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TEMPORAL FLOODPLAIN CHANGE ASSESSMENT USING GIS: A CASE OF TINAU RIVER, BUTWAL

Pankaj Adhikari*

Department of Civil Engineering, Pulchowk Campus, Institute of Engineering, Tribhuvan University, Nepal

*Corresponding author: appathik@gmail.com

Abstract

The understanding of historical floodplain change plays a pivotal role in the minimization of flood risk to communities. Though many research works in Nepal have attempted to study the Land Use Land Cover (LULC) change in different parts of the country, they have not dealt with identification of the floodplain and its change pattern over the period of the time. This study is aimed at understanding the historical change in floodplain of Tinau River in Butwal city which has repeatedly witnessed devastating flooding events. For the purpose, historical Landsat images for the year 1988, 1999, 2009 and 2020 were acquired from earth explorer site of USGS. The supervised classification was performed in QGIS by classifying into vegetation, agricultural land, water bodies, floodplain and settlement. The result shows that there is significant decrease in the area of the floodplain. In the span of around 32 years, its area has decreased by around 229 hectares. The major regions of floodplain encroachment are found to be Buddhanagar, Majuwa and Sundarnagar. Moreover, significant increase in the area of settlement and decrease in agricultural land was observed. The result could be helpful for the policy makers to formulate strategies to prevent floodplain encroachment and cope with flood risk. Likewise, it can be baseline for further studies which delve into the details of change analysis of floodplain.

Keywords: Floodplain Change, GIS, LULC Assessment, Tinau River, Butwal sub-metropolitan city

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1. Introduction

Flood is one of the most devastating disasters in the world which causes loss of lives and property (Sharma et al., 2021). Nepal is ranked 4th in terms of vulnerability due to climate change and 30th in flood (Guragain and Doneys, 2022). From the year 2017 to 2022, altogether 538 people have died and there has been economic loss worth hundreds of millions (in Nepali Rupees) due to the flooding events in different parts of the country (Ministry of Home Affairs, 2023). Every year the southern plain in Nepal is badly affected by the flood in the local rivers. The Koshi flood of 2008 (Kafle et al., 2017) , the Terai flood of 2017 (Pathak et al., 2020) and Melamchi flood of 2021 (Maharjan et al., 2021) are some of the big flooding events in recent decades.

The changes in Land Use Land Cover (LULC) represent the main changes carried out by humans on the Earth's surface with these alterations occurring due to environmental and socioeconomic characteristics, such as population growth, urbanization, industrial development and environmental policy (Perović et al., 2018). The processes of LULC change have directly impacted the biodiversity, biosphere–atmosphere interactions, ecosystem service provisions and the sustainable utilization of natural resources (Msofe et al., 2019) . In the watershed areas, it has an ongoing impact on water availability, as well as the form and breadth of surface and subsurface water interactions (Butt et al., 2015). The relentless change in land use can affect flood propagation, flood frequency and flood volume (Yang et al., 2016). Thus, the LULC changes play a significant role in increasing hydrological hazards (Hasan et al., 2023).

Floodplains are the periodically inundated areas adjacent to river bodies (Jia et al., 2020). They are prominent element of riverine landscapes that provide a broad variety of ecosystem services (Alam et al., 2021) . One of the major reasons for the huge impacts of flood is the rampant floodplain encroachment in the urban areas. With the advancement in Geographical Information System (GIS) and the usage of Digital Elevation Models (DEM), computer-based auto-classification of landform units have become easier (Roy and Das, 2021). The remote sensing and GIS techniques have immense potential in determining and assessing the spatial variability of the LULC (Thakur et al., 2020). The floodplain change analysis could be helpful in minimization of flood risk and its impacts to communities.

Many studies have been conducted in Nepal to analyze the change in land use over a period of time. For example: Rimal et al. (2019) in the south eastern plain, Shrestha and Acharya (2020) in Kathmandu valley (Kathmandu, Lalitpur and Bhaktapur district) Adhikari et al. (2020) in Chitwan, Rimal et al. (2020) in western Terai, Kc et al. (2021) in Rupandehi, Gautam and Rai (2022) in Kathmandu district, Devkota et al.(2023) in 12 major cities namely Bharatpur, Biratnagar, Birendranagar, Dhangadhi, Ghorahi, Hetauda, Janakpur, Kathmandu, Nepalgunj, Pokhara, Rajbiraj, and Tulsipur. However, these recent contributions do not delve into details of change in floodplain. Their primary focus has been to estimate the change in settlement and vegetation only. Thus, there prevails the deficiency of knowledge of floodplain change. Consequently, it has led to increasing flood risk. Therefore, this study attempts to fill this void by assessing the historical floodplain change in the Tinau River in south western plain of Nepal.

There are two reasons behind selection of the Tinau River as study area. First of all, it has repeatedly witnessed big flooding events triggering scores of deaths and property damages worth millions (in Nepali Rupees) (Dhungana et al., 2016). Secondly, the floodplains in the river are facing encroachment due to increasing squatter settlements (Marasini and Chidi, 2021). Through the review of literature, it has been found out that there is dearth of research works which focus in the study of floodplain change in Tinau River. So, this study has been carried out with the objective to study the change in floodplain over the years.

For the purpose, the historical Landsat images of Tinau River in Butwal city representing different decades since 1988 have been acquired. The supervised classification was performed in QGIS by dividing the landforms into vegetation, agricultural land, water bodies, floodplain and settlement. Finally, the change in the area of the landforms were estimated and analyzed. The findings on floodplain change could help in mitigating the flood risk and reduce the loss of lives and property. It would be useful for governmental bodies, policy makers and researchers to understand the status of land use and implement sustainable development policy.

2. Materials and methods

2.1 Study area

Butwal sub metropolitan city lies in Lumbini province of Nepal. It is located 177 meters above the sea level. The Tinau River flows through the central part of the city. The climate is warm and temperate. The annual rainfall in the town is 2085 mm whereas the average annual temperature is 22.0 °C (Thapa and Poudel, 2018). For the purpose of this research work, the Tinau river vicinity in ward number 1, 2, 3, 5, 6, 8, 9, 11, 17 and 19 of Butwal submetropolitan city and ward number 3 of adjoining Tilottama municipality are chosen as study area. The study area is shown in Figure 1.

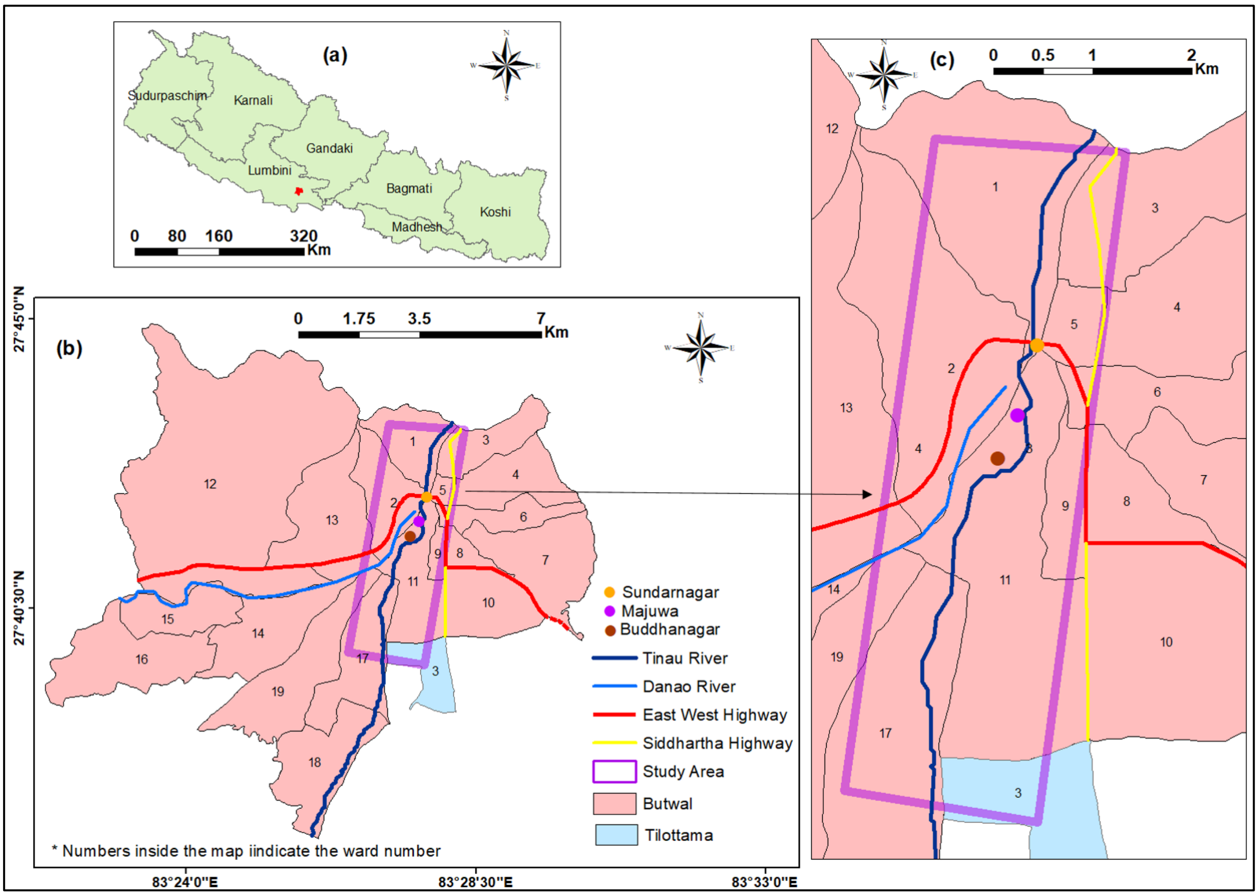

Figure 1: Location Map (a) Nepal with provinces (b) Administrative map of Butwal city and Tilottama ward (c) Study area

2.2 Methodology

The process of defining a floodplain is an ambiguous task (Croke et al., 2016). According to Thayer and Ashmore (2016), the geological structure which preserve alluvial deposits previously laid down by river channels and which is essential archives in understanding depositional processes and channel dynamics is known as floodplain. Likewise, Jia et al. (2020) defined it as the relatively low and periodically inundated areas adjacent to rivers, lakes, and oceans which are rich in wetlands due to good hydrological conditions. For the purpose of this study, the land alongside the river bed which gets inundated during flood and the part which had been formed due to the sedimentation after flood has been considered as the floodplain.

In order to assess the change in floodplain area, this research used the historic Landsat images. The methodological framework used for this study is shown in Figure 2. The details are provided in following subsections.

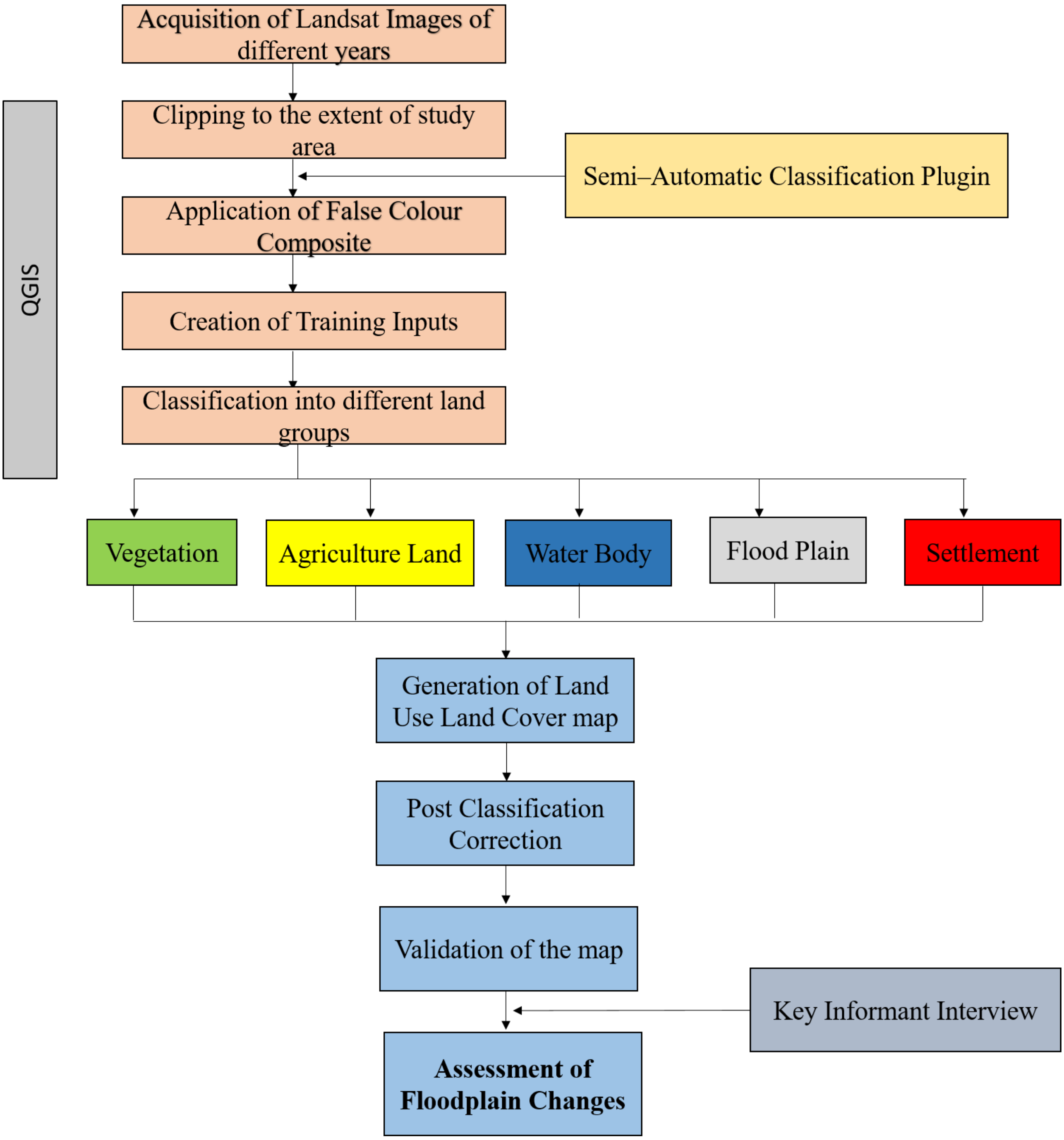

Figure 2: Methodological Framework of the research

2.2.1 Acquirement of Data

Landsat images are popular for their long term availability and cost effectiveness (Zhu et al., 2019). This study used the freely available Landsat 30m spatial resolution images for detection of floodplain changes (Details in Table 1). They were downloaded from United States Geological Survey (USGS) Earth Explorer website. The earliest date of image availability for the study area is the year 1988. For the purpose of this research work, an interval of a decade has been considered. Accordingly, the images for the year 1988, 1999, 2009 and 2020 were fetched. Since images with cloud cover affect the accuracy of the classification, it was ensured that the downloaded images had the least cloud cover percentage.

Table 1: Specifications of Landsat data used

SN	Acquisition Date	Path	Row	Cloud cover (%)	Satellite	Sensor	Resolution (m)
1	11/4/1988	142	041	15	Landsat_5	L4-5 TM	30
2	10/10/1999	142	041	10	7	L7 ETM+	30
3	11/30/2009	142	041	8	Landsat_5	L4-5 TM	30
4	1/29/2020	142	041	7.56	8	L8-9 OLI/ TRS	30

2.2.2 Image Processing and Classification

The processing of the images was done in QGIS 3.30. The composite images were formed by stacking Band-1 to Band-7. The irrelevant bands (for example: Band-8 to 10 of Landsat 8) were avoided. The images were re-projected to Universal Transverse Mercator (UTM) projection of World Geodetic System (WGS) 1984 (Zone: 44N). Using clip feature, the region of study area was clipped out from each images. Afterwards, supervised classification was performed using Semi-Automatic Classification Plugin (SCP) available in QGIS. The study area was classified into five land use types- vegetation, agricultural land, water body, floodplain and settlement.

For each class, training samples (n=18 to 23) were taken into count by demarcating polygons known as Region of Interest (RoI). Each class was provided a unique class ID in order to differentiate it from one another. Different band combinations were applied for easy identification of each classes. The accurate visualization was not possible only through natural colour combinations viz. (3-2-1) in Landsat 4, 5, 7 and (4-3-2) for Landsat 8 images. So, the False Colour Composite (FCC) was applied to correctly identify the features. A number of combinations was tried for floodplain and other land use classes so that they could be accurately visualized and designated. For example: the combination (5-4-3) and (7-5-3) were applied for identification of vegetation and settlements respectively.

The process was repeated for all classes of each images. For the classification purpose, the maximum likelihood algorithm was used. This algorithm evaluates both the variance and covariance of the spectral response patterns quantitatively and each pixel is assigned to the class for which it has the highest possibility of association (Alam et al., 2020). After the classification was completed, the images were smoothened for correction.

2.2.3 Accuracy Assessment

Since the classification of LULC is subject to incur errors, accuracy assessment is very significant to validate the results (Alam et al., 2020). In this research, accuracy assessment was carried out using samples from Google Earth Pro as ground truth and cross checked with the classified LULC map images. However, the Google Earth image for the study area is available only after the year 2002. So, only the years 2009 and 2020 were used for the estimation of accuracy. In order to validate the result, several reference areas were digitized into a reference shape file. Each digitized area is assigned the code of land use similar to the prepared land use map. The validation was performed by developing an error-matrix for the selected years. Afterwards, user's accuracy (Equation-1) and producer's accuracy (Equation-2) were calculated for each category. Similarly, the overall accuracy and Kappa coefficient has been calculated applying equation-3 and 4 respectively.

$$User's\ Accuracy\ (\%) = \frac{x_{ii}}{x_{i+}} X\ 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$Producer's\ Accuracy\ (\%) = \frac{x_{ii}}{x_{+i}}\ X\ 100 \ldots\ldots\ldots (2)$$

$$Overall\ Accuracy\ (\%) = \frac{\sum_{i=1}^{r} x_{ii}}{x} X\ 100 \quad \ldots\ldots (3)$$

$$Kappa\ Coefficient\ (\hat{K}) = \frac{n\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r} x_{i+} . x_{+i}}{n^2 - \sum_{i=1}^{r} x_{i+} . x_{+i}} \quad \ldots\ldots\ldots\ldots\ldots (4)$$

Where,

r is the number rows in the matrix

x_{ii} is the number of observations in row i and column i

x_{i+} is marginal total for row

x_{+i} is marginal total for column

n is the total number of observations

Key Informant Interview (KII) was conducted from 6th December 2021 to 10th December 2021 in Butwal to comprehend the field situation. The participants included local residents, senior citizens and officials of the sub metropolitan city. The interview was conducted in Nepali and afterwards transcribed in English. The information about occurrences and impacts of past flood such as in 1981, level of river, the extent of floodplain in the past and trend of its encroachment was obtained through KII.

3. Result

3.1 Floodplain and Land Use change dynamics

The classified land use maps for the year 1988, 1999, 2009 and 2020 are shown in Figure-3. It was observed that in the time interval between the years 1988 and 2020, there has been significant changes in floodplain and other land uses. The area of floodplain in the Tinau River in Butwal is consistently decreasing. In 1988 the area was 334.3 hectares. It was reduced to 294.7 hectares in 1999. The trend of decrement continued with reaching 228.6 hectares and 105.3 hectares in 2009 and 2020 respectively. The decrease rate was slower in the early phase but increased rapidly afterwards. It was found out that the decrease percentage in 1988 to 1999 is 3.02%. It became 5.06% in between 1999 to 2009. From the year 2009 to 2020, 9.41% decrement of floodplain occurred. From Figure-3, it can be observed that the floodplains have been turned into settlements. The major areas where significant encroachment of floodplain has taken are Buddhanagar, Majuwa and Sundarnagar

Similarly, the area of agricultural land is also prominently diminishing. From 1988 to 2020, the area decreased from 509 hectares to 217.7 hectares. In between 1999 and 1988, the decrease in agricultural land was 86.3 hectares. In 1999 and 2009, the area of agricultural land was 422.7 hectares and 217.7 hectares respectively. An increase in vegetation area has been observed in the decade after late 1980s. In 1988 and 1999, the area of vegetation is 322.7 hectares and 345.8 hectares respectively. However, in the next decade there is reduction by 26.5 hectares. In between the year 2009 and 2020, the area of vegetation increased by 11.3 hectares (319.3 hectares in 2009 and 330.6 hectares in 2020). Moreover, the area of settlements increased from 105 hectares in the year 1988 to 628.2 hectares in 2020. In 1999 the area was 190 hectares and further increased in 2009 reaching 361.4 hectares. Likewise, the areas for water bodies in 1988, 1999, 2009 and 2020 are 2.9, 4.2, 2.67 and 2.07 hectares respectively. The change in area of each land use in each decade is shown in Table 2.

Table 2: Land Cover Classes Change in Each Decade

Class	**Area Change in Hectare**			
	1988-1999	**1999-2009**	**2009-2020**	**Total Change (1988 To 2020)**
Vegetation	23.08	-26.4	11.3	7.8
Agricultural Land	-86.3	-58	-146.9	-291.3
Water Body	17	-20	-7.8	-10.8
Floodplain	-39.6	-66.1	-123.2	-228.9
Settlement	85.5	170.7	266.7	522.9

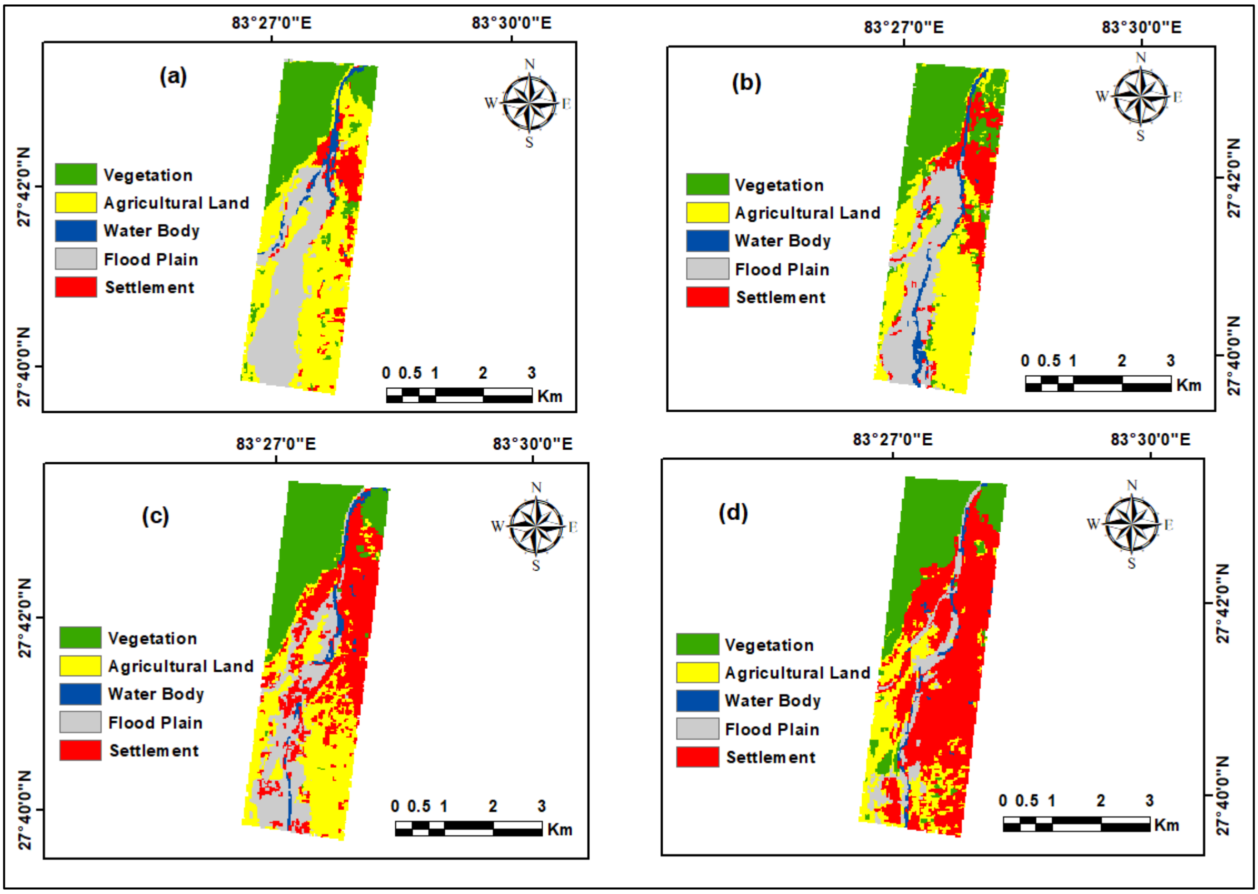

Figure 3: LULC Map Generated for: (a) Year 1988; (b) Year 1999; (c) Year 2009; (d) Year 2020

3.2 Accuracy Assessment

Using the accuracy assessment tool in QGIS supervised plugin, the digitized shape file was compared with the prepared land use map. For the year 2009, out of selected 406 pixels, 330 were correctly matched i.e. 81.28%. Similarly, in case of the year 2020, 415 pixels matched out of 502 i.e.82.66 %. Thus, in overall, out of selected 908 pixels, 745 pixels were correctly matched i.e. 82.04% accuracy. The error matrix for the year 2009 and 2020 have been shown in Table-3 and Table-4 respectively. The value of Kappa coefficient is 0.7 and 0.72 for the year 2009 and 2020 respectively. Kappa values of <0 means no agreement, 0–0.2 as slight, 0.2–0.41 as fair, 0.41–0.60 as moderate, 0.60–0.80 as substantial and 0.81–1.0 as almost perfect agreement(Chowdhury et al., 2020; Tewabe & Fentahun, 2020; Wang et al., 2020). It implies that the finding of this research is substantial and the classification accuracy is acceptable.

Table 3: Error Matrix for Year 2009

	Vegetation	Agricultural	Water	Floodplain	Settlement	Total (User)
Vegetation	84	13	0	4	0	101
Agricultural Land	15	75	3	5	0	98
Water body	0	1	16	0	3	20
Floodplain	3	11	0	78	3	95
Settlement	2	7	0	6	77	92
Total (Producer)	104	107	19	93	83	**406 pixels**
Users Accuracy	83 %	77%	80%	82%	84%	
Producers Accuracy	81%	70%	84%	84%	93%	
Kappa Coefficient	0.7					

Total Sample=406, Sum of diagonal elements =330, Overall Accuracy =81.28%

Table 4: Error Matrix for Year 2020

	Vegetation	Agricultural	Water	Floodplain	Settlement	Total (User)
Vegetation	105	10	0	4	6	125
Agricultural Land	9	86	2	3	0	100
Water body	0	4	18	3	0	25
Floodplain	0	6	0	78	5	89
Settlement	6	14	0	15	128	163
Total (Producer)	120	120	22	103	137	**502 pixels**
User Accuracy	84%	86%	72%	88%	78%	
Producers Accuracy	88%	72%	90%	76%	92%	
Kappa Coefficient	0.72					

Total Sample= 502, Sum of diagonal elements=415, Overall Accuracy= 82.66%

4. Discussion

The quantitative evidence of this study indicate that the surrounding area of Tinau river in Butwal metropolitan city have undergone significant changes. There is an increasing trend of settlement areas whereas decrease in the area of Tianu river floodplain and agricultural land. Similar trends have been reported by Kc et al.(2021) and Mandal (2014) in their study in case of agricultural land and settlement areas. The research work by Thapa and Poudel(2018) confirms the findings on vegetation. However, no prior studies have been conducted with regards to estimation of the floodplain change in the region. That is why, the findings on floodplain change could not be compared with other research works.

One of the key factors to be considered to comprehend the floodplain encroachment and increment of settlement in the study area is demography. As a matter of fact, the demographic transformation of Nepal is characterized by a rapidly growing population density along highways and road corridors (Apostolopoulou and Pant, 2022). Butwal is the emerging urban center of Nepal with two important highways East-West highway and Siddhartha highway. Naturally, it has been witnessing the big flow of immigrants from neighboring districts (Chidi, 2019) such as Gulmi, Palpa, Syangja and Argakhanchi. According to a key informant, the encroachment of the floodplain in Tinau River began from 1990. With the internal violence that started in 1996, there occurred the increase in the squatter settlements in the floodplain (Marasini and Chidi, 2021). The key informant believes that the encroachment of the floodplain became rampant after the political changes of 2006. The findings of this study also coincides with this statement as the change in floodplain area between the years 2009 and 2020 is found to be decreased by 123.2 hectares.

Moreover, the changing morphology of the river is also to be considered to analyze the floodplain and settlement change. During KII, a senior citizen residing in Butwal revealed that the Tinau river level in Butwal section was nearly same as that of the land in the past and the width of the floodplain was around three kilometers. On 29th September 1981, one of the worst flooding events in the history of Butwal occurred claiming lives of 70 people and sweeping away more than 100 houses (Dhungana et al., 2016). The key informant said that the event caused the bifurcation of the river near the East West Highway (Figure 1). Consequently, the Tinau River started flowing in the east and the newly formed Danao River in the west. The flooding changed the morphology of the river and caused further lowering of its level due to sedimentation. From the field visit, it has been found out that the floodplain of the river is divided into two regions: first region is around 10 m higher than the river bed and the other one is in the same level with the river bed.

It was observed that there are organized settlements with infrastructures such as pitched roads, electricity, big shops, medical stores and also expensive Reinforced Cement Concrete (RCC) structures in the floodplain above the river bed. However, all these structures are standing in the land whose materials are the elements of floodplain. It implies that the floods of higher magnitude in future could sweep away these encroached settlements. For example: In June 2021, the flood in Melamchi river, which for a long time had not witnessed a disastrous flood, took the life of more than 20 people, washed away more than 100 homes lying within or near the river floodplain, swept away 12 suspension footbridges and seriously damaged the Melamchi water supply project (Subedi et al., 2023). In case of Tinau River, in addition to inundation, the cutting of land (upper floodplain regions) by flood has been observed in different places. The flood on 15th June 2021, induced bank cutting in floodplain of Buddhanagar area (Figure 4-b). The newly constructed Reinforced Cement Concrete (RCC) embankment was swept away by one of the 2021 floods (Figure 4-a). Clearly, due to floodplain encroachment, the residents living near the river bed are directly exposed to the risk of flood. Likewise, the settlements which stand in the historic river floodplain could also be the victims of high magnitude future floods. Furthermore, the reckless extraction of gravels and sand from the river bank (Figure 4-c) has also disturbed the ecological balance of the river (Dahal et al., 2015) increasing the risk of flood.

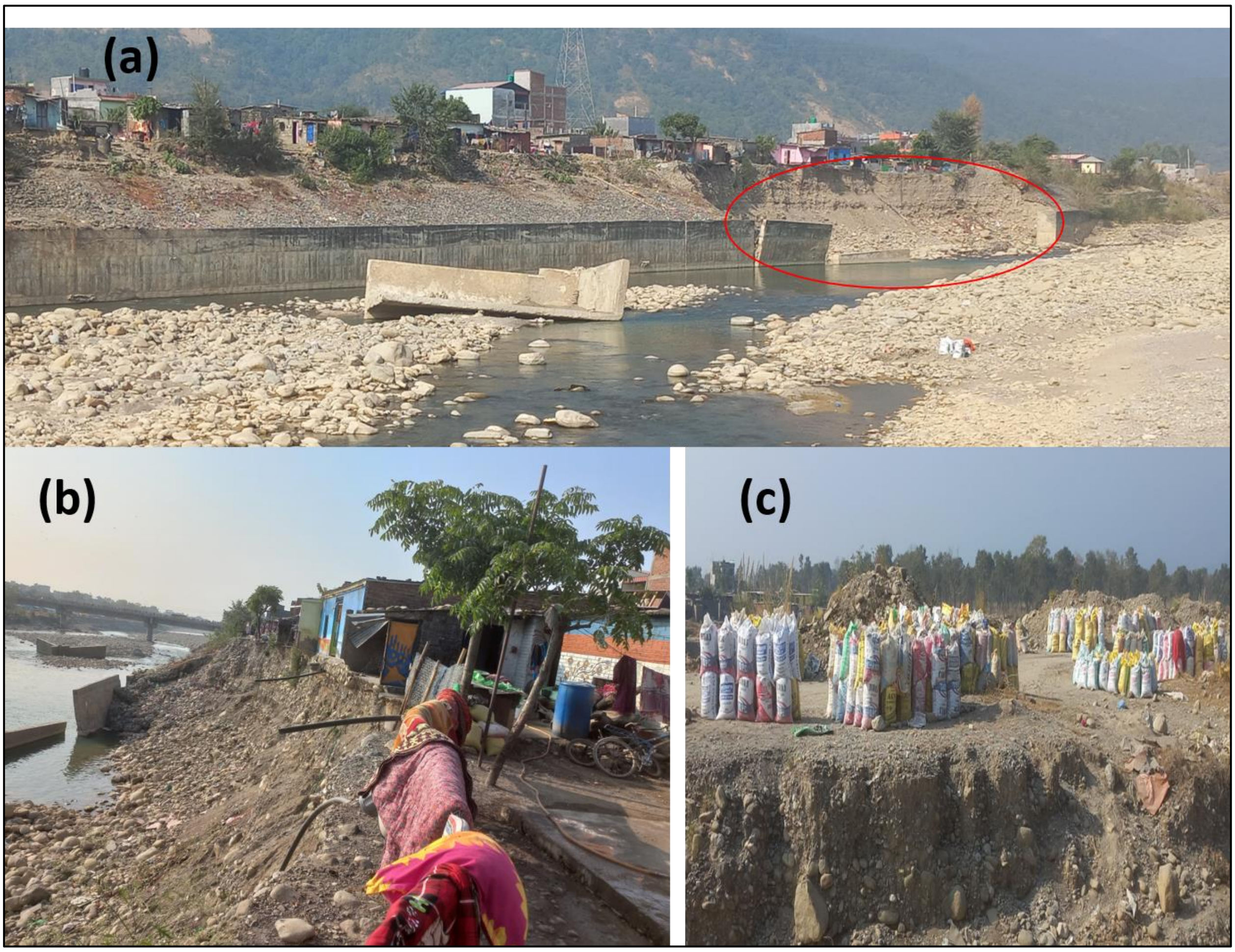

Figure 4: Risks due to Tinau River flood plain encroachment: (a) Sweeping away of RCC embankment and land cutting (Shown in red ellipse) at Buddhanagar due to flood of June 2021; (b) Houses at brink of collapse (zoomed in region of red ellipse); (c) Gravels and sand being collected in sacks from the river floodplain in unlawful manner. Pictures were taken by the author on 8th and 9th of December, 2021.

In this backdrop, the local government plays the leading role in managing the floodplains and ultimately mitigating flood risks in Tinau. It is a well-established fact that the community is the first responder to any disaster event. The constitution of Nepal, 2015 and the Local Government Operational Act, 2017 have offered authority to local government to formulate and implement Disaster Risk Management plans and policies (Ministry of Home Affairs, 2022). Butwal sub metropolitan city in collaboration with People's Embankment Programme has been involved in the construction of embankments in the potential risk areas of river bank. It has initiated the delineation of right of way of river bank of Tinau River. But it does not seem to have the official record of historic floodplain of the river. Therefore, the delineation process has not been agreeable to all the relevant stakeholders such as environment activists, policy makers and people of squatter settlements. Notably, each of them have varying and often contradicting stands regarding the process. It is recommended that the local governments, along with the Federal and Provincial governments, need to consider the trend of change in floodplain the Tinau region before the implementation of any new initiatives in and around the river.

This study used Landsat images for the change in floodplain analysis. Similar methodology, though for different landforms and using different software, have been successfully applied in many international studies. For example: (Gilani et al., 2015) in Bhutan, (Thakur et al., 2020) in India, (Shah et al., 2021) in Pakistan, (Moniruzzaman et al., 2021) in Bangladesh. Thus, the significance of Landsat images for analyzing and interpretation of the historic land use changes is further reestablished. The limitation of this research work is that the Landsat images for the study area are not available for the years before 1988. So the status of land use, especially the floodplain, could not be analyzed for the decades preceding late 1980s. Likewise, the accuracy assessment could not be conducted for the year 1988 and 1999 since the google satellite images for comparison was not available for these years. As no prior studies in case of Nepal particularly focuses on the change in historic floodplain, this article can be the baseline for future studies on the subject matter.

5. Conclusion

Though the issue of floodplain encroachment and consequent flood risk is a burning issue, there is dearth of literature that deals with the assessment of change of floodplain. So this research work was carried out with an objective to estimate the historic change in floodplain area in the Tinau River of Butwal. For this purpose, Landsat images for the year 1988, 1999, 2009 and 2020 were acquired, processed in QGIS and the change assessment conducted. The findings of the study highlight that there is a trend of decrease in the floodplain area since 1988. Moreover, it was observed that the area of settlement has been increasing whereas the area of agricultural land has been decreasing. The migration of people to Butwal from surrounding districts since the 1990s and the rapid urbanization has further fueled the encroachment of the floodplain areas. The area of floodplain which was 334.3 hectares in 1988 has been reduced to 105.4 hectares in 2020. Different flooding events have swept the structures built in the river vicinity. If the present trend of encroachment continues, the impacts of flood in the future would be more adverse.

Since there is absence of past works on the floodplain change in the study region, this research work could act as the baseline for further studies. The policy makers and officials of local, provincial and federal government ought to consider the trend of change in floodplain while formulating and implementing the plans and policies for flood risk management. This could contribute in minimizing the risk and impacts of flood to communities.

Further research works on the topic with enhanced resources and methodology would assist in exploring new findings.

Conflict of interest statement

The author declares that there are no conflicts of interest regarding the publication of this paper.

Author's contribution statement

The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

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