.152	3.60125
2025-11-21T11:46:38Z	1527.155	1.582761
2025-12-12T08:31:41Z	1538.051	8.715982
2025-12-13T19:24:50Z	1529.5	2.477974

Figure 1: WSE and Area Trend

Given the abrupt changes in elevation, a manual, pass-by-pass review of the datasets was conducted in ArcGIS to investigate potential anomalies. The different cases that were seen in the study which includes:

Case1: Correct Reservoir Representation:

The reservoir is properly delineated by the single pass vector product, and this is evident with the lake polygon in figure 2(a). The product identifies a lake polygon with WSE of 1535.944 m and with total area 5.98 km².However, the polygon area (5.98 km²) is over three times larger than the true reservoir area determined by independent digitization (1.84 km²) (See Fig. 2a vs. 2b). This indicates a potential over-classification of "water" in the surrounding terrain raising question on accuracy of lake area field in the product for the narrow valley like Kulekhani.

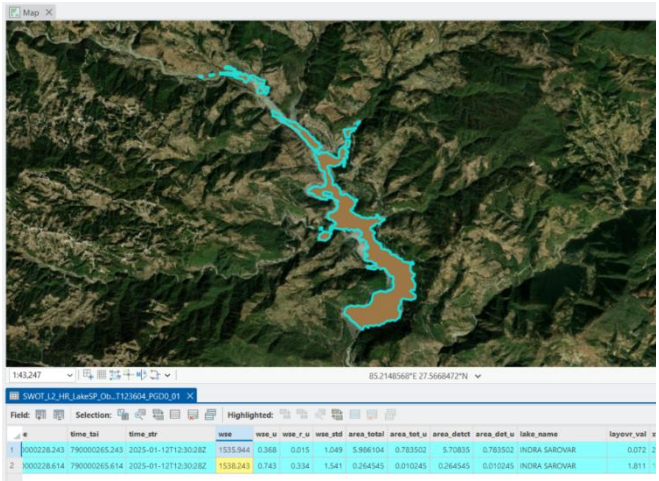


Figure 2(a): Represent the lake detected by SWOT

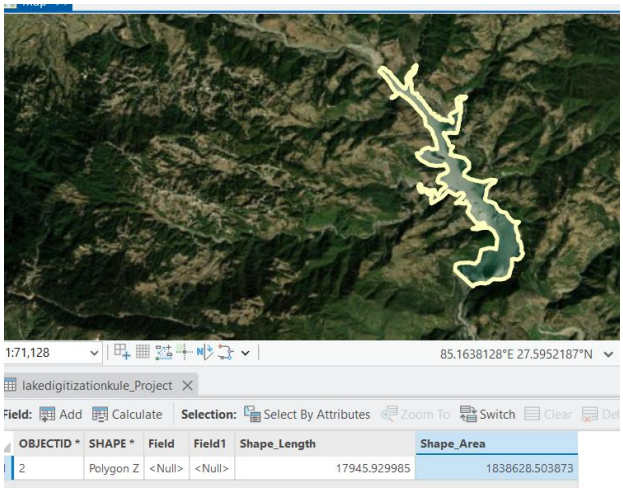


Figure 2 (b): Represent the area acquired by digitization of reservoir

Case 2: Spatial Shift in lake Polygon:

In both the figure , the detected polygon is spatially offset from the true resorvoir extent. In given passes, the lake mask appears displaced (Fig. 3a & 3b). This strongly suggests geolocation inaccuracies in the Level 2 product. This error can be a contributor to the anomalous elevation jumps in the time series.

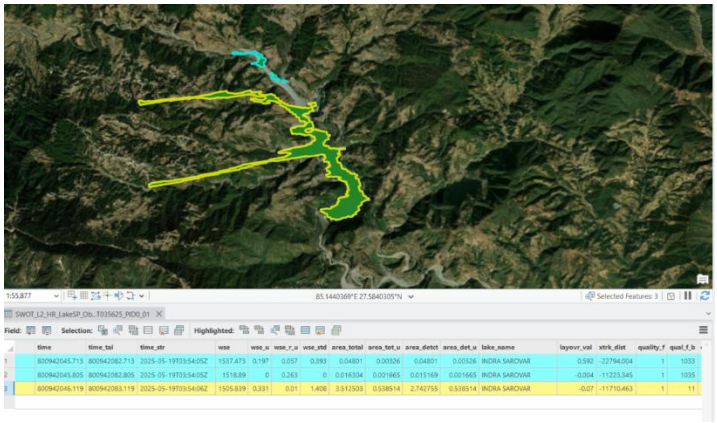


Figure 3(a)

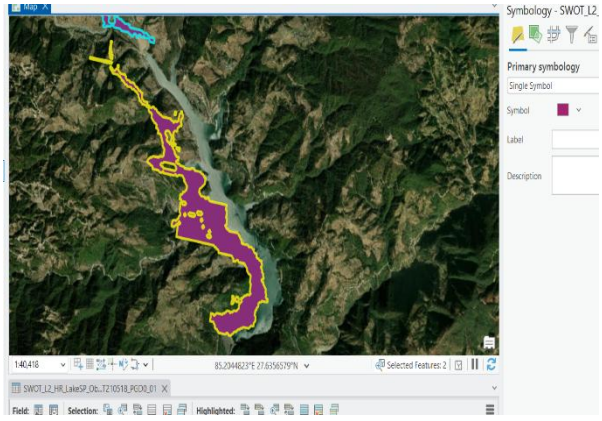


Figure 3(b)

Case 3: Low Elevation During Rainy Season

The measured WSE is anomalously low during the peak monsoon and post-monsoon period (July-September). This is evident with wse readings cluster between 1503 m and1512 m as shown in figure 4(a) and 4(b), which is lower than levels measured in the dry winter month of January. This contradicts the expected hydrology.

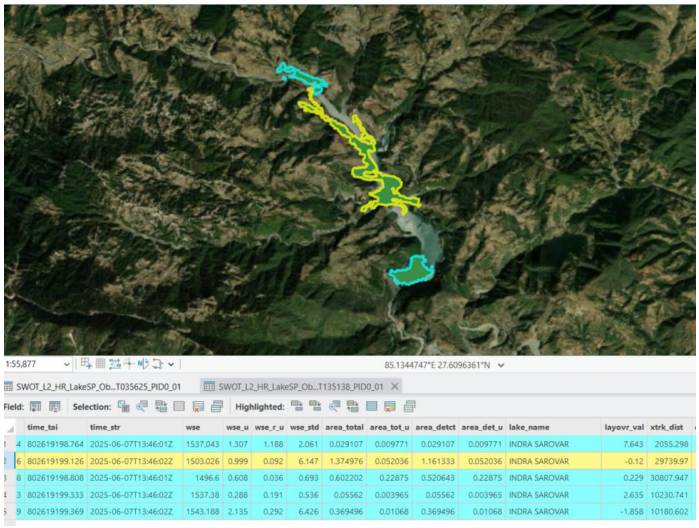


Figure 4 (a)

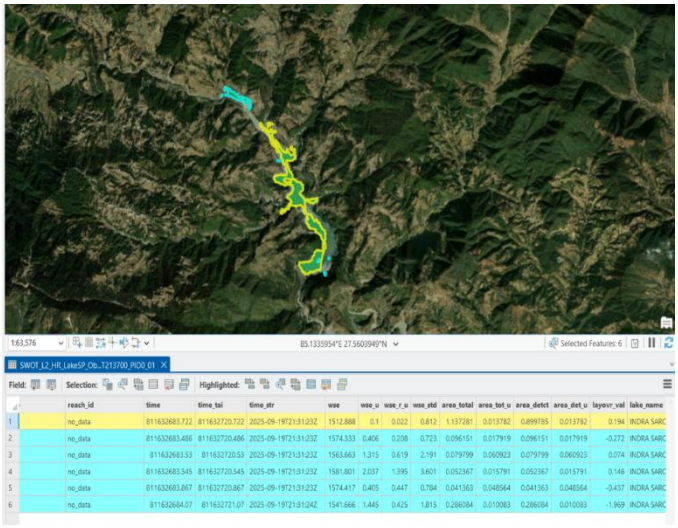


Figure 4 (b)

Case 5: Partial Lake Detection and Lake Misclassification as Water

(Fragmented Detection): The reservoir is detected as multiple, small, disconnected water bodies with highly inconsistent elevations. In one pass (Fig. 5a), four separate sections are classified as lake, with WSE values differing by over 37 meters—a physical impossibility for a connected reservoir. Similarly, in other case in the figure 5 (b), the adjacent pixel's wse is measured as the 1503.526m and 1645.894m respectively. The difference is more than 100m. On having closer look on the figure 5(b), it seems the surrounding terrain of reservoir has been

classified as water surface, which might have introduces the bias into the elevation measurements.

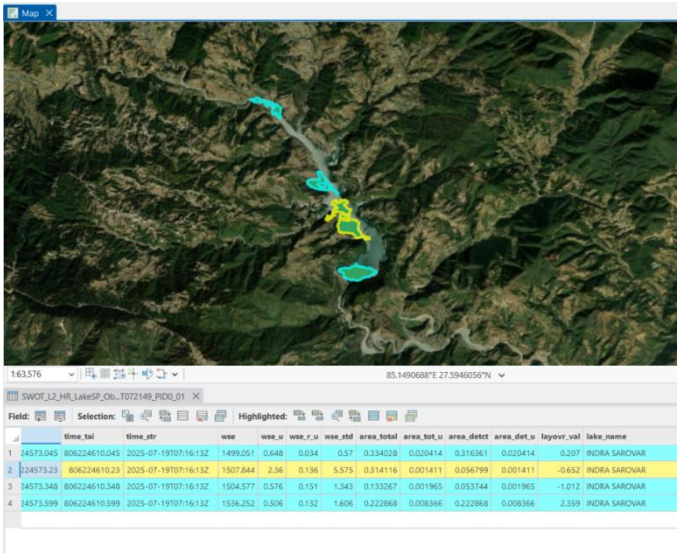


Figure 5(a)

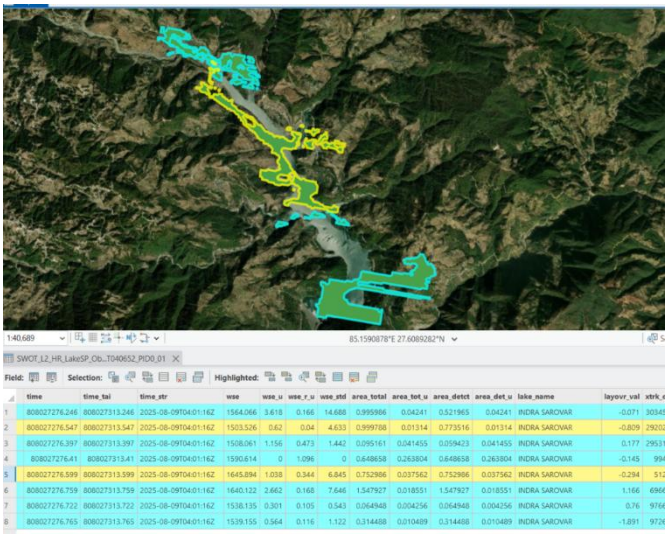


Figure 5 (b)

Analysis of Imja Lake Using SWOT Level 2 Single-Pass Lake Vector Data (2024)

1. **Study Overview:**

   Lake: Imja Lake

   Coordinates: 27.900171°N, 86.918720°E

   Study Period: January 2024 – December, 2024

   Data Product: SWOT Level 2 Lake Single-Pass Vector Data, Version D

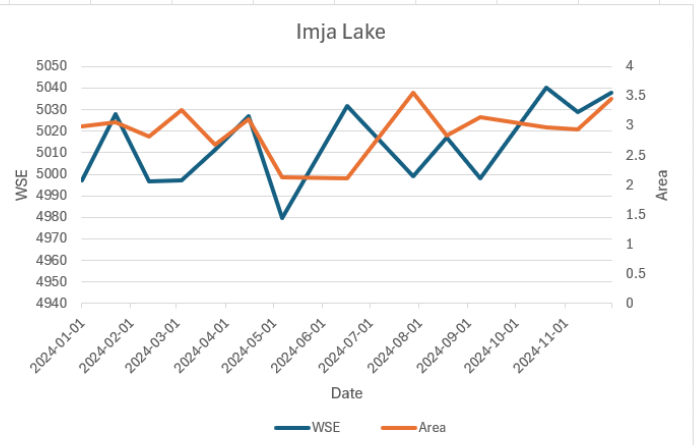
   SWOT Passes: 523

2. **Initial Findings:**

   Initial inspection of the Level 2 Lake Single-Pass Vector dataset for Imja Lake revealed notable variability in both Water Surface Elevation (WSE) and surface area across the 2024 observation dates. The analysis of the water surface elevation and area over the study period yielded the following key metrics:

   - **Highest WSE:** 5040.09 m (observed on October 20, 2024)
   - **Lowest WSE:** 4979.656 m (observed on May 06, 2024)
   - **Total WSE Range:** 60.434 m
   - **Largest Lake Area:** 3.566 km² (observed on July 28, 2024)
   - **Smallest Lake Area:** 2.108 km² (observed on June 16, 2024)

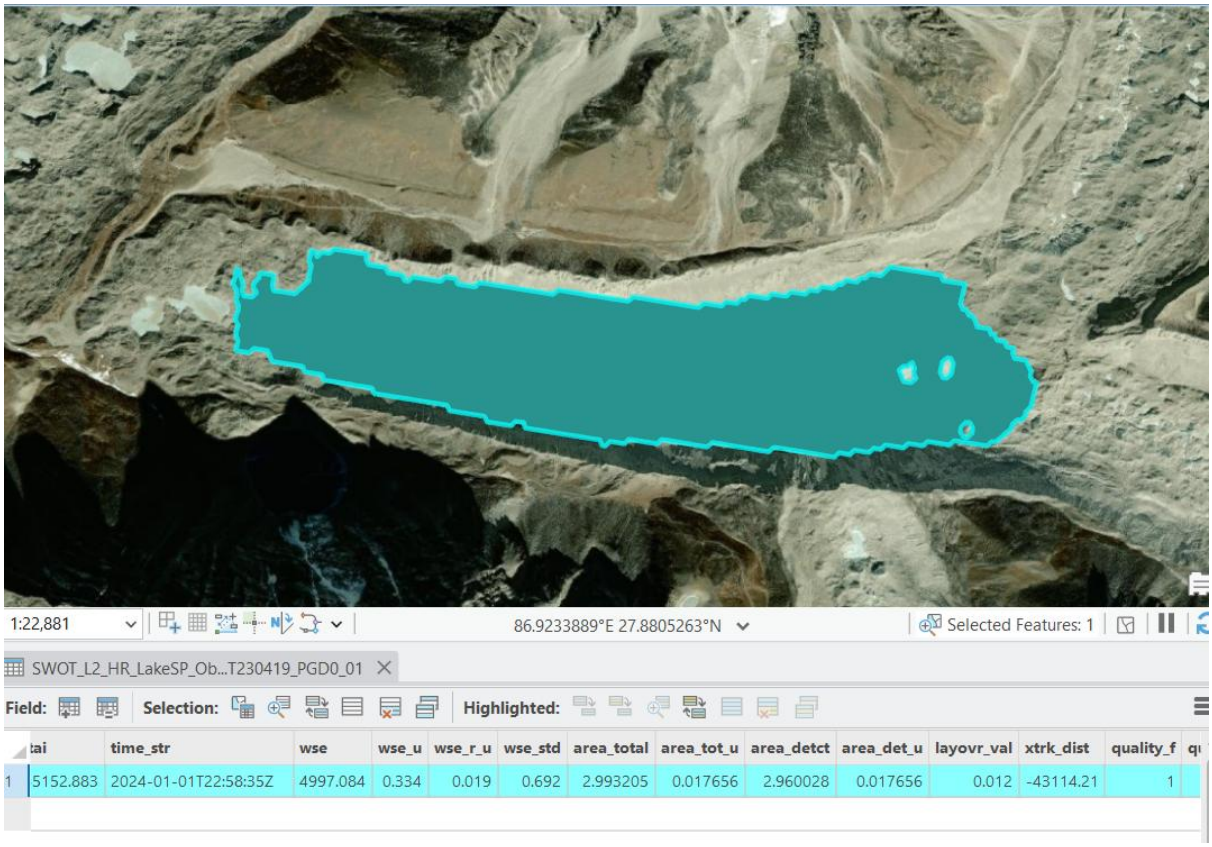
Date	WSE	Area
2024-01-01	4997.084	2.993205
2024-01-22	5027.984	3.055882
2024-02-12	4996.648	2.811823
2024-03-04	4997.238	3.258201
2024-03-25	5011.302	2.688656
2024-04-15	5026.838	3.110674
2024-05-06	4979.656	2.13743
2024-06-16	5031.469	2.108073
2024-07-28	4999.15	3.566268
2024-08-18	5016.815	2.833598
2024-09-08	4998.136	3.138583
2024-10-20	5040.09	2.978754
2024-11-09	5029.011	2.937302
2024-11-30	5037.711	3.461952



The time-series data reveals abrupt WSE changes so the manual inspection of every dataset was done to find the possible causes.

Case 1: Proper Delineation of Imja Lake

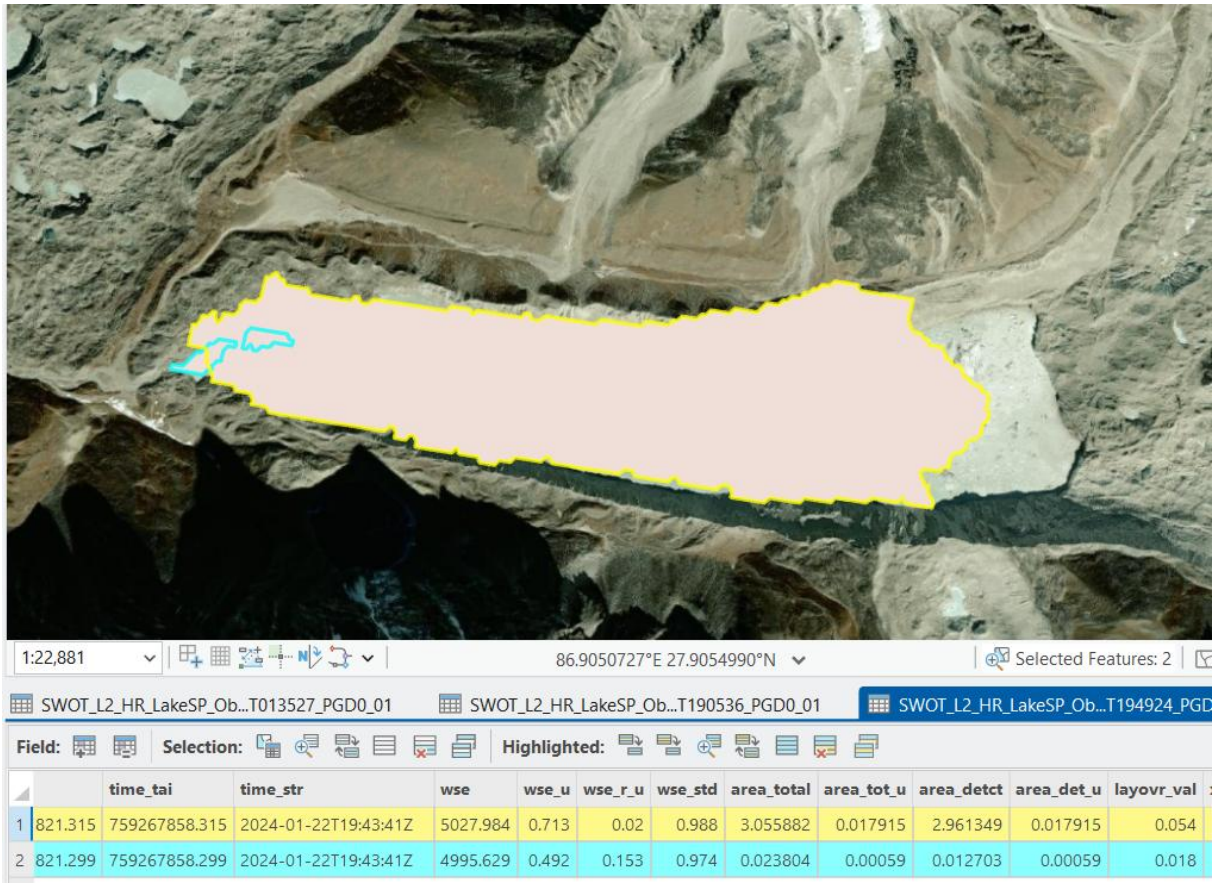
On January 1, 2024: The Imja Lake polygon seems to be correctly delineated when compare with the world imagery. The measured WSE of this date is 4997.084 m and a surface area of 2.99 km² which is represented in the figure 7.



	tai	time_str	wse	wse_u	wse_r_u	wse_std	area_total	area_tot_u	area_detct	area_det_u	layovr_val	xtrk_dist	quality_f	qu
1	5152.883	2024-01-01T22:58:35Z	4997.084	0.334	0.019	0.692	2.993205	0.017656	2.960028	0.017656	0.012	-43114.21	1	

Figure 5: Delineation of Imja Lake with proper spatial coverage with wse 4997.084m

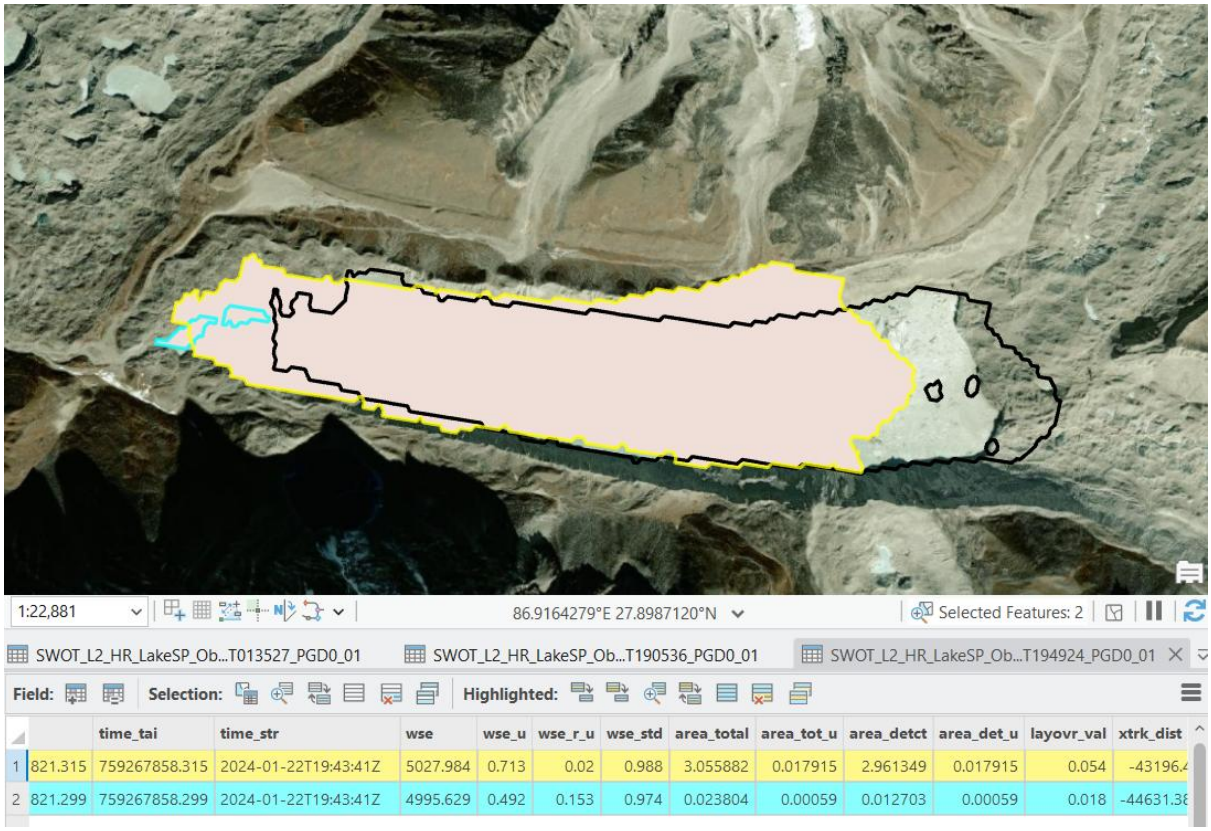
On January 22, 2024: The recorded WSE increases by ~30.9 m to 5027.984 m, while the area changes to 3.06 km², which is show by figure 6.



	time_tai	time_str	wse	wse_u	wse_r_u	wse_std	area_total	area_tot_u	area_detct	area_det_u	layovr_val
1	821.315	759267858.315	2024-01-22T19:43:41Z	5027.984	0.713	0.02	0.988	3.055882	0.017915	2.961349	0.017915	0.054
2	821.299	759267858.299	2024-01-22T19:43:41Z	4995.629	0.492	0.153	0.974	0.023804	0.00059	0.012703	0.00059	0.018

Figure 6: Imja Lake Observed in Jan 22 with wse 5027.984m

Since, the huge difference was observed within the 21 days, so the overlay of two datasets was done. The overlay of the two datasets reveals lateral shift in the lake polygon between acquisitions. This spatial misregistration suggests that the radar footprint for the January 22 might sampled adjacent terrain, resulting in a biased elevation measurement that does not represent the true water surface. The figure 9 represent the shift. The lake with the black boundary is one acquired in Jan 1 and other with pink fill on Jan 22.



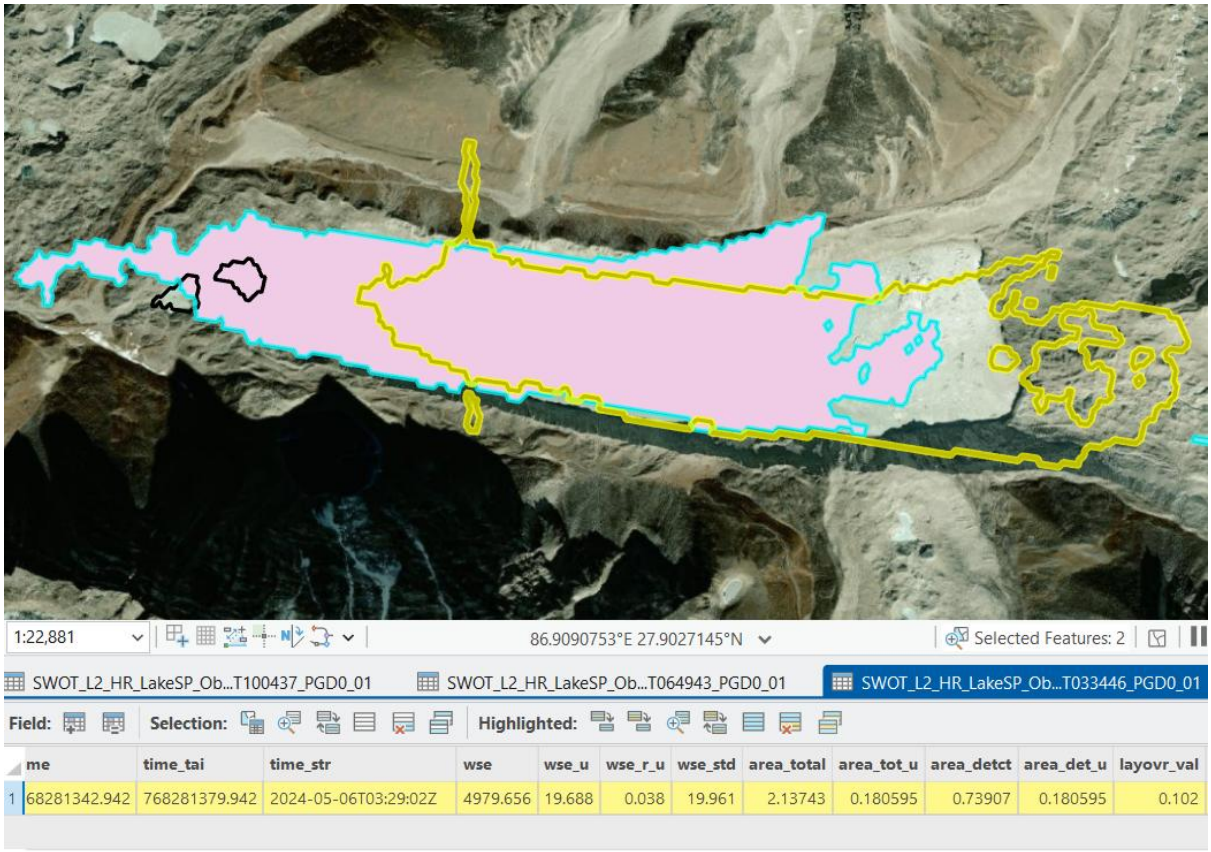
	time_tai	time_str	wse	wse_u	wse_r_u	wse_std	area_total	area_tot_u	area_detct	area_det_u	layovr_val	xtrk_dist
1	821.315	759267858.315	2024-01-22T19:43:41Z	5027.984	0.713	0.02	0.988	3.055882	0.017915	2.961349	0.017915	0.054	-43196.4
2	821.299	759267858.299	2024-01-22T19:43:41Z	4995.629	0.492	0.153	0.974	0.023804	0.00059	0.012703	0.00059	0.018	-44631.36

Figure 9: The overlay of lake polygon acquired in 1st of January (one with yellow boundary) and 22nd of January (with black boundary)

Similarly, there is another example when the water surface elevation decreases by 47.2m within the month.

- **April 15, 2024**: WSE recorded at 5026.838 m.
- **May 6, 2024**: WSE drops sharply to 4979.656 m—a decrease of ~47.2 m.

To compare the changes between the datasets, both the datasets were overlayed. The one with the yellow boundary is data of May month and rest is of April. As with the January case, the lake polygon for May 6 is visibly displaced relative to the April 15 extent. And with this shift there is huge difference in elevation, which might be due to measurement of elevation of nearby terrain rather than lake surface. The difference is shown in figure 10.



	me	time_tai	time_str	wse	wse_u	wse_r_u	wse_std	area_total	area_tot_u	area_detct	area_det_u	layovr_val
1	68281342.942	768281379.942	2024-05-06T03:29:02Z	4979.656	19.688	0.038	19.961	2.13743	0.180595	0.73907	0.180595	0.102

Figure 10: The overlay of polygon acquired on two different dates. Polygon with Yellow Boundary represent the data acquired in May and other with pink fill represent the data acquired in April.

Analysis of SWOT Level 2 Lake Single-Pass Vector Data for Phewa Lake

1. **Study Overview:**

   Lake: Phewa Lake

   Coordinates: 28.2163912°N, 83.9445695°E

   Study Period: January 2024 – December 2024

   Data Product: SWOT Level 2 Lake Single-Pass Vector Data, Version D

   SWOT Passes: 314 and 273

2. **Initial Finding:**

   An analysis of the water surface elevation (WSE) of Phewa Lake for the year 2024 reveals the following key observations:

   - **Highest Water Surface Elevation (WSE):** 813.934 m on 9 August 2024
   - **Lowest Water Surface Elevation (WSE):** 789.842 m on 10 August 2024
   - **Highest Detected Lake Area:** 10.159797 km² on 9 August 2024
   - **Lowest Detected Lake Area**: 3.769093 km² on 7 April 2024

   Although the total variation in WSE reaches approximately 24 m, the temporal pattern of elevation change appears relatively consistent when compared to highly regulated water bodies such as the Kulekhani Reservoir and Imja Lake.

   However, the lake area detection remains unreliable, as illustrated in the figure 11(b).

Date	WSE	Area
2024-01-13T21:22:01Z	794.562	3.944628
2024-01-15T08:14:50Z	794.469	4.435427
2024-02-03T18:07:07Z	794.375	4.435427
2024-02-05T04:59:56Z	794.288	3.816901
2024-02-24T14:52:13Z	794.411	4.252726
2024-02-26T01:45:01Z	793.249	4.196689
2024-03-16T11:37:15Z	794.296	4.126047
2024-03-17T22:30:03Z	794.269	4.69034
2024-04-07T19:15:08Z	794.385	3.769093
2024-04-27T05:07:25Z	794.444	4.604651
2024-04-28T16:00:13Z	794.452	3.854589
2024-05-19T12:45:18Z	794.378	3.943494
2024-06-07T22:37:35Z	794.809	4.40161
2024-06-30T06:15:27Z	795.812	10.1598
2024-07-21T03:00:32Z	795.309	7.632353
2024-08-09T12:52:48Z	813.934	10.1598
2024-08-10T23:45:37Z	789.842	7.536261
2024-08-31T20:30:41Z	794.638	8.724926
2024-10-12T14:00:53Z	795.393	4.879988
2024-10-31T23:53:08Z	792.872	5.258962
2024-11-21T20:38:14Z	794.543	3.958573

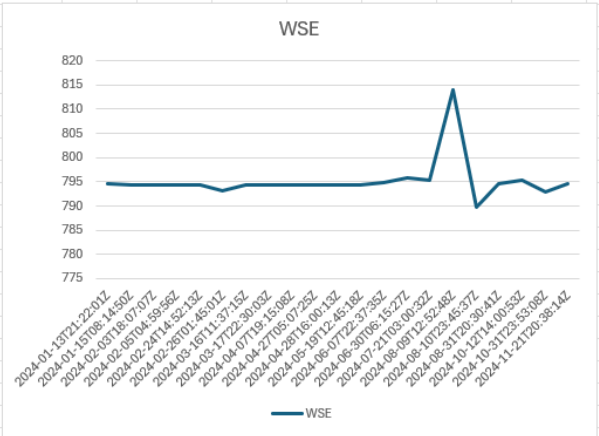


Figure 11 (a): WSE Change of Phewa Lake

Date	WSE	Area
2024-01-13T21:22:01Z	794.562	3.944628
2024-01-15T08:14:50Z	794.469	4.435427
2024-02-03T18:07:07Z	794.375	4.435427
2024-02-05T04:59:56Z	794.288	3.816901
2024-02-24T14:52:13Z	794.411	4.252726
2024-02-26T01:45:01Z	793.249	4.196689
2024-03-16T11:37:15Z	794.296	4.126047
2024-03-17T22:30:03Z	794.269	4.69034
2024-04-07T19:15:08Z	794.385	3.769093
2024-04-27T05:07:25Z	794.444	4.604651
2024-04-28T16:00:13Z	794.452	3.854589
2024-05-19T12:45:18Z	794.378	3.943494
2024-06-07T22:37:35Z	794.809	4.40161
2024-06-30T06:15:27Z	795.812	10.1598
2024-07-21T03:00:32Z	795.309	7.632353
2024-08-09T12:52:48Z	813.934	10.1598
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2024-08-31T20:30:41Z	794.638	8.724926
2024-10-12T14:00:53Z	795.393	4.879988
2024-10-31T23:53:08Z	792.872	5.258962
2024-11-21T20:38:14Z	794.543	3.958573

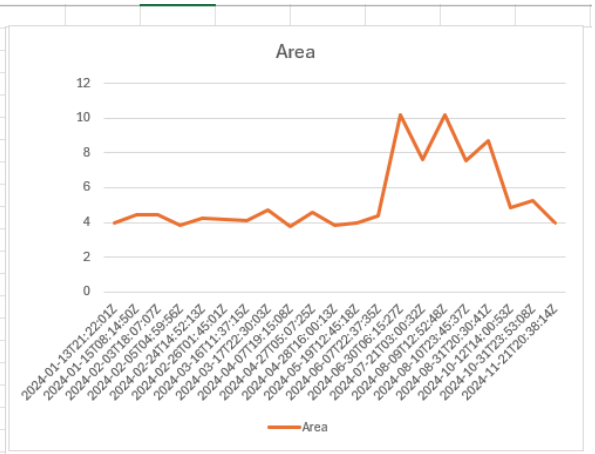

Figure 11(b): Represent the change in Water Surface Area of Phewa Lake

Case I: Abrupt Change in Water Surface Elevation:

On 9 August 2024, the observed WSE of 813.934 m is significantly higher than values recorded during other acquisition dates. A closer inspection of the corresponding lake polygon indicates that adjacent land areas were also classified as water during this pass. This misclassification might have contributed WSE to increase by 19m.Similarly, in this case there is overestimation of lake surface area with measurement approximately 10.28 km², far exceeding typical values for Phewa Lake i.e 4.43 km².

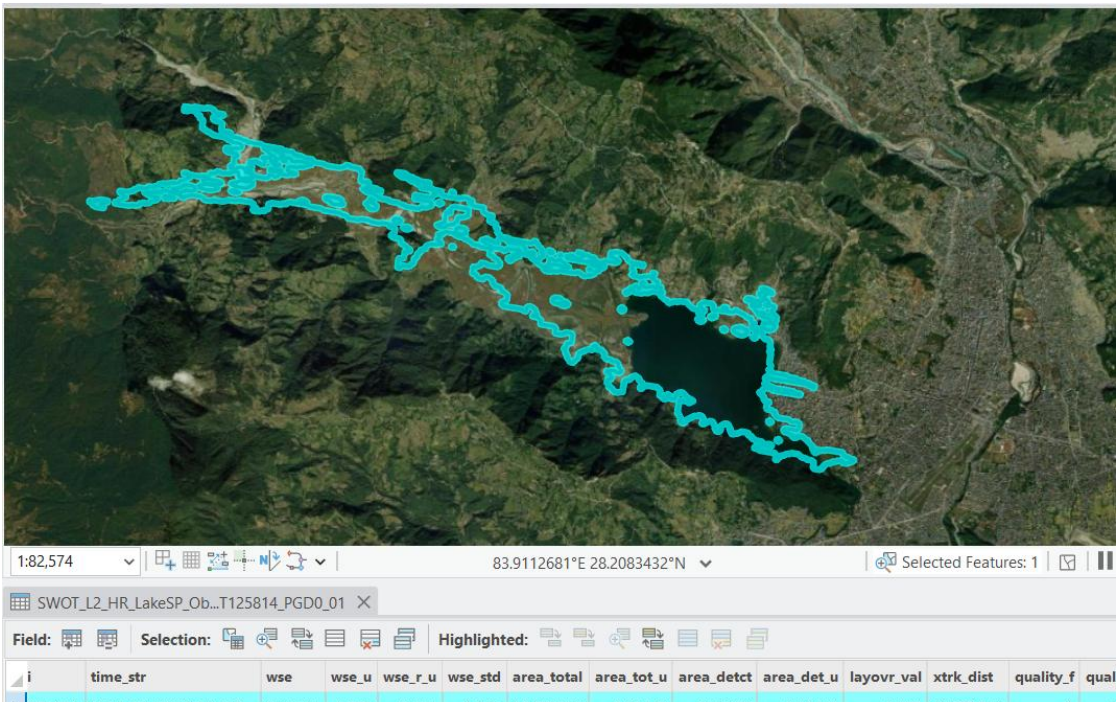

Figure 12: Represent the adjacent terrain areas being detected as Phewa Lake