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Monitoring Ungauged Manchar Lake (Pakistan) using ICESAT-2 Data

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ABSTRACT

Inland water is crucial for global water and food security, particularly in developing countries. Lakes are crucial in meeting the world's increasing water demands and are a vital component of inland water resources. Therefore, developing an efficient monitoring system is essential for water resources management. This study employed ICEsat2, a satellite laser altimetry technology, to monitor Manchar Lake in Dadu district, Sindh, Pakistan. Multiple satellite altimetry missions, such as Sentinel 3, ICESat2, and Jason3, traverse Pakistan's largest natural lake, providing valuable data for monitoring purposes. In the absence of an in-situ gauge in Manchar Lake, Sentinel 3 and Jason 3 were employed for comparison with the findings of ICESat2. Jason3 and Sentinel 3 data were acquired, respectively, from Dahiti and Earth Console. ICESat2 data were downloaded from NASA's official website known as open altimetry. They utilized permanent water surfaces from Hydro Lakes for masking the Manchar Lake area. The correlation coefficient (R=0.534/0.928 Dahiti/S3), root mean square error (RMSE=0.443 m/0.4717 m Dahiti/S3) and mean square error (MSE=0.196/0.22258 Dahiti/S3) were calculated as validation metrics. This study has limitations, including the short time series of ICESat2 due to its low temporal resolution. Another limitation is the lack of exact matching satellite data acquisition dates, which could be addressed by installing in-situ gauges in the Lake. Reevaluating ICESat2 data in the future using in-situ gauges can significantly enhance the validation of this dataset.

KEYWORDS: Manchar lake, icesat2, dahiti database, sentinel-3, inland water

1. INTRODUCTION

Due to erratic variations in climate and seasonal cycles, water availability is currently the biggest concern. A significant portion of global freshwater is stored in inland water, and lakes are one of the primary elements of the freshwater system. Therefore, government authorities are interested in monitoring lakes' spatial and temporal changes [1].

Due to low network of gauges, it is extremely difficult to improve the monitoring of these Lakes, triggering issue of data availability. Moreover, it is also difficult to install multiple gauges in different part of Lakes which again creates capacity issues in organization of developing countries. To eradicate these issues, satellite data can play a crucial role in ameliorating the management of water resources[2]. This study uses ICESat2 satellite laser altimetry to monitor water levels in an ungauged lake in Pakistan with tremendous economic and ecological importance in the region.

Water level is the crucial parameter of inland water body. It is the critical parameter to forecast the frequency of extreme events such as Flood and Drought. Continuous monitoring of these data is essential for the development of early warning system[3][4]. Therefore, it is necessary for water resources managers to utilize the satellite altimetry technology in their measurement and validate it with their real data for accurate management of water bodies[5].

ICESat2 is laser Altimetry technology which is the part of remote sensing technique to compute the height of myriad topography. A laser is attached in this satellite which releases series of laser light toward the Earth Surface. These laser pulses are available in the near-infrared part of electromagnetic spectrum. After passing through the atmosphere, it interacts with feature or target of earth surface, and then return back to satellite. Main function of altimetry technology is to measure the cycle of emitted rays and return of rays toward the satellite which is known as time of flight. By knowing the time of flight and speed of light, altimetry technology can compute the distance between the satellite and target[6].

One of the most significant advantages of the ICESat2 data is the availability of six laser beams—three pairs of beams separated by 3 km in one track, improving the spatial resolution of water level calculations. No doubt, it has better spatial resolution but revisit time of ICEsat2 is 90 which manifests low temporal resolution. However, the smaller footprint enables accurately measuring the small lakes. The main objective of this research paper is to monitor the water levels of Manchar Lake using ICESat2 time-series water surface data[7].

Due to the unavailability of in-situ data, water levels derived from DAHITI and Sentinel 3 were employed to validate ICESat2 data. Some previous studies have shown good agreement between satellite radar altimetry datasets and the in-situ data in the same region [3].

2. STUDY AREA

Manchar Lake is in the Dadu district of Sindh, located on the west bank of the Indus River and three different lines show the virtual station of different satellites: Jason (Red), Icesat2(Green) and Sentinel-3(Black) as shown in (Figure 1). Manchar is one of Asia's largest freshwater lakes and Pakistan's largest lakes. There are multiple sources which provide significant inflow to the Manchar lake such as Hill torrents from Kirthar range, Main Nara Valley Drain (MNVD) and at last, drained into Indus River. Owing to drastic impact of climate change, this lake is facing serious challenges of surface area and water level variation. Recently, due to unprecedented precipitation in Sindh, situation of flood has been created in Manchar Lake which devoured multiple villages and big cities situated near by it. Moreover, the quality of this lake is under serious concern due to effluent coming from Main Nara valley drain. Therefore, efficient management techniques are required to ameliorate the condition of this mighty lake which is impossible without redressing the monitoring strategies[1].

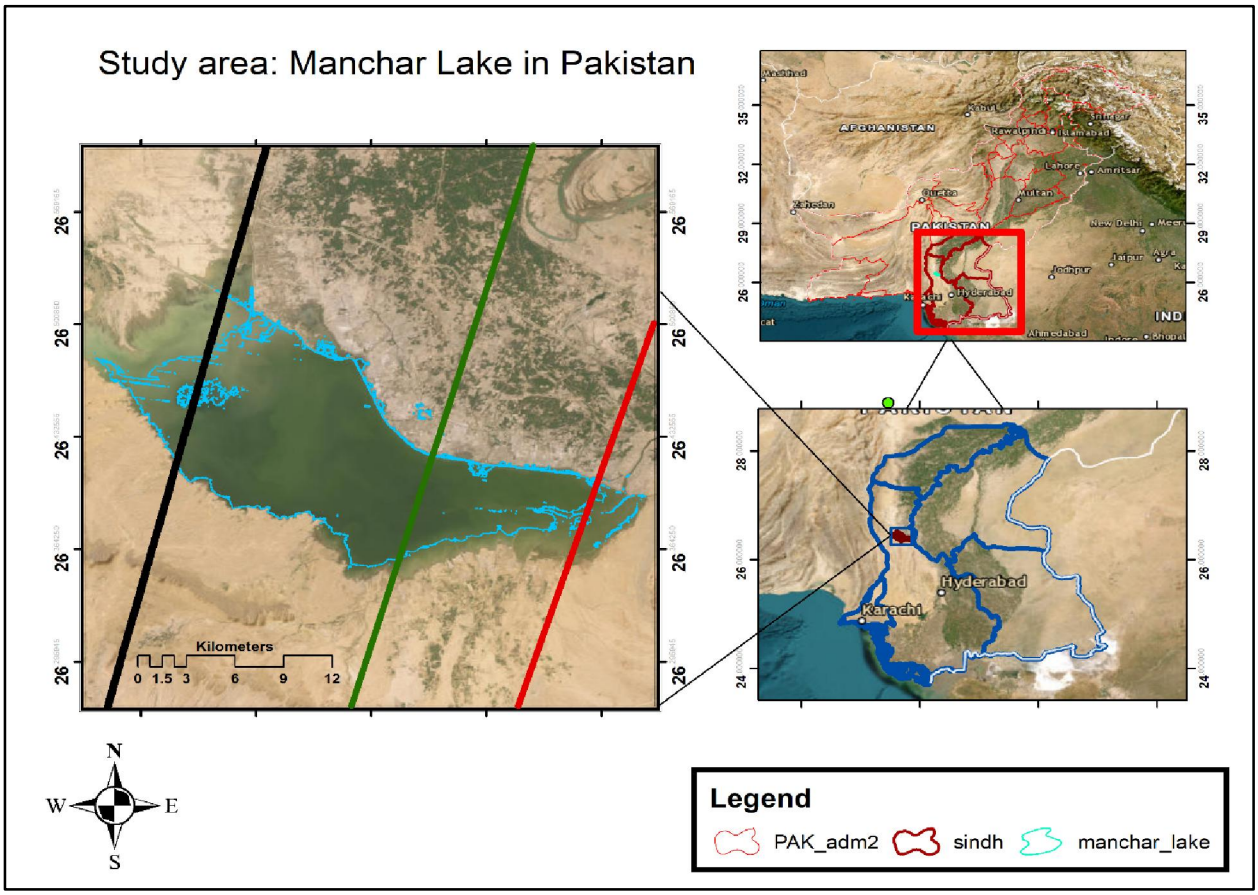

Figure 1: Study Area (Manchar Lake)

3. METHODOLOGY

3.1 Data Acquisition and Processing

ICESat2 surface water levels of Manchar Lake were acquired from NASA's official website, Earth data. Earth data has given access to the Open Altimetry from which ICESat2 data were acquired (https://openaltimetry.org/data/icesat2/). The Open Altimetry website processes ICESat2 datasets. They masked Manchar Lake using the permanent water surface of Hydro Lakes[6]. The ICESat2 water levels were compared with DAHITI observations.

In DAHITI, only Jason's satellite water levels were available for Manchar Lake (https://dahiti.dgfi.tum.de/en/). ICESat2 has many observations in a single day. Therefore, taking the median values of the passes was preferred to remove the water level outliers while comparing them with the DAHITI database[8]. A challenge encountered in this study was the inability to obtain precise matching dates for comparing the two datasets. However, data of the nearest available dates were compared. It was found that there were only difference of 2 days between

satellites dates and according to different literatures, no major activities were found between these days[1] [3] [4].

Similarly, ICEsat2 data were compared with Sentinel 3. Sentinel 3 data downloaded from Earth Console and processed in ArcGIS 10.8 (https://earthconsole.eu/). First Netcdf format was converted into table viewer to show the data in ArcGIS. Altimetry data set comprises myriad variables; However only required variables were selected for computation of water level. Water level was calculated through formula written as under [9]

$$Water\ levels\ =\ Altitude - Range - Geiod\ -\ \sum Correction\ equ. \quad (1)$$

Where altitude is the elevation of satellite from mean sea level (Reference ellipsoid), Range is elevation of satellite from earth surface, geoid is the reference correction and other atmospheric correction were also subtracted to calculate water levels. Its processing is done through model builder in ArcGIS which is shown in figure 2 and figure 3. [3] [9]

To ensure a robust comparison, data of the nearest available dates were compared to check the correlation between the two satellite datasets. There is no need of datum correction in this study. Because all satellite technology calculates water level elevation from same datum which is Mean Sea level.

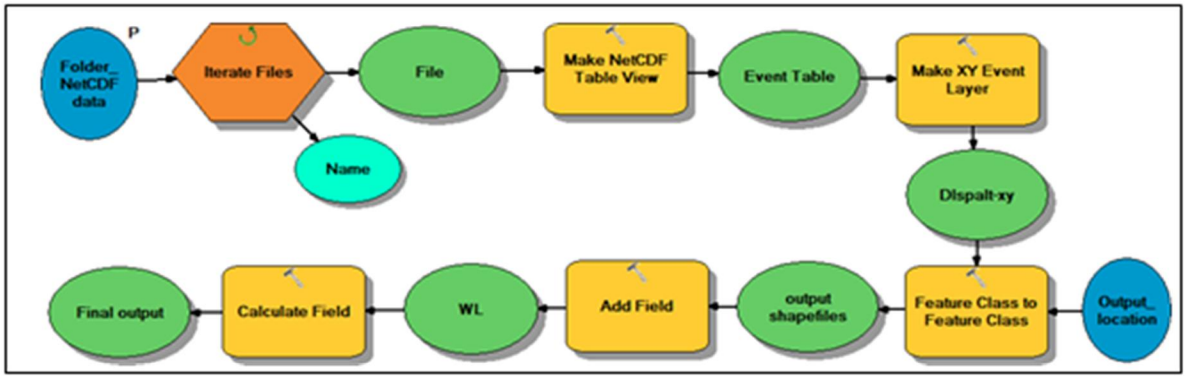

Figure 2: Processing of water level through Model builder

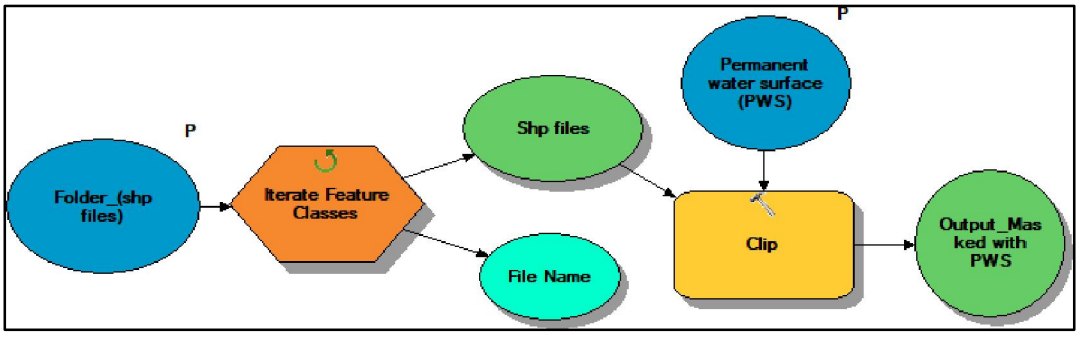

Figure 3: Masking satellites passes with Permanent water surface of study area.

3.2 Statistical Analysis

Correlation coefficient(R)

Correlation coefficient(R) is a statistical mechanism which elucidates the linear relationship between two variables: Independent and dependent variable. Pearson correlation coefficient was utilized to calculate the correlation between two variables. If it is close to 1 then it shows a positive correlation; However, -1 depicts negative correlation and 0 manifests no linear relationship between variables.

Mean square error (MSE)

Mean square error is metric technique which computes the average difference between predicted and observed data in dataset. It manifests the fitness between both outputs. Lower MSE shows better performance of model and enhance the validation of predicted dataset. However, Root means square error (RMSE) is also calculated among datasets to validate the accuracy of their relationships. RMSE is the square root of MSE which is not sensitive when dealing with errors. Therefore, these both techniques were utilized in these studies to improve the validation of these satellites.

4. RESULTS AND DISCUSSION

The water levels from ICESat2 and DAHITI are presented in Figure 4. It was further validated through statistical measurements in which the correlation value (R) was 0.534, an average Mean Square Error (MSE) of 0.196, and an RMSE error of 0.443 m. In the same way, water levels from ICESat2 and Sentinel 3 are shown in Figure 5. ICESat2 was compared with Sentinel 3 in which the correlation value(R) was 0.928, the average mean square error (MSE) was 0.22258, and the RMSE error was 0.4717 m.

Although not very strong, the water levels derived from ICESat2 have exhibited a statistically satisfactory agreement with DAHITI observations. Similar studies conducted in various regions worldwide have also revealed a strong correlation between water levels derived from ICESat-2 and DAHITI[6] [7].

Water levels from ICESat2 and Sentinel 3 have also shown a good agreement, and their correlation is better than that with DAHITI water levels. It might be attributed to the shorter time series due to the low temporal resolutions of both satellites. While there is a level of agreement between the water levels derived from ICESat-2 and Sentinel 3 observations, it is important to note that the MSE and RMSE values are relatively higher than DAHITI values. This indicates a relatively poor correlation between the two satellites. Thus, it is suggested to reevaluate the correlation in the future to ensure a more robust validation.

It is also suggested to install in situ gauges in Manchar Lake. The shorter time series available for ICESat2 resulted from its low temporal resolution, and the late mission started in 2018 affects the comparison with other datasets. To address the lack of exact date matching, incorporating in-situ observation gauges for a specific period could improve temporal alignment and enhance the accuracy of the comparisons. By utilizing an in-situ gauges, ICESat2 data can be compared with its exact matching data which will further ameliorate the validation of ICESat2 derived water levels. Therefore, it is suggested to work further on processing of ICESat2 datasets to address the issue of time series.

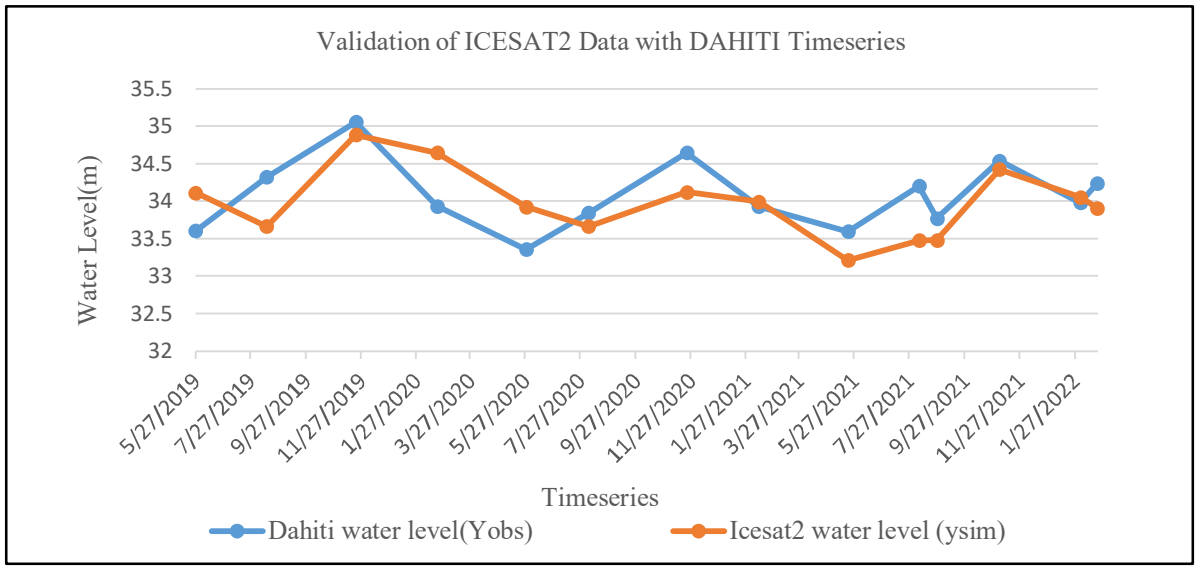

Figure 4: Dahiti vs ICESat2

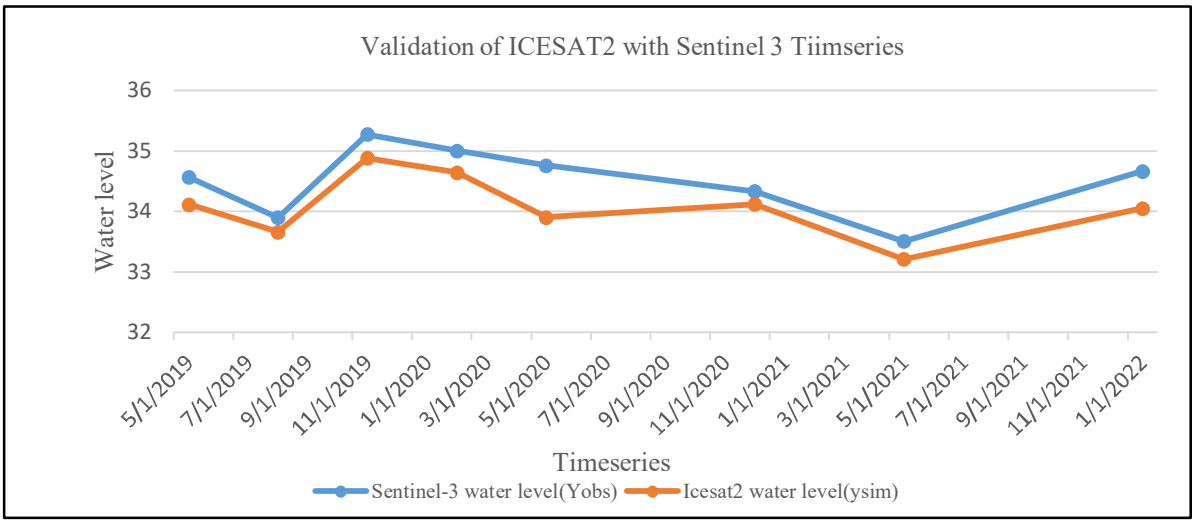

Figure 5: Sentinel-3 Vs ICESat-2

5. CONCLUSION

ICESat-2 altimetry data represents an advanced technology capable of computing water levels for inland water bodies of various sizes. From the above analysis, it has been concluded that ICESat2 data manifest an acceptable agreement with DAHITI retrieved water levels. DAHITI utilized multiple satellites to compute the water level and compared it with in-situ gauges. Therefore, data derived from DAHITI is considered validated data[8].

Sentinel-3 data from the Earth console had already been validated with in situ data in previous studies [3]. Therefore, ICESat2 data were also compared with Sentinel-3 data, which indicated a good agreement and ensured the validation of ICESat2. However, a significant limitation of this analysis is the low temporal resolution of ICESat-2, which restricts the frequency of data acquisition and can impact the accuracy of the results. Despite the limitation of low temporal resolution, the data from ICESat-2 can still be valuable in water resources management, particularly for predicting water levels in ungauged lakes. By combining the ICESat-2 data with observations from other satellites, monitoring these lakes can be significantly enhanced, filling the gap in water level data and improving overall management efforts.

Conflicts of Interest

[1] There are no conflicts of interest reported by the writers.

[2] Authors contributions

SJ is the first author and did all work related to methodology under the supervision of Arjumand Zaidi. TA and JR are altimetry experts which helped in processing altimetry satellites. Areeb Ul Haque helped with software and generating maps and charts.

[3] Data Availability statement

The data presented in this study are available on request from the corresponding author.

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