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Evaluating Lakes Boundary Change: A Case Study from Ward Number 26 of Pokhara Metropolitan City

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Abstract: Lakes are crucial for their multi-faceted services, including drinking water, irrigation, tourism, and more. Understanding their status, including area coverage, is important, and continuous monitoring is essential. Lakes can be monitored through various approaches, ranging from traditional ground-based surveys to advanced earth observation satellites. This study aimed to monitor several lakes in Ward Number 26 of Pokhara Metropolitan City, including Khaste, Neurini, and Gunde Lakes, using high-resolution cadastral maps, ground-based field surveys, and Sentinel-2 earth observation satellites. Additionally, focus group discussions and key informant interviews were conducted. Supervised land use and land cover classification and the Normalized Difference Water Index method were employed to determine the area of each lake in 2017 and 2021. The focus group discussions and key informant interviews investigated factors affecting lake dynamics. The study found that climate change, land use change, floods, water abstraction, and landslides are major factors contributing to changes in lake areas. The results showed that the satellite-derived lake boundaries were smaller than those indicated on the cadastral map. Ground surveys using total station equipment also revealed that Khaste Lake shrunk by 6122.73 m^2 (0.01 km^2), Neurini Lake lost 474.95 m^2 (0.00005 km^2), and Gunde Lake shrunk by 4226 m^2 (0.004 km^2) due to encroachment. Although satellite images are useful for detecting large-scale changes, this study indicates that the lake boundary areas identified through satellite imagery were smaller than those delineated by cadastral maps and ground surveys. This suggests that remote sensing analysis alone is insufficient for studying small lake boundary changes and should be combined with ground-based surveys. Therefore, a combination of satellite images and ground-based surveys is recommended for accurately and comprehensively detecting changes in lake areas.

Keywords: Land Use Land Cover (LULC), Normalized Difference Water Index (NDWI), Normalized Difference Vegetation Index (NDVI), Remote Sensing, Cadastral Mapping

1. Introduction

Pokhara-Lekhnath is home to a thriving wetland ecosystem, with nine lake clusters that were nominated as Nepal's 10th Ramsar site in 2016 (Paudel et al., 2017). These lakes serve as unique biodiversity hotspots and habitats. The lakes are a beautiful source of naturally occurring freshwater, with nine major lakes in the area: Fewa Lake, Begnas Lake, Rupa Lake, Dipang Lake, Maidi Lake, Khaste Lake, Neurini Lake, Gude Lake, and Kamalpokhari (Paudel et al., 2017). These lakes are under severe pressure due to rapid urbanization, natural erosion, encroachments, land use changes in the catchment, and anthropogenic inputs, resulting in the loss of area and deteriorating hydrological, economic, and ecological characteristics (Paudel et al., 2018). Although a comparison of ground-based surveys is a time-consuming and laborious process, it is still essential for obtaining more accurate results. In recent years, local people and relevant stakeholders have been increasingly concerned about protecting water bodies and the entire ecosystem (Hughes-Allen et al., 2023).

Many studies have used different satellite spectral indices to identify the lake boundary change (Rembold et al., 2000). The spatial-temporal changes of Lake Namak between the years 2001-2021 -in three decades-; Calculated using Landsat 5-TM, Landsat 7-ETM+, and Landsat 8-OLI images. "Initial interdisciplinary studies conducted in the Lakes region of central/south Ethiopia revealed a diverse land cover distribution marked by intricate interplays between environmental and socio-economic factors (Rembold et al., 2000). Ecologically, the region exhibits significant sensitivity, with escalating concerns over food security and soil conservation arising due to the burgeoning population. The substantial alterations in land cover witnessed over recent decades necessitate precise examination. Consequently, an in-depth analysis of long-term land cover changes was conducted." Analysis of aerial photographs from 1972 and the classification of a Landsat TM image from 1994 were conducted. Challenges stemming from the diverse characteristics of the data were addressed by employing a technique to quantify land cover on the aerial photographs, resulting in data that could be compared to the TM classification outcomes. As land cover is linked, through land use, to social dynamics, ground control use was made of the results of parallel socio-economic investigations. During the analysis, a consistent rise in cultivated areas was observed. Distinctive approaches to land distribution based on physical conditions were detected. A pattern in the development of Bad Lands emerged: the rapid resurgence of past erosion in newly cultivated regions was evident, reaching a quasi-stable state within a few decades. While the methods employed had some accuracy constraints, they facilitated a 22-year analysis of land cover changes, offering valuable insights into recent trends. They have utilized the Normalized Differential Water Index (NDWI), Modified Difference Water Index (MNDWI), Water Ratio Index (WRI), and Automatic Water Extraction Index (AWEI). As a result, the changes in the water surface that occurred in the 20 years were compared spatially in (km^2) and it was determined by the NDWI index (Özvan, 2021). “The International Federation of Surveyors (FIG) published a statement on the Cadastre in 1995, which defines the Cadastre as a parcel-based and up-to-date land information system containing a record of interests in the land (e.g., rights, restrictions, and responsibilities)”. A Cadastre is like a map that shows the shape of different pieces of land.

This study aims to detect Lake Boundary change through remote sensing and field-based measures. The existing cadastral map was prepared in 1975 through a ground-based survey using a total station to evaluate changes in the boundaries of the lakes. The changes will also be evaluated using Normalized Difference Water Index and Land Use Land Cover (LULC) maps. The findings from these methods have been compared. Focus group discussions and key informant interviews were used to identify the causes and consequences of the changes in the Lake Region. Local people, Farmers, Fisherman, and government representatives were among the participants in these conversations and interviews

The study helps to understand the lake boundary change and its surrounding human and natural environmental impact on it. The results will also help develop effective management strategies to protect these lakes, which are essential for both ecological and economic purposes. This project will be critical for local people, related stakeholders, and policymakers in making informed decisions regarding the sustainable management of the wetland ecosystem in Pokhara.

2. Methods and Materials

2.1 Study Area

In terms of administrative boundary, Pokhara is one of the largest metropolitan cities in Nepal. It is located in central Nepal, and is the headquarters of the Kaski district as well as the capital of Gandaki Province according to the recent federal restructuring of Nepal.

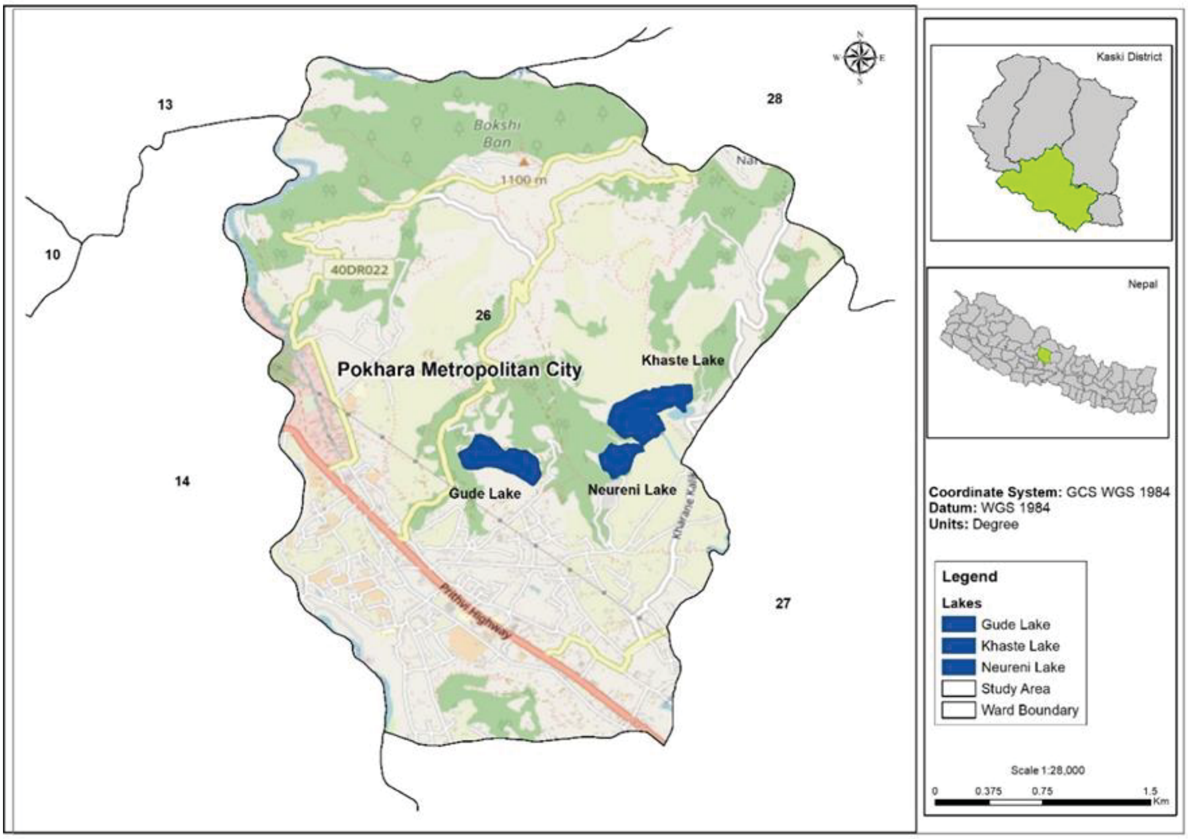


Figure 1. Figure Depicting the Study Area, Namely: Khaste, Neurini and Gunde Lakes. Data Source: www.dos.gov.np, Openstreetmap.org

The total area of Pokhara is 464.94 km² representing 23.01% of the Kaski district and 0.31% of the country. The average temperature in Pokhara ranges from 7ºc minimum to 31ºc, with an annual rainfall of 3800 mm. Out of the nine lake of Pokhara Metropolitan City, three lakes namely Khaste, Neurini, and Gunde were taken as the study area for this research. According to the census data of 2021, the population of Pokhara Metropolitan City is 513,504, with a sex ratio of 93.04 males per 100 females. The population density is 1,106 people per square kilometre, and there are a total of 140,459 households in the city (Census Nepal, 2021). The literacy rate is 88.7%, with 94.2% of males and 83.7% of females being literate (Census Nepal, 2021). Khaste Lake, Niureni Lake, and Gunde are freshwater bodies located within ward number 26 of Pokhara Metropolitan City. They have been listed under the Ramsar convention along with Phewa, Begnas, Rupa, Dipang, and Maidi lakes.

2.2 Data Collection Methods

Various data sources, such as satellite remote sensing data, total station survey, cadastral maps, focus group discussions, and key informant interviews, were used to detect changes of lake areas in the Khaste, Neurini, and Gunde lakes. The analysis incorporated methods including NDWI computation, supervised LULC, and change detection and focuses on changes that have been placed between 2017 and 2021. A thorough understanding of the changes that have taken place in the lakes over time is provided using field surveys to validate the changes detected using satellite imagery and the use of focused group discussions and informant interviews are utilized to understand the factors responsible for the changes (Figure 2).

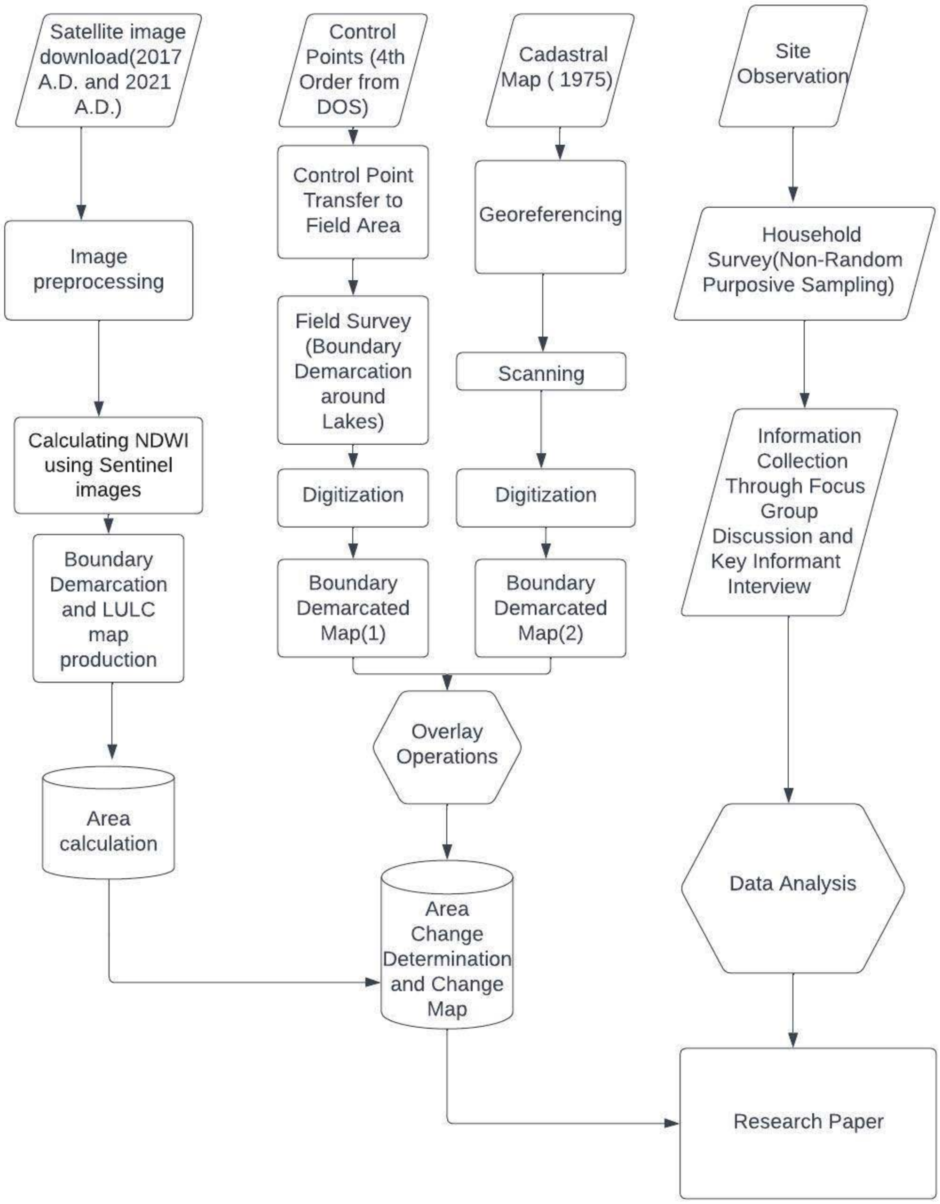


Figure 2. Flowchart of the Methodology

Downloading satellite imagery and gathering cadastral maps for the study region was the first step in the technique. The cadastral maps offer details on local land use and ownership patterns and can be used to spot prospective changes in the lake area. The maps, which were collected from the Survey office Lekhnath were used to spot any potential land-use changes that might have affected the lakes, like the conversion of agricultural areas into urban developments or deforestation.

2.3 Satellite Image Download and Preprocessing

The Copernicus Open Access Hub provided access to the Sentinel satellite imagery, and images from 2017 and 2021 were selected for this study. Sentinel2 multispectral data was used to calculate the Normalized Difference Water Index (NDWI). The NDWI calculation, LULC classification, and change detection were performed using Sentinel2 images. The red and near-infrared bands of the satellite imagery were utilized to generate Normalized Difference Water Index (NDWI) values. A threshold value of zero was established to differentiate pixels containing water from others. This approach was employed for water extraction from satellite images using bands 3 and 5 (Acharya et al., 2018). We utilized a threshold value of zero to distinguish surface water bodies from the image data. Any NDWI values above zero were categorized as water, while those below were classified as non-water features.

NDVI = (NIR - RED) / (NIR + RED).................................1

Where, NIR= spectral reflectance value near infra-red

RED = spectral reflectance value in the red range

Depending on the quality of the images and the desired level of accuracy, LULC classification was carried out using supervised methods. The NDWI and LULC values of two images taken at various times were subtracted, and a threshold value was established for the difference image.

2.4 Ground Survey

Field survey was the other data collection method used in this study.The information collected from the field was used to compare the changes extracted from satellite remote sensing data analysis. The total station survey was carried out to determine the size of the lakes and to confirm the changes in land use noted on the cadastral maps. The accuracy of the field data was verified using ground-truthing techniques. The information gathered from field surveys was compared to the alterations found by satellite images.

2.5 Focus Group Discussions and Key Informant Interviews

These methods were used to identify the causes and consequences of the changes in the Lake Region. Local people, Farmers, Fisherman, and government representatives were among the participants in these conversations and interviews. Finding the reasons behind the changes in the lake area, such as the usage of the lakes for irrigation, urbanization, and pollution, was the main goal of the discussions and interviews. A total of 42 respondents participated in the household survey using non-random purposive sampling statistical measure. The perception of people about the factors affecting the boundary of the lake was analysed and discussed using graphical measure.

3 Results

3.1 Land Records of Khaste Lake, Neurini Lake

According to the information obtained through the survey office, the area of Khaste lake which is situated in Kananidada VDC (Village Development Committee) ward no. 1 and parcel no 199 is 332-14-2-2 (Ro-A-P-D) and Neurini lake which is situated in Kananidada VDC ward no. 1 and parcel no. 294 is 74-15-2-2 (Ro-A-P-D) i.e., 0.16 km^2. According to the information obtained through survey office the area of Gunde lake which is situated in Kananidada VDC ward no. 4 and parcel no. 185 is 82-1-3-3 (Ro-A-P-D) and also the parcel no 146 which is barren land of area 97-4-0-0 area is included in the lake.

3.2 Land Use Land Cover Map and Lake Area Change

Supervised LULC classification was performed using Sentinel 2 imagery to identify the land cover classes from the satellite data. The training samples of each class were collected from pixel, the LULC class was determined from field and their corresponding spectral values were assigned in the image and the rest pixel values of image were classified based correspondence pixel value.

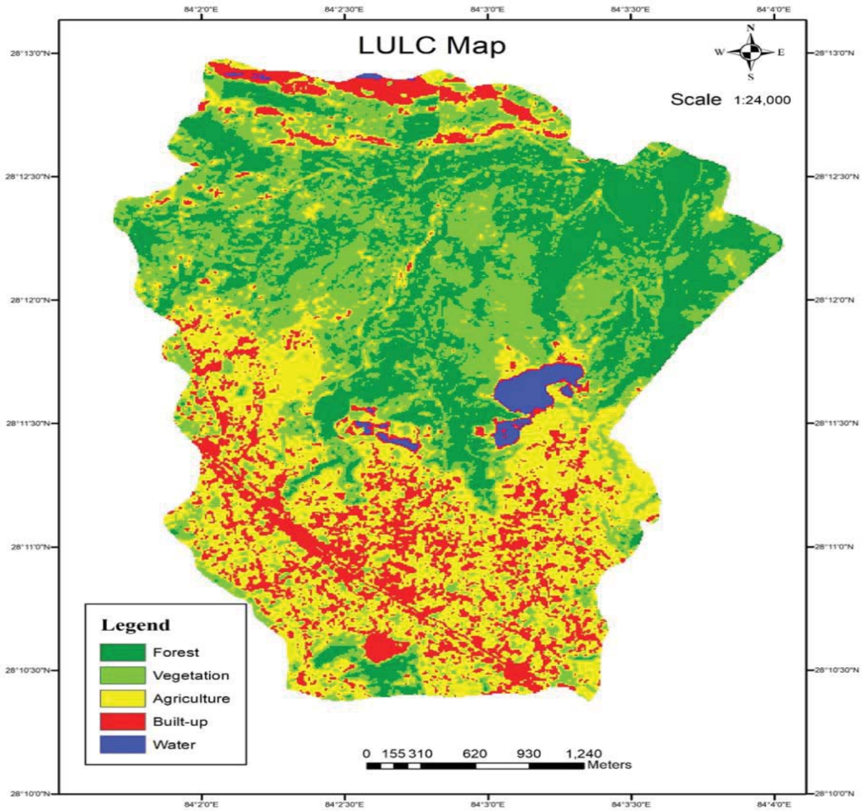
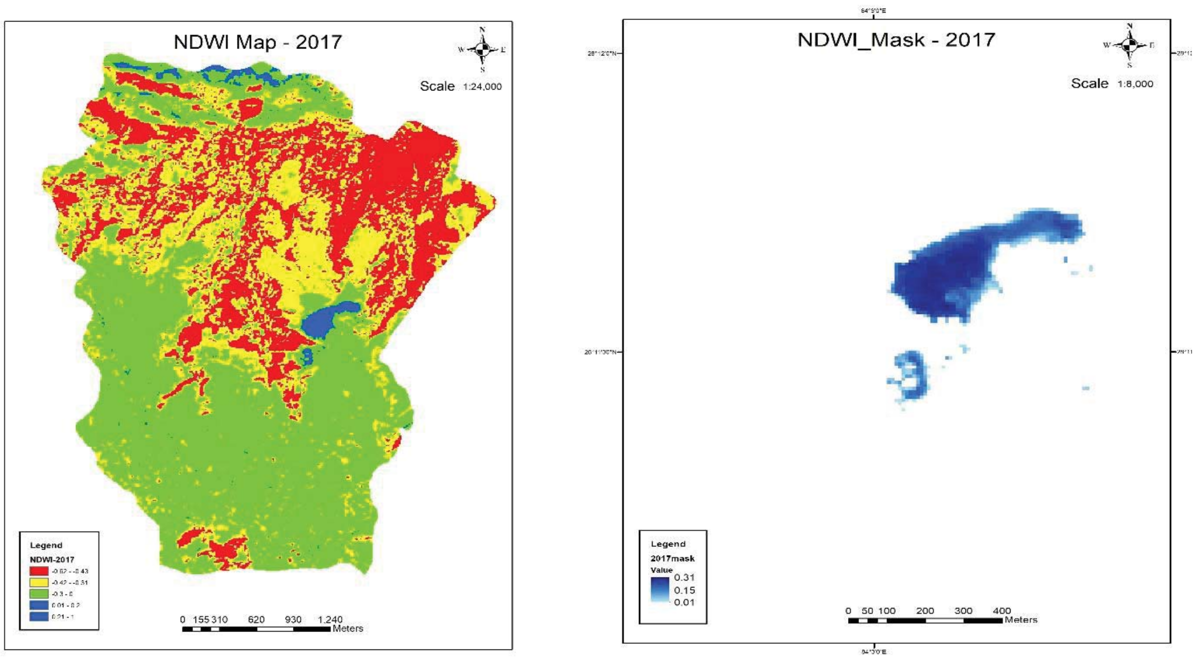


Figure 3. Land Use Map – 2021

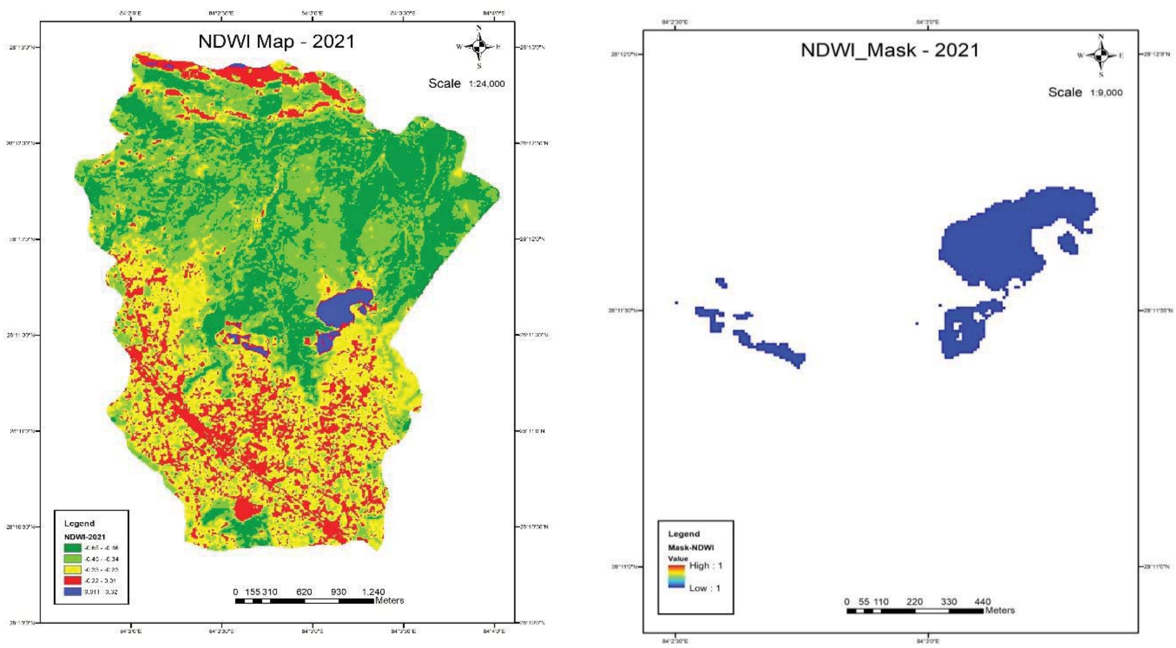
The area mainly covered by forest and cultivated area followed by built-up area. Least area was covered by water bodies. Detail about present land use and cover of the study area can be seen in the Figure 3.



a

b

Figure 4. a) NDWI for the Year 2017; b) b) NDWI mask



b

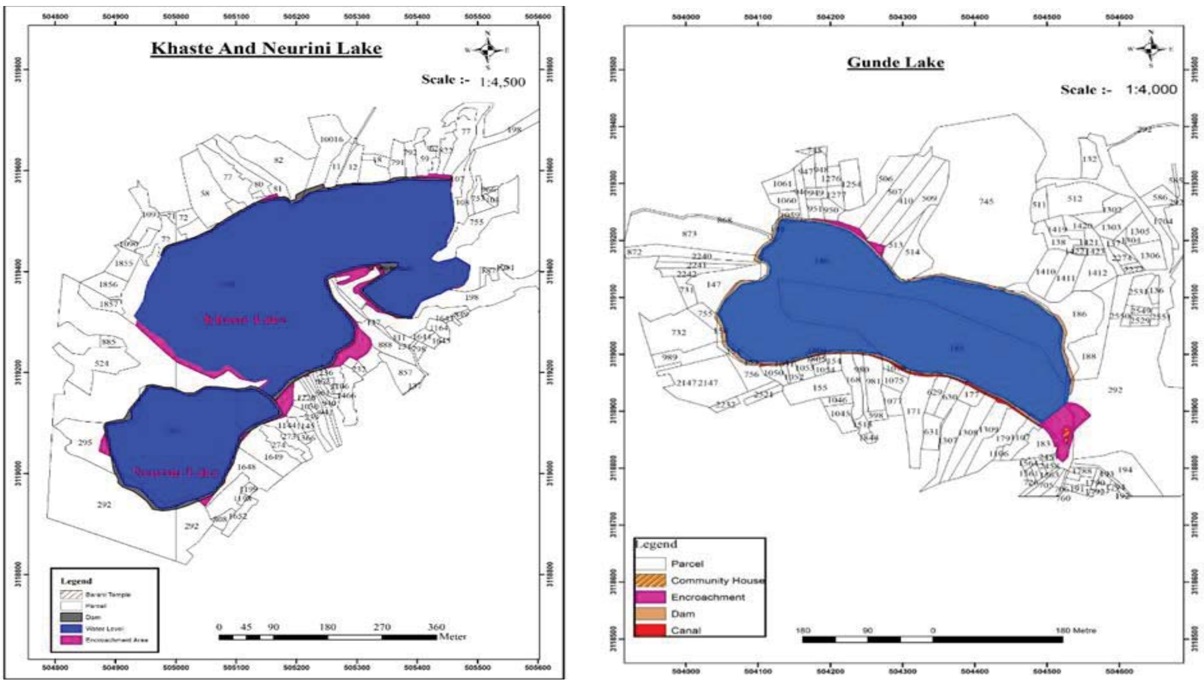
a

Figure 5. a) NDWI 2021; b) NDWI mask

Once the NDWI is computed, threshold values are applied to extract water from the NDWI data. The NDWI formula is (Green - NIR) / (Green + NIR), where Green represents the reflectance in the green band and NIR represents the reflectance in the near-infrared band. Figures 4a and 5a show the NDWI values of the interested region. A threshold value was set, with pixels categorized as water if their NDWI values surpassed the threshold, and as non-water if they fell below it. This process allowed for the creation of a binary image that distinguishes water and non-water areas.

3.3 Field Records of Khaste and Neurini Lake

After the field survey, the actual area covered by the water level was calculated in all three lakes, where Khaste Lake occupies 136138.83 m^2 i.e.0.14 km^2 267-9-2-2 (Ro-A-P-D) and the area covered by the roads and dams in Khaste Lake is 4896.59 m^2i.e.0.005 km^2 9-10-0-0 (Ro-A-P-D). The total area of encroachment obtained by overlapping the cadastral shape file of the lake and the recent condition of Lake Boundary is 6122.73 m^2 i.e., 0.01 km^2 12-0-2-1 (Ro-A-P-D), which we can be seen in Figure 6 (a). Also, 3958.61 m^2 i.e., 0.004 km^2 7-12-2-0 (Ro-A-P-D) area of Khaste lake which is mapped as Khaste Lake during parcel survey is now taken by Neurini lake boundary.



a b

Figure 6. Lake Boundary Changes a) Khaste and Neurini Lake b) Gunde Lake

After the field survey, the actual area covered by the water level in Neurini lake can be seen on figure 6(a) was found to be 46597.14 m^2 i.e., 0.05 km^2 91-9-2-0 (Ro-A-P-D) and the area covered by the roads and dams was 3688.34 m^2 i.e., 0.004 km^2 7-4-0-0 (Ro-A-P-D). The encroached area obtained by overlapping the cadastral shape file of the lake and the recent condition of lake boundary was 474.95 m^2 i.e., 0.00005 km^2 0-14-3-3 (Ro-A-P-D).

3.4 Field Records of Gunde Lake

After the field survey, the actual area covered by the water level in Gunde lake is 86451.5 square meter i.e. 169-14-3-3 (Ro-A-P-D) and the area covered by the roads and dams is 5377.51 square meter i.e., 10-9-0-2 (Ro-A-P-D) and the area covered by the canal is 1081 square meter i.e., 2-2-0-0 (Ro-A-P-D). The total area of encroachment obtained by overlapping the cadastral shape file of the lake and the recent condition of lake boundary is 4226 square meters i.e., 8-4-3-2 (Ro-A-P-D). This area has been used by community buildings and rest of it is open field.

3.5 Overall Change Detection of Lake Boundary

In this study, the NDWI was used to measure the size of three lakes in the region: Khaste Lake, Neurini Lake, and Gunde Lake. After calculating the NDWI from the satellite image in 2017 A.D., Khaste Lake covered an area of 0.08 sq. km, Neurini Lake covered 0.02 sq. km, and Gunde Lake was barely visible using the NDWI method, indicating minimal water content. However, upon re-computation of the NDWI in 2021 A.D., changes in the lake areas were observed. Khaste Lake expanded to 0.03 sq. km, Neurini Lake increased to 0.01 sq.km, and Gunde Lake also showed an increased area of 0.02 sq. km. The overall change detection of Lake Boundary is tabulated below Table 1.

Table 1. Overall Change Detection of Lake Boundary

Lakes/years	2017(Satellite Image Survey)	2021(Satellite Image Survey)	Ground Survey (2022)	Cadastral Survey (near about 1975)
Khaste Lake (in Sq. km)	0.08	0.11	0.14	0.16
Neurini Lake (in Sq. km)	0.02	0.03	0.05	0.04
Gunde Lake (in Sq. km)	Nearly Invisible	0.02	0.08	0.09

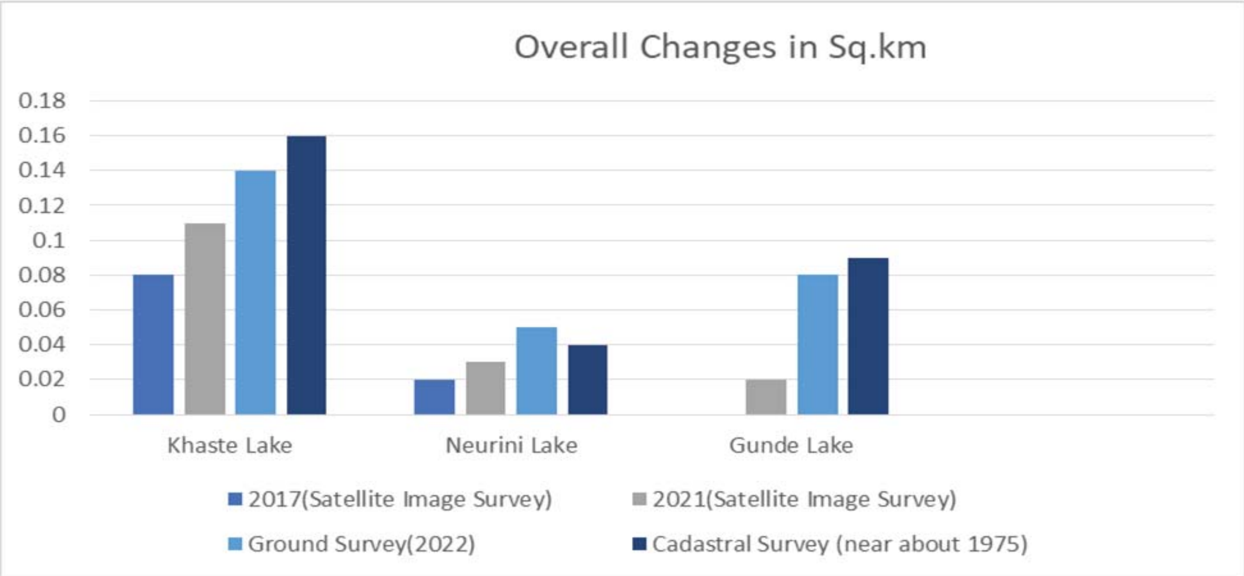


Figure 7. Bar Diagram Showing the Overall Change

Based on the analysis, the study found that the area of Khaste Lake was 80,000 m^2, i.e 0.08 km^2 in 2017. While the area of Neurini Lake is 0.02 km^2. However, the area of Gunde Lake was nearly invisible in the Normalized Difference Water Index method. In 2021, Khaste Lake measured 0.03 km^2, Neurini Lake was 0.01 km^2, Gunde Lake also covered 0.02 km^2.

The study findings indicate alterations in the lake boundaries from 2017 to 2021. It's worth mentioning that a cadastral survey conducted around 1975 estimated Khaste Lake's area to be approximately 0.16 km^2. Conversely, field ground surveys revealed an area of 0.14 km^2, while NDWI satellite image calculations for 2017 and 2021 depicted areas of 0.08 km^2 and 0.11 km^2, respectively.

During a cadastral survey around 1975, Neurini Lake was measured at 0.04 km^2. However, field ground surveys indicated a slightly larger area of 0.05 km^2. NDWI satellite image calculations for 2017 and 2021 revealed areas of 0.02 km^2 and 0.03 km^2, respectively.

Similarly, the area of Gunde Lake during a cadastral survey around 1975 was recorded as 0.09 km^2. Field ground surveys confirmed this measurement at 0.09 km^2. However, NDWI satellite image calculations for 2017 showed no water area, whereas for 2021, the area was determined to be 0.02 km^2.

3.6 Social Aspect

Out of the 42 respondents who took part in the household survey, the majority were men, making up nearly 72% of the participants. A significant portion of the respondents had completed secondary-level education, while approximately 12% reported being illiterate and unable to read or write. The survey indicated that the largest occupational group among the respondents was farmers, constituting 52.38% of the total.

About 54% of respondents believed that extreme rainfall was a prominent cause of soil erosion into the lakes, while 45% thought that floods were the main issue. A majority (55%) perceived a medium amount of sediment carried by flooded water. About 33 respondents identified soil erosion, sediment load deposition, and floods as adverse factors affecting lakes, while 9 believed cultivated land was affected. Knowledge of engineering/bioengineering techniques for mitigating sedimentation was limited. Respondents perceived lower sediment deposition in lakes in the past 3 years due to dams, but higher deposition in the past 3-8 years. Encroachment on lakes was poorly understood, with some attributing it to human activities, natural calamities, or development activities. Overall, respondents believed that scientific techniques such as check dams, embankments, and bioengineering could protect lakes from floods and landslides and that development activities should be adopted for lake preservation. The perception of people on these issues provides insights for potential strategies and actions to mitigate hazards and protect lakes.

The lakes have faced issues such as encroachment, floods, and sediment deposition. However, various programs have been implemented over the past decade to restore their condition. Human activities and natural forces like soil erosion and sedimentation have caused encroachment, resulting in a decrease in lake depth. As a result, grass has grown over some parts of the lake, making them look like islands. The Khaste Neurini Tal Conservation Committee and Gunde Tal Conservation Committee have been actively working towards the development of these lakes. The Hariyo Ban Program of WWF Nepal is dedicated to the preservation of the environment. They have been constructing foot tracks and gabion walls with funding from Lions Clubs within Pokhara Metropolitan City.. The District Forest Office inKaski, has also contributed by building gabion walls near the rivers to preserve forest areas. Neurini Lake is known as a bird watching lake, with various bird species found in its vicinity. The Soil and Watershed Management Office has also contributed to maintaining dams and other construction activities. Overall, concerted efforts from multiple stakeholders have been made to address the issues affecting these lakes and restore their condition.

4. Discussion

Lakes change over time due to natural processes and human activities, impacting their physical and biological characteristics. Similarly, the area of Khaste Lake had decreased to 0.02 km^2, Neurini Lake had increased to 0.01 km^2, and Gunde Lake remained almost the same at 0.02 km^2.

Various studies have used different methods to detect changes in lake area, including remote sensing, aerial photographs, and ground-based surveys (Wdowinski et al., 2016). For instance, (Wdowinski et al.,2016) used satellite imagery to study the changes in the Salton Sea in California and found that the lake had lost approximately 20% of its area due to increased evaporation and reduced inflows (Zhang et al., 2017). Similarly, Zhao et al. (2019) used Landsat images to study the changes in the Poyang Lake in China and found that the lake area had decreased by 31.1% over 30 years due to climate change and human activities (Liu et al., 2019). On the contrary, a combination of satellite and in-situ measurements was utilized to investigate changes in lake temperature. The findings revealed that lakes are warming at a faster rate compared to the surrounding atmosphere (O'Reilly et al., 2015).

In our study, we employed cadastral maps, field surveys, NDWI calculations, and LULC maps to identify changes in Khaste, Neurini, and Gunde Lakes. Through this approach, we discovered the significance of their interconnectedness.

The encroachment area obtained by overlapping the cadastral shape file of Khaste Lake and the recent condition of Lake Boundary was 6122.73 m^2i.e.12-0-2-1(Ro-A-P-D). Almost 3958.61 m^2 i.e., 7-12-2-0 (Ro-A-P-D) area of Khaste lake which was mapped as Khaste Lake during the parcel survey is now taken by Neurini lake boundary. The total area of encroachment obtained by overlapping the cadastral shape file of Neurini lake and the recent condition of the lake boundary was 474.95 m^2 i.e., 0-14-3-3 (Ro-A-P-D). Similarly, encroachment obtained by overlapping the cadastral shapefile of Gunde Lake and the recent condition of the lake boundary was 4226 m^2 i.e., 8-4-3-2 (Ro-A-P-D). This area has been used by community buildings and the rest of it was used as an open field.

The area of Khaste Lake was 0.08 km^2, that of Neurini Lake was 0.02 $km^2$and that of Gunde Lake was nearly invisible in the Normalized Differenced Water Index method in the year 2017 (Figure 4a). We obtained the area of Khaste Lake to be 0.11 km^2, Neurini Lake to be 0.03 $km^2$and Gunde Lake to be 0.02 km^2 by computing NDWI in 2021. The area of Khaste Lake had decreased to 0.03 km^2, Neurini Lake had increased to 0.01 km^2, and Gunde Lake remained almost the same at 0.02 km^2. Thus, in delineating the boundary of the lakes from field ground survey are more accurate for the small area rather than using satellite image of the coarse resolution as the reasons accuracy highly depends on the spectral and spatial resolution.

The findings of this study highlight the potential of remote sensing techniques in identifying and monitoring changes in water bodies over time. However, the accuracy of the results obtained using remote sensing depends on various factors such as spectral and spatial resolution of the satellite images, atmospheric conditions, and topography of the area under study. In this section, we will discuss these factors in more detail and provide references to support our arguments.

One critical factor influencing the precision of remote sensing data is the spectral resolution of satellite images. Spectral resolution refers to the quantity and width of spectral bands utilized in remote sensing data. Several studies have indicated that employing narrow spectral bands with high spectral resolution can enhance the accuracy of water body mapping (Gao, 1996; Hansen et al., 2008). However, spectral resolution alone may not suffice for accurately mapping water bodies, as it can be impacted by atmospheric conditions and other variables (Jensen et al., 2007).

Another crucial factor impacting the accuracy of remote sensing data is the spatial resolution of satellite images. Spatial resolution refers to the smallest object size that can be distinguished in the image. Numerous studies have demonstrated that using high spatial resolution images can enhance the accuracy of water body mapping (Brodie et al., 2018; Suel et al., 2021). Nonetheless, high spatial resolution images may not always be accessible, and achieving precise water body maps with low spatial resolution images can pose challenges (Hansen et al., 2008).

Although remote sensing techniques offer significant potential in identifying and monitoring changes in water bodies, it is essential to meticulously consider these factors during data analysis. Ground truthing and field surveys remain crucial for validating the accuracy of remote sensing data, particularly for small water bodies, as indicated by the findings of this study.

5. Satellite Data in Small Area Mapping

The area of the lakes, as determined by cadastral surveys conducted around 1975, exhibits a decreasing trend compared to the current lake boundary area. While the Normalized Difference Water Index (NDWI) method indicates an increase in lake area between 2017 and 2021, the overall area still shows a decrease compared to the cadastral survey. This discrepancy may be attributed to vegetation growth over the lakes or the limited coverage area of the study, which affects the accuracy of water detection using NDWI with low spatial resolution satellite images.

Field surveys conducted on Khaste Lake, Neurini Lake, and Gunde Lake reveal encroachment on the lakes due to human activities, agricultural practices, and signs of community buildings and open fields encroaching on their areas. Consequently, for delineating lake boundaries, on-field ground surveys prove to be more accurate for smaller areas compared to satellite imagery due to their coarse resolution. This discrepancy underscores the importance of spectral and spatial resolution in achieving accuracy. Ground-based surveys provide more precise data for detecting changes in lake areas, potentially attributed to vegetation growth over the lakes or the limited coverage area affecting water detection through NDWI with low-resolution satellite images

The lakes faced several challenges, including encroachment from human activities, floods, and sediment deposition. Agriculture was also practised along the lake basins. Declining lake depths were attributed to sedimentation deposition on the lake beds, exacerbated by extreme rainfall leading to landslides and soil erosion. While engineering and bioengineering constructions aim to minimize sedimentation, proper management of these structures is deemed necessary.

The study recommends expediting a survey of the lakes based on cadastral surveys to address encroachments. Additionally, suggestions from local communities included the construction of check dams to mitigate landslides and soil erosion, siltation dams in rivers to prevent sedimentation deposition in lake beds, and the construction of lake dams to manage overflow.

6. Conclusion

The study of Lake Boundary change was carried out using Sentinel 2 multispectral image, field survey and compare it with the cadastral map of the lakes. The surrounding physical environment and human activities were assessed while studying the lake boundary change. Supervised land use and land cover map and Normalized Difference Water Index (NDWI) were used to identify the lake area from the satellite image. Lake boundary changes over the last five years were analyzed using satellite images. The NDWI-derived result shows that the lake area has increased over the study period in all three lakes. On the other hand, the cadastral map and ground survey (total station) survey result shows the lake area has reduced due to surrounding human interference and soil erosion. Contrary to that, the satellite-derived lake area was lesser than the cadastral map and total station survey data. This can be attributed to the resolution of satellite images, and it can be difficult to accurately identify the boundaries of small lakes. Therefore, the study concludes that satellite remote sensing data with coarse resolution alone are not enough to study Lake Boundary change, which needs to combine with other field-based data collection and analysis techniques for better results.

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