Abstract. Subansiri River is the largest tributary of the Brahmaputra River running through the Indian states of Assam and Arunachal Pradesh, and Tibet, the Autonomous Region of China. The Subansiri River is 442 km long with a drainage basin of 32,640 km$^2$ and it contributes approximately 7.92% of the Brahmaputra's total flow. Sequential Channel shifting has been witnessed as the most important characteristic of the Subansiri River of Assam. The detailed study on channel migration of the present course of the Subansiri River through the upper floodplain of Brahmaputra valley indicates that the area is under active erosion for a long time. Therefore, an attempt has been made to understand the relationship between the rate of channel migration and successive land use/land cover changes in its surrounding floodplain area. The Support Vector Machine (SVM) and the Artificial Neural Network (ANN) algorithms are applied on Landsat images of the years 1973, 1988, 2001, and 2017 for generating land use/land cover maps through supervised classification technique. The overall accuracy of the land use/land cover classification ranges between 81% (for the year 1988) and 84% (for the year 2017). The land use/land cover maps show an increase in the built-up area and a decrease in the agricultural area. The change has been observed vis-a-vis channel migration indicating that the migration directly affects the floodplain habitats which in turn affects the land use. Findings of this study highlight geomorphological instabilities of the study area and the vulnerability of the habitations residing near the Subansiri river.

Keywords: Subansiri River, Channel migration, Land Use Land Cover, Sinuosity, Support Vector Machine (SVM), Artificial Neural Network (ANN)
1. Introduction
An alluvial floodplain area is always susceptible to active bank erosion due to river dynamics caused by natural and anthropogenic factors, hence it is considered as one of the most endangered areas continuously experiencing degradation by river regulations and enhanced land-use pressure (1, 2, 3). In the last few decades, the floodplain of the Subansiri River is subjected to erosion and deposition by the river to reach the equilibrium condition (4, 5, 6, 2). Therefore, mapping and monitoring of altered channel positions are crucial for assessing the erosional hazard and changes in land use/land cover (LULC) characteristics and also for understanding the cause of the alterations (2). While reviewing research paper on river dynamics and its effects on landforms it is found that many researchers have studied the morphological and erosional aspects of the Brahmaputra River and its tributaries and to name a few like Coleman, Goswami, Bristow, Klaassen and Masselink, Thorn, et al. and Kotoky and Sarma (7, 8, 9, 10, 11, 12). Bank erosion studies using topographic maps and satellite data have been carried out for the river Brahmaputra and of its tributaries by Sarma and Basumallick, Kotoky et al., Sarma, Sarma and Phukan, Sarma et al., (13, 14, 15, 16, 17,18). The present study has been carried out to understand the relationship between the channel migration and subsequent LULC changes in its surrounding floodplain area utilizing satellite remote sensing data of the period from the year 1973 to 2017. Historical satellite imageries provide an opportunity to go back in time and understand the changes in LULC categories that have taken place concerning the recent data.

The Subansiri River, the largest tributary of the Brahmaputra, originates from the Himalayas at an altitude of 5340m. In its upper reaches, the river takes an easterly course from its origin around 91º33’04”E and 28º29’38”N to 94º01’48”E and 28º21’32”N and then takes a south-easterly course up to the point at 94º20’49”E: 27º43’26”N, from where it takes a sharp turn towards the southwest and continues up to 94º12’43” E: 27º36’18” N. It afterward travels to the position 94º17’02” E: 27º13’52” N, which the area of the study and then takes a curvilinear trend convexing southeastward and meets the Brahmaputra River at an acute angle. The river takes its southerly course emerging out of the Himalayas and enters the Brahmaputra River valley near Gerukamukh. In its upper reaches, the river is known as Tsari Chu. In mountainous terrain, the river length is 208 km, and from the dam site to the confluence with Brahmaputra (near Jamuguri, 5 km southeast of Hawajan) is 126 km. The Lower Subansiri dam site is located at latitude 27º33′15″ N and longitude 94º15′30″E. The present study is carried out to understand the relationship of river channel migration with changes in LULC (figure1).

Figure 1. Location map showing the extension of the basin of the Subansiri River.
2. Database and Methodology

Historical channel change by using topographical maps and satellite images combined with the GIS technique has been used by many researchers in their river morphological changes (19, 20, 21, 7, 22, 23, 24, 25, 26, 6, 27, 28). In this current work, Remote Sensing and GIS techniques are used to delineate the channel dynamics and its impact on land use. Landsat 4 & 5 TM images of the years 1973, 1988, 2001, and Landsat 8 OLI image of the year 2017 are used in the study as they provide continuous multispectral data of 30m spatial resolution for landscape analysis and are available for download from USGS Earth Explorer data portal. For this study, the entire course of the river from Subansiri dam to confluence point was divided into 3 reaches and 25 sites were selected for cross-sections. For identifying the river and its characteristic parameters such as channel width, shift, sinuosity index, deposition, area of erosion, unchanged area (table-1), and historical migrated area were measured and studied along the cross-sections (3).

Table 1. Characteristics of reaches of Subansiri River.

| Parameter                  | Reach-1                        | Reach-2                        | Reach-3                        |
|----------------------------|--------------------------------|--------------------------------|--------------------------------|
| Areal extent               | Subansiri Dam to Chaldhowa ghat| Chaldhowa ghat to Chenimora Kangkur No 1 | ChenimoraKangkur No 1 to the confluence at Brahmaputra River |
| Length                     | 12.33 km                       | 79.56 km                       | 27.57 km                       |
| Sinuosity index            | 1.13                           | 1.36                           | 1.11                           |
| Dominant bed material      | Sand                           | Sand and silt                  | Sand                           |
| Morphological character    | Sinuous and Anabranching        | Sinuous and Anabranching       | Sinuous and Anabranching       |

The cross section-wise study is applied for detection of widening of channel, whereas for calculating sinuosity index and capturing of the total area by the river, the reach-wise study is applied (29). The riverbank lines for both the left and right banks were identified and digitized from topographical maps and satellite images. Then the digitized vector data were overlaid and migration of the channel was identified and extracted from the overlaid maps. Deposition, Erosion, unchanged, and historical migrated areas were calculated (3).

Sinuosity index, which deals with the meandering nature of the river and indicates, meandering in quantitative terms, is calculated as the ratio between observed (actual) length and the expected straight distance of a meandering river between the endpoints. It is expressed as follows:

\[ \text{Sinuosity index (S)} = \frac{\text{OL}}{\text{EL}} \quad \text{(Schumm; 1963)} \]

where S = sinuosity index,

\( \text{OL} = \text{observed (actual) length of a river, and} \)

\( \text{EL} = \text{expected straight distance of a meandering river.} \)
For mapping the LULC classes, two classification techniques were used. Support Vector Machine (SVM) is a biased classifier that is defined by a separable hyper plane, it is used in classification or regression for learning algorithms but is mostly used for classification (30).

Artificial Neural Network (ANN) is a computer technology-based method that is inspired by the human brain networking system. ANN has features to store experimental information and keep the information and able to use when it is required. Because of the ability in domains with non-linear relationships ANN is proposed as an alternative and valuable tool to evaluate. The process of valid and factual comparison is made between SMV (31, 32) and ANN for the selection of better land use classification techniques; this was done by using ERDAS Imagine 9.2 and ENVI 5.2 by collecting different samples of land use categories. Kappa coefficient was used in the post-classification analysis for the accuracy assessment of LULC classified images (2). For accuracy assessment, 155 points were taken randomly and superimposed on the classified images. The LULC class type for each point was compared with the LULC class as observed on high spatial resolution Google Earth data and ground truth data obtained through field survey (30).

3. Result and Discussion

Based on the techniques used to analyze channel plan form and land use classification, the results of the study are presented into two parts – Channel widening and migration, and subsequent adjustment of land use is associated with the change (3).

3.1 Channel widening and migration.
Lateral channel erosion is a significant characteristic that has been observed throughout the Subansiri River primarily leading to the widening of the channel (5, 33). Two maps of 1973 and 2017 have been used to determine the width of the channel and for the understanding of the vertical and lateral erosional processes and morphological characteristics of the bank. The continuous recession of the water level leads to disequilibrium conditions between the water level and river banks, resulting in massive erosion (3). Erosion is intensified by the non-cohesive sandy bank which ultimately leads to the widening of the channel (3).
For understanding river widening and migration, the Subansiri river has been measured at 25 stations (profiles) in the two maps to observe reach-wise channel migration (figure 2). It was observed that the Subansiri river has migrated vigorously to west, northwest, and southeast directions along with the stations (table 2). Maximum erosion (8.06km) has been observed in the left bank near cross-section KK’ whereas in the right bank it was near cross-section LL’ (7.2km) (table 2). The cross section-wise measurements of active width indicate some important aspects of the river. It is observed that the overall width of the river in the upper, middle and lower courses have increased (table 2, figure 3).
Figure 2. Channel migration of Subansiri River between (a) 1973 – 1988, (b) 2001-2017 and (c) 1973 - 2017.

Table 2. Channel migration and Variations in the active channel of Subansiri River between the years 1973 and 2017

| Station | Direction of migration | Migration (m) | Channel width (in m) |
|---------|------------------------|--------------|----------------------|

5
| Stat | Direction | 1973   | 2017   |
|------|-----------|--------|--------|
| AA'  | Westward  | 5      | 521.44 | 1058.56|
| BB'  | Westward  | 16     | 618.23 | 1187.32|
| CC'  | Westward  | 223.66 | 739.56 | 519.46 |
| DD'  | Westward  | 812.32 | 659.14 | 631.7 |
| EE'  | Westward  | 4146.29| 1024.26| 667.41 |
| FF'  | Westward  | 5921.11| 601.85 | 375.17 |
| GG'  | Westward  | 6129.93| 774.26 | 773.21 |
| HH'  | Westward  | 7278.4 | 113.58 | 699.81 |
| II'  | Westward  | 4510.54| 561.28 | 502.19 |
| JJ'  | Westward  | 9705.4 | 215.19 | 636.63 |
| KK'  | Westward  | 8068.06| 306.31 | 621.72 |
| LL'  | North-Westward | 7229.82 | 396.22 | 494.46 |
| MM'  | South-Eastward | 780.28  | 551.53 | 415.65 |
| NN'  | North-Westward | 1943.09 | 280.78 | 663.55 |
| OO'  | South-Eastward | 115.4   | 363.23 | 808.94 |
| PP'  | North-Westward | 1220.33 | 370.5  | 661.88 |
| QQ'  | North-Westward | 1928.82 | 448.11 | 488.58 |
| RR'  | South-Eastward | 2629.31 | 606.81 | 850.07 |
| SS'  | South-Eastward | 1746.16 | 606.43 | 666.04 |
| TT'  | South-Eastward | 1243.59 | 538.8  | 412.65 |
| UU'  | South-Eastward | 1685.14 | 356.79 | 970.03 |
| VV'  | South-Eastward | 4319.83 | 614.95 | 444.96 |
| WW'  | South-Eastward | 3921.29 | 485.58 | 1000.04|
| XX'  | South-Eastward | 1711.41 | 278.95 | 1116.09|

**Figure 3.** Cross section-wise width of Subansiri River during the years 1973 and 2017 (width in meters).
3.2 The area occupied by the river and associated changes in LULC:

Riverbank erosion is a complex phenomenon caused by the interplay of several factors including river discharge, hard rock, and/or riparian vegetation cover (3). Based on the remote sensing data derived observations, the projected area drained by the river Subansiri has been grouped into four classes - area under erosion, area remained unchanged, the area under deposition, and migrated area (3) (table 3). The total eroded area has been calculated from the active course in 2017 by subtracting from the unchanged area. It is observed that from 1988 to 2017, river Subansiri covers a total of 25842.19 hectares area under deposition (figure 4).

| Category                | Area in Hectare |
|-------------------------|-----------------|
| Unchanged Area          | 2676.9          |
| Erosion                 | 5272.45         |
| Deposition              | 25842.19        |
| Historical migrated area| 60167.65        |

**Table 3.** Projected area drained by the Subansiri River.

**Figure 4.** The projected area drained by the Subansiri River.
Table 4. Land use/Land cover classes of the study area in the years 1988 and 2017.

| Class            | 1988 Area (in hectare) | % of area | 2017 Area (in hectare) | % of area | Change Area (in hectare) |
|------------------|-------------------------|-----------|-------------------------|-----------|--------------------------|
| Waterbody        | 10583.55                | 4.797309  | 10812.78                | 4.901214  | 229.23                   |
| Vacant land      | 15703.47                | 7.118065  | 14236.92                | 6.453308  | -1466.55                 |
| Vegetation       | 29583.18                | 13.40946  | 29455.29                | 13.35149  | -127.89                  |
| Agriculture      | 148327.19               | 67.23368  | 138146.9                | 62.61917  | -10180.26                |
| Current Fallow land | 3487.86                | 1.580976  | 7956                    | 39.76716  | 4468.14                  |
| Built-up Area    | 12929.13                | 5.860513  | 20006.46                | 9.068524  | 7077.33                  |

Subansiri River has witnessed a substantial and rapid change in land use configuration in its surroundings as observed in the LULC maps of the three years (figure 6). The rapid land-use changes particularly in the agricultural area can be attributed to urbanization in the last decade (34).

Landsat imageries of the three-time periods were classified using the supervised classification method employing the Support Vector Machine (SVM) algorithm to generate LULC maps and understand the land-use transition taken place during the time scale. Kappa coefficients of the classified images (1988 and 2017) are 0.81, 0.84 which indicates decent agreement between the actual land-use patterns and classified images (34).

Table 4 tabulates the land use statistics of the classified images of different temporal periods. Land use analysis shows that between 1988 and 2017, built-up area has increased from 5.86% to 9.06%. On the other hand, there is a decline of the vacant land from 7.11% in 1988 to 6.45% in 2017 and a decline of agricultural land from 67.23% to 62.61% from 1988 to 2017 respectively (34).
Figure 5. Land use/Land cover change of the study area between the years 1988 and 2017 adjoining the Subansiri River.

For analyzing the result of the land-use transition based on 'from' and 'to' changes, a matrix of land-use changes from the year 1988 to 2017 was generated (table 5).

**Table 5. LULC change matrix of the Subansiri River**

|                  | Waterbody | Vegetation | Vacant land | Built-up Area | Agriculture | Current Fallow land | Total 1988 |
|------------------|-----------|------------|-------------|---------------|-------------|---------------------|------------|
| Waterbody        | 223.6     | 82.0       | 201.4       | 57.1          | 484.5       | 32.6                | 108.13     |
| Vegetation       | 43.3      | 1618.3     | 29.7        | 137.7         | 1111.6      | 05.0                | 294.55     |
| Vacant land      | 213.8     | 99.4       | 420.5       | 60.1          | 575.9       | 53.9                | 142.37     |
| Built-up Area    | 68.0      | 274.6      | 77.4        | 211.4         | 1333.6      | 35.6                | 200.06     |
| Agriculture      | 441.2     | 793.9      | 754.4       | 777.9         | 10855.7     | 191.5               | 1381.47    |
| Current Fallow land | 68.4 | 90.1       | 86.9        | 48.7          | 471.3       | 30.2                | 79.56      |
| Total 2017       | 1058.4    | 2958.3     | 1570.3      | 1292.9        | 14832.7     | 348.8               |            |

The transition matrix indicates that between 1988 and 2017, 575.9 hectares of vacant land were converted to agricultural land, while at the same period 777.9 hectares of agricultural land were converted to built-up land (34)(figure 7). From the other land use categories transformation, it is observed that nearly 1111.6 hectares of vegetation cover has been converted to agricultural land and 10.65% of it transformed into built-up land. The scrupulous observation over the land use classified maps makes it clear that from 1988 to 2017, vacant land, vegetation, and built-up areas have changed significantly. The built-up area has increased at the cost of the decrease in agricultural land, vegetation, and waterbody areas (table 6) (34).
Figure 6. Correlation matrix between LULC classes 1988 and 2017 adjoining the Subansiri River.

Table 6. Losses and Gains between 1988 and 2017 in Subansiri River (Area in hectare).

| Landuse class       | Losses | Gains | Total change |
|---------------------|--------|-------|--------------|
| Water               | -8348  | 8577  | 229          |
| Vacant land         | -11498 | 10032 | -1467        |
| Vegetation          | -13401 | 13273 | -128         |
| Agricultural field  | -39770 | 29590 | -10180       |
| Current Fallow land | -3186  | 7654  | 4468         |
| Built-up area       | -10815 | 17892 | 7077         |

Figure 7. Losses and Gains between 1988 and 2017 in Subansiri River (Area in hectare).

Table 7. Net change between 1988 and 2017 in the Subansiri River (Area in hectare).

| Landuse class       |        |
|---------------------|--------|
| Water               | 229    |
| Vacant land         | -1467  |
| Vegetation          | -128   |
| Agricultural field  | -10180 |
| Current Fallow land | 4468   |
| Built-up area       | 7077   |
Figure 8. Net change between 1988 and 2017 in the Subansiri River (Area in hectare).

Table 8. Contribution to the net change in water between 1988 and 2017 in the Subansiri River (Area in hectare).

| Water                | 0  |
|----------------------|----|
| Vacant land          | -124 |
| Vegetation           | 388 |
| Agricultural field   | 433 |
| Current Fallow land  | -357 |
| Built-up area        | -109 |

Figure 9. Contribution to the net change in water between 1988 and 2017 in the Subansiri River (Area in hectare).

Table 9. Contribution to the net change in vacant land between 1988 and 2017 in Subansiri River (Area in hectare).

| Water    | 124 |
|----------|-----|
Vacant land | 0  
Vegetation | 698  
Agricultural field | -1785  
Current Fallow land | -330  
Built-up area | -173

**Figure 10.** Contribution to the net change in vacant land between 1988 and 2017 in Subansiri River (Area in hectare).

| Water       | 109  
Vacant land  | 173  
Vegetation   | 1369  
Agricultural field | 5557  
Current Fallow land | -131  
Built-up area | 0

**Table 10.** Contribution to the net change in the buildup area between 1988 and 2017 in the Subansiri River (Area in hectare).

| Water       | 109  
Vacant land  | 173  
Vegetation   | 1369  
Agricultural field | 5557  
Current Fallow land | -131  
Built-up area | 0

**Table 11.** Contribution to the net change in current fallow land between 1988 and 2017 in Subansiri River (Area in hectare).
Figure 12. Contribution to the net change in current fallow land between 1988 and 2017 in Subansiri River (Area in hectare).

Table 12. Contribution to the net change in agriculture land between 1988 and 2017 in Subansiri River (Area in hectare).

|            |                |
|------------|----------------|
| Water      | 357            |
| Vacant land| 330            |
| Vegetation | 851            |
| Agricultural field | 2799 |
| Current Fallow land | 0    |
| Built-up area | 131  |

Figure 13. Contribution to the net change in agriculture land between 1988 and 2017 in Subansiri River (Area in hectare).

Table 13. Contribution to the net change in vegetation between 1988 and 2017 in the Subansiri River (Area in hectare).

|            |                |
|------------|----------------|
| Water      | -388           |
| Vacant land| -698           |
| Vegetation | 0              |
Agricultural field | 3177
Current Fallow land | -851
Built-up area | -1369

**Figure 14.** Contribution to the net change in vegetation between 1988 and 2017 in the Subansiri River (Area in hectare).

**Table 14.** Area on the file: Gain and loss in vacant land.

| Category | Hectares       | Legend  |
|----------|----------------|---------|
| 0        | 508764.06      |         |
| 1        | 11498.22       | Losses  |
| 2        | 4205.25        | Persistence |
| 3        | 10031.67       | Gains   |

**Table 15.** Gain and loss in the area of water in Subansiri river (from 1988 to 2017).

| Category | Hectares | Legend |
|----------|----------|--------|
| 0        | 515338.6 |        |
| 1        | 8347.7   | Losses |
| 2        | 2235.7   | Persistence |
| 3        | 8577     | Gains  |
Figure 15. Gain and loss in the area of water in Subansiri river (from 1988 to 2017).

The gain and loss of land during 1988 to 2017 as shown in table 6 and figure 7 for all the landuse class shows that loss of fertile agricultural land is more than it gained. Likewise, open or vacant land loss is more compared to its gain. A negative change is observed for the agricultural land during the study period (table 7, figure 8). How different land use categories contributed to the net change between 1988 to 2017 is shown in table 8, 9,10, 11, 12, and 13 and graphical representation in figure 9, 10, 11, 12, 13, and 14). The gain and loss statistics indicate that 8347.7 hectares fall under loss and area gain is 8577 hectares whereas 2235.7-hectare area is unchanged (table 15). It is found that drastic land-use change has taken place in this part of the river course.

4. Conclusion

Sequential Channel shifting has been witnessed as the most important characteristic of the Subansiri river of Assam. The study on channel migration of the present course of the Subansiri river through the upper floodplain of Brahmaputra valley indicates that the area is under active erosion for a long time (3). These changes in the course are due to the changes in the hydrologic regime of the river, e.g., an increase or decrease of either water or sediment discharge provided to the channel reach. Since Lower Subansiri Hydro Electric Power Project (LSHEP) construction works are going on from the year 2005, the hydrologic regime may have been disturbed and it may have also influenced the channel morphological changes. The classified image generated using the Support Vector Machine (SVM) and the Artificial Neural Network (ANN) shows change in the course of the river and the resultant land use change. Both the SVM classification approach and ANN were found very promising for such analysis. The land use/land cover classification shows that there is an increase in the built-up area and a decrease in an agricultural area. The channel migration directly affects the land use and this change in land-use change thereby affects the floodplain inhabitants (3, 35). The present study of the geomorphological instabilities of the area highlights the vulnerability of the people residing near the Subansiri river. This study proves the importance and utility of the application of remote sensing and GIS technology in assessing river morphological changes as well as detecting the resultant Land use and land cover changes.
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