INDONESIAN JOURNAL ON GEOSCIENCE
Geological Agency
Ministry of Energy and Mineral Resources

Journal homepage: http://ijog.geologi.esdm.go.id
ISSN 2355-9314, e-ISSN 2355-9306

Land Management for Reducing Bank Erosion: Using AHP Method and GIS Technique: A Case Study in Dibru River Basin, Assam India

Gulap Sonowal[1] and Gitika Thakuriah[2]

[1]Assistant Professor, Department of Geography, Darrang College, Tezpur-784001, Assam
[2]Assistant Professor, Department of Geography, Cotton University, Guwahati-781001

Corresponding author: gulapsonowal15@gmail.com; gitika.thakuria@cottonuniversity.ac.in
Manuscript received: August, 23, 2024; revised: August, 30, 2024;
approved: January, 21, 2025; available online: February, 24, 2025

Abstract - The site suitability for land management in reducing bank erosion is an important step towards sustainable development by adopting conservative measures. Land is considered to be very crucial for maintaining an ecosystem which is helpful to sustaining all forms of life. The increasing bank erosion day to day has been one of the common issues in Assam. The present study aim is to identify the sensitive areas of the bank erosion within the Dibru River Basin. Multicriterion calculation was carried out using geographic information system (GIS) technique to help the choice makers in identifying the fit sites of bank erosion. Different parameters which were considered for multicriterion evaluation, *ie*. landuse-landcover, geomorphology, soil capability, soil texture, slope, and river distances were taken for identifying the vulnerable zones of bank erosion. Analytical hierarchy process (AHP) was used to find the sensitive areas of the bank erosion for land management by weighted sum of different parameters. The suitability site map was classified into low, moderate, and high erosion zone. This map would help implement some preventive measures to mitigate the bank erosion within the Dibru River Basin.

Keywords: land management, AHP, remote sensing, GIS

How to cite this article:
Sonowal, G. and Thakuriah, G., 2025. Land Management for Reducing Bank Erosion: Using AHP Method and GIS Technique: A Case Study in Dibru River Basin, Assam India. *Indonesian Journal on Geoscience*, 12 (1), p.25-41. DOI: 10.17014/ijog.12.1.25-41

Introduction

Background

Management of degrading geomorphic environment is necessary by adopting conservative measures which strengthen and intensity the self-regulatory and self-maintenance mechanism of the geomorphic system. Degradation of land leads to threaten to the environmental and food security that has an impact on the long-term growth of the society and economy. Land degradation is a serious problem in India affecting around 36.6 % (120 Mha) of the total geographical area (Maji *et al*., 2010). It is an utmost importance to inverse or to halt the land degradation due to the increased burden on the development of land and water resources. A better understanding of the methods and extent of land degradation will help to recover the degraded areas, which will in turn help to achieve land degradation neutrality (LDN) (Saha *et al*., 2022). It is also one of the main sustainable development goals (SDG) of the UN programme. India has committed to the ambitious goal of achieving LDN and restores 26.0 Mha of degraded land by 2030.

The major factors for the increasing land degradation are soil erosion, seawater intrusion, salinization, and rampant urbanization. The other complex issues which lead to land degradation are industrial wastes, mining wastelands, *etc*. Land suitability analysis is necessary to make the best use of land resources that are already at our disposal. It aids in establishing strategies for increasing agricultural output and planning for sustainable landuse. FAO (1985) land suitability management main objectives are to promote the development of sustainable agriculture and rational land use (Hopkins, 1977; FAO, 1993; Habibie *et al*., 2019; Herzeberg *et al*., 2019; Salifu *et al*., 2022; Kılıç *et al*., 2023; Bhagya *et al*., 2023; Khan and Ahmed, 2023).

According to Shukla (2017), the Geographic Information System (GIS) and Analytic Hierarchy Process AHP methods are tools for identification, comparison, and multicriterion decision making analysis of urban development site proper planning and management. The AHP model has different applications in several studies, like groundwater quality assessment study (Srinivas *et al*., 2007; Shanwad *et al*., 2011; Prasad *et al*., 2014; Badhe *et al*., 2019; Mega and Khechana, 2021; Thakuriah, 2023) and environmental risk study (Abdelhalim *et al*., 2017; Waseem *et al*., 2023). This method has also been used by several authors in planning studies, such land suitability analysis (Jahangeer *et al*., 2018; Hussain *et al*., 2023), land suitability model field for citrus cultivation (Tercan and Dereli, 2020; Abolfazl *et al*., 2023), land suitability for ecotourism decision making (Zabihi *et al*., 2020), and suitability evaluation of urban construction (Ustaoglu and Aydinoglu, 2020; Mundhe and Jaybhaye, 2023).

AHP is one of the multicriterion decision methods, which is effective in solving the practical problems involving decision-making process (Saaty, 2005). The AHP theory involves pair wise comparisons of multiple variables. The combination of remote sensing and GIS technique along with AHP helps in decision making, and provides accuracy in the assessment of land degradation at the regional and local scale (Barman *et al*., 2021; Santosa *et al*., 2024). The AHP is a multicriterion decision making (MCDM) method for assessing the landuse suitability based on GIS (Satty, 1980; Malczewski, 2004; Hansen, 2005), and is one of the popular methods widely used to resolve MCDM problems (Chang *et al*., 2007). AHP and GIS based land suitability analysis has widely been applied to numerous land suitability assessment problems in the last few decades (Feizizadehab and Blaschkeb, 2013; Ullah and Mansourian, 2015).

In recent times many researchers have modelled and assessed the land degradation vulnerability zones using RS (Related Substances), GIS, and AHP techniques like Abuzaid *et al*. (2021) in hyper-arid Western Desert Oases in Egypt, in the semi-arid region of southern India (Parmar *et al.,* 2021), in the Kachchh District of Gujarat (Tolche *et al*., 2021), in the Wabe Shebele River Basin, Ethiopia, and Mzuri *et al*. (2021) in the Kurdistan region of Iraq.

Saaty (1980), who was the first researcher to create AHP, established a hierarchical approach for solving complicated problems of land management with the best options (Everest *et al*., 2021; Cengiz and Akbulak, 2009; Chen *et al.* 2010). The AHP is often used to make multicriterion decisions on the suitability of a land area for a certain field. Based on pairwise comparisons of numerous factors in accordance with their relative relevance, it establishes the weight of importance for various land uses (Cengiz and Akbulak 2009; Roig-Tierno *et al.,* 2013).

In Dibru River Basin, the significant impact on natural and cultural landscapes are mainly affected by the action of the river processes like widening its channel, process of erosion and deposition, high discharge, and a heavy pour of precipitation (Sarma *et al*., 2011).

The region is fond of cash crops like tea cultivation, paddy cultivation, betel nut cultivation, and orange cultivation. Because of the erosion, deposition, and flood, many hectares of tea garden, betel nut, paddy field, orange cultivation are lost, and many more. The lower course of Lohit River is widening its channel, making washed away many villages and cultivation fields. It is observed in some places where government and community had taken to minimize the bank erosion by the techniques like installing porcupine and geotextile tube or bag.

Modelling of land management is crucial for the sustainable management of natural resources and development of this region. This can be achieved by assimilating various parameters and modelling the index using advanced geospatial techniques, like remote sensing, GIS, and AHP (Thakuriah, 2023).

The objectives of this paper are to find the sensitive areas of bank erosion in Dibru River Basin, and to formulate a strategy to mitigate the bank erosion with some suggestive measures.

Geographic Settings

Dibru River Basin

The Dibru River is a left-bank tributary of the Brahmaputra River. The basin drains into the plain region of Assam, experiencing the tremendous sub-Himalayan terrain and bounded by Brahmaputra and Lohit Rivers in the north, Noa Dihing River in the east, and some tributaries of the Burhi Dihing River in the south and west borders of the basin. Geographically, its latitude and longitude extension are 27º25'30″−27º46'30″N and 95º6'0″-95º58'30″E, covering about 1,779 km^2 area of Tinsukia, Dibrugarh, Dhemaji District of Assam and part of Arunachal Pradesh (Figure 1). The basin slope varies from gently sloping to base level slope (0°-5º).

The Dibru River origin is at an altitude of about 155 m above mean sea level, and runs down to 132.95 km, where the channel gradient is 0.35 m/km.

A significant portion of the studied area is a plain region. The population concentration is very high in the southern part of the basin. The Dibru River Basin consists of four revenue circles: Chabua, Doom Dooma, Margherita, and Tinsukia (Sonowal *et al*., 2022 and 2023).

Materials and Methods

Materials

Survey of India (SOI) toposheet was taken as a basemap to generate the slope map at the 10 m control interval, and the base river is extracted from it Table 1). The approach for preparing the thematic map like soil texture, soil capability,

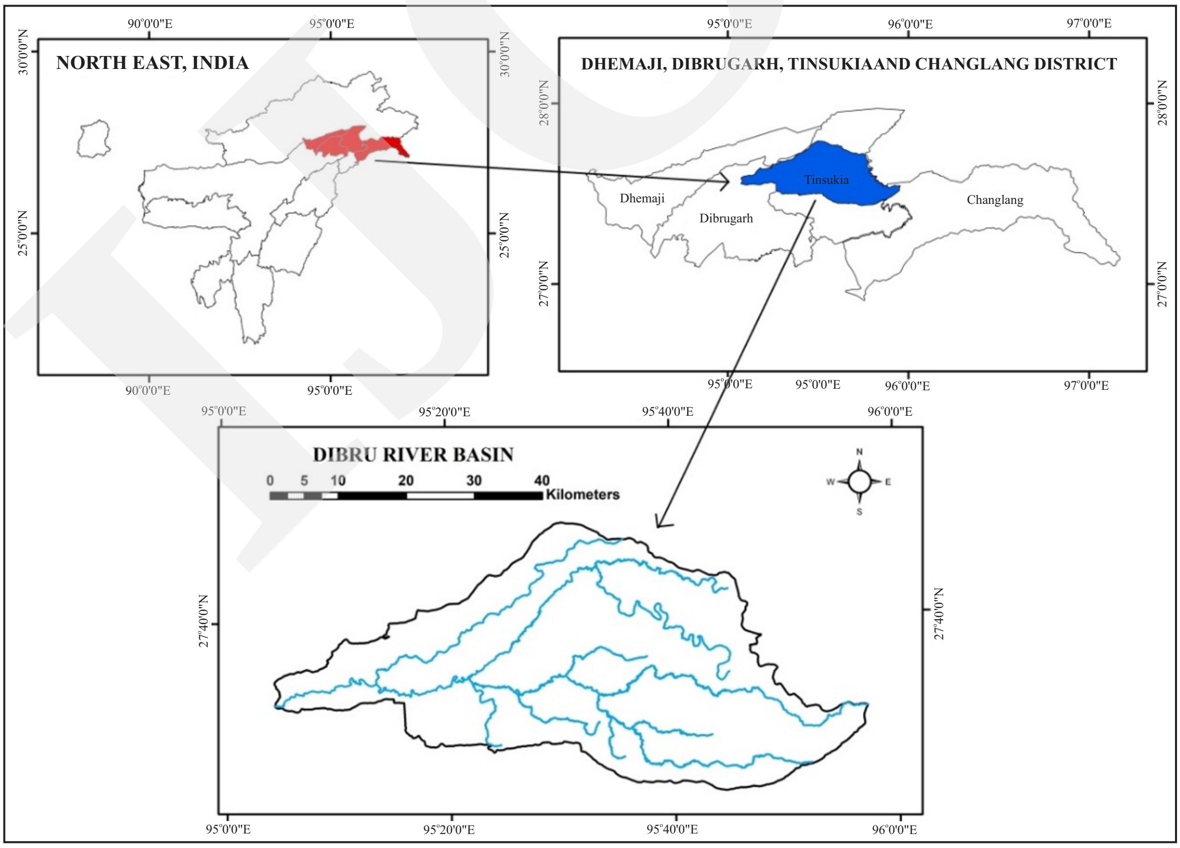

Figure 1. Location map of the studied area.

Table 1. Details of Database

Data Types	Details of Database	Source of Database
Toposheet (Slope & River distance)	83M/2, 83M/5, 83M/6, 83M/7, 83M/9, 83M/10, 83M/11, 83M/13, 83M/14, and 83M/15	Survey of India
Thematic Map	Soil: texture, capability	National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) Regional Centre, Jorhat, Assam, India, Digital Soil Map of The World
	Geomorphology	Geological Survey of India
GPS Ground truth	Location of bank erosion site	GPS

and geomorphic map involved visual observation, preliminary interpretation downloaded from the authentic government website, and was also collected from various departments at the scale of 1:50,000. All the final processing was done with the help of Arc GIS platform. The GPS point has been collected in order to verify the ground truth. After the preparation of the land management for reducing bank erosion map, in order to check the validity of the sensitive site of the bank erosion, GPS point had been collected (from 2019–2022 primary survey) for the validity of the map.

In order to prepare the landuse-landcover map from the Sentinel 2 sensor, band 8, 4, 3 converted to false colour composite (FCC) that were red, green, and blue (RGB); analysis was done using spatial versus nonspatial model (Table 2). Spatial models aim at spatially explicit representations of landuse change at some level of spatial detail, in which landuse change was indicated for individual pixels in a raster or other spatial entities such as administrative units. The group of nonspatial models focuses on modelling the rate and magnitude of landuse change without specific attention for its spatial distribution. All the features were visually identified and digitized using Arc GIS software and assigned their landuse category of each features.

Methods

Multicriterion calculation analysis using AHP is the most common and well-known GIS-based method for delineating land management for a bank erosion map. This method helps assimilate all thematic layers. A total of six diverse thematic layers were considered for this study. These six thematic layers are imaginary to control the factor of land management in the area of study. The associations of these influencing factors are weighted according to their response to land management and expert opinion. A parameter with a high influence was weighted with high impact value, and a parameter with a low influence was weighted with small impact value on land management in a given area. The weights of each class were assigned according to Saaty's scale (1–9) of relative importance value (Saaty, 2008).

Further, the weights were assigned considering the review of past studies and field experience. The Saaty's scale of relative importance value reveals that the value of:

Table 2. Detail of Satellites Imagery of Landuse-Landcover (Lulc)

Details of satellite imagery of landuse-landcover			
Sensor	Date of acquisition	Bands used	Resolution
Sentinel-2	31 Dec. 2020	8,4,3	10 m

- 9 is extremely importance
- 8 : very strong
- 7 : very extreme importance
- 6 : strong plus
- 5 : strong importance
- 4 : moderate plus
- 3 : moderate importance
- 2 : weak; and
- 1 is equal importance

As per the classification, weights are given to the thematic layers based on their position for bank erosion capacity in a given region. Accordingly, all the thematic layers have been compared in a pairwise comparison matrix (Table 3). The sub-classes of thematic layers were reclassified using the natural break classification method in the Arc GIS platform for assigning weight. Each thematic layer was ranked on a scale of 1 to 5, based on its relative influence on the land management for the bank erosion map (Table 4 and Figure 2), which shows the assigned rank and weights of thematic layers. For calculating the consistency ratio (CR), the following steps are adopted: (1) Principal Eigen value (λ) was computed by the Eigen vector technique (Table 5) and (2) Consistency Index (CI) was calculated from Equation 2 (Saaty, 2008) given below:

λ max=49/07=7

CI=λ max-n/n-1 ....(1)

where n is the number of factors used in the analysis.

CI= (06-06)/ (06-1= 0 ....(2)

Consistency ratio is defined as CR= CI/RCI (Equation 3), where RCI= Random Consistency Index value, which were obtained from Saaty's standard (Table 5).

CR= 0/1.24= 0 ....(3)

Saaty has opined that a CR of 0.10 or less is acceptable to continue the analysis. If the consistency value is more than 0.10, then the judgment needs to be revised to locate the causes of inconsistency and to correct it accordingly (Table 5). If the CR value is 0, there is a perfect level of consistency in the pairwise comparison. The threshold value is not exceeding 0.1, which means the judgment matrix is reasonably consistent. Six thematic layers were integrated with the weighted overlay analysis method in the Arc GIS platform to generate land management for reducing the bank erosion of the Dibru River Basin.

The consistency indices of randomly generated reciprocal matrices were suggested by Saaty (2008). After computing the comparison matrix using the Saaty's Rating Scale (Table 5) with the help of AHP in Arc GIS, the consistency ratio is 0, which is a good sign of judgment among all the given parameters.

Suitability map for land management to reduce bank erosion (Table 6) was prepared using the weighted overlay method from contributed geofactor map which was already shown in shown in the methodology part (Figure 3).

Table 3. Pairwise Comparison Matrix Table of Six Thematic Layers Chosen for the Action Plan for Land Management from Bank Erosion

			1	2	3	4	5	6
SL. No	**Parameters**	**Weight**	**Lulc**	**Geomorphology**	**Soil**	**SC**	**Slope**	**River distance**
1	Lulc	9	9/9(1)	9/7(1.28)	9/5(1.8)	9/4(2.25)	9/3(3)	9/9(1)
2	Geomorphology	7	7/9(0.77)	7/7(1)	7/5(1.4)	7/4(1.75)	7/3(2.33)	7/9(0.77)
3	Soil	5	5/9(0.55)	5/7(0.71)	5/5(1)	5/4(1.25)	5/3(1.66)	5/9(0.55)
4	Soil capability	4	4/9(0.44)	4/7(0.57)	4/5(0.8)	4/4(1)	4/3(1.33)	4/9(0.44)
5	Slope	3	3/9(0.33)	3/7(0.42)	3/5(0.6)	3/4(0.75)	3/3(1)	3/9(0.33)
6	River distance	9	9/9(1)	9/7(1.28)	9/5(1.8)	9/4(2.25)	9/3(3)	9/9(1)

Table 4. Rank And Weightage of Land Management for Bank Erosion Map Based on Saaty's Rating Scale Using Weighted Overlay Method

SL No	Contributing factors	Classes	Rank	Assign weight (%)
1	Land use/ land cover	Forest	1	26
		Sand bar	1	
		Settlement	4	
		Tea garden	5	
		Water bodies	1	
		Cropland	5	
		River	1	
2	Geomorphological	Water bodies-River	1	18
		Braid Bar	1	
		Channel Island	2	
		FluOri-Active Flood plain	4	
		Meander Scar	2	
		Abandoned Channel	3	
		DenOri-Pediment-Pediplain Complex	1	
		3FluOri-Older Flood plain	4	
		Pediment	1	
		Palaeochannel	2	
		Lateral Bar	2	
		Channel Bar	1	
		Point bar	1	
		FluOri-Younger Alluvial Plain	5	
		Crevasse Splay	1	
		Back Swamp	1	
		Water bodies-Pond	1	
3	Soil Map	Fine clayey	1	13
		Fine silty	2	
		Fine loamy	2	
		Coarse loamy	3	
		Sandy	4	
4	Land Capability	II w	5	11
		III es	4	
		III w	3	
		IV es	1	
5	Slope (%)	0–0.5	5	8
		0.5–1.0	2	
		>1.0	1	
6	Distance from the river (m)	150	5	24
		300	4	
		450	3	
		600	2	
		750	1	

Results and Analysis

The analysis made indicates that high erosion zone covers an area of 96.15 km^2. Basically, it is represented by the area like Dighal Tarang T.E. (Figure 4a and b), Guijan Ghat (Figure 5); Minalpur Village, and Rohmoria (Figure 6). The moderate and low erosion zones cover an area 72.85 km^2 and 68.46 km^2. 1541.54 km^2 is observed as the safe zone from bank erosion.

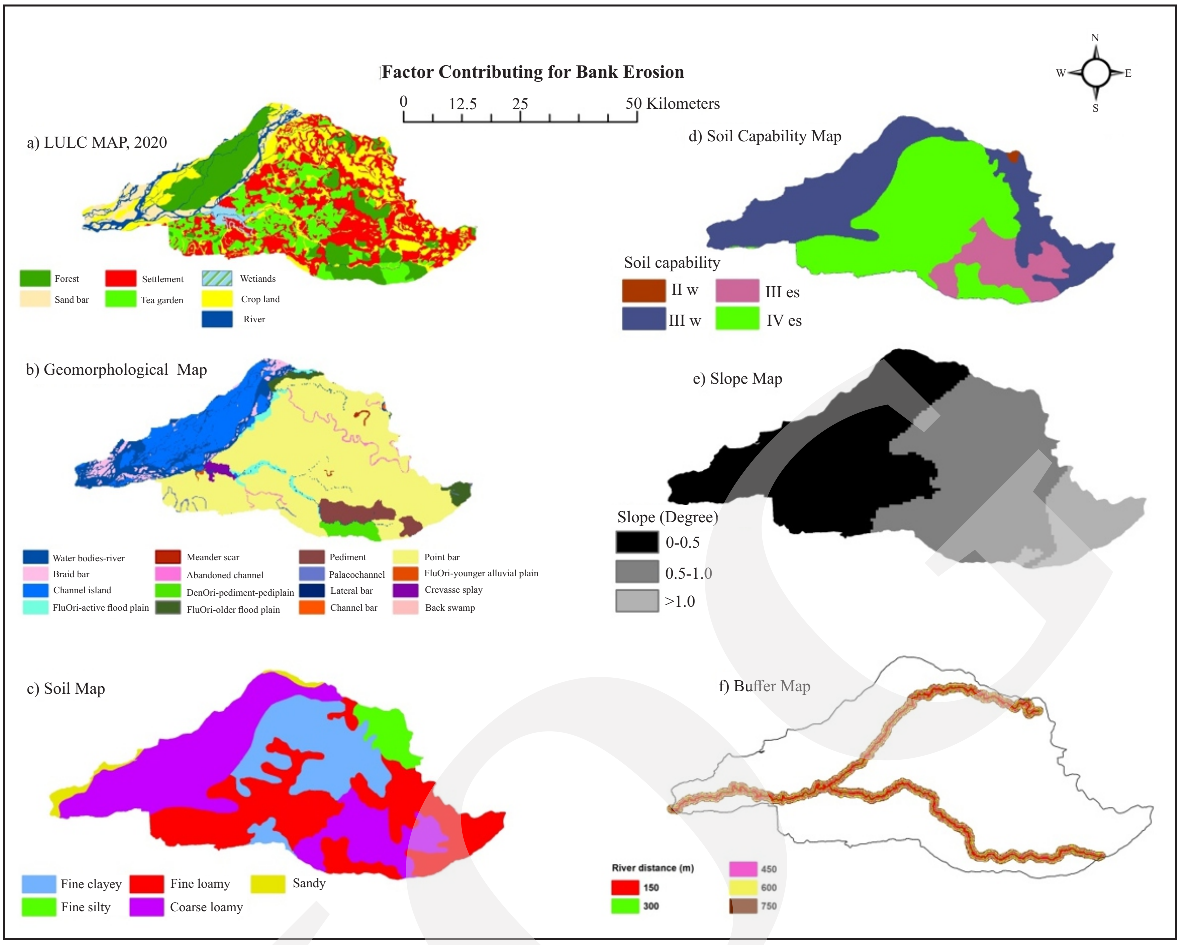

Figure 2. Factors contributing to bank erosion.

Table 5. Saaty's Ratio Index for Different Values of N

	Order of the matrix											
N	1	2	3	4	5	6	7	8	9	10	11	12
RCI Value	0.00	0.00	0.85	0.90	1.12	1.24	1.3	1.41	1.45	1.49	1.51	1.48

Table 6. Details of Reducing Bank Erosion Zone (area km^2)

Sl. No	Suitability zone	Area (km^2)	Area in (%)
1	Low	68.46	3.84
2	Moderate	72.85	4.09
3	High	96.15	5.40
	Unsuitable	1541.54	86.65
4	Total area	1779	

Recommendation to reduce the bank erosion is given in Table 7.

To check the validation of the map, 16 GPS points had been collected from the studied area for the ground truth. After those point had been collected, they were verified with the map. Out of 16 GPS points, 12 GPS points fall according to the map. The accuracy is almost 75 % (Figure 3) which means that the model prepared by using Saaty's scale and AHP taking the 6 parameters which contribute for bank erosion is valid in the studied area.

Discussion

Action Plan for Each Site

The results of action plan covering Dibru River Basin carried out during 1977-2020 is presented in Figure 7 and 8. The action activity of

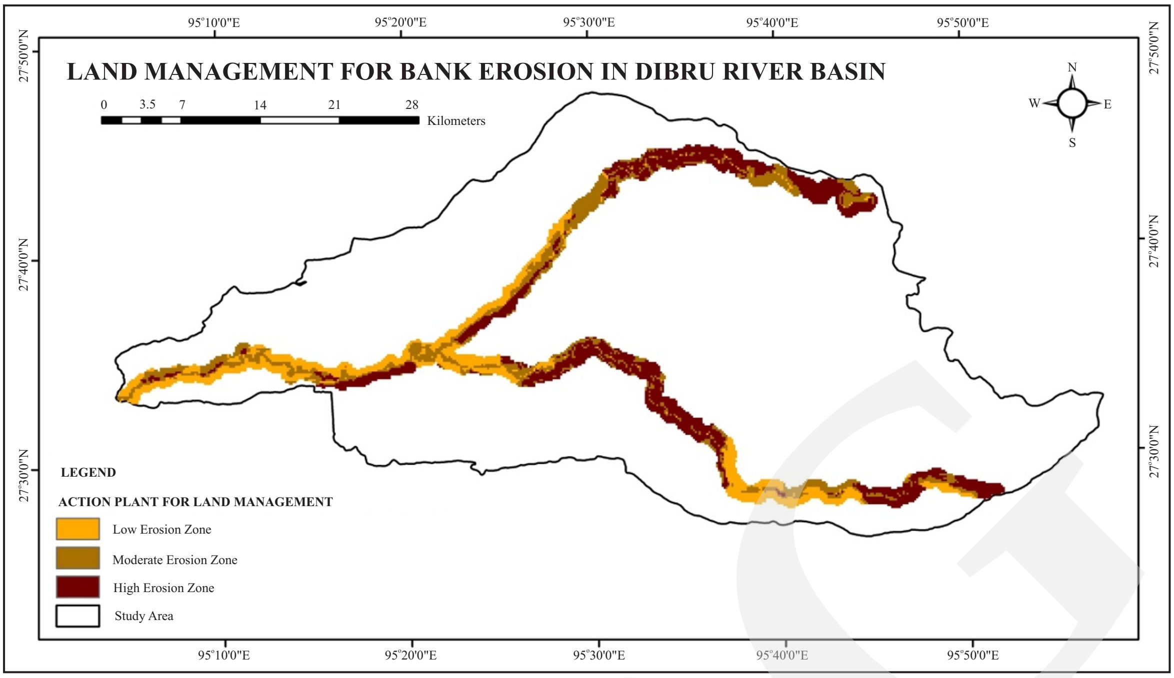

Figure 3. Validity map for land management to bank erosion.

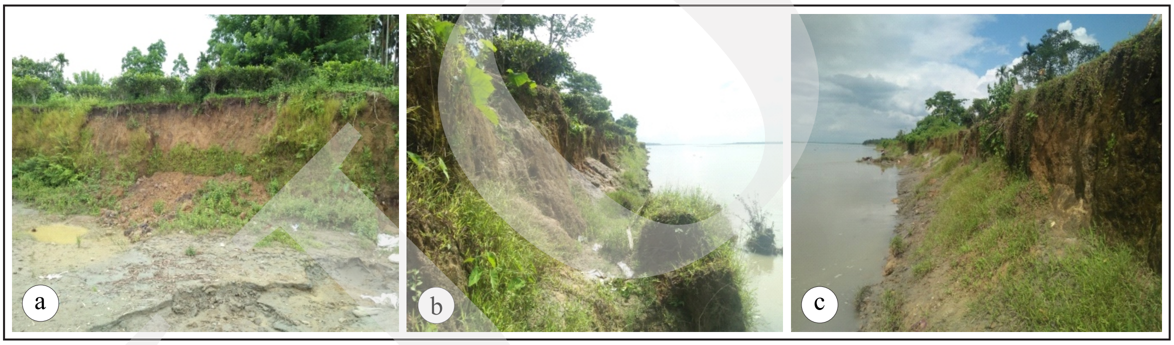

Figure 4. Photographs of: a and b) Bank erosion (Dighal Tara T.E.), and c) Bank erosion (Dighal Tara Gaon).

Figure 5. Photograph of bank erosion (Guijan Ghat).

the plan in each site, those are Minalpur Village, Dighal Tara Tea Estate, and and Notun Gaon are explained below.

Near Minalpur Village

The physical background of this site is the slope of 0 - 0.5º, categorized as a base level

Figure 6. Photograph of bank erosion (Rohmoria).

slope. The region is known as the old and active flood plain zone region, which belongs to the Meghalyan Age group. Characteristically, the soil is very deep, well-drained, fine loamy soil, occurring on gently sloping to undulating upland having a loamy surface with moderate erosion. The region is mainly covered by cropland class categories followed by settlement. By looking at these characteristics, the region is categorized as an active flood plain zone, leading to flood, erosion, and siltation.

Erosion, siltation, and flood are frequently observed at this site. Villages had been washed away because of the shifting of the channel, which led to the deposit on of sediment in the agricultural field (Rahman, 2010; Das, 2014 and 2017). It is observed that the construction of embankment by using the geotextile technique (Figure 9), which is also called as a geotube or geobag, has been seen. This technique is a cost-effective and ecologically-friendly process to mitigate erosion on the river bank. Proper maintenance and frequent monitoring system have already led this geotube embankment to a success story of preventing flood and bank erosion in different parts of the world.

Table 7. Recommendation Action Table for Land Management from Bank Erosion

Recommended Action	Physiography	Soil	Slope	Pop. distribution	Drainage den	LULC	Soil capability	Rainfall (mm)	Area (km^2)	Impact
Geotextile bags, Riprap Deep-rooted grass e.g. Vetiver plant	Flood plain (active and old flood plain zone)	fine loamy	0°–0.5°/1°	Low–Moderate density	Moderate to high	Cropland, settlement, tea garden	III w–IV es	<17,112.07 17,112.07-18,773.13 >18,773.13	Moderate Erosion Zone (72.85) High Erosion Zone (96.15)	Reducing bank erosion

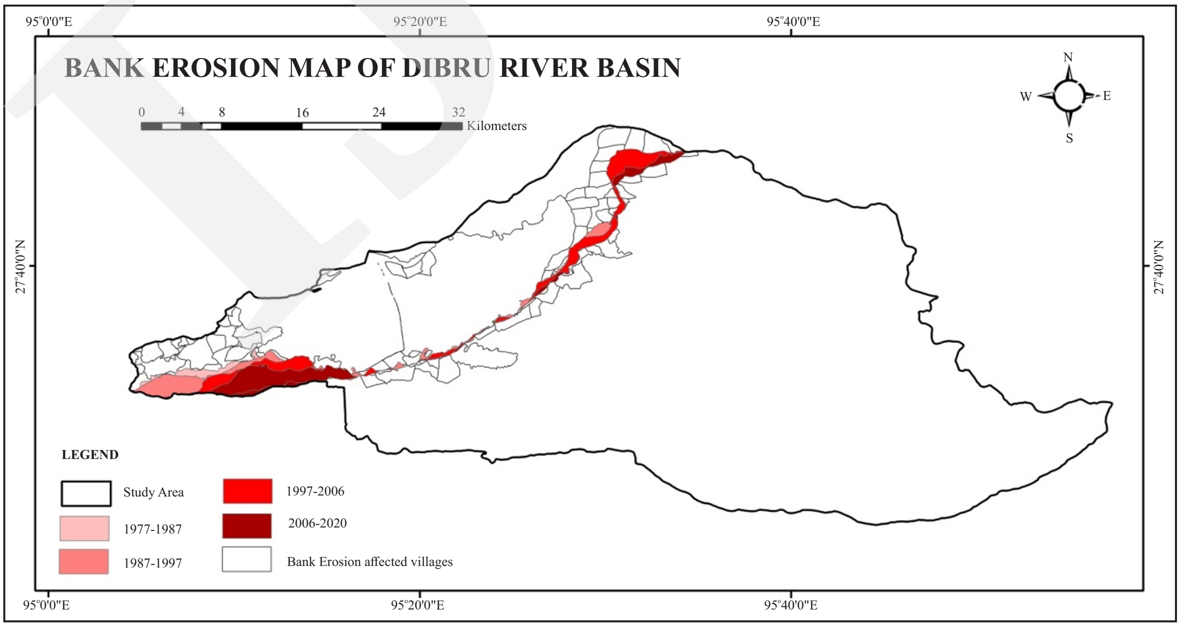

Figure 7. Bank erosion map (Dibru River Basin) (Minalpur Village, Dighal Tara Tea Estate, Guijan Ghat, and Rohmoria).

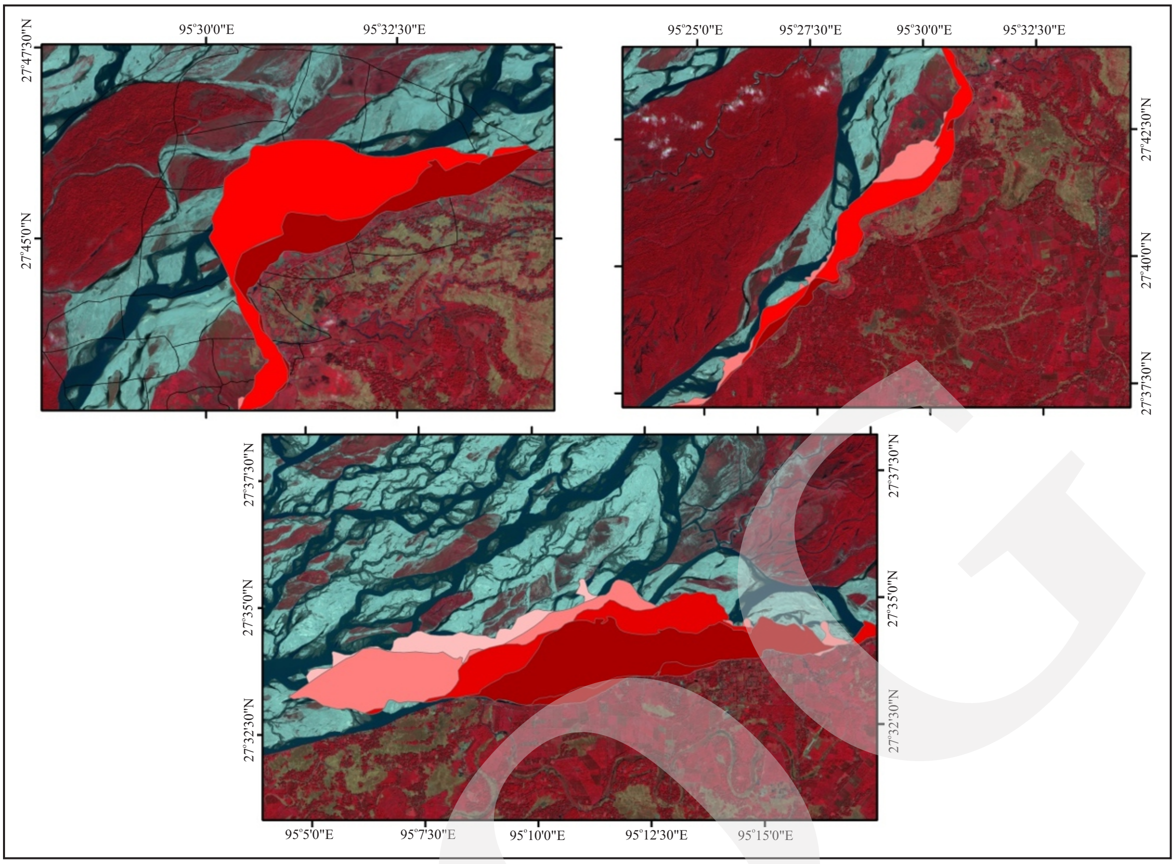

Figure 8. Satellite imagery showing the action plan for each site, near Minalpur Village, Dighal Tara Tea Estate, and Notun Gaon.

Figure 9. Photograph of Minalpur Village using geotextiles technique. Anti-erosion works along with the left bank of Jiabharali River, Assam Manish Gupta, Suresh Maurya, and Chitra River, Central Soil and Materials Research Station (CSMRS), New Delhi– 110016.

Noteworthy, by constructing a geotube embankment at a nearby village, the problem of bank erosion can minimize the recent flood. So, the construction of such a geotube embankment in the remaining villages of the area will be pretty practical to mitigate this problem (Gupta *et al.*, 2027).

This technique is observed all over Assam to minimize bank erosion took place 1977-2020 in Dibru Basin (Figures 9 and 10). Geotextile embankment is observed in Matmora in Dhakukhana Subdivision of Lakhimpur District, left bank of Jia-Bharali River (Figure 9).

Dighal Tara Tea Estate

The physical background of this site is the slope of 0.5−1.0º, categorized as a nearly level slope. The region is known as an active flood plain zone that belongs to the Meghalyan age group. The nature of soil is very deep, well-drained, fine loamy soil occurring on gently sloping to undulating upland, having a loamy surface with moderate erosion. The region is mainly covered by tea garden crops, followed by settlement. By looking at these characteristics, the region is an active flood plain zone, leading to flood, erosion, and siltation.

In this site, erosion and flood are frequent events. Many tea gardens and villages have been washed away till contemporary time. No proper action has been taken in this region till now. People are facing this problem and adopting ecofriendly events. The region is a highland, which is suitable for porcupine method as this is lacking in this region. Porcupine usually reduces the flow capacity of the water, and can lead to low erosion in this region.

During the postmonsoon period, the water retreat and leave a large area full of flood plain with small to medium size of sand deposit. Riparian vegetation is one of the most effective techniques for protecting river banks from erosion. Mainly, planting the *Australian Vetiver* (Figure 10), locally known as '*Birina Bon*, is effective in this sector (Focks *et al*., 2006). The specialty of this plant is that its root grows 3-4 ft inside the ground, which holds the soil firmly together. According to some studies conducted by scholars from different parts of the world, the *Vetiver* plant can establish a full stop to bank erosion as a less expensive measure. Its robust and compact root system can hold even the loose soil firmly if it is grown upon them. It is considered as a sustainable and innovative solution for the protection of river banks, and a socially acceptable solution for bank erosion.

Both riparian and brackish environments provide suitable conditions for the luxuriant growth of *Vetiver* plants. Mangroves, reeds, and grass sods are already applied as bank protection measures in different parts of the world (Kee *et al*., 2003). Along with these species, Vetiver plants can now be used as an anti-erosion measure that has been already tested as a bank protective mechanism on several test sites in China, Vietnam, Australia, and the Philippines. For this purpose, the Dum Dooma region near the bank of the river area can be protected from severe bank erosion during the summer season by planting Vetiver grass during the dry period. The Vetiver system was introduced in Assam at the beginning of 2009 with the formation of the Eastern Vetiver Network, India. This experiment was implemented on the hill slope on Noonmati–Kharghuli Road, Guwahati. The Vetiver demonstration site for the bridge approach was selected in the river island Majuli. Majuli is known for the notorious of erosion, and the local soil is silty sand. There is no rock/boulder available on the entire island. The transportation of boulders from elsewhere is exorbitantly costly. The planting was carried out in April 2010, and the first phase was completed in May 2010. The condition of the slope was monitored before and after the monsoon season in 2010. Again, it is observed in river bank protection work at Afala.

Notun Gaon

The physical background of this site is the slope of 0º–0.5º, categorized as a base level slope. The region is known for water bodies, channel bar, and braided bar zone region that belongs to the Meghalyan and Holocene age groups. The soil of Notun Gaon, Guijan Ghat, and Rohmoria

Figure 10. Photographs of Vetiver plant.

is very deep, well-drained, coarse loamy soil occurring on a very gently sloping flood plain having a loamy surface with moderate erosion and moderate flooding. The region is mainly covered by water bodies and cropland, followed by a sand bar. By looking at these characteristics, the region is an active flood and erosion zone, which leads to flood and erosion within the region.

In this site, it is observed that erosion and flood are frequent events in this region. Many villager crop lands and tea gardens have been washed away until contemporary. In this region, dampeners in cluster technique was installed and observed, as this technique was not suitable for minimizing erosion. The Oil India Company mainly supplies dampeners in a cluster technique. This technique minimizes the velocity of the water. It is observed that it is not the best technique to minimize the recent problem of controlling bank erosion. Application of riprap or rock fill (Figure 11) technique can protect the banks from erosion. Riprap is a method in which loose stones form a foundation layer near the bank of the river. By forming a permanent ground cover structure through the riprap method, it is somewhat possible to save the remaining parts of the villages shortly.

Construction of protective wall-like structures, including revetment wall, groyne, and porcupine minimizes the effects of erosion. River revetments are sloping structures placed on banks to protect them against erosion. Similarly, groynes (Figure 12) are structures constructed perpendicularly toward the river to protect the banks from erosion. In the case of porcupines, it is one of the novel techniques to overcome the problem mentioned above. Several studies revealed that these structures could resist the velocity of water flow to some extent.

Safety Measures to Overcome River Bank Erosion

Riparian vegetation is one of the most effective techniques for protecting river banks from erosion. Mainly, planting the *Australian Vetiver plant* is effective in this sector. Suitable condition for the luxuriant growth of *Vesiver* plants are provided by riparian and brackish vegetations. It can be considered a sustainable and innovative solution for the protection of river banks.

Very recently, the method of porcupine (Figure 13) has been adopted by the government. However, the villagers are not satisfied with applying this method during the monsoon period instead of non-monsoon.

Construction of embankment by using geotextile technique also called geotube or geobag embankment (Figure 9), is a cost-effective and ecologically-friendly process to mitigate erosion on the riverbank (Mondal *et al*., 2012). The geotube embankment to a success story of preventing flood and bank erosion was due to proper maintenance and frequent monitoring system. Remarkably, the problem of bank erosion nearby a village can be minimized by building a geotube enbankment.

Figure 11. Photographs of riprap or rock fills/river revetment (Poa St. James. Erosion Control and Pond Bank Stabilization Methods).

Figure 12. Photographs of groyne structure.

Figure 13. Photograph of installation of porcupine method in Minalpur Village.

Issues Faced by the Native People of the Area

Severe river-bank erosion is associated with the losses of cultivable lands, households, tea gardens, domestic animals, *etc* (Baishya, 2013). Rarely, the victims of the washed-out villagers get Miyadi Patta land to make the shelter after losing their own personal land. However, they become frequently homeless due to bank erosion which has been occurring since 1990. From a primary survey, it came into light that there was a loss of human life, around 50−55 villages were washed out in the flood in the last twenty-two years. Every year people experiences flood, bank erosion, shifting of the channel, becomes homeless, and losses agricultural fields, several cattle, goats, poultry, *etc*.

After being displaced from their original land, the sufferers moved to nearby land or villages to take shelter by making huts in embankments and on sand bars. The victim people experienced both happiness and bitter in the newly settled areas. This lead to changing family status or degradation of their quality of life due to losses of their livelihood pattern (as most people are engaged in the primary activities), becoming poor to very poor and trying to engage in some new occupations for survival. Sometimes they get separated from society by being treated as illegal migrant people or 'Bangladeshi' (Quencez, 2011).

Frequently, occurring flood creates excellent havoc in this physical and cultural landscapes. Sometimes, water levels rise to 3 ft from the actual land surface, which can create an unhealthy environment by spreading diseases and shortage of food stuff.

To protect the area from severe bank erosion, crores of rupees had already been sanctioned, but due to massive misappropriation, people of this area have to spend sleepless nights during the rainy season.

Conclusions

The optimum landuse action plans had been prepared to mitigate the fluvio-geomorphic problem. A land management action plan to reduce bank erosion mapping had been prepared to mitigate the hazards to some extent.

Some structural and vegetative measures can be adopted to reduce bank erosion. The basin area of 96.15 km^2 was identified for structural measures like geotextile bags, riprap, or rockfill techniques that can be used to protect in controlling bank erosion. The basin area of 72.85 km^2 was identified for vegetative measures.

Minalpur Village, Dighaltara Tea Estate, and Notun Gaon sites are suggested for instantaneous action to protect the banks from erosion. The construction of embankment by using the geotextile technique, planting the *Birina Bon*, and applying the riprap or rock fill technique suggests the banks can be protected from erosion.

Acknowledgments

The author would like to thank the supervisor for guiding to frame this manuscript by giving suggestions. Special thanks to National

Bureau of Soil Survey and Land Use Planning (NBSS&LUP) Regional Centre, Jorhat, Assam, India, for providing the soil texture.

References

Abdelhalim, G., Mohamed, H., and Akram, S., 2017. Analysis of bitemporelle images to follow-up the flooding phenomenon in the western high plains of Algeria. *International Journal for Light and Electron Optics,* 139, p.61-71.

Abdelhalim, G., Mohamed, H., Brahim, D., and Nabil, M., 2022. Application Multicriteria Decision Analysis- Approach AHP- to develop land suitability for urban sprawl. *Turkish Journal of Computer and Mathematics Education*, 13 (03), p.500-511. DOI: 10.17762/turcomat.v13i03.13019.

Abuzaid, S.A., Abdel Rahman, M.A.E., Fadl, M.E., and Scopa, A., 2021. Land Degradation Vulnerability Mapping in a Newly-Reclaimed Desert Oasis in a Hyper-Arid Agro-Ecosystem Using AHP and Geospatial Techniques. *Agronomy*, 11 (1426), P.1-23. DOI: 10.3390/agronomy11071426.

Abolfazl, A., Gholamreza, Z., and Sirous, S., 2023. Digital Mapping of Soil Fertility for Some Agricultural Lands by Using Fuzzy-AHP (FAHP) Techniques and GIS in Highly Calcareous Soil, Southwest Iran. *Communications in Soil Science and Plant Analysis,* p.1-13. DOI: 10.1080/00103624.2023.2245413.

Abuzaid, A.S. and Abdellatif, A.D., 2021. Integration of multivariate analysis and spatial modeling to asses agricultural Potentiality in Farafra Oasis, Western Desert of Egypt. Egyption Journal Soil of Science, 61, p.171-180.

Badhe, Y.P., Medhi, S.R., and Shelar, T., 2019. Site Suitability Analysis for Water Conservation Using AHP and GIS Techniques: A Case Study of Upper Sina River Catchment, Ahmednagar (India). *Hydrospatial Analysis,* 3 (2), p.49- 59.

Baishya, S.J., 2013. A Study on Bank Erosion by the River Baralia (Bhairatolajan) in Melkipara Village of Hajo Revenue Circle, Kamrup district, Assam, India. *International Journal of Scientific and Research Publications*, 3 (9), p.1- 10.

Barman, A., Basak, N., Narjary, B., and Mitran, T., 2021. Land Degradation Assessment Using Geospatial Techniques. *Geospatial Technologies for Crops and Soils. Springer* Singapore, p.421-453.

Bhagya, S.B., Sumi, A.S., Balaji, S., Danumah, J.H., Costache, R., Rajaneesh, A., Gokul, A., Chandrasenan, C.P., Quevedo, R.P., Johny, A., Sajinkumar, S.K., Saha, S., Ajin, S.R., Mammen, C.P., Abdelrahman, K., Fnais, S.M., and Abioui, M., 2023. Landslide Susceptibility Assessment of a Part of the Western Ghats (India) Employing the AHP and F-AHP Models and Comparison with Existing Susceptibility Maps. *Land*, *12*, 468. DOI.org/10.3390/land12020468.

Cengiz, T., and Akbulak, C., 2009. Application of analytical hierarchy process and geographic information systems in land-use suitability evaluation: A case study of Du¨mrek Village (Canakkale, Turkey). *International Journal of Sustainable Development and World Ecology*, 16 (4), p.286-294.

Chang, N., Parvathinathan, G., and Jeff, B.B., 2007. Combining GIS with fuzzy multi criteria decision-making for landfill siting in a fast-growing urban region. *Journal of Environmental Management*, 87, p.139-153.

Chen, Y., Yu, J., and Khan, S., 2010. Spatial sensitivity analysis of multi-criteria weights in GIS-based land suitability evaluation. *Environmental Modelling and Software*, 25 (12), p.1582-1591.

Das, K.T., 2014. River Bank Erosion Induced Human Displacement and its Consequences. *Living Reviews in Landscape Research*, p.5-2−8. DOI: 10.12942/lrlr-2014-3.

Das, K.T., 2017. Impact of Riverbank Erosion: A case study. *Australian Journal of Disaster and Trauma Studies*, 21 (2). p.73- 81.

Everest, T., Sungur, A., and Ozcan, H., 2021. Determination of agricultural land suitability with a multiple-criteria decision-making method in North-western Turkey. *International Journal of Environmental Science and Technology*, 18 (5), p.1073-1088.

FAO, 1985. Guidelines: Land evaluation for irrigated agriculture. *Soils Bulletin,* 55. Food and Agriculture Organization of The United Nations (FAO)*,* Rome, Italy.

FAO, 1993. *Guidelines for land use planning. Development Series 1. Food and Agriculture Organization of the United Nations*, Rome.

Feizizadehab, B., and Blaschkeb, T., 2013. Land suitability analysis for Tabriz County, Iran: a multi-criteria evaluation approach using GIS. *Journal of Environmental Planning and Management*, 56 (1), p.1-23.

Focks Jaspers, D.J. and Algera, A., 2006. Vetiver Grass for River Bank Protection, p.1- 14.

Gupta, M., Maurya, S., and Chitra, R., 2017. Anti-erosion works along the left bank of Jiabharali River, Assam*. Indian Geotechnical Conference* (GeoNEst).

Habibie, M.I., Noguchi, R., Shusuke, M., and Ahamed, T., 2019. Land suitability analysis for maize production in Indonesia using satellite remote sensing and GIS-based Multicriteria decision support system. *Geojournal,* 86, p.777- 807.

Hansen, H.S., 2005. GIS-based multicriteria analysis of wind farm development. In: Proceedings 10th Scandinavian Research Conference. *Geographical Information Science*, Stockholm, Royal Institute of Technology, p.75-87.

Herzberg, R., Pham, T.G., Kappas, M., Wyss, D., and Tran, C.T., 2019. Multi-Criteria Decision Analysis for the Land Evaluation of Potential Agricultural Land Use Types in a Hilly Area of Central Vietnam. *Land*, 8 (6), 90. DOI: 10.3390/land8060090.

Hopkins, L., 1977. Methods for generating land suitability maps: An evaluation. *Journal of the American Planning Association*, 34 (1), p.19-29.

Hussain, J., Zhang, J., Saleem, A., Luo, Yi., Hussain, A.M., Hussain, J., Fitria, F., Akram, W., Arifullah., and Hussain, H., 2023. Suitability Assessment Constraints of Potential Aggregate Resources Using an Integrated GIS Approach. *American Society of Civil Engineers*, 35 (9), 04023307. DOI: 10.1061/JMCEE7.MTENG-14684.

Jahangeer, A. P. and Showkat, A. G., M, B., 2018. GIS based land suitability analysis using AHP model for urban services planning in Srinagar and Jammu urban centers of J&K, India. *Journal of Urban Management*, 7 (2), p.46- 56.

Ke, C.C., Feng, Z.Y., Wu, X.J., and Tu, F.G., 2003. Design principles and engineering samples of applying Vetiver eco-engineering technology for landslide control and slope stabilization of riverbank. *Proceedings, Third International Conference on Vetiver*, Guangzhou, China, October 2003.

Khan, R.M. and Ahmed, P., 2023. Agricultural land use suitability analysis using GIS and AHP technique in Baramulla district of the Kashmir valley, India. *Research Square Platform LLC,* p.1-15. DOI:10.21203/rs.3.rs-3080748/v1.

Kılıç, M., Gündoğan, R., and Günal, H., 2023. An illustration of a sustainable agricultural land suitability assessment system with land degradation sensitivity. *Environment Development and Sustainability*, 26, p.6085-6107. DOI:10.1007/s10668-023-02951-5

Maji, A.K., Reddy, G.P.O., and Sarkar, D., 2010. Degraded and Wastelands of India. Status and Spatial Distribution. *Indian Council of Agricultural Research and National Academy of Agricultural Science.*

Malczewski, J., 2004. GIS-based land-use suitability analysis: a critical overview. *Progress in Plan*, 62 (1), p.3-65.

Maurya, S., Gupta, M., and Kumar, N., 2013. Use of geosynthetics in restoration and bank protection from Dhola-Hatiguli to Rohmoria along the river Brahmaputra—A case study. *International Journal of Latest Trends in Engineering and Technology*, 3 (1), p.136-144.

Maurya, S., Kumar, N., and Gupta, M., 2013. Use of Geobags for restricting the flow of river Dibang, a tributary of river Brahmaputra, Assam-A case study. *Proceedings, Indian Geotechnical Conference*, Roorkee. p.1-6.

Mega, N. and Khechana, S., 2021. Groundwater quality assessment by Analytic Hierarchy Process (Geographic Information Systems based model) in Souf Region (South-East of Algeria). *International Journal of Environmental Science and Technology*, 18, p. 3459- 3468.

Mondal, M., Bhunia, G.S., and Shit, P.K., 2012. Vulnerability analysis of embankment breaching—A case study of Moyna drainage basin in Prurba Medinipur, West Bengal, India. *International Journal of Geology, Earth, and Environmental Science*, 2 (3), p.89-102.

Mundhe, N.N. and Jaybhaye, R.G., 2023. Land suitability analysis for In situ slum redevelopment of pune city using AHP, Remote sensing and GIS techniques. *Journal of the Indian Society of Remote sensing*, 51, p.1777-1795. DOI: 10.1007/s12524-023-01731-y.

Mzuri, R.T,, Mustafa, Y.T., and Omar, A.A., 2021. Land degradation assessment using AHP and GIS-based modelling in Duhok District, Kurdistan Region, Iraq. *Geocarto International*, 37 (1), p.1-18. DOI:10.1080/10106049.2021.1987534.

Parmar, M., Bhawsar, Z., Kotecha. M., Shukla, A., and Rajawat, A.S., 2021. Assessment of Land Degradation Vulnerability using Geospatial Technique: A Case Study of Kachchh District of Gujarat, India. *Journal of the Indian Society of Remote Sensing*, 49. p.1661-1675. DOI: 10.1007/s12524-021-01349-y.

Poa St. James. Committee Erosion Control and Pond Bank Stabilization Methods.

Prasad, H.C., Bhalla, P., and Palria, S., 2014. Site Suitability Analysis of Water Harvesting structures using remote sensing and GIS- A case study of pisangan watershed, Ajmer district, Rajasthan. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 11 (8), XL-8. ISPRS Technical Commission VIII Symposium, 09-12 December. p.1471- 1482.

Quencez, M., 2011. Floods in Bangladesh and migration to India. *The State of Environmental Migration,* 2011.

Rahman, M.R., 2010. Impact of River Bank Erosion Hazards in the Jamuna floodplain area in Bangladesh. *Journal of Science Foundation*, 8 (1&2), p.55- 65.

Roig-Tierno, N., Bavierta-Puig, A., Buitrago-Vera, J., and Mas-Verdu, F., 2013. The retail site location decision process using GIS and the Analytical Hierarchy Process. *Applied Geography*, 40, p.191-198. DOI: 10. 1016/j.apgeog.2013.03.005.

Saaty, T.L., 1980. *The analytical hierarchy process*. McGraw Hill, New York., 9 (3-5), p.161-176.

Saaty, T.L., 2005. *Analytic Hierarchy Process*. Encyclopedia of Biostatistics. John Wiley & Sons, Ltd, Chichester, UK, DOI: 10.1002/0470011815.b2a4a002.

Saaty, T.L., 2008. Decision-making with the analytic hierarchy process. *International Journal of Service Science,* 1 (1), p.83-98. DOI: 10.1504/IJSSCI.2008.017590.

Saha, A., Pal, S.C., Chowdhuri, I., Islam, A.R., Roy, P., and Chakraborrty, R., 2022. Land degradation risk dynamics assessment in red and lateritic zones of eastern plateau, India: A combine approach of K-fold CV, data mining and field validation. *Ecological Informatics,* 69 (101653). DOI: 10.1016/j.ecoinf.2022.101653.

Salifu, E., Agyare, A.W., and Ganiyu, S.B., 2022. Evaluation of land suitability for crop production in Northern Ghana using GIS and AHP based techniques. *International Journal of Environment and Geoinformatics*, 9 (4), p.046-056. DOI: 10.30897/ijegeo.1022275.

Santosa, I., Sulaksana, N., Yuningsih, E.T., and Zakaria, Z., 2024. The Sliding Surface Determination of A Deep-seated Landslide on Cisumdawu Highway, West Java, Based on The Electrical Resistivity Tomography. *Indonesian Journal on Geoscience*, 11 (2), p.189-199. DOI: 10.17014/ijog.11.2.189-199

Sarma, J. N., Acharjee, S., and Gogoi, C., 2011. Application of DEM, Remote Sensing and Geomorphic Studies in Identifying a Recent or perhaps Neogene Upwarp in the Dibru River Basin, Assam, India. *Journal of the Indian Society of Remote Sensing*. DOI.10.1007/S12524-011-0115-1.

Shanwad, U.K., Patil, V.C., Gowda, H.H., Dasog, G.S., Shashidhar, K.C., 2011. Generation of water resource action plan for medak nala watershed in India using remote sensing and GIS technologies. *Australian Journal of Basic and Applied Sciences*, 5 (11), p.2209- 2218.

Shukla, A., Kumar,V., and Jain, K., 2017. Site suitability evaluation for urban development using remote sensing, GIS and Analytic Hierarchy Process (AHP). *Proceedings of International Conference on Computer Vision and Image Processing*.

Sonowal, G., Thakuriah, G., Hazarika, S., 2022. Role of Channel migration and influencing hydro-geomorphic attributes in Dibru river basin using remote sensing and GIS. *Nature Environment and Pollution Technology*, .

Sonowal, G and Thakuriah, G., 2023. Using Geospatial tools to detect the Flood hazards in Dibru River Basin, Assam (India). *Disaster Advances*, 16 (1), p.42-52.

Srinivas, P., Sarala, C., and Chowdary, P.P., 2007. Integrated watershed management using remote sensing and GIS techniques. *Nature Environment and Pollution Technology,* 6 (2), p.463- 470.

Tercan, E. and Dereli, M.A., 2020. Development of a land suitability model for citrus cultivation using GIS and multi-criteria assessment techniques in Antalya province of Turkey. *Ecological Indicators*, 106549.

Thakuriah, G., 2023. Geospatial and Analytical Hierarchical Process approach for potential sites of water harvesting in lower Kulsi basin, India. *GeoScape* ,17 (1). p. 58- 73. DOI: 10.2478/geosc-2023-0005.

Thakuriah, G., 2023. Geospatial Tool-Based Geomorphological Mapping of The Lower Kulsi Basin, India. *Indonesian Journal on Geoscience*, 10 (2), p.229-230. DOI: 10.17014/ijog.10.2.229-244.

Tolche, A.D., Gurara, M.A., Pham, Q.B., and Anh, D.T., 2021. Modelling and accessing land degradation vulnerability using remote sensing techniques and the analytical hierarchy process approach. *Geocarto International*, 37 (24), p.7122-7142. DOI: 10.1080/10106049.2021.1959656

Ullah, K.M. and Mansourian, A., 2015. Evaluation of land suitability for urban land-use planning: case study Dhaka City. *Transactions in GIS*, 20 (1), p.1-18. DOI:10.1111/tgis.12137.

Ustaoglu, E. and Aydinoglu, A.C., 2020. Suitability evaluation of urban construction land in Pendik district of Istanbul, Turkey. , 99, 104783.

Waseem, M., Ahmad, S., Ahmad, I., Wahad, H., and Leta, M.K., 2023. Urban Flood risk assessment using AHP and geospatial techniques in Swat Pakistan. *SN Applied Sciences*, DOI: 10.1007/s42452-023-05445-1.

Zabihi, H., Alizadeh, M., Wolf,I.D., Karami, M., Ahmad, A., and Salamian, H., 2020. A GIS-based fuzzy-analytic hierarchy process (F-AHP) for ecotourism suitability decision making: A case study of Babol in Iran. *Tourism Management Perspectives*, 36, 100726.