DEVELOPMENT OF ALLUVIAL FANS AND THEIR PEDO-GEOMORPHIC SIGNIFICANCE ON THE LANDUSE IN TERAI REGION, WEST BENGAL, INDIA

A Thesis submitted to the University of North Bengal

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Geography & Applied Geography

BY
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November, 2018.
DECLARATION

I declare that the thesis entitled "Development of Alluvial Fans and their Pedo-Geomorphic Significance on the Landuse in Terai Region, West Bengal, India" has been prepared by me under the guidance of Dr. Sudip Kumar Bhattacharya, Assistant Professor, Department of Geography & Applied Geography, University of North Bengal. No part of this thesis has been formed the basis of award of any degree or fellowship previously.

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CERTIFICATE

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Abstract

North Bengal alluvial plains at the Himalayan margin has a long drawn historical perspective since the Pleistocene period. Subsequently with the passage of time the fan areas were reshaped and are also being modified by the post-periglacial processes i.e. the fluvial action by the major rivers and their tributaries. Hence the alluvial fans are the result of the complex interaction of different processes which the present researcher seeks to be concerned with for understanding their detailed modes of action responsible for the evolution, development and modification of the coalescence of fans and fan segments as well as the interrelationship between the Pedo-Geomorphic character of the fans and land use of the study area.

The present researcher analysis the correlation of the existing landuse with the pedo-geomorphic character of the study area. This correlation study is based on some different perspectives and interrelationships. Finally on the basis of these correlations the lands of the study area have been assessed with a precise objective to recommend the agro climatic resilient land utilization.

The study of geological and tectonic characteristics of the study area is always vital for the study of alluvial fans because the tectonic characteristics confirm the proportion of streams vertical erosion and deposition of new sediments. Lithology of the study area determines the character of the sediments and therefore influencing the form of the fan and its pedogenesis. The tectonic influence on the development of alluvial fans can be considered in terms of fan intrenchment, fan segmentation and also the sedimentology, shape and thickness of each new and old depositions of the alluvial fans.

The study area extends from 26º30’00” N to 26º55’00” N Latitudes and 88º05’00” E to 88º37’15” E Longitudes comprising the whole Terai plains. The area lies in between the right bank of river Tista and left bank of river Mechi. The major rivers of the study area are Tista, Mahananda, Balason, Mechi, Rakti, Rohini etc. Rohini and Rakti are the tributaries to the Balasan which finally meets Mahananda at downstream. The total area of study is about 888.9 km².

The present study area is having diverse physical & climatic characteristics which have been classified into different land segments based on the capability classes to investigate the numerous notch of the competence of the lands for agriculture with other type of applications.
in the primary stage and distinguish the arable lands from that of non-arable lands in the secondary stage. Based on the findings, the best fit landuse types and management methods, which will be essential for the preservation lands for future, will be recommended in the next chapter for the sustainable utilization of lands as well as to minimize additional risks of damage of this unique study area.

The shapes of the apex of the fans are changing with modifying fans characteristics after debouching on to the rolling plain. Mass deforestation, unscientific settlement construction on the vulnerable hill slopes, rapid growth of urbanization and associated phenomenon like, construction of roads which results in the addition of extra sediment load in the river channels. Consequently, severe soil erosion continuously take place on the hill tracts and huge quantity of eroded materials come down by the rivers to the lower course of the channels. Thus, the materials distributed onto the fan surface must have varied constitutional and nutritional values in different parts of the fans. As such the present researcher feels it essential to investigate the pedo-geomorphic significance of the fan region on landuse. The result of the analysis speaks about the mechanical & chemical properties of soil with the degree of pedogenesis of the whole study area.

Objective

For a comprehensive study of the alluvial fans and their pedo-geomorphic significance on landuse some objectives have been taken into consideration. These are:

i. To investigate in detail the complex interaction of the fan forming processes and their mode of operation by which fans are being developed and the pedo-geomorphic characteristics are being resulted as an outcome.

ii. To correlate the pedo-geomorphic characteristics of this region with the landuse pattern existent in present scenario.

iii. To see how far the present landuse is suitable and adjusted in the existing pedo-geomorphic set up.

iv. To find out the contrasts between the present land use and their pedo-geomorphic environment and thereby formulate the more scientific land use method to achieve better result.
Hypothesis

i. The litho-tectonic and high rainfall induced fluvially erosive land characteristics of the Darjeeling Hills provide huge bed loads, wash loads and dissolved load to the stream network which are accelerated by various anthropogenic effects.

ii. The lower courses of the rivers get various types of debris in different regions supplied from the upstream tracts having certain geologic origin and the materials are reshuffled further by the action of the overflow of the braided streams to form the coalescence of fans.

iii. The alluvial fan segments as such may consist of various pedo-geomorphic characteristics in the different parts.

iv. These pedo-geomorphic diversities should have influence on the landuse of this area.

This study is based on primary and secondary data. Relevant primary data were collected from field survey through conventional survey techniques. Hence, different methodologies were adopted for different objectives. These are:

Analyse the development of alluvial fans in this region referencing of previously published data, research works has been done. Digital Elevation Modeling has been created with the help of GIS platform to visualize the relief of the study area. Analyses of hydrological characteristics have been done on the basis of field observations and drainage maps. Climatic data from different tea gardens were collected and analyzed with statistical tools.

Different morphometric analysis have been carried out such as cross and longitudinal profiles were drawn with the help of GIS tools, average slope, relative relief, drainage density, area-slope distribution study, slope map generation etc. During field survey soil samples were collected from different pits and measurements of fan materials have also been done in logical techniques. Testing of soil samples has been done in well-equipped laboratory. On the basis of the outcomes of these techniques alluvial fan segmentation map was generated.

To identify the existing landuse and land cover of the study area vectorisation of the different topographical maps of Survey of India and open source USGA topographical sheets in support of Govt. of West Bengal’s Forests Department etc. have been done with the help of Arc-GIS 10.5 platform and statistical analysis of data was also performed.
To understand the importance of Soil Water Potentiality the Battelle formula of SWP has been relevantly cited. To establish the correlation between Rainfall and runoff the Rational method has been used with other statistical techniques.

Analytical Hierarchy Process (AHP) implemented by weighted overlay technique has been practiced to determine a classified structure of landuse and its suitability as specified by FAO.

Satisfactory standard procedures were maintained during the field survey for the land capability classifications. Determination of capability classes had been done as per the main principles of the land classifications of FAO with required adjustments. Distinctive physical & climatic characteristics of the study area are given highest importance during the identification of capability classes & their sub classes as this area under study is consisted of diversified soil types. The outcomes of different land classes were based on the general rule of observation of the land restrictions of the present study area.

The study revealed that the Development of alluvial fans and their morphometry are strongly controlled by several factors which are segmented as Geo-tectonic factors, relief, climate, lithology, and hydrology since the Pleistocene period. So, on the basis of these dynamic factors of fan development and the morphological characteristics of the fans, it can be said that fan formation process of the study area is still in action.

The pedogenic process here is more in the nature of Podsolization than Laterization. These soils may be taken as typical soils formed by weathering as the presence of iron oxide, alumina and clay indicates considerable amount of weathering. The Red bank soil is generally highly acidic due to the removal of lime and other bases by weathering and leaching action. This soils, however, is very rich in essential plant foods. This is why most of the land under these segments to some extent is occupied by tea gardens and natural vegetation. Upper part has immature soil cover due to soil slips and high surface runoff due to massive deforestation the arable land are not so fertile for crops. The area is however blessed with large nos. of perennial rivers, khals, beels and water bodies. Approximately 141.05 sq.km area which is about 15.87% of the whole study area is under agricultural landuse.
Maximum settlement cover found in the lower fan segment where about 148.51 sq.km. area which is approx. 25.16% of this segment area is under settlement. In many cases the socio-economic parameters and population pressure also drove the configuration of land use parameters by artificial management. In lower fan segment potential crop fields has been converted into small tea gardens supported by artificial drainage system which is also accelerated by legacies of large tea gardens dominated economy. This unprecedented phenomenon adversely affect the physical characteristics like water holding capacity, bulk density, porosity, nutrients stratus etc. of soil in the study area.

The study also depicted that the land use is vastly controlled by the pedo-geomorphic characteristics mainly in the upper fan segment where the slope, altitude, runoff, climate, soil are relevantly synergistic with the land use and vice-versa. In case of soil sand % and altitude are positively correlated where the silt % is having negative correlation with altitude. The water holding capacity somehow manipulated mainly in the lower fan segment with land conversion and artificial drainage. Hence, the harmony becomes questionable in case of middle and lower fan segment where the land use land covers to some extent is not adjustable with the pedo-geomorphic scenario of the study area.

It is also found that the lower fan segment is dominated by silted soil characteristics, more water holding capacity in comparison with the upper and middle fan segment, high rainfall with uneven yearly distribution, stagnation of water in patches, prolong low average temperature etc. based on which some sustainable land use may also be adopted in the lower fan segment.

It can be concluded on the basis of information gathered from the field and from the analysis of morphometric maps, that, the alluvial fans over the study area are divided into three separate segments having different characteristics and pedogenesis. Steep to gently steep gradient, semi-deep trenches and enormous sub angular boulders widely spreading over moderately developed soil are the major features of the upper fan segment.

Hence, the current study illustrates that the agricultural and horticultural land use will be more sustainable land use than small tea gardens in this part of the lower fan segment supported by prolong winter season and compatible pedo-geomorphic characters. Being situated in the highly susceptible to erosion zone, if, any adverse changes stuck down the monopoly tea based economy, this substitute sustainable high value agricultural and
horticultural landuse may control the situation in a positive approach with the support of agriculturally favorable pedo-geomorphic conditions of this segment.

Though agriculture and construction sites are may be targeted away from the fragile zone of the stream bank area with proper planning as this region is formed by diversified alluvial detritus carried by different streams from mountainous tracts.

Over all the following recommendations have been proposed for the study area:

i. Cultivation of high value crops like Gherkin, Baby corn etc. can be practiced on the basis of soil suitability and water potentiality.

ii. In the lower fan segment agricultural activities can be carried out based on soil characteristics and fertility available as suitable soil cover is changeable as new alluvium covers the surfaces by the river bank side almost every year due to seasonal floods and flash floods.

iii. Leguminous crops which develop nitrogen capital and soil compactness resisting soil loss like Arhar (Cajanuscajan. L) and pulses (Vignaradieta, Vignamungo etc.) can make a sustainable approach towards the development of the area.

iv. Photo and thermo insensitive crop variety can be adopted.

v. Submergence tolerant crop variety may be applicable in the patches of water stagnation.

vi. Deep rooted crops should be avoided.

vii. Intermittent drought tolerance crops can be cultivated with temporal variations.

About 61% of the land surfaces of the study area is occupied by tea gardens and forests. Greater portion of cultivated land is located on the lower fan. Mainly in the upper part of the lower fan segment and lower part of the middle fan segment destruction of forest to meet the demand of land for cultivation and settlement is a regular feature here which initiates soil erosion, landslides, flooding and hinders process of soil found in the upper fan region.
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PREFACE

There are extensive historical perceptions behind the growth of the North Bengal alluvial plains at the Himalayan margin since the Pleistocene period. Consequently, the physiographic arrangements of the fan areas were restructured and are also being modified due to climatic variations in collaboration with the post-periglacial processes.

Hence, considering that complex interaction of different processes is mainly responsible behind the formation of alluvial fans, the present researcher seeks to understand their thorough modes of action liable for the evolution, expansion and modification of the coalescence of fans and fan segments as well as the interrelationship between the pedo-geomorphic character of the fans and landuse of the study area. To meet the demands of the objectives intensive field study with data analysis has been done and suitability analysis with specific perspective finally revealed the significance of this study.

For the appropriate arrangement of this work, I express my hearty thank to my supervisor Dr. Sudip Kumar Bhattacharya for the intensive support he has given to me, so that I could incorporate my own ideas with the topic. I express my sincere thanks to my parents, my wife, my daughter and all the family members for all their sacrifices they have made in supporting and motivating me through all the difficult times.

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Date: 

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CHAPTER-I

Introduction

1.1 Introduction

The development of the North Bengal alluvial plains at the Himalayan margin has a long drawn historical perspective since the Pleistocene period. Subsequently with the passage of time due to climatic changes the physiographic configurations (Dorn R.I. 1994, Twidale, 2004) of the fan areas were reshaped and are also being modified by the post-periglacial processes i.e. the fluvial action by the major rivers and their tributaries. So, the alluvial fans are the result of the complex interaction of different processes which the present researcher seeks to be concerned with for understanding their detailed modes of action responsible for the evolution, development and modification of the coalescence of fans and fan segments as well as the interrelationship between the Pedo-Geomorphologic character of the fans and land use of the study area.

1.2 Area of study

The present researcher has selected this study area (Figure. 1.1) located at the foothills of the Darjeeling Himalayas, in the state of West Bengal, India widely known as the Terai which means moist undulating land with some complex research questions. The study area extends from 26º30’00” N to 26º55’00” N Latitudes and 88º05’00” E to 88º37’15” E Longitudes comprising the whole Terai plains. Tectonic characteristics, relief, climate etc. of this study area are very suitable for the development of alluvial fan. Major rivers flowing through the study area along with their tributaries are coming from the Himalayas and formed alluvial fan which is the main focus of this study. These alluvial fans conjoined and finally formed a piedmont zone. The area lies in between the right bank of river Tista and left bank of river Mechi. The major rivers of the study area are Tista, Mahananda, Balasan, Mechi, Rakti, Rohini etc. Rohini and Rakti are the tributaries to the Balasan which finally meets Mahananda at downstream. The total area of study is about 888.9 km².
1.3 Scope of study

It has been observed that rivers from the different mountainous tract are carrying detritus characteristically diversified in nature and depositing accordingly over the different parts of the fans and thereby modifying fans characteristics after debouching on to the rolling plain.

The legacies from the past events in the form of scattered big boulder deposits on the upper part of the fans are getting further transported by severe flash floods and redistributed over the fan areas. Thus the shapes of the apex of the fans are changing which needs detailed investigation for accurate analysis.

In addition to it, defilement of environment in the form of mass deforestation, unscientific settlement construction on the vulnerable hill slopes, rapid growth of urbanization and associated phenomenon like, construction of roads, passing of heavy vehicle through these roads have become the triggering factors for severe soil creeping, sheet slides, slips and other types of slope failure, which results in the addition of extra sediment load in the river channels.
Due to above activities the soil surface in many places has been exposed and lost the compactness to a great extent since the pore spaces of the soils are filled up with water particles after direct contact with rain in the monsoon and has increased the shearing stress in the soil shattering the soil coherence. As a result severe soil erosion continuously take place on the hill tracts and huge quantity of eroded materials come down by the rivers to the lower course of the channels.

Moreover in absence of sufficient vegetative cover the surface runoff on the hilly tracts becomes higher and finally reaching the stream channels earlier than usual which results in sudden peak flood flow in the channel cross-section due to the reduction of Lag Time.

All these factors are ultimately resulting severe degradation of the hill areas and the materials are carried out by the mountain rivers down to the terai rolling plains, finally contributing unwanted detritus on the river beds which are getting incremented on the fan areas in an accelerating manner.

Thus human induced causes beside the natural causes play a very active role in the development and modification of the alluvial fans.

It is interesting to mention that the materials which are deposited on the alluvial fans have a very significant impact on the land use since the materials are transported by the rivers from the different parts of the hill areas which are consisted of the substances having different geologic, pedologic and geomorphic origin. Thus, the materials distributed onto the fan surface must have varied constitutional and nutritional values in different parts of the fans. As such the present researcher feels it essential to investigate the pedo-geomorphic significance of the fan region on landuse.
1.4. Objective of study

For a comprehensive study of the alluvial fans and their pedo-geomorphic significance on landuse some objectives have been taken into consideration. These are:

i. To investigate in detail the complex interaction of the fan forming processes and their mode of operation by which fans are being developed and the pedo-geomorphic characteristics are being resulted as an outcome.

ii. To correlate the pedo-geomorphic characteristics of this region with the landuse pattern existent in present scenario.

iii. To see how far the present landuse is suitable and adjusted in the existing pedo-geomorphic set up.

iv. To find out the contrasts between the present land use and their pedo-geomorphic environment and thereby formulate the more scientific land use method to achieve better result.

1.5. Hypothesis

i. The litho-tectonic and high rainfall induced fluvially erosive land characteristics of the Darjeeling Hills provide huge bed loads, wash loads and dissolved load to the stream network which are accelerated by various anthropogenic effects.

ii. The lower courses of the rivers get various types of debris in different regions supplied from the upstream tracts having certain geologic origin and the materials are reshuffled further by the action of the overflow of the braided streams to form the coalescence of fans.

iii. The alluvial fan segments as such may consist of various pedo-geomorphic characteristics in the different parts.

iv. These pedo-geomorphic diversities should have influence on the landuse of this area.

1.6. Review of literature

The present researcher is interested to work in the field of alluvial fans and the tentative topic is “Development of Alluvial Fans and Their Pedo-Geomorphic Significance on the Landuse in Terai Region, West Bengal, India”. So, the present researcher has consulted some books and articles regarding the different aspects related to the study of alluvial fans, its development, pedo-geomorphic characters and impact on landuse. During the library work the researcher
found that till date few rich and applicable works have been done in the field. In all climatic conditions alluvial fans may play an important buffering role in mountain geomorphic or sediment system (Harvey, 1996, 1997, 2002b). In mountainous terrain, alluvial fans are conspicuous locations for infrastructure and residential status development, and are excellent locations for growing trees, but these landforms can present significant risks because they are frequently the runout zones for landslides. David J. Wilford and Matthew E. Sakals in their paper ‘Forest management for landslide risk reduction on alluvial fans’ said that “A fan is a cone-shaped deposit of sediment formed where a stream channel leaves the confines of a mountain (Bull 1977). It is an expression of its watershed; the fan is created by and represents a summary of the hydrologic and geomorphic processes in the watershed. The watershed, or catchment, is the source area for water, sediment, and woody debris, the stream channels are the transport zone, and the fan is the deposition zone. Together, they constitute the fan-watershed system which is the basic unit for hazard and risk analyses”. But while stream channels in the watersheds of fans transport material, it is common for stream channels on fans to be unconfined: when landslides or flood flows enter onto a fan there is usually a broadcasting of sediment and water. On fans with forests this leads to a characteristic “hydrogeomorphic riparian zone” with buried trees, log steps, scars on trees, and groups of trees of different ages (Wilford et al. 2005b). It is therefore important that resource development in watersheds above fans be planned and undertaken with an understanding of the fan-watershed system; the risk to downstream features must be critically considered (Jakob et al. 2000). The challenge facing on alluvial fan sedimentary sequences is to develop interpretive models that are compatible with the findings of research on contemporary processes and on extant Quaternary alluvial fans (Steel, 1974). In the research paper ‘Differential effects of base-level, tectonic setting and climatic changes on Quaternary alluvial fans in the northern Great Basin, Nevada, USA” A.M. Harvey said that “The interaction between tectonics, climate, base level change have produced distinctive fan geometric relationships between younger and older fan segments, also expressed in the morphometric properties of the fan”. Alluvial fans develop at the base of drainages where feeder channels release their solid load (Blair and McPherson, 2009; Leeder et al., 1998; Harvey et al., 2005). A classic fan-shape forms where there is a well-defined topographic apex. Multiple feeder channels, however, often blur the fan-shape resulting in a merged bajada. Alluvial fans can be found in almost all terrestrial settings. These include alpine (Beaudoin and King, 1994), humid tropical (Iriondo, 1994; Thomas, 2003), humid mid-latitude (Bettis, 2003; Mills, 2005), Mediterranean (Robustelli et al., 2005; Thorndycraft and Benito, 2006), periglacial (Lehmkuhl and Haselein, 2000), and different paraglacial settings (Ballantyne,
2002). If we talk about the sedimentation and its processes we can take the reference of the research paper ‘Luminescence dating of alluvial fans in Intramontane basin of NW Argentina’ written by R.A.J. Robinson, J.Q.J. Spencer, M.R. Strecker, A. Richter and R.N. Alonso; it is “Alluvial fans are sensitive recorders of both climatic change and tectonic activity. The ability to constrain the age of alluvial fan sequences, individual sedimentary events and the rates of sediment accumulation are key for constraining which mechanisms most control their formation”. Actually “alluvial fans are ubiquitous along mountain fronts, and their evolution is tied to tectonic and climatic conditions” (Bull and Harvey, 1977). McSweenay et al (1994) provides a framework for soil landscape modeling particularly for soil properties prediction.

Modeling process follow four consecutive stages: 1) physiographic domain characterization that involves integration of available data sets to define and characterize the physiographic area under study, to consolidate a priori knowledge about the area, and to identify other data that might be valuable for defining soil pattern; 2) geomorphometric characterization of the landscape by primary and secondary landscape attributes derived from a digital elevation model (DEM); 3) horizon stratigraphy characterization that includes development of a soil horizon legend that is used to determine the distribution and spatial relationship among soil horizons and other layers in the landscape; and 4) soil property characterization that involves laboratory and statistical analysis of soil horizon attributes collected during the third stage. However, the study of soil-landform relationship itself has begun since 1935, since catena concept was established (Milne, 1935). At the beginning of the 19th century all these fans of Terai region were well covered with tropical forests of densely growing Sal (Shorearobusta), Segun (Tectonagrandis) or Sturdy Sheesham (Dalberghiasiso),(S.R.Basu and S.Sarkar, 1990, pp328). In this field some attention being paid to floods and aggradation on alluvial fans in Duars, these damaging railway and road bridges and tea gardens. These were mainly focused in a valuable paper by Dutt (1966). The rivers which are fed partly by melt water form mega-fans with frequent avulsions (Sing, 1993). In the 1980s geomorphologists from North Bengal University studied landslides and alluvial fans in the catchments of two left-bank tributaries of the Tista, called the Lish and Gish (Basu, Ghatowar 1986, 1988, 1990; Basu, Ghosh, 1993). In the mean time the foothills-fed start in the marginal part of the Himalaya (mainly the Siwalik zone) where rainfall is higher, building a system of small fans and changing channels from braided to meandering within the wide inter-fan-zones (cf. Shukla, Bora, 2003). The detritus classification with relation to altitude has been done as, sands and gravels in the middle part (called the Terai–40 km wide) and further down stream of sandy loams and even clays (L.Starkel, S.Sarkar, R.Soja and P.Prokop, 2008). The overall changing pattern of landuse and

6
its distribution has been shown as the gradual establishment of tea gardens after 1866 on the undulating terrain having suitable soil and adequate drainage; more and more forests were cut. At present tea gardens cover about 40% of the total area under study. Moreover, tea gardens occupying about 5% of the region have been deserted by their owners as these were no longer economical (S.R.Basu&S.Sarkar, 1990, pp-328) or since boarder difficulties with the China in 1962, military installations have also been increased, occupying more & more of the forest land and uneconomical tea gardens (S.R.Basu&S.Sarkar, 1990, pp-328). The present researcher found it interesting that the materials which are deposited on the alluvial fans have a very significant impact on the land use since the materials are transported by the rivers from the different parts of the hill areas which are consisted of the substances having different geologic, pedologic and geomorphic origin. In the research paper ‘Development of Alluvial Fans in the Foothills of The Darjeeling Himalayas and Their Geomorphological and Pedological Characteristics’ S.R.Basu&S.Sarkar said that “in the area of study, the fan deposits are coarse-grained, poorly sorted and immature sediments. Usually gravel, cobbles, and boulders predominate with subordinate amount of sand, silt and some clay. The coarsest and the thickest deposits occur near the fan heads. Maximum grain size and thickness of sediments decrease rapidly toward the base of the alluvial fan deposits. The roundness of coarse grains also increases with increasing distance from the apex of the fan”. Thus, the materials distributed onto the fan surface must have varied constitutional and nutritional values in different parts of the fans. The study of soil-landform-landuse relationship itself has begun since 1935, since catena concept was established (Milne, 1935). Soil-landscape model represents both relationships between soil and landform and the relationships between the pattern of soil-landform-landuse relationship and processes of pedo-geomorphic evolution. There are very complex relationships between soil and landform in the soil landscape system and the relationship between pattern and process of pedo-geomorphic evolution (McSweenay et al., 1994). But interestingly there is a firm research gap in the development, land use system and land evaluation of that alluvial fan as well as in their interrelationships. So, the alluvial fans at present are the result of the complex interaction of different processes which the present researcher seeks to be concerned with for understanding their detailed modes of action responsible for the evolution, development and modification of the coalescence of fans and fan segments as well as the interrelationship between the Pedo-Geomorphic character of the fans and land use of the study area.
1.7. Methodology

For the fulfilment of the objectives discussed above the present researcher has adopted a rationalistic and quantitative methodology which can be divided into different parts:

1.7.1 Pre-field Methods

To study the physiography like Geomorphology, Geology, Landuse, Soil and Climatic conditions of the area basic data and associated maps have been collected and prepared with the help of the Survey of India topographical maps no. 78 B/1, B/5, B/6, A/4 and A/8 (1:50,000), NG 45-8 and 45-7 series U502 surveyed in between 1931 to 1944, published in 1959 and also published maps of NBSS&LUP, Govt. of West Bengal’s Forests Department. Preparation of base maps of the study area from Topographical maps, NBSS&LUP maps and satellite imagery.

1.7.2 Field Method

1.7.2a Study of the fan geometry

i) Study of the fan forming materials by field survey.

ii) Measurements of the fan material size.

iii) Collection of soil samples for determining pedo-genesis of different fan segments.

iv) Determination of the coarseness of regolith.

v) Measurement of hydrologic properties.

vi) Identification of legacies from the past.

vii) Fan segmentation following break of slopes.

1.7.2b. Scheme for collection of primary data from the field

The collection of primary data has been done by a number of field studies. Such crude data have been collected through appropriate geomorphological, statistical and mathematical techniques for finding out the actual situation of the targeted aspects. GIS software have been used to draw different profiles and curves.
In addition, different samples of soil have been collected directly from the field for preparing soil zone map. Similarly the land use of the study area have been carefully observed and noted to chalk out the proper interrelationship with the present pedo-geomorphic set up of the fan area.

1.7.2c. Collection of secondary data

To get the exact view of rainfall, temperature and other elements of weather and climates, the different meteorological data of in and around the study area have been collected from the Regional Meteorological office, Silliguri, Bagdoga, Jalpaiguri, Alipurduar and Kolkata. For the agricultural data, the Department of Agriculture of Silliguri and Jalpaiguri, the Uttarbanga KrishiViswavidyalaya has been consulted carefully. For the land use, the satellite images of the study area have been studied cautiously.

1.7.3. Post-field Method

The detailed outline of the adopted methods is as follows-

A. **Graphical Methods:**

a) **Profiles:**
   i) Cross profiles.
   ii) Long profiles.

B. **Quantitative Methods:**

a) Slope analysis.
b) Relief analysis
c) Drainage density
d) Channel morphology and Hydraulics.

C. **Cartographic Methods:**

a) Morphometric mapping.
b) Soil mapping.
c) Landuse Mapping.


d) Land evaluation mapping.

**D. Statistical Methods:**

a) Correlation Analysis.
b) Analytical Hierarchy Process (AHP) with Weighted Overlay.
c) Quantification techniques.

**E. Remote Sensing & GIS:**

a) Analysis of satellite imagery & data extraction.
b) Data analysis with the help of DBMS software.
c) Map digitization & generation of relevant maps.
d) Drainage line density maps analysis.
e) Terrain modelling.
f) Land suitability classification model by AHP with weighted overlay method.

**1.7.4 Library Work**

For the compilation of the bibliography as well as the reference works the Libraries of North Bengal University, Library of Ananda Chandra College, The National Library, The Geological Survey of India, The Survey of India, Uttarbanga Krishi Biswavidyalaya, has been consulted thoroughly.

Finally, all the data collected from the field and various institutional sources have been analyzed, processed and computed in the laboratory to predict the exact nature of the problem and to provide a workable modus operandi for the corrective measures for overall development of the study area.
CHAPTER-II

Physical background of the study area

2.1 Introduction
The physical formation of the study area is basically depends on its geologic structure, the controlling factor of landform evolution. The subsequent physical formations of this study area are influenced by different geomorphic processes, each of which has developed its individually accumulated landform characteristics. The present study area has hills, foothills and undulating which are found in a horizontal cross-section. The study area, thus, evoked a great combination of climate and elevation. In this chapter, the present researcher attempted to explore the physical set up of the study area with its nature and extent of variations in landform characteristics.

2.2 Methodology
This part is mostly based on the available topographical maps prepared by the Survey of India and the available published literatures about this region’s geology, topography, drainage, soils, climate, natural vegetation, and landusepattern. The maps have been generated with the help of Arc-GIS 10.5 platform in collaboration with satellite imageries on the basis of available secondary data.

2.3. Geology
The geological structure of this area is very unique in terms of structural configuration as the Himalayan mountain fronts are contributing the major essence in form of sediments. There are three important formations extended in N-S direction under this geology of the study area. The Table 2.1 and Figure 2.1 below provide a broad as well as compact perception about the formations of different geological periods and their approximate coverage percentage of study area under study. From this table 2.1 the outline of geology of diverse units and sequences, the evolutionary styles of the study area emerge out distinctly. The geological structure of this area also depicts the alluvium dominance on the study area the main thing by which the alluvium fans are made of.
<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Geological Structure</th>
<th>Geological Period</th>
<th>Nature of Formations</th>
<th>Types of Rock</th>
</tr>
</thead>
<tbody>
<tr>
<td>a)</td>
<td>Alluvium</td>
<td>Recent (Holocene) Pleistocene</td>
<td>Sub-aerial formations (soil, alluvial, colluvial) Raised Terraces</td>
<td>sand, gravel, pebble, etc. and soil covering the rocks sandy, clay, gravel, pebble etc.</td>
</tr>
<tr>
<td>b)</td>
<td>Lower Siwalik</td>
<td>Miocene</td>
<td>Sedimentary in origin.</td>
<td>Micaceous Sandstones (grey in colour), Conglomerates &amp; Silts with bands of limestones.</td>
</tr>
</tbody>
</table>

If a) Himalaya Front Tectonic Line (HFTL)

Table 2.1 The geological structure of the study area
(Source: Based on Mallet, 1874; Gansser, 1966; Pawde and Saha, 1982)

a. Miocene

The Lower Siwalik rock formation had taken place during the geological period of Miocene. Along the Whole length of the outer most hills of the Himalaya from Indus to Brahmaputra the newer Tertiaries had occurred in a large scale which is known as Siwalik system (Bhattacharya, 1993). The lower Siwalik is also a part of Siwalik system occurs along the foothill zones dipping between 30°–60° towards N-NE. From the lithological perspective it can be observed that the Siwaliks are principally formed with the debris washed out and carried by the different streams originating from the core of the central Himalaya. The top surface of this formation are generally pebbly and comprises of rounded pebbles of quartz either randomly orientation or are aligned parallel to the bedding plane (Tamang, 2013). This part of formation is occupying about 18% of the area under study.

b. Pleistocene

The southern part of the study area comprises of Pleistocene & Sub-recent alluvial deposits with gravels and coarse sand by the numerous rivers coming down to the debouching plain and forming several alluvial fans. These alluvial fans, the main focus of the present research are finally merged and formed the piedmont plain of Terai. The places covered by this plain under the study are, Merechebong, Khaprail, Sevok, MechiBasti, Naxalbarietc & same tea gardens Simulbari, Longview, Patinbari etc. The major portion of the study area is composed of Alluvium formations with Sedimentary rock type covering approx. 82% of the total study area.
2.4. Topography

The entire study area reflects its heterogeneous topographic characteristics with a unique combination of plains, hills. The initial surface slope from north to south forces the rivers of this area to flow towards southward directions. The Terai (moist undulating land) traverses east-westward along the base of the Darjeeling Himalayas being drained by numerous rivers coming down from the Himalayan hills. From the relief map (Figure 2.2) it can be viewed that the highest altitude of the study area is 510 m and the lowest is 75 m. Though, the general effective extension lies between the contour 400 m to 100 m, some patches of peaks are having the height of 500 m or more in the northern part and some depression patches of 75 m can be observed in the southern part of the study area. There are mentionable break of slopes were observed in the long-sectional profile (Figure 4.7) of the study area which creates the most favourable condition for the formation of alluvial fans in the study area. Some terraces are also observed having moderate to steep slope at the northern part of the study area and the southern part from the middle of the study area is monotonously flat with undulating patches.
2.5. Drainage

The study area is blessed with rivers and most of them are perennial. The Tista, the Mahananda, the Balasan, the Rakti, the Rohini and the Mechi are the major streams flowing through the study area along with their tributaries. The pattern of the drainage of the study area is mostly dendritic. These rivers are flowing from north to south direction maintaining the initial slope of the surface of the study area. All the major rivers are originated from the Himalayas and flowing a long way from different mountainous tracts and thus carrying a huge load of diversified sediments which are finally deposited on the alluvial fans followed by break of slope. In the northern part or at the apex of the alluvial fans of the study area the rivers are moderately narrow and showing vertical erosional features due to slope whereas the braided pattern of rivers are observed in the middle and lower part of the study area with lateral erosional features. Flash floods, stream bank erosion etc. are the natural characteristics of the rivers of the present area of study. The drainage map (Figure. 2.3) can give a glimpse of the drainage types and patterns of the study area.
To study the characteristics of soil of the study area, a number of soil samples from different pits covering the whole study area were collected (Figure 4.12), tested in laboratories and analysed the result (Table 4.4). The result of the analysis speaks about the mechanical and chemical properties of soil with the degree of pedogenesis of the whole study area. The detailed test report of some of the soil profiles are given in the appendix I.

It is found that the northern portion of the study area that is above the 200 mt. contour line up to an altitude of 350 mt. approximately the development of soil has become more distinct with markedly leached horizon having moderately fine texture varying from sandy clay loam to sandy clay as seen in different soil profiles. But from above 350 mt. up to 400 mt. approximately (approximately as because there are some patched of 500 mt. are present) the soil of this region are comparatively less developed because of relatively higher slope, coarseness in alluvial deposits due to stream action and mass wasting.
The middle part of the study area along 200 m contour comprises with soils, relatively coarse textured varying between sandy loams to loamy sand. Though, in some patches over the study area, the top soils are composed of comparatively finer texture in comparison with the subsurface soil. The lower or southern portion of the study area ranging contours from 100 mt. up to 200 mt. is belonging to gently sloping surface with comparatively finer soil texture like loam to clay loam than the soil just above it.

2.7. Climate

As the study area is consisted of the hill, foothill & plain topography the overall climatic characteristics of this area is interestingly diversified and related with altitude. To understanding the climate as a whole of the study area three sub-segments are given below.

2.7.1. Seasons of the study area

The present study area experiences four main seasons with altitudinal dissimilarities. The major seasons are:

**Figure 2.4** Soil map of the study area.
(Source: Field survey and NBSS&LUP)
i. Summer season (May to September)
ii. Autumn season (October to November)
iii. Winter season (December to February)
iv. Spring season (March to April)

The upper portion experiences extended rainy days throughout summer season with continuous rainfall. The winter is generally cold with rare rainfall. The middle and lower part of the study area which is also known as the southern lowlands having semi long humid summer with mild winter (Tamang, 2013). The whole study area experiences pleasant autumn and spring season.

2.7.2. Temperature:

From the collected data (Table no. 2.2) from the different part of the study area it can be said that the temperature distribution of all over the months of the lower part of the study area is higher than that of upper part or the semi-hill area. The mean annual temperature of the whole study area is about 23.54°C. The northern uplands are having a mean annual temperature of 17.17°C whereas in the southern parts it is recorded 24.70°C. In summer season, the mean temperature ranges between 16°C to 21°C in the upland and 23°C to 29°C in the lowlands. In winter, cold temperature ranging between 5°C to 12°C can be observed in the northern part of the study area, while, the southern part is having temperature between 13°C to 20°C.

2.7.3. Rainfall:

From the Figure 3.3 based on Table no.2,2, it can be said that from April to October for both upper and lower regions of the area under study, the mean monthly distribution of rainfall is getting a sharp rise, but from October up to March the sharp decrease of the monthly rainfall can be experienced. The Southwest monsoon winds which contribute about 85% of the total annual precipitation is the main controlling factor of the rainfall over this whole study area. From the collected data it is seen that the heavy rain months are mainly June, July and August with the average rain fall 550.63mm, 668.87mm, 572.15mm respectively. December is the month of lowest rainfall both in the upper and lower part of the study area. The average number of rainy days in the plains is 103 days and 128 days in the upper segment of the study area.
Table 1.2 Rainfall and Temperature of the study area
(Source: Tea Gardens record collected in 2014-2017)

Hence, from the above findings we can draw following conclusions concerning the climatic characteristics of all segment of the area under study

1. The characteristics of rainfall and temperature are considerably different in the upper and lower part of the study area.
2. Comparatively heavy rainfall in the upper part of the study area contributing high amount of water in the different streams and channels through runoff resulting heavy sediment loads in form of surface erosion.
3. The climate the plain part of the study area bear a resemblance to Koppen's Am (Tropical Rain-forest climate) type of climate since the average temperature of all the
months (21.54 °C) remains high above 18°C. Also, the annual rainfall of this part is also amply high being 3276.82 mm. It seems like Koppen’s 'A' climate. Hence, the climate of the plain portion of the Basin under study can be termed as Tropical rainy type (Bhattacharya, 1993).

4. It is also found that from mid of October to mid of March the whole study area is experiencing the below average temperature.

2.8. Natural Vegetation

At the beginning of the 19th century the Terai region were well covered with tropical forests of densely growing Sal (Shorearobusta), Segun (Tectonagrandis), or sturdy sheesham(Dalbarghiasiso). (Basu&Sarkar, pp-328). Other than this the study area also have some species like, Champak (MicheliaChampaca), Almond (TerminaliaMyriocarpa), Gokul (Ailanthus grandis) etc with valuable commercial timbers. It is observed during field survey and analyzing remote sensing data that mainly the upper segment has the major forest cover with tea gardens than middle and lower. For example Sevok, Upper Rohini, marchebong, Mechibastietc. areas are mostly forest covered than middle areas like Sukna, Khaprail, Samalbong etc. and lower fan areas like 2.5 miles, Matigara, Bagdogra etc. But, unfortunately deforestation in different ways making slopes of the upper apex areas vulnerable resulting loss of soils from the slope due to which rivers are getting more sediment load which are finally deposited at the foothills.

Plate 2.1 Glimpse of natural vegetation near the apex of alluvial fan.
Figure 2.5 Natural vegetation cover and tea garden map of the study area.  
(Source: Bhuvan Satellite image.)

Plate 2.2 Soil erosion/ Slope failure at Sevok on Shivakhola River
2.9. Conclusion

From the above discussion it can be concluded that the whole study area is geologically young and friable region with mostly consisted of sands, gravels & older alluvium. The whole area is unevenly composed of sandy, fine, coarse and fine loamy soils with a large intensity of average annual rainfall and temperature variations. Vegetation cover of the study area has rapidly decreased from high altitude to lower altitude which is from north to south.

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CHAPTER III

Development of the alluvial fans in the study area

3.1 Introduction

The development of the north Bengal alluvial plains at the Himalayan margin has a long drawn historical perspective since the Pleistocene period. It is thought that the initial development of the coalescence of alluvial fans in this region was the result of the Pleistocene phenomenon.

The mentionable fact is that thick beds of boulder overlie on the north-word dipping Siwalik strata unconformably at the eastern Himalayas foot hill during Pliocene-Pleistocene period. It means that the boulder formation evolved during Pleistocene period, after the completion of upliftment, tiltation and sectional denudation of the Siwaliks. It is thus evident during Pleistocene, when the higher parts of the Darjeeling Himalayas were experiencing wide spread glaciation.

During the period of Pleistocene, initial fan materials were deposited at the foothills, which further re-distributed by the fluvial actions. Tista, Mahananda, Balasan, Rakti, Rohini and Mechi, the major streams flowing through the study area along with their tributaries are carrying a great volume of periglacial debris are solifluction materials which are further redistributed over the fans and deposited accordingly to shape and reshape the fans.

The rivers of the study area i.e. Tista, Mahananda, Balasan, Mechi, Rakti, Rohini etc. have formed a thick cover of poorly stratified and unsorted sediments at the base of the foot-hills and formed alluvial fans. These alluvial fans coalesce to form a piedmont zone. The evolution, materials, modes of deposition of debrises, morphology, pedology and stratigraphy of the alluvial fans are strongly influenced by factors like tectonics and lithology, local relief, climate and hydrology.

3.2 Methodology

To analyze the development of alluvial fans in this region the research works has been done based on the data, literature published by early workers as well as the Digital Elevation data from SRTM sources, SOI topographical sheets 78B/1 and B/5, LISS IV satellite images having resolution of 23.5 m after necessary ground truthing in the selected sites. Mapping has been done with the help of GISand terrain analysis tools to to visualize the relief of the study area, the mode of deposition by the rivers and different breaks of slopes as a guide line for
identification of the alluvial fans. Analyses of hydrological characteristics have also been done on the basis of field observations and drainage maps. Climatic data from different tea gardens were collected and analyzed with statistical tools. Intensive field investigations have also been done to identify the controlling factors of alluvial fan development.

3.3 Controlling factors of alluvial fan development

The Development of alluvial fans and their morphometry are strongly controlled by several factors which may be segmented as:

a) Geo-tectonic factors of the area.
b) Lithology.
c) Relief of the study area.
d) Climate.
e) Hydrological Characteristics of the study area.

May any one of the above factors is dominant but naturally all the above factors are equally responsible for genesis and structuring the fans of the present study area.

3.3. a) Geo-tectonic factors of the area

The study of geological and tectonic characteristics of the area is important for the study of alluvial fans as the rate of channels vertical erosion and funding of fresh debris are determined mainly by the tectonic characteristics. Lithology of the area controls the character of the debris and thus influencing the shape of the fan and its pedogenesis. The tectonic impact on the development of alluvial fans is considered in terms of fan entrenchment, fan segmentation and the sedimentology, shape and thickness of both modern and ancient alluvial fan deposits (Lecce, 1990). Although alluvial fans may form in areas where tectonic upliftment is not an important factor, they are especially prominent where uplift of mountainous regions provides a continual supply of fresh debris from steep drainage basins. The rate of tectonic upliftment in mountainous region relative to the rate of stream channel down cutting largely determines the thickness of the alluvial fan deposits, locus of deposition and the degree of entrenchment at the apex (Beaty, 1970). Where the rate of channel down cutting at the mountain front exceeds the rate of upliftment of the mountain mass, the fan head becomes entrenched and the locus of deposition moves downward from the apex of the fans (Bull, 1977).

All the rivers of the present study area i.e. Tista, Mahananda, Balasan, Mechi, Rakti, Rohini etc. have formed alluvial fans with mentionable thickness of their debauchers and all the rivers
show deep fan head trenching. The transverse cross sections across the study area clearly indicate that the apex area of the fans has been entrenched deeply and at places it is about 30 meter deep. To explain this great thickness of the fans and deep fan head trenching it is necessary to study the past tectonic activities of the study area. The most dominant feature of the study area, in the Pleistocene period is depression in front of the newly uplifted mountains, which origin is undoubtedly connected with the origin of the Himalayas. The Neo-Tectonic movements of Post-Pleistocene period have significant influence in the formation of alluvial fans at the foot of the Darjeeling Himalayas. Isostatic adjustments are still going on in this orogenic belt; consequently the region is geologically unsteady. As a result the rivers of this region to some extend are rejuvenating.

3.3. b) Lithology

Lithology of the surrounding area has a major impact on the alluvial fans as the fan forming materials are supplied to the streams from the surrounding areas. Proceeding northwards from the southern plains the foothills show a low relief usually comprises the raised terraces which represent the older flood plain deposits of the Himalayan drainage. Northwards, these are generally followed by the Siwalik (Figure 2.1).

Within the study area in the south of the Siwalik system the alluvial plain, the most important part of the enormous extension of the North Bengal Terai plain is situated. Younger flood-plain sediments of the rivers consisted of sand, gravel, pebble, etc. as well as the soil layering by the sandy, clay, gravel, pebble, boulders etc. are developing a number of alluvial fans which habitually merge or coalescence to form the wide piedmont plain of Terai along the Darjeeling Himalayas foot hills.

During field survey it has been observed that the alluvium of the study area is composed of sand, silt and clay with some bands of gravel. The thickness of the alluvium is variable. Garidhura, Southern Panighata, Mechi Basti, Marchebong, Simulbari, Marionbari, Sevok etc. covering about 700 sq.km of the total study area which fall under this formation. Change of course of the rivers flowing through those deposits sometimes giving rise to terraces (Basu & Sarkar, 1990).

Raised Terraces usually form a fringe bordering the hills on which the apex or upper parts of the alluvial fans are mostly situated. These comprises with gravels, pebbles and boulders mixed
with clay and sand. The formation of this is somehow amalgamated, stratified and shows indications of turmoil at places.

The Siwalik is the foothill belt exposes the rocks of the Siwalik system, varying in age from Middle Pliocene to Early Pleistocene. This comprises with sandstones with siltstone, clays, lignite etc. the top bed of this formation are generally covered with pebble and contain rounded to semi rounded pebbles or quartz. The composition of the Siwalik deposits shows that they are nothing else than the alluvial debris the numerous streams coming down through different mountainous tracts and deposits at the foothills.


<table>
<thead>
<tr>
<th>Period/ Age</th>
<th>Type/ Series</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recent</td>
<td>Alluvium</td>
<td>Younger flood plain deposits of the rivers and ‘kholas’ comprising sand, gravel, pebbles etc. and soil covered rocks.</td>
</tr>
<tr>
<td>Pleistocene</td>
<td>Raised Terraces</td>
<td>Sand, Clay, gravel, pebble, boulders etc. representing older flood plain deposits.</td>
</tr>
<tr>
<td>Miocene</td>
<td>Siwalik</td>
<td>Sandstones with siltstone, clays, lignite etc.</td>
</tr>
</tbody>
</table>

**Table 3.1 Stratigraphic Succession of the study area**

(Source: Pawde & Saha, 1976, Basu & Sarkar, 1990.)

3.3. c) Relief

The most typical relief feature for the formation of alluvial fans is marginal to uplifted structural blocks bounded by faults with significant dip-slip. In this case the basic condition for alluvial fan formation in the study area is a sudden decrease of slope from the upper gradient which is about 15° from the mountains to the foothills. In this particular place the major rivers of the study area like Tista, Mahananda, Balasan, Rakti, Rohini and Mechi become unconfined and the hydraulic conditions require deposition of sediments being transported.

Relief plays a dominating role in the formation of alluvial fans as dominant break of slope is essential for the formation of fans. The primary condition for the formation of fans at the base
of the mountains is a sudden change of slope where the emerging streams become unconfined and the hydraulic conditions require deposition of sediments being transported (Basu, 1989).

Figure 3.1 Contour Map of the Study area
(Source: SRTM Data)

There are two distinct physical regions in the area under study: the hills and the plains of Terai. The slope is from north-west to south-east. The hills of the area rise abruptly forming the Terai plains, and the elevation increases north-westward. Change of slope from mountains to foothills is sudden and abrupt, being about $15^\circ$ from the mountains to the foothills. The mean elevation of Terai is 91.44 meter above sea level while some of the hills within the district rise to more than 300 m. Terai lies between the mountains and the plains and is traversed by numerous small hill streams. It is a sort of neutral country being composed neither of the alluvium of the plains nor of the rocks of the mountains, but for the most part of alternating beds of sand, gravel and boulders brought from the mountains. It has been found through DEM analysis considering hypsometric purview that the landscape of the Terai is gentle and generally North to south slope is maintained everywhere.
Plate 3.1 Type of soil creeping in study area

This surrounding hill section is very much prone to landslips and erosion. Heavy rainfall decomposition of rocks steep and unprotected hill slopes and high angle inclination of the bedded rocks in the same direction as the hill slopes some of the factors causing fall of boulders sliding of rock masses and soil creeps. Particularly the landslips of 1951, 1968 and Aila Land Slides in 2009 are mentionable. These landslides and soil creeps particularly during heavy rains help continuous supply of fresh materials necessary for active fan formation. Over grazing, deforestation, unscientific construction, Load of heavy vehicle and step cultivation in the lower slopes are the other factors contributing heavy erosion and landslips.
Climate is one of the most important factors influencing fan formation (Dorn R.I. 1994, Twidale, 2004). Climate change influences the development of alluvial fans by inducing variability in the magnitude of fluvial process which in turn influences alluvial fan features. Fans tend toward equilibrium in adjustment to different climatic conditions. The fan aggradation occurs regardless of climatic regime also. During wet periods aggradation takes place within the drainage basin and below the mountain front. During dry conditions trenching occurs in the upper portion of the fan as debris flow becomes the dominant erosional process. This causes fan head entrenchment and the shift of deposition down fan, but the fan still builds out from the mountain front (Lusting, 1968).

Figure 3.2 Digital Elevation Model of the Study area
Source: SRTM data

3.3. d) Climate

Climate is one of the most important factors influencing fan formation (Dorn R.I. 1994, Twidale, 2004). Climate change influences the development of alluvial fans by inducing variability in the magnitude of fluvial process which in turn influences alluvial fan features. Fans tend toward equilibrium in adjustment to different climatic conditions. The fan aggradation occurs regardless of climatic regime also. During wet periods aggradation takes place within the drainage basin and below the mountain front. During dry conditions trenching occurs in the upper portion of the fan as debris flow becomes the dominant erosional process. This causes fan head entrenchment and the shift of deposition down fan, but the fan still builds out from the mountain front (Lusting, 1968).
To explain the evolution and formation of alluvial fans of the study area it is necessary to deal with both the past and the present climate of the area. Nearly 1 million years ago during the Pleistocene epoch there was a great refrigeration of climate, culminating in what is known as the Ice Age or glacial age. The higher parts of Darjeeling Himalayas undoubtedly experienced wide-spread glaciations and the ice sheets came down along the hill slopes to distances far more south than their present limit. The region lying beyond the margins of glaciers experienced a periglacial climate being followed by a cold pluvial climate.

Then after melting and gradual regression of the ice sheets with gradual warming of the globe the climate changed and now the area is experiencing a very hot and humid Tropical monsoon type of climate (Am.). This type of climate is generally characterized by strong seasonal distribution of rainfall. About 80% of the annual rainfall occurs during the south-west monsoon i.e. from June to October, July being the wettest month. Whereas rest of the year it remains dry by receiving only 20% of the total rainfall. On account of the hilly nature of the terrain there are sharp variations in rainfall, generally increasing north-wards. The highest mean annual precipitation has been recorded at Long-view Tea Garden (428.9mm) and lowest at Simulbari Tea Garden (369.3mm) signifying that the apex zone of the fans receives more precipitation than the distal part.

**Figure 3.3** Mean monthly rainfall (mm) and temperature (°C) of the Study area

*(Refer Table 2.2)*
The rainfall-temperature graph shows (Figure 3.3) shows clearly that there is an exceptionally heavy concentration of rainfall during the monsoon months particularly during the months of May June, July and August. This heavy precipitation being added with other factors is undoubtedly influencing the geomorphic features of the study area. This peculiar concentration of heavy rain during a particular part of the year is responsible for the fact that the fan building process has not been stopped here. Formation and its further modification have continued.

The factors influencing fan formation and morphology have been dealt in detail in this chapter. In the following chapter the geomorphology and the characteristics of the fans will be dealt in detail along with the influence and effect of these fan forming factors.

3.3. e) Hydrological characteristics of the study area

Great amounts of debris deposited on the alluvial fan surfaces which are widely expand over the entire study area. On the fan surface the trunk streams feeds the distributary channels and water discharge come down along its course. Furthermore, as the fans comprise of more permeable deposits, further runoff is nearly insignificant due tovertical percolation of water. Finally this discharge enhances the rate of deposition on the alluvial fans of the study area.

The surface morphology of fans is controlled by sediment and water supplied to the fan and reflects diversified characteristics. During high intensity rainfall events, the drainage basin infiltration capacity of fans can be exceeded. At this time water is transported to the alluvial fan surface and the location of deposition can be altered, fan head entrenchment can be deepened and fan dissection can occur. The relationship between stream channels and the fan surface is said to be reflective of the erosional/depositional behavior of fan systems and can determine whether fan formations are still in action and the fans are in active mode. Hence, active fans obtain sediment from the drainage basin area which is further deposited at distal settings on the alluvial fan. this is what actually is going on in the present study area which is discussed in different chapters. It can be considered that the streams in this study area are tremendously in action and supplying diversified sediments on the alluvial fans as shifting of channel results in the shift of the locus of deposition on the alluvial fan and entrenched or fossil channel system does not deposit sediment on the fan surface(Harvey, 1997).
The axial drainage of the alluvial fans of the terai region flows in southward direction. The most mentionable feature of these alluvial fans is the deep entrenchment of the axial stream at the fan apex portion. The deep entrenchment of axial stream channel is related to tectonic activity and moderate to steep slope. The drainage pattern of this area is dendritic type. During the period of Pleistocene, initial fan materials were deposited at the foothills, which further re-distributed by the fluvial actions. Tista, Mahananda, Balasan, Rakti, Rohini and Mechi, the major streams flowing through the study area along with their tributaries are caring a great volume of periglacial debris are solifluction materials which are further redistributed over the fans and deposited accordingly to shape and reshape the fans.

All of these streams have deposited huge amount of debris at the point where they come down from the hilly region to the plain. The main cause for the deposition of a large amount of debris in the alluvial fan region is the decrease in the velocity of flow of the stream as a result of fall in gradient. Carrying capacity of stream is directly dependent upon the velocity and as a result fall in velocity initiates immediate deposition of load and the subsequent spreading of the stream water from the apex of the fans. On the fan surface the trunk stream feeds distributaries channels and water discharge diminishes along its course. Moreover as the fans consists of relatively permeable sediments additional discharge is lost because of downward percolation of stream water. These discharge losses in downfan direction promote an increased sediment concentration within the water sediment mixture during flow of any type. This leads to sediment deposition on fan surfaces.

The discharge of streams on the alluvial fans depends upon the amount of rain on the fan surface and adjoining hills. Maximum discharge is found during the rainy season and minimum discharge found in winter and the difference between maximum and minimum discharge is very high indicating strong seasonal distribution of rainfall, as it has been found during field survey that the quantum of deposition is peak in rainy season.

Besides the five main streams there are innumerable small streams which are mostly seasonal and locality known as Jhoras. They carry rainwater during the months of rain and remains almost dry during rest of the year. The number of such tributaries is highest in the upper fan part. Along the hill slopes the tributaries are parallels to each other and along domal hills the streams show a centrifugal pattern.
3.4 Conclusion
From the above study it can be concluded that The Himalayas in the north of the study area providing the required slope and detritus through streams with sudden break of slopes at the foothills where the rivers are depositing those detritus which finally leads the alluvial fan formation. The alluvial fans constructed by the major rivers are the Balasan, the Mahananda, the Tista and the sub catchments like the Rungsung, the Rakti, the Rohini and the Sukhia. The study area is having perfect backdrop for the alluvial fan development as discussed above. The Development of alluvial fans and their morphometry are strongly controlled by several factors which are segmented as Geo-tectonic factors, relief, climate, lithology, and hydrology since the Pleistocene period. So, on the basis of these dynamic factors of fan development and the morphological characteristics of the fans, it can be said that fan formation process of the study area is still in action.

References


CHAPTER- IV

The pedo-geomorphological characteristics of the alluvial fans

4.1 Introduction
This chapter deals with the different pedo-geomorphic characters of the alluvial fans of this study area. The pedo-geomorphological characters reveal the modus operandi and structural configuration of the alluvial fans of the study area as it has been found that the materials which are deposited on the alluvial fans are transported by the rivers and tributaries from the different parts of the hill areas which are consisted of the substances having different pedo-geomorphic origin. Hence, it is necessary to study the detailed pedo-geomorphic characters of the alluvial fans of this study area.

4.2 Methodology
In this chapter to establish the findings regarding the pedo-geomorphological characteristics of the alluvial fans in the study area different morphometric analysis have been carried out following the works done by the previous workers (Mark, 1975, Sridevi et.al. 2005, Bhattacharya, 2018) such as cross and longitudinal profiles were drawn with the help of GIS tools, average slope, relative relief, drainage density, area- slope distribution study, slope map generation etc. During field survey soil samples were collected from different pits and measurements of fan materials have also been done in logical techniques. Testing of soil samples has been done in well-equipped laboratory. On the basis of the outcomes of these techniques alluvial fan segmentation map was generated.

4.3 Fan material
In the area of study, the fan deposits are coarse rained, poorly-sorted and immature sediments. Usually gravels, cobbles and boulders predominate with subordinate amount of sand, silt and some clay. The coarsest and the thickest deposits occur near the fan heads i.e. in the proximal fan region. Size of materials and thickness of sediments decrease rapidly base wards and the roundness of grains increases with increasing distance from the apex of the fan.

The proximal or upper fan region is characterized by huge boulders and gravels along with very fine sands and clay. Particularly the base of the mountains, from where the alluvial fan
starts is characterized by huge amount of boulders of extraordinarily large size. The bed of the rivers is almost blocked with such deposits, through which a very narrow channel of water is flowing (Plate 4.1). Boulders are mainly of granitic gneiss, granites and schistose rocks and are elongated in size, indicating a near source deposition. These boulders are mostly supplied by the surrounding hills by debris flow along the bare slopes during heavy rains. In the inter-fluve region also in between the river valleys such big boulders are not uncommon lying almost deep jungle or fields of step cultivation. The average length of the boulders in 2.6 to 4 m and the width is about 2m. One of the boulders is lying on the cultivated land.

As the rivers have incised their valleys deeply in the proximal region it can be assumed that the occasional large boulders in the interflumes are the remnants of once extensive deposition only. These boulders are heavily weathered and oxidized and have broken into pieces along foliation or cleavage planes particularly in the case of gneisses and schists. The materials are very poorly assorted and unstratified. However micro-slumping with layers of different size materials are found at places along the sides of the deeply incised valleys.

In the middle fan region very large boulders are not common, but occasionally large boulders are found varying in length from 1.5 to 2m. and width 1 to 1.5m. Though the boulders are elongated in shape here also; the degree of roundness is somewhat greater than that of the proximal fan region. Boulders are found near jungle, tea garden or agricultural field, highly weathered and oxidized. Loose sandy sediments dotted with pebbles and gravels are the characteristic deposits in the middle fan. The pebbles or gravels are not much rounded and retain a somewhat elongated shape though the edges are not sharp. This poorly assorted and unstratified sediment is found almost all over the middle fan as evidenced during the field survey.

The size and shape of the materials are quite different in the lower or distal part of the fan. Here large boulders are totally absent. Fine grained sands, silts and clay with small pebbles are the characteristic deposits here. The broad river valley with brained channel pattern shows a somewhat coarser sand and rounded pebbles and ravelv. But the intervening region in between the rivers shows a distinct absence of coarser materials. Therefore, it is quite clear that through the alluvial fans are generally formed of poorly assorted and unstratified materials of different size; there is a clear gradation of materials from apex to base. The shape of the materials also vary and the degree of roundness increasing from apex to base.
4.4 Modes of deposition

During field it was observed that there are four major modes of deposition plays the active role in alluvial fan formation. These are, flash floods, stream action, stream floods and debris flow.

**Flash flood**

Deposits of Flash flood are infrequent and occur when the streams release all of a sudden increment because of high precipitation. Vast measure of debris residue rises up out of the high mountains and when it reaches it is stored instantly. Generally, such deposits are unasserted, coarse grained sediments and the materials are mostly restored at or close to the fan head as the flash floods generally cannot move a long distance with same velocity and intensity. Hence, according to the field observations it can be said that the accumulation of sediments by the flash floods suddenly disrupted and the water discharge becomes tremendous and unexpected which ultimately modifies he proximal fan region.

**Stream Action**

Alluvial fans are undoubtedly depositional features build by stream due to decrease in velocity and subsequent sedimentation along its path. In the source region over the mountains the trunk stream is fed by numerous tributaries which increases the discharge of water continually. As soon as the trunk stream emerges from the mountain its velocity suddenly decreases, resulting in deposition of huge amount of debris at the base of the mountain. Thus the fan head becomes
thicker and thicker, and the thickness of sediments is highest at the proximal fan. With continual stream action channelization starts gradually and as soon as it starts the locus of deposition is shifted down fan. Here due to fall in gradient the river spreads in broad basins, through which the distributaries flow. As a result water discharge diminishes along the course of the trunk stream allowing large scale deposition forming sand bars, chars within the river. Moreover, stream deposition is also caused by down-ward percolation of water through permeable fan sediments which causes further loss in discharge.

**Stream Flood**

This mode of deposition adds material mainly in middle and distal parts of the alluvial fans, the braided river basin with almost flat valley is quite incapable to carry the high monsoonal discharge, resulting the flooding of respective basins. This causes deposition of fine grained sands and silts particularly in the lower and middle fan region. This also causes modification and grading of the materials of the upper fan. In exceptional cases the upper fan is also partly inundated as in the year 1968 when exceptional rainfall resulted in an exceptional flood condition in North Bengal.

**Debris Flow**

This is an important mode of deposition in alluvial fan regions, both in humid and arid areas. As already mention in second chapter the area lies in earthquake prone zone and fall of boulders, sliding of rock masses and soil creep are almost regular feature of the surrounding hill section, due to factors mentioned earlier. This region experienced severe shock in the years of 1849, 1863, 1869, 1930, 1934, 2011, 2015 and 2016 which were also invariably accompanied by landslides. Extensive masses of coarse sediment with materials of all size, moves down the bare slopes of the surrounding hill section during heavy downpour. Therese materials are mainly deposited in the fan head area and change the general slope of the fan heads at the foot of the hills. Moreover, these are characterized by huge sub angular boulders of 1 to 2m. average diameter. The fan head near Bamonpokhri, Rakti and Rohini near Merchenbong and fan head near Sevok is characterized by sub angular gneissic and schistose boulders. Debris flow undoubtedly supply material to proximal fan region but one should keep in mind that these deposits are modified, graded and re-deposited in the middle and distal parts, by stream action.
Soil creep and rock slides under the influence of gravity supply materials to the fans during dry season. Careening of heavily decomposed material along steep, bare surface is a common feature in the surrounding hill section. Over grazing and deforestation helps easy movement of soil. Materials are added by this process only to upper part of the fan.

All the modes of deposition discussed above work together, though differences in their areas of impact is distinct, as debris flows and flash floods are important in supplying material in the proximal region, while stream floods are important in supply materials in the middle and lower fan region.

4.5 Stratigraphy of deposits

Though the alluvial fan region is mostly composed of poorly assorted and unstratified sediments, however a low degree of stratification is found which reflects the effect of climate and tectonic changes and change in modes of deposition, stratigraphic arrangements of fan sediments are normally found along the deep incision of the rivers, particularly in the upper fan where the incision is about 30 inches. The rockbeds stretches almost horizontally over the general base of the are and parallel to each other. Boulders and pebble beds alternate with sandy, silty and muddy beds rich in organic matter are found. Undoubtedly the pebbles are deposited during the heavy monsoonal rainy season, the rivers being charged with high discharge and extensive load. The finer deposits undoubtedly indicate deposition during dry season. The organic matter is supplied by the seasonal bushes, undergrowths and grasses which generally flourish during the rainy months and dries down during the winter months and mixes up with the sediments. Such stratification is disturbed in places by occasional mass movement and flash flood deposits which superimpose upon normal sequence. Huge boulder beds near Bamonpokri Reserve forest and also near Merchenbong can be sited as example.

In the middle and lower fan such clear and distinct layering of different size materials is not common. In many places along newly cut surface in middle fan, the sediments show very poor stratification, different sized materials are found in a common sandy matrix. They are easily erodible and completely loose. In the lower fan absence of stratigraphic sequence is due to the continuous use of the land for agriculture.

The formation of alluvial fan is a piecemeal work. At first the materials are deposited just at the base of the mountain. But with progressive sedimentation and down cutting the locus of
deposition is generally shifted in lateral and down fan direction and this happens when the main rivers starts channeling in the upper part. This progressive shifting of locus of deposition down fan results in interrupted sedimentary sequence over the fan. Nowhere a total stratigraphic sequence has been maintained exhibiting a lateral continuity of deposition over the entire fan surfaces.

4.6 Morphology of the alluvial fans

Morphology of the alluvial fans have been studied with the help of different morphometric maps vide Relative Relief, Dissection Index, Drainage Density, Slope Analysis and Longitudinal and Transverse profiles. Geomorphological map of the area shows that the upper part of the fan area is characterized by close spaced contours, high relief, steep gradient, deep fan head trenching whereas the middle part shows somewhat low relief with low gradient, characterized by somewhat distant contours and low degree of trenching.

Terracing is also found here and two distinct terraces (Balasan and Rakti) undoubtedly indicates rejuvenation in the course of river due to changes in tectonic features. The Lower part of the fan is characterized by almost flat surface with widely spaced contour, very low gradient and wide river valley. The contour height varies in the upper fan between 300 m to 460 m whereas in the middle fan between 200 m to 300 m and in the lower fan between 200 m to 100 m (Bhattachaty, 2004, 2010) The cross and longitudinal profiles over the fan show very clearly its change in morphology from head to base.

Plate 4.2: View of fan from the apex near Marchebong
4.6.1 Longitudinal Profile study

Two major longitudinal profiles have been drawn with the surficial slope of the river Balasan and river Mahananda. Both the profiles show three distinct steps in front of mountain with distinct change in gradient. The steps have been termed as the upper, middle and lower fan progressively. Later the fan segments will be dealt in detail.

![Longitudinal Profile of Balasan River](image1)

**Figure 4.1:** Longitudinal profile of Balasan River within the study area

![Longitudinal Profile of Mahananda River](image2)

**Figure 4.2:** Longitudinal Profile of Mahananda River within the study area
CROSS SECTIONAL PROFILES OF THE ALLUVIAL FANS UNDER THE STUDY AREA

Figure 4.3: Cross sectional profiles of the alluvial fans under the study area
4.6.2 Cross-Sectional Profile Study

Three cross profiles (Figure 4.3) have been drawn with the help of GIS software over the study which are arranged according to the fan segmentation and slope. The cross section line A-B shows a clear undulation of surface topography similar to the upper alluvial fan with altitudes ranging from 450 m to 260 m and sloping from North to West. In the middle part the cross section line C-D depicts an overall decrease in altitude ranging between 230m from 180m whereas the cross section line E-F shows a nearly flat surface with gentle slope. The altitude is extending between 100 m (in places 75 m) to 180m.

It can also be estimated from these cross sections (Figure 4.3 ) that the river valleys in the upper fan is experiencing more down cutting or entrenching than the middle and lower fan part as the river valleys of these segments are more wide mostly due to lateral erosion organized by gently steep to gentle slope.

![Cross Profiles of Alluvial Fans Under the Study Area](image)

**Figure 4.4:** Cross Section line demarcation map of the study area

A slope analysis map has been produced to determine the average slope of the area. The slope map shows a general slope from north to south. The fan shows a slope varying from 100 to 400. The Northern part of the upper fan possesses a slope varying from 300 to 400. The middle part of the alluvial fan shows a slope varying from 150 to 300. The slope is greater in eastern
and western and. In the lower part of the fan the slope varies from 20 to 100. Therefore it is quite clear that the gradient of the fan area is steep in the upper part. Gentle in the middle part and the lower fan shows an almost flat topography with very low gradient.

In case of the geomorphological configuration of the study area it can be said that all the morphometric maps given in this chapter including the cross and longitudinal profiles show a distinct difference in topography from apex to base which depicts three well-defined segments termed as the upper middle and lower fan segments which is also discussed further in this chapter.

4.7 Morphometric analysis of the alluvial fans

4.7.1 Average slope
Slope is the angular inclination between different elevations. It is a very significant morphometric property as it is the indicator of the stage of development of a landform. There are different processes of slope analysis based on contours of relative topographical maps have been practiced by a number of famous geomorphologists. The present researcher went with Wentworth's (1930) method of slope determination which is very effective among all for explanation of the spatial distribution of average slope of a particular area (Bhattacharya, 1993).

Figure 4.5: Slope map of the study area (Wentworth’s method)
Wentworth (1930) explained a method which covers the whole study area with an equally spaced grid. Then we can count the number of contour lines which are crossing the square grid from four sides. After that the following formula can be used for calculation. In the present research work the following formula has been adopted:

Tangent values of angular slope (in degree) are

$$\tan \theta = \frac{C_n \times C_i}{W_k}$$

Where,

$C_n =$ average number of contour crossing per unit grid.
$C_i =$ Contour interval in meters.
$W_k =$ Wentworth’s constant (636.6).

4.7.1.1. Classes of Average Slope
Based on the above method the whole study area has been classified into four slope categories.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Categories</th>
<th>Values in Degree</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Low</td>
<td>$\leq 1^\circ$</td>
</tr>
<tr>
<td>II</td>
<td>Gentle</td>
<td>$1^\circ$ - $3^\circ$</td>
</tr>
<tr>
<td>III</td>
<td>Gently steep</td>
<td>$3^\circ$ - $5^\circ$</td>
</tr>
<tr>
<td>VI</td>
<td>Moderately Steep</td>
<td>$&gt; 5^\circ$</td>
</tr>
</tbody>
</table>

**Table 4.1:** Classification of slope categories

Spatial distribution of Average Slope Categories:

The spatial distribution of the different average slope categories are discussed below:

I. **Low:** The slope value of this category ranges $< 1^\circ$ degree distributed over the southern part, and some middle parts of the study area.

II. **Gentle:** This slope area comprising range values from $1^\circ$ to $3^\circ$ is spread over the northern and central part of the fan.
III. Gently steep: The gently steep slope zone having slope value ranging between 3° to 5° are mainly covered the apex area of the fans that is laying mainly in the northern part of the study area.

IV. Moderately Steep: This moderately slope zones having value more than > 5° are mainly some patches found near Sevoke, machebong and MechiBasti.

Table II

<table>
<thead>
<tr>
<th>Category Name</th>
<th>Slope Limits</th>
<th>Area (sq. km.)</th>
<th>% of the Fan area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderately Steep</td>
<td>&gt; 5°</td>
<td>60.45</td>
<td>6.8</td>
</tr>
<tr>
<td>Gently steep</td>
<td>3° - 5°</td>
<td>150.22</td>
<td>16.9</td>
</tr>
<tr>
<td>Gentle</td>
<td>1° - 3°</td>
<td>264.00</td>
<td>29.7</td>
</tr>
<tr>
<td>Low</td>
<td>&lt; 1°</td>
<td>414.23</td>
<td>46.6</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td><strong>888.90</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

Table 4.2: Area Slope Distribution of the Study area

4.7.1.2. Area-slope distribution

The average slope map provides information on slope-distribution over the entire alluvial fan area. In general, the inclination of slope increases from south to north. The highest inclination (above 5°) of terrain is naturally marked on the apex areas of the fans. An evaluation of the Table II will disclose the area-slope distribution, which is the proportion of the total surface falling within each group of slope. Table II indicates that nearly 75% of the total area is lies between < 1° - 3° of slope and almost all which lies in the lower and middle fan area.

**Figure 4.6:** Area-Slope Distribution of the Study area

(Source: Table 4.2; Appendix C)
It is already mentioned that the whole study area has been divided into four slope categories, where it is clearly seen that the maximum portion of the alluvial fans come into the slope class of $<1^\circ - 3^\circ$ of slope which prevails more or less in the middle and lower fan zone comprising the total area of 54 Sq.km. In the cross section of the fans, it is clearly seen that there is a sharp break of slope at an elevation of around 200 m from where the middle fan zone starts. The landuse patterns are interestingly changed from this slope zone which remains more or less same in the rest portion of the fan area. From the analysis of Table II it is observed that nearly 75% of the total study area comes under the low to gentle slope zone (i.e. $<1^\circ - 3^\circ$) and only 6.8% of the area falls under Moderately Steep zone which is $>5^\circ$. From the field survey the present researcher observed that this Moderately Steep zones are scatterly distributed in the upper fan zone which falls under the foot hill region.

**Figure 4.7:** Cross Section of the Study Area

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**Fig. 4.8:** The coverage of total area (Sq. Km) under different major contours

**Reference:** Table 4.6(Appendix B)
4.7.2 Relative Relief of the Alluvial Fans of the Study Area

A zonation has been made to split the Alluvial fans of the study area on the basis of amplitude or relative relief by considering the highest and lowest elevation falling within the grid area of Sq.Km. The existence of different relative relief zones (Fig. 4.9) ranging mostly moderate over the Fans under study undoubtedly suggests that the entire region has been accompanied by a gentle sedimentation by the different distributaries on the alluvial fans with no such evidences of geomorphic as well as geologic disturbances, though some weathering phenomenon are observed during field survey. Still, the upper Fan portion, mainly some patches to some extent shows variations in amplitudes. The whole study area has been categorically segmented into four major relative zones ranging between 0 to more than 300 m. The maximum or highest amplitude occurs in the northern portion of the fans covering the apex (above 300 m) and it decreases towards the southern direction which is middle and lower alluvial fan zones with minimum amplitude of below 100 m.

![Figure 4.9: Area (in %) of alluvial fans under different amplitude of Relative Relief zones.](image)

Reference Table: 4.7 Appendix B

4.7.3 Drainage pattern and density

Drainage direction of the study area is from north to south according to the slope of the area. The main rivers of the area are the Balasan, Mahananda, tista and mechi. Balasan is having two major tributaries namely Raktikhola and the Rohinikhola. The alluvial fans of the study area were constructed by these main rivers and Balasan’s left bank tributaries between the two south
ward evolving spur of the Himalayas. Though, many minor non-perennial and perennial streams were played important in this process.

Generally, the drainage pattern of the study area is dendritic, though parallel and radial drainage patterns are also observed. At the base of the mountains over the upper fan segment, all the main rivers are having narrow and deeply embedded channels. In the middle fan segment the channels flowing with much less down cutting whereas in the lower fan segment wide, open valleys of the rivers flow in innumerable distributaries and braided pattern can be observed.

The longitudinal Profiles have been generated of the two main rivers with the help of GIS software. In case of Balasan river the Longitudinal profile shows a graded style with slope deviations from north to south, while a sudden drop from the mountain front can be observed in case of the Rakti, the Rohini, the Runsung, and the Sukhia rivers. The other profiles of river distinctly confirm a higher degree of gradation with slope variations, from north to south, establishing the three fan segment concept of the study area. To find out the density of drainage networks over the study area, A Drainage Density map has been created. According to the map, the middle fan segment has the lowest density, whereas, the upper fan segment is having the

Figure 4.10: Drainage Density map of the study area

in case of the Rakti, the Rohini, the Runsung, and the Sukhia rivers. The other profiles of river distinctly confirm a higher degree of gradation with slope variations, from north to south, establishing the three fan segment concept of the study area. To find out the density of drainage networks over the study area, A Drainage Density map has been created. According to the map, the middle fan segment has the lowest density, whereas, the upper fan segment is having the
density in mountain front zone varying from 8 to 10 per km². The numerous streams and jhoras, which are carrying water during the heavy monsoon from the different mountainous tracts, are responsible for this deep density. Similarly, due to different distributaries, the drainage density of the lower fan segment is also high varying from 3 to 8 per km². These main rivers of the lower fan segment are mostly braided.

4.8 Fan segments

Studying all the geomorphic characteristics through the analysis of morphometric maps and field experiences it can be concluded that the fan area under our study can be divided into three district zone – The upper or proximal zone the middle zone and the lower or distal zone. Each of these three sections is characterized by distinct geomorphic and drainage pattern. The upper or proximal part just in front of mountains is highly dissected with thickest sediments deepest incision steep gradient extensive sub-angular boulders high drainage density formed fan segment. Along with incision and channeling here the locus of deposition shifted generally down fan where action sedimentation started and the upper section is now only under processes of modification and gradation by the streams. But the process of mass movement continually adds materials to this part.

<table>
<thead>
<tr>
<th>Fan Segment</th>
<th>Materials</th>
<th>Degree of roundness of materials</th>
<th>Process</th>
<th>Major Landuse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper</td>
<td>Coarse grained gravels cobbles and boulders</td>
<td>Sub-angular</td>
<td>Flash Floods, debrises flow, solifluction and stream action</td>
<td>Forests and Tea Gardens</td>
</tr>
<tr>
<td>Middle</td>
<td>Medium grained Sand Silt and Clay</td>
<td>Sub-Rounded</td>
<td>stream action and stream floods</td>
<td>Tea gardens, forests, settlements and arable lands</td>
</tr>
<tr>
<td>Lower</td>
<td>Fine grained sand silt and clay</td>
<td>Rounded</td>
<td>stream action and stream floods</td>
<td>Tea gardens, forests, settlements and arable lands</td>
</tr>
</tbody>
</table>

**Table 4.3:** Alluvial fans segment, materials, processes and major landuse of the study area

**Ref:** Soil Map.
Thus, the middle part gradually developed. This area is characterized by lower relative relief, lower degree of incision, low gradient, lower amount of boulder, low drainage density, and lower degree of stratification than the upper part.

**Figure 4.11:** Alluvial fan segmentation of the study area

The lower or the outer most area south of the limiting contour of 100m is the youngest segment formed and this is the zone of coalescence of all the fans. Frequent flooding of the braided stream channel with deposition of thin cover of sediments which coalesce with each other in the marginal areas. This area is characterized by thinnest sediments, lowest gradient, open wide braided stream channel, high drainage density, and finer materials with rounded pebbles.

### 4.9 Pedogenesis

Alluvial fans from a transitional zone between the high mountains and flat alluvial plains. They present a completely different landscape and morphology than that of the mountains above or plains below. As a result, the soil type and character of the area is also different resulting in completely dissimilar landuse pattern. Therefore, a number of soil samples were collected from the different parts of the field during survey and investigated to explain and determine the
pedological characteristics (Table 4.4) of the existing soils of the alluvial fans under study. The outcomes are discussed here in different parts and components.

Plate 4.3: Naturally exposed Soil layers near Sevoke

4.9.1 Development of soil profile of the study area

Fan sediment also works as a parent material for emerging soils, specifically on the sedentary parts where the surface is steady. Soils develop by the translocation of clay or solutes from the surface to shallow depth by infiltrating water, usually from precipitation directly on the fan that then dries in the vadose zone to produce horizons enriched in clay, carbonate or silica. On the other hand vegetation has long been rated an important factor concerning sediment yield from a catchment. In as much as vegetation reflects climate, it is a climate variable. One factor commonly attributed to catchment plant cover is an increase in clay production due to the enhanced chemical weathering caused by organic acids near roots, and due to the greater preservation of soil moisture (Lustig 1965). Plant roots also affect sediment slope stability by strengthening its resistance to gravity as a result of increased shear strength (Greenway 1987). Differing plant types will have a variable effect on slopes due to the multitude of styles and depth of root penetration, and to the density of the ground cover (Terwilliger and Waldron 1991)
Table 4.4: Pedological data of different parts of the study area

(Source: Primary data collected by the researcher and tested at the laboratory of the dept. of Agriculture (Soil Conservation), Siliguri, West Bengal. Year 2016)

Contrarily, plants may serve to produce long-term instability by causing the slopes to become steeper than they would be if the plant cover did not exist. This effect is illustrated by the common failure of slopes after vegetation is disturbed, such as after forest or brash fires (Wells 1987, Meyer and Wells 1996, Cannon and Reneau 2000, Cannon 2001).

The type of bedrock underlying the catchment is the main control on the primary processes of alluvial fans (Blair and McPherson 1994, 1998, Blair 1999). Soil-profile development in fan sediment is a function of the time that a fan surface has been stable, the local or aeolian flux of the materials, from which the horizon is composed, and the typical amount and wetting depth of precipitation (Machette 1985, Reheis 1986, Mayer et al. 1988). The presence of plant roots in sediment promotes soil development by providing pathways for infiltrating water. The extent of soil-horizon development in a given area is useful for determining the relative age and correlation of fan deposits (Wells et al. 1987, Slate 1991).

South of the Darjeeling hills Red earth or the Red bank soils are developed extensively in the Terai. They generally occupy high grounds in the Pleistocene plateaus and terraces in the
transition zone between the Darjeeling hills and the plains. At Rohini and Longview spurs of red soils extend into the plains.

**Picture 4.4:**

A) During Soil sample collection near Bengal Safari.

B) Soil erosion due to surface runoff and importance of forest conservation, arare co-existence at Sukna forest under the study area.

The genesis of this red soil is very interesting. Both the climate and the lithology of the rock play an equally important role in the formation of this soil. These soils are formed over the weathered rocks of the Nahun sandstones under Lower Siwaliks in the Teari and developed extensively on huge Pleistocene deposits of boulders, gravels and clays, which form parts of the transported Darjeeling gneisses. The study area gets a heavy monsoonal rainfall. The comparative older age of the rocks, a dense forest cover, a humid sub-tropical climate and also the high content of mineral silicates in the Dalings led to a thorough chemical weathering with formation of weak organic acids as well as breaking of silicates with consequent leaching. The pedogenic process here is more in the nature of Podsolization than Laterization. These soils may be taken as typical soils formed by weathering as the presence of iron oxide, alumina and clay indicates considerable amount of weathering. The Red bank soil is generally highly acidic due to the removal of lime and other bases by weathering and leaching action. This soils, however, is very rich in essential plant foods. It contains high percentage of phosphoric acid, potash, nitrogen and organic matter compared to other average tea soils of North East India. It is to be mentioned that these features soundly prevails mainly in the upper and middle fan
segments. This is why most of the land under these segments to some extent is occupied by tea gardens and natural vegetation.

![Soil Sample Collection Map of the Study Area](image)

**Figure 4.12**: Soil sample collection site map of the study area

### 4.10 Conclusion

It can be concluded on the basis of information obtained from the field and morphometric analysis, that, the alluvial fans over the study area are divided into three separate segments i.e. the upper fan segment, the middle fan segment and the lower fan segment which are bearing absolutely dissimilar characteristics due to slope variations. However, it also has been observed that the slope variation of the study area regulates the quantum of sedimentation. The upper fan segment is consisted with steep gradient, semi-deep trenches and enormous sub angular boulders widely spreading over moderately developed soil. Flash floods, debris flows and mass wasting are the key sedimentation factors of this zone. The middle fan segment exhibits moderate gradient with shallow trenching. Braided pattern of rivers originate from here. Semi large boulders and pebbles are spreading over this portion. Stream overflow/floods, occasional flash floods are the major reasons for sedimentation in this segment. The topography of the
lower fan segment is configured with very low gradient and almost flat terrain. Streams with high density over this segment are wide and braided. This area is covered with fine sediments and rounded pebbles. Stream overflow/floods are the major sedimentation processes of this part of study.

References


CHAPTER-V
The landuse and land cover of the study area

5.1 Introduction
It has substance to mention that the results of the investigations of the previous chapters have clearly showed the details processes of alluvial fan formation and their pedo-geomorphic characteristics from which it may be said that the alluvial fans of the present study area are having distinct characteristics segment wise and individually. Hence, the landuse and land cover pattern on these fans should also have some unique characteristics as they are influenced by the fans pedo-geomorphology and other individualities. So, the present study has been attentive on the logical identification of the existing landuse pattern developed on the different alluvial fan segments of the study area. For doing so, some important perspectives have been taken into consideration; such as, soil characteristics, temporal changes of landuse land cover etc.

5.2 Methodology

To identify the existing landuse and land cover of the study area vectorisation of the Survey of India topographical maps no. 78 B/1, B/5, B/6, A/4 and A/8 (1:50,000), open source USGA topographical sheets of NG 45-8 and 45-7 series U502 surveyed in between 1931 to 1944, published in 1959 and also published maps of NBSS&LUP, Govt. of West Bengal’s Forests Department etc. have been done with the help of Arc-GIS 10.5 platform and statistical analysis of data was also performed. Case studies were done with the quantification of landuses by means of area coverage as calculated by the GIS software and references of time zone satellite imageries have been taken from the Google Earth as open source platform.

5.3. Existing Landuse and Land cover of the study area

The identification and analysis of the existing landuse and land cover of the study area has also been done according to the alluvial fan segments as established in the Chapter-III. While doing these some major landuse types were selected to be discussed about. The table 5.1 gives a compact landuse scenario of the study area.
<table>
<thead>
<tr>
<th>YEAR</th>
<th>LANDUSE TYPE</th>
<th>UPPER FAN</th>
<th>MIDDLE FAN</th>
<th>LOWER FAN</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% sq.km</td>
<td>% sq.km</td>
<td>% sq.km</td>
<td>% sq.km</td>
<td>% sq.km</td>
</tr>
<tr>
<td>2017</td>
<td>FOREST</td>
<td>70.05</td>
<td>63.27</td>
<td>24.34</td>
<td>38.50</td>
</tr>
<tr>
<td></td>
<td>TG</td>
<td>19.49</td>
<td>26.56</td>
<td>22.72</td>
<td>22.87</td>
</tr>
<tr>
<td></td>
<td>AGRI LAND</td>
<td>4.60</td>
<td>5.89</td>
<td>21.22</td>
<td>15.87</td>
</tr>
<tr>
<td></td>
<td>SETTLEMENT</td>
<td>1.64</td>
<td>1.77</td>
<td>25.16</td>
<td>17.28</td>
</tr>
<tr>
<td></td>
<td>OTHERS</td>
<td>2.29</td>
<td>4.25</td>
<td>6.57</td>
<td>5.48</td>
</tr>
<tr>
<td></td>
<td>TOTAL</td>
<td>100</td>
<td>143.08</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 5.1: Fan segment wise landuse variations
(Source: Primary data)

Figure 5.1 Present Landuse map of the study area

5.3.1 Forest

In the early 19th century the fans of the Terai region were mostly covered with tropical forests of densely growing Sal (*Shorearobusta*), Segun (*Tectonagrandis*), or sturdy sheesham (*Dalbarghiasiss*) (S.R.Basu&S.Sarkar,). Other than these the study area also have some species like, Champak (*MicheliaChampaca*), Almond (*TerminaliaMyriocarpa*),Gokul (*Ailanthus grandis*) etc. with valuable commercial timbers. These are mixed jungle of
deciduous trees and undergrowth bushes and scrubs. “Till 1835, the area was densely covered with forests with few migratory Lepchas in the hills and the Meches in the southern foothills. But with the construction of road (Hill Cart Road) in 1839, the degradation of these virgin natural forests slowly started. Soon large tracts of forests were replaced by roads, Tea Gardens railway lines and settlement. With time, a pronounced decrease in the forest cover became apparent and at present the forest is mainly restricted in the north and north eastern section of the study area with small natural patches at Singbulli, Selim Hill, and Manjwa and between Pankhabari and Longview” (Lama, 2003).

It is observed during field survey and analyzing remote sensing data that mainly the upper fan segment has the major forest cover which is approximately 100.23 sq.km. covering about 70.05% of the whole upper fan segment. For example Sevok, Upper Rohini, marchebong, Mechibasti, etc. These areas are mostly forest covered. Unfortunately, deforestation in different ways in this segment making slopes of the upper fan areas and apex areas vulnerable resulting loss of soils from the slop due to which rivers are getting more sediment load which are finally deposited and distributed in the lower fan segments.

In the middle fan segment the forest cover became 98.36 sq.km which is about 63.27% of the whole middle fan segment. The forests on this segment have been under threat of encroachment with increasing tea gardens and human occupancy.

The forests have extended upto lower fan segments mostly in form of patches except the Baikunthapur range covering 143.68 sq.km. area of the whole lower fan segment which is about 23.34 % of the total lower fan area. It can be eventually said that the patches are the indicators of huge uncontrolled deforestation and encroachments as this part is having a competent ration of other landuses also.

5.3.2 Tea Plantation

From the very beginning of 1866, the British empires started the process of tea cultivation in this region. The whole Terai region has a very rich physio-cultural environment which is very perfect for the tea cultivation. The Terai as the researcher stated earlier that the major portion of the study area was covered by forests, so the tea merchants overviewed the environmental factors and no other way they started to cut the forests resulting intensive defilement of
environment in form of slop failure, soil erosion etc. With the gradual establishment of tea
gardens after 1866 on the undulating terrain mainly in the upper and middle fan segments
having suitable soil and adequate drainage, more and more forests were cut. At present tea
gardens cover about 22.87 % (203.3 sq.km.) of the total area under study. As the present
researcher stated earlier that the major portion of the study area was covered by forests,
unfortunately, the tea merchants overviewed the environmental factors and no other way they
started to cut the forests resulting intensive defilement of environment in form of slop failure,
soil erosion etc.

The major and renowned tea gardens are mainly situated in the upper fan segment like,
Longview, Makaibari, Ambootia etc. They got a pretty good response from the favorable
topography of this region as this segment fulfilled the basic criterions for the successful
cultivation of tea i.e. soil, temperature, rainfall etc. The tea cultivators were encouraged by this.
They started to expand the periphery of tea gardens. Hence by 1871, more than 20 tea gardens
with about 890 hectares of forest area were leased out for tea plantation (TamangLakpa, 2013).
However, the upper fan segment is having 27.89 sq.km. of tea plantations which is about 19.49
% of the whole upper fan segment.

Tea garden occupancy interestingly increased in the middle fan segment. About 26.56% of the
middle fan segment which is nearly 41.29 sq.km. is presently covered by tea gardens.

The lower fan segment is also having significant tea plantations of 134.12 sq.km.areawhich is
about 22.72% of the whole lower fan segment. Though, the present researcher observed that
the most of the tea garden are new and formed in scattered pattern as patches. These tea gardens
in lower fan segment encroached forests and agricultural lands in most of the places.

5.3.3 Temporal variations of Forest and Tea gardens

During the field observations and data collection the present researcher felt the necessity to
identify the legacies of the forest cover and tea gardens from the past. While doing this, the
present researcher used the then topographical sheets number NG 45-8 and 45-7 series U502
surveyed in between 1931 to 1944 and compared these with the recent satellite images of 2016
in Arc-GIS platform.
After generating maps and comparing data the results showed the huge transformations of forests into tea gardens. It clearly exhibited the dilapidated surfaces of the study area which are in no way as advantageous as before for the local people who extracts their living absolutely depending on the natural resources of the study area.

It can be assessed from the Figure 5.1 that the major landuse type transformation from forest to tea garden experienced in the middle to western part of the study area in all fan segments. Though, the adverse effect of this uncontrolled deforestation is equally affecting the whole study area but the consequent buffer effects are mainly executed in and from the upper fan segment.

With the establishments of tea gardens, settlement and small cultivable patches were also evolved adjacent to the tea gardens mainly in the upper and middle fan segments which ultimately accelerated the rate of forest depletion.

In addition to it, defilement of environment in the form of mass deforestation, unscientific settlement construction on the vulnerable hill slopes, rapid growth of urbanization and associated phenomenon like, construction of roads, passing of heavy vehicle through these roads have become the triggering factors for severe soil creeping, sheet slides, slips and other types of slope failure, which results in the addition of extra sediment load in the river channels.
Figure 5.2 Temporal comparisons of forest cover and tea gardens between year 1931 (Topographical sheets number NG 45-8 and 45-7 series U502) and 2016 (Bhuvan satellite image)
Figure 5.3 Differences of forest cover and tea garden cover in between year 1931 and 2016

Reference: Table: 5.3 (Appendix B)

In the lower fan segment mostly very new and small patches of tea gardens can be observed and either they have encroached forests or agricultural lands by converting its character artificially. In the year 1959 the total coverage of forest was 473.99 sq.km. where total tea
garden were only 84.105 sq.km. But, in 2016, huge differences are marked and unfortunately that is against the nature. In 2016 the forest coverage decreased about 27.8% and the present total forest cover is 342.27 sq.km. where the tea garden cover increased by 141.7% and the present tea garden area is 203.3 sq.km of the whole study area.

The present researcher made this case study of temporal comparison from the perception to get the changing scenario of landuse pattern of the study area.

5.3.4 Agricultural Land

As per the agricultural zonation made by the SLUSI the present study area falls under Teesta-Terai Agro Climatic Sub Region with alluvial soil cover. In comparison to the upper fan segment the middle and lower fan segments are the ideal option for agriculture. As the diversified debris from different mountainous tract are spreading over and depositing mainly on this part, the middle and lower fan segments get a fertile soil characteristics in the form of flood deposited top soil. The fine and coarse loamy soils with sandy clay makes this foothill landform suitable for agriculture. In the upper part of the fan some terrace cultivation can be observed. Interesting thing is that, due to the deforestation in the upper and middle fan areas, the rivers started to erode extensively and then they were dumping that detritus on the lower fan areas having gentle or no slope.

Hence, the lower fans are growing as a very rich and fertile land for agriculture. But as this upper part has immature soil cover due to soil slips and high surface runoff due to massive deforestation the arable land are not so fertile for crops. In rest of the segments paddy, vegetables etc. are the main agricultural products. The area is however blessed with large nos. of perennial rivers, khals, beels and water bodies. Approximately 141.05 sq.km. area which is about 15.87% of the whole study area is under agricultural landuse.

The upper fan segment is having 6.45 sq.km. agricultural area which is about 4.60% of the total area of this segment. The cultivation in this part is being done mainly for self-consumption and through terrace farming method. Major crops are maize, corn, patches of very few paddy and vegetables. It is also important to mention that most of these terraces are also formed through destroying the forests and some are done on the areas left vacant by the garden owners.

Agricultural landuse slightly increases in the middle fan segment where about 9.33 sq.km. area is under agriculture landuse which is 5.89% of the total middle fan segment.
Major agricultural landuse are observed on the lower fan segment, Approx. 125.27 sq.km. area which is about 21.22% of this fan segment is under agricultural use. Mainly low gradient, fine loamy, loamy and coarse loamy soils with siltation played the major role of stimulator behind advantageous agro environment. Paddy, jute, vegetables, mustard, wheat, potato etc. are the major crops of this area.

![Figure 5.4: Line graph showing fan segment wise coverage of landuse type](image)

**Reference:** Table: 5.4 (Appendix B)

### 5.3.5 Settlements

In the present study area human settlements have increased by decreasing forest and agricultural lands. With the increasing population the settlements are established encroaching the forests, arable lands and even different stream banks. Transportation networks are developed rapidly with increasing settlements. The middle and lower fan areas have the conglomerated settlement pattern whereas the upper fan has scattered or dispersed settlement pattern. But defilement of environment in the form of mass deforestation, unscientific settlement construction on the vulnerable hill slopes, rapid growth of urbanization and associated phenomenon like, construction of roads, passing of heavy vehicle through these roads have become the triggering factors for severe soil creeping, sheet slides, slips and other types of slope failure, which results in the addition of extra sediment load in the river channels.
The present study area is having two international boundaries with Nepal, and Bangladesh. Consequently infiltration due to immigration is a triggering factor behind the faster growth of population and settlement construction in this area.

On the upper fan segment dispersed settlement pattern can be observed on the vulnerable hill slopes. Most of these settlements were initially developed with the expansion of tea gardens. But with the construction of road (Hill Cart Road) in 1839, the degree of settlement became faster than usual. Hence, large tracts of forests and hill slopes were replaced by roads, railway lines and settlement. Still only 2.35 sq.km area which is approx. 1.64% of the total upper fan segment is under settlement cover.

**Plate 5.2** Terrace cultivation in the upper fan segment

The middle fan segment is also having clustered settlement pattern with tea factories, quarters, basti areas etc. Defence establishment is one of the largest human settlement is situated on this segment. Approx. 3 sq.km.area which is nearly 1.77% of the total middle fan segment is covered by settlement. That defence occupancy is a major factor behind the deforestation in this part of the study area which also starched upto lower fan segment.
Figure 5.5: Diversified landuse occupancy on the different fan segments

Reference: Table: 5.5 (Appendix B)
Figure 5.6: 3D visual comparison of the study area fan segments and landuse
Maximum settlement cover found in the lower fan segment where about 148.51 sq.km. area which is approx. 25.16% of this segment area is under settlement. The Siliguri metropolitan township is the largest conglomerated settlement cover on this lower fan segment. The present landuse map (Figure 5.1.) depicts that conglomerated settlement area flourished rapidly in the lower fan and middle fan mainly surrounding the interfluve of River Mahananda and River Balasan, though linear, scattered, and dispersed settlements are also noticed throughout the lower fan segment.

5.4 Shifting paradigm of landuse

It has been mentioned that the present study area is going through a dynamic process of landuse conversions. Hence, landuse types are also changing with time. However it has been found that the pedo-geomorphic characteristics did not resultant into compatible landuse pattern in all cases. In many cases the socio economic parameters and population pressure also drove the configuration of landuse parameters by artificial management. In lower fan segment potential crop fields has been converted into small tea gardens supported by artificial drainage system which is also accelerated by legacies of large tea gardens dominated economy. This unprecedented phenomenon adversely affect the physical characteristics like water holding capacity, bulk density, porosity, nutrients stratus etc. of soil in the study area.
Plate 5.3: A) Conversion of landuse from paddy land to small tea garden, a common scenario of the study area

B) Artificial drainage system in a tea garden, a major factor responsible for decreasing soil’s water holding capacity

Interestingly, the encroachment of urbanisation replaces the statutory field of vegetation into uncultivable land as happened in (lower fan area) Chandmoni Tea Estate. A large scale lavish township, situated by the side of river Chamta in the lower fan segment is the most recent example of significant landuse conversion (Picture 5.4). The whole township area was a well-
Plate 5.4: A) Chandmoni Tea Estate, an example of latest large scale land conversion

B) The present township at the place of Chandmoni Tea Estate

known large tea garden named Chandmoni Tea Estate. But, due to unavoidable socio economic demand almost the whole tea garden area was handed over for the construction of a new
township. This reality proves that population pressure is also a major reason behind the change of landuse pattern in this study area.

The conversion stages of Chandmoni Tea Estate to a new township have been found from field observation supported by satellite images of different time scale (Picture5.4 A, B, C.). The landuse pattern of the surrounding areas are also influenced by the buffer effect and came into the grasp of urbanisation as an obvious phenomenon.

Plate 5.5: A) The Chandmoni Tea Estate with large scale tea gardens. Satellite image of year 2003
(Source: Google Earth image)
(Source: Google Earth image)

(Source: Google Earth image)
5.5 Land capability

The land capability classification is an exclusive technique to establish the extent of a land or logically distribute a land for definite way of landuse & to fix the threat of loss due to the landuse (Hudson 1977, Davidson 1980 and Dent & Young, 1981, Bhattacharya, 1993). The present study area is having diverse physical & climatic characteristics which have been classified into different land segments based on the capability classes to investigate the numerous notch of the competence of the lands for agriculture with other type of applications in the primary stage and distinguish the arable lands from that of non-arable lands in the secondary stage. Based on the findings, the best fit landuse types and management methods, which will be essential for the preservation lands for future, will be recommended in the next chapter for the sustainable utilization of lands as well as to minimize additional risks of damage of this unique study area.

Satisfactory standard procedures were maintained during the field survey for the land capability classifications. Determination of capability classes were been done as per the main principles of the land capability classifications of USDA (1961 and 1964) with required adjustments. Distinctive physical & climatic characteristics of the study area are given highest importance during the identification of capability classes & their sub classes as this area under study is consisted of diversified soil types. The outcomes of different land classes were based on the general rule of observation of the land restrictions of the present study area.

5.5.1 Land Capability Classes

The present researcher, on the basis of systematic field survey found five major land classes with sub classes which have been shown in the table 5.2. In this context it is important to mention that the study area does not have any class I land according to findings as per USDA system. The detailed descriptions of the different land classes and sub classes are discussed here with.

1. Class II

Almost the lower segment of the fan area is having the Class II soil which is the most fertile soil for arable farming. Having a good reputation for agricultural productions, this class of land also has some limitations from the utilization perspective of very intensive farming. Due to these limitations like heavy rainfall, gentle slopes, occasional damaging overflow,
coarseness of sandy soils etc. in this land class the cropping options are inevitably abridged. Hence, based on these limitations this class II land is further segmented into the following sub-classes:

i) **Sub-class II CE (Climate & soil erosion)**
This sub-class is found mainly in the younger alluviums found in the river flood plains of the study area situated in the lower fan segment. This sub-class is formed due to high precipitation and bank erosion. Arable farming, tea gardens, fallow land of scattered trees, forest and linear patches of settlement are the major existing landuse of this sub-class.

ii) **Sub-class II W (Wetness limitation)**
Almost the whole lower fan segment of the study area comes under this sub-class with existing landuse as arable farming. Poor soil drainage, occasional waterlogging, high water table, and overflow etc. are the major limitations of this part of the study area. Present landuse is arable farming as observed during field survey.

2. **Class III:**
Soils of class III have more limitations than the soils of class II especially when it is used for cultivated crops. The applications of conservation processes are generally much problematic and not easy to solve. Still, in the present research area, soils belong to this class are reasonably good lands for cultivation of crops. The class III lands are found mainly in the middle fan segment with gentle to moderate slope. This class III soil is also divided below into sub-classes based on its restrictions or limitations.

i) **Sub-class III C (Climatic limitation)**
The major part of the class III land comes under this sub-class with existing landuse of arable farming, tea gardens, forest, fallow lands and settlements. The land under this sub-class is suffering from low moisture content, high rainfall and low to moderate temperature.

ii) **Sub-class II E (soil erosion)**
This sub-class of land is found in the north and north eastern part of class III land over the middle fan segment. This part is mainly covered with natural forest and some settlements which are spreading rapidly by destroying forests.

3. **Class IV**
The utility limitations in the soils under class IV are larger than the soils of class III. So, the options of arability are more limited by their natural characteristics. Hence, more watchful supervision is required to manage this land class. This class IV land types are mainly traced in
the lower part of the upper fan segment and some patches of this class is also found within class III land situated over the middle fan segment. The major limitations of Class IV land type are moderate to steep slopes, high precipitation, unsorted stony surface etc. based on which this class has been into following sub-classes:

<table>
<thead>
<tr>
<th>Capability Classes</th>
<th>Capability Sub-Classes</th>
<th>Relief</th>
<th>Slope</th>
<th>Status of Soil Water Potentialities</th>
<th>Existing Landuses</th>
</tr>
</thead>
<tbody>
<tr>
<td>II</td>
<td>CE</td>
<td>Gentle</td>
<td>&lt; 1°</td>
<td>Moderate to Low</td>
<td>Arable farming, tea gardens, fallow land of scattered trees, forest and linear patches of settlement</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Arable farming</td>
</tr>
<tr>
<td>III</td>
<td>C</td>
<td>Gentle to Moderate</td>
<td>&lt; 1°</td>
<td>Moderate to Low</td>
<td>Arable farming, tea gardens, forest, fallow lands and settlements</td>
</tr>
<tr>
<td></td>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td>Natural forest and some settlements</td>
</tr>
<tr>
<td>IV</td>
<td>C</td>
<td>Gentle to Moderate</td>
<td>1° - 3°</td>
<td>Moderate to Low</td>
<td>Tea gardens and scattered trees</td>
</tr>
<tr>
<td></td>
<td>ES</td>
<td></td>
<td></td>
<td></td>
<td>Tea gardens, dispersed settlements, patches of unfertile agricultural lands</td>
</tr>
<tr>
<td>V</td>
<td>ES</td>
<td>Moderate to Undulating</td>
<td>3° - 5° &amp;&gt; 5°</td>
<td>Low Moderate</td>
<td>Forest, tea gardens and scattered settlements</td>
</tr>
</tbody>
</table>


i) Sub-class IVC (Climatic limitation)

In the middle of class III land on the terai plain which has been segmented as middle alluvial fan of area under study, the patches of this land of this sub class are traced. Excessive rainfall is mainly responsible to brought down the land under this category. Tea gardens and scattered trees are the only existing landuse found in this part.

ii) Sub-class IV ES (Erosion & unsorted stony surface limitations)

This sub-class found in the lower part of the upper fan segment in between contours ranging from 200 mt. up to 350 mt. These like mechibasti, Longview T.E etc. are having problems of soil erosion and unsorted stony surfaces (though boulders were detected in a scattered pattern
at some places) because of moderate to semi steep slopes and surface flow of water finally leads to immature soil with stone deposition. Tea gardens, dispersed settlements, patches of unfertile agricultural lands are the exiting landuse in this sub-class.

4. Class V

This land category falls under the initial type of non-arable lands which restrict usual cultivations of crops. The areas under this class of the present study are also facing the problems of soil erosion due to slope in collaboration with surface runoff and stoniness of the surface. Some parts like Marchebong, Upper Mechibasti, Sevok etc. falls under this land class. Consequently, these areas became unfit for cultivation of regular crops at present. Based on above mentioned limitations, this land of Class V further divided into following sub-classes:

i) Sub-class V ES (Erosion & unsorted stony surface limitations)

The whole Class V land comes under this sub-class which is found mainly in the upper most part of the study area or in the apex areas of the alluvial fans this is because of moderate to steep slope of surface and excessive rainfall mainly in the rainy season. Nutrient loss through erosion on sloping soils is also an important problem of this area under this sub-class. Unsorted stones are prevailing on the surface which restricts proper cultivation over this area. Mainly forest, tea gardens and scattered settlements are the existing landuse of this sub-class.

5.6 Conclusion

As the alluvial fans present study area are characteristically diversified in all respect, the landuse pattern on the fans is also different from the surrounding areas. The above landuse land cover study over the steep and hilly terrain along the sandy and gravelly of the rivers like Balasan, Mahananda, Tista etc. forests are found. Bamonpokri reserve forest. Rakti Reserve forest and Panighata Reserve forest etc. are the main forests of the area. They are mixed jungle of deciduous trees and undergrowth bushes and scrubs. Mountain fronts and upper fan segments are mostly occupied by forest. At places the forests has extended upto middle fan. Temporal study of landuse land cover also reveals the unfortunate phenomenon of uncontrolled deforestation. The rest of the fan area is occupied by tea gardens and local habitants. The gently undulating topography of the area with absorbent acidic soil and high rainfall helps the cultivation of the tea. The landuse map shows vast stretches of tea garden with occasional shade trees and settlements. Case studies done under this chapter portrays the major dynamic landuse
conversions phenomenon happening mainly in the lower fan segment may or may not adjustable with the pedo-geomorphic pattern of the study area. Study area management measures do have a distinct influence on improving the water regime of this area, reducing erosion from the land and sediment load in the streams, increasing soil fertility and productivity from the land and otherwise stimulating the general economic development of the area. However it is not easy to quantify the impact of these measures on all aspects.

References


Tamang, Lakpa. 2013: Effects of boulder lifting on the fluvial characteristics of lower Balasan basin in Darjeeling district, west Bengal, pp. 12-29.
CHAPTER VI

Correlation study of the existing landuse and pedo-geomorphic character

6.1 Introduction

It is one of the major objectives of the present research to correlate the existing landuse with the pedo-geomorphic characteristics of the study area. As such the present study has been concentrated on the evaluation of the probable sustainable landuses. The present researcher will also try to analysis the correlation of the existing landuse with the pedo-geomorphic character of the study area. This correlation study is based on some different perspectives and interrelationships. Finally on the basis of these correlations the lands of the study area have been assessed with a precise objective to recommend the agro climatic resilient land utilization.

6.2 Methodology

Collected primary data from the field survey and laboratory analysed results were further verified with the available information from different relevant secondary sources. The information were analysed followed by the suitable statistical methods for different purposes. To understand the importance of Soil Water Potentiality the Battelle formula of SWP has been relevantly cited.

\[ \psi_t = \psi_g + \psi_m + \psi_o + \psi_h \]  
(Bittelli, M, 2010)

To establish the correlation between Rainfall and runoff the Rational method has been used with the given equation.

\[ Q = \frac{CIA}{360} \]

Other than these co-relation analysis has been done to analysis and establish different correlations under this study.
Analytic hierarchy method implementing by weighted overlay technique is one in every of the leading important multi-criteria decision-making procedures. The method is realistic to a group of criteria or sub-criteria to determine a classified structure by giving the weightage of every criterion to pursue the decision making method (Kiker, 2005). Each raster layer is consigned a weight in the suitability analysis. Values in the rasters are reclassified to a common suitability scale which ranges between 1-9 wherever nine specifies maximum significance and 1 indicates the lowest importance (Saaty 1980).

The weight value evaluates the comparative impact of different criterion and therefore to be chosen deliberately. Analytical Hierarchy Process (AHP) provides an operational ground for enumerating the assessment of criterion and components with a rational technique by decreasing the complexity of decision-making method (Saaty 1977). With the pairwise comparison matrix, the AHP computes the weights for the different criterion by taking the eigenvalue equivalent to the highest eigenvector of the completed matrix to regularize the weightage of the elements to unity (Saaty 1980; Malczewski 1999; Feizizadehet 2014).

In the AHP method, an index of consistence, known as the consistency ratio (CR), consistency index is termed as CI and the average of the resulting consistency index depending on the order of the matrix or the random index as assumed by Saaty in 1980 is termed as RI. The efficiency standards of AHP are predictable by consistency relationship (CR) which is measured by the following formula:

\[
CR = CI / RI
\]

It denotes the probability of the establishment of random matrix judgments (Park et al. 2011; Saaty 1977). The CR actually depends on the CI and RI. Hence, the Consistency Index (CI) can be derived by:

\[
CI = \frac{(\lambda_{max} - n)}{(n - 1)}
\]
Here, $\lambda_{max}$ is the prime or computed principle eigenvalue from the matrix and $n$ signifies the order of the matrix. Now, RI is the mean value of the CI depending on the computed matrix order as proposed by Saaty (1977). The weight values of the matrix indicate a rational level of consistency if the value of CR is less than 0.10 and may provide significant results (Saaty 1980). In this current research the calculated CR value is less than 0.067, specifies an acceptable range of consistency in the comparison between set of layers and provides a justified and valid weight values. Finally, for the final outcome through weighted overlay analysis in Arc-GIS the calculated weight factors are transformed into percentage values.

Weighted overlay in Arc-GIS version 10.5 platform is one of the most advantageous technique of suitability modelling. This technique is applied to decide the influential factors in the hierarchy of selected different layers to weighted overlay analysis. Through these processes ultimately suitability map layer is generated with the help of Arc-GIS version 10.5 platform. In the present study the Land suitability map has been generated using weighted overlay techniques based on analytical hierarchy process and multi-criterion decision making method for sustainable utilization of land from agricultural perspective.

### 6.3 Correlation between Pedo-geomorphic characters and Landuse of the study area

Before explaining this it will be worth mentioning that the results of investigations discussed in the previous chapters have distinctly revealed that the pedo-geomorphic characteristics of different segments of alluvial fans over the area under study are mostly controlled by the rivers coming down from the different mountainous tracts and carrying detritus which are finally deposited in the debouching plains mainly during flash floods or as usually. In the source region over the mountains the trunk stream is fed by numerous tributaries which increases the discharge of water continually. As soon as the streams reach the lower degree of slope its velocity suddenly decreases, resulting in deposition of huge amount of debris at the base of the mountain. Thus the fan head becomes thicker and the thickness of sediments is maximum at the proximal fan. With continual stream action channelization starts gradually and as soon as it starts the locus of deposition is shifted towards down fan. Contour and relief map (Figure 3.1 &2.2) of the area shows that the upper part of the fan area is characterized by close spaced contours, high relief, steep gradient, deep fan head trenching whereas the middle part shows somewhat low relief with low gradient, characterized by somewhat distant contours.
and low degree of trenching. Hence, it is clear that the pedo-geomorphology of the study area is diversified.

Water holding is one of the most variable characteristics of soil. The soil plays the role of a container for water from where the plants consume their life-fluid. The water absorbent ability of the soil can be considered as a basic parameter for the question of survival & growth of plant’s life and not only this but because nutrients required for plant growth are also present in the soil solution (Bhattacharya, 1992). Major soil reactions i.e. weathering, decomposition of organic matter, fertilization etc. are also controlled by the soil water relationships. There are some elements such as rainfall, temperature, slope, gravitation, soil characteristics etc. which directly and indirectly controls the Soil Water Potentiality (SWP) of an area. That is why the SWP varies in different places which the changing pattern of these controlling factors.

The SWP can be well-defined as the potential energy of water in soil. The SWP is quantified relative to a standard state where water has no solutes, free from external forces except gravity, at a reference pressure, at a reference temperature and at a reference elevation. Hence, the SWP can be termed as the energy state of water in soil with respect to the energy of water at the reference state. The total SWP ($\psi_t$) is determined by a variety of forces acting on the soil water, such as, gravitation ($\psi_g$), matric (capillary and adsorptive, $\psi_m$), osmotic ($\psi_o$) and hydrostatic ($\psi_h$) (Bittelli, M, 2010).

$$\psi_t = \psi_g + \psi_m + \psi_o + \psi_h$$

The gravitational potential can be determined by the elevation of the soil water in respect to the chosen soil surface of the study area. The matric potential can be determined by the forces given by the soil particles on water, which are capillary and adsorptive forces. The osmotic potential is set by the existence of solutes in the soil solution, which reduces the potential energy of water. The hydrostatic potential can also be determined by a force applied by overlaying water over a point of interest in the soil. Other components of the water potential can also be defined. Since the SWP signifies an energy, it should be stated as a unit of energy per unit mass (J kg$^{-1}$) or per unit volume of water (J m$^{-3}$) (Bittelli, M, 2010). The ‘energy per unit mass’ process is more suitable as because it does not require to include the changes of water volume with temperature in the calculation. On the other hand, SWP is often stated in related units like energy per unit weight, which is the same of a head of water. The energy is equivalent to the pressure applied by a liquid column of a given height. For example, a column
of water of ~10 meters corresponds to a pressure of 1 bar. This unit is more effective because it is much easier and it permits for easy visualize of the gravitational potential and the pressure potential, which generally stated in meters (Bittelli, M, 2010).

Though the major part of the study area is covered by forest and tea plantation, the agricultural fields are also significant in the landuse pattern of this area. It is mentioned earlier that the major agricultural fields are found mainly in the middle and lower fan segments where the survey data shows that paddy is one of the major crop here. But interestingly soils, as a whole are not suitable for paddy like ‘water happy’ crops due to its low water holding capacity because of high percentage of sand or sandy loam (Table 6.1). Still, due to heavy rainfall accompanied with silt deposition in patches experienced by this study area, paddy like water happy crops are cultivated mainly in the rainy season.

In the major part of the study area moisture content of soil is low due to its sandy character. Though some silt deposited patches are detected which are suitable for paddy like semi submergence crops, but these are very much seasonal.

The soils of the study area are very light textured and the porosity level is also high. So, the water holding capacity is naturally low due to infiltration and percolation loss. But, in the rainy season some parts of lower fan region are getting waterlogged as the infiltration rate is lower than the rate of precipitation. In this case it becomes suitable for Aman Paddy cultivation.

Different soil samples were collected from different parts of the study area. The laboratory test report of these soil samples are indicating the soil pH is around 4.5-6, which means, this soils are mostly of acidic nature. From intensive field survey the present researcher found that the upper fan region is having mostly forest cover and tea gardens. Consequently, the soils are rich of pre-humus substances, which is acidic in nature resultant of un-decomposed organic material due to prolong low temperature and in this case the forests are the major source of these organic materials. Hence, the upper fan regions are having more acidic soils which is apparently non-suitable agricultural soil and the leaching effect comes to the middle and lower fan.

As is discussed in the previous chapters the different streams coming down form mountainous tracts are carrying down debris randomly and depositing them at their lower stream banks. Due to such variant deposition, the asymmetrical precipitation occurs flash flood. The acidic nature of the fans is symmetrically variant with the slope gradient. As a result, mostly the whole region is suffering from adverse conditions in terms of high cropping intensive zone though; some exceptions are there in patches.
Study revealed that soil texture, soil structure and slope largely influenced the process of water permeation or the movement of water from the surface into the soil profile. The size of soil particles and their arrangement regulates how much water drifts by gravity into the open pore spaces in the soil ultimately can flow in. Coarse soils maintain upper infiltration rate than fine soils as wide pore spacing of the soils at the surface escalate the rate of water infiltration. We know permeability, the mechanism of air and water through the soil, is vital as it controls the supply of air to the plants root-zone along with moisture and available nutrients for plant. Permeability of soil can be estimated by relative rate of moisture and air movement through the layer within the upper 40 inches of the operative root-zone. The coarse soils with granular subsoils do not confine water or air movement as it remains loose when it is moist. Moderately fine subsoil with angular to subangular structure bears the characteristics of slow permeability with moist steadiness and dry hardness. Vegetation responses vary with the heterogeneity of the available pore spaces and permeability of study area.

Basically, the soil texture and organic matter ultimately controls the water holding capacity. Soils with smaller particles i.e. silt and clay, have a larger surface area than those with larger sand particles, and large surface area allows a soil to hold more water (Ball Jeff, 2001). Hence it may be said that, a fine soil with a high percentage of silt and clay particles, bears a greater water-holding capacity. The table 6.1 shows water-holding capacity. According to this table it can be said that the available water decreases from clay soil to coarse sand.

In the long run, arable lands suffer from organic matter deficiency due to rigorous farming system. From the field survey and sampling it was found that the soil physical characteristics and properties significantly changed with the change of landuse, i.e. from forest to cultivated land, settlement, plantation and also settlement in the river banks and in river terraces formed due to river shifting.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Textural class</th>
<th>Available water capacity (inches/feet of depth)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Coarse sand</td>
<td>0.25-0.75</td>
</tr>
<tr>
<td>2</td>
<td>Fine Sand</td>
<td>0.75-1.00</td>
</tr>
<tr>
<td>3</td>
<td>Loamy sand</td>
<td>1.10-1.20</td>
</tr>
<tr>
<td>4</td>
<td>Sandy loam</td>
<td>1.25-1.40</td>
</tr>
<tr>
<td>5</td>
<td>Fine sandy loam</td>
<td>1.50-2.00</td>
</tr>
<tr>
<td>6</td>
<td>Silt loam</td>
<td>2.00-2.50</td>
</tr>
</tbody>
</table>

Table continued.
To drain excess water from the slope the planting configuration of the vegetation can enhance drainage thereby avoiding saturation and slumping of material. Vegetation in from of the above mentions plants can also reduce pore water pressure within the slope by extracting water from roots and transpiring it out through leaves.

Plants affect the hydrological condition in and around a slope in a variety of ways. Major of them are:

i) Interception: Rain strikes the leaves before striking the surface.

ii) Evaporation: Water may evaporate from leaf surface.

iii) Storage: Leaves and stems hold water for some time before it eventually reaches the ground through leaching.

iv) Dry Leaf Mulch: Minimize the splashing effect to the surface.

v) Runoff Prevention: Roots may trap water running over the ground to minimize surface runoff.

The table given below may help us to choose the proper plantation for this study area.

**Table 6.1:** Available water capacity of soil based on textural class

(Source: Ball, Jeff. Soil and water relationships, I.A.N.R, University of Nebraska-Lincoln, Sep. 2001.)

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Textural class</th>
<th>Available water capacity (inches/feet of depth)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Silty clay loam</td>
<td>1.80-2.00</td>
</tr>
<tr>
<td>8</td>
<td>Silty clay</td>
<td>1.50-1.70</td>
</tr>
<tr>
<td>9</td>
<td>Clay</td>
<td>1.20-1.50</td>
</tr>
</tbody>
</table>

**Table 6.2:** Suitable plantation mechanism for the study area

In the upper fan segment the slope is moderately steep to gently steep which is $> 5^\circ$ and $3^\circ - 5^\circ$ (table 4.1) respectively. As per the rainfall data (table 2.2) it is also seen that this zone is experiencing the high average rainfall which ultimately accelerates the volume of water in the streams flowing through these tracts. Consequently steep slope and heavy rainfall ultimately increases the surface runoff (Table 6.4) and as well the water flow through the streams. Decreasing forest canopy, heavy rainfall and steep slope makes the ideal combination for soil erosion. Due to stream actions the apex of the fans are deeply entrenched. Huge flash floods, debris and mass-movement materials are frequently seen scattered all over the fan surface (Basu&Sarkar, 1990). These materials are further redistributed towards the middle and lower fan. Coarse-loamy soils with sandy loamy and sandy loam textural classes covered almost 90% of the study area with low water holding capacity. The maximum part of the study area having soils with moderate acidic soils with pH ranges from 4.8 – 5.5 (Table 4.4.).

The middle fan segment is having moderately steep slope which is $1^\circ - 3^\circ$ (Table 4.1) respectively. Rainfall is also high in this segment also, but due to gently steep to gentle slope the surface runoff and flow of water through rivers is lesser than that of the upper fan segment and thus rate of erosion is lesser than upper fan but rate of deposition is higher. Mainly small size deposits can be observed in this segment. Though, due to less slope, altitude and distance from the fan head flash floods, mass movement types of hazards are not so effective in this segment, but stream action and floods are quite effective in this segment. Almost all the middle fan segment is covered by sandy, fine and coarse loamy soils with moderate to low water holding capacity and moderately acidic character with pH 5.2-5.8(Table 4.4).

The lower fan segment exhibits the gentle semi flat terrain with $\leq 1^\circ$ slope. Overall rainfall is rather high but it is the gentle slope which actually reduces the surface runoff. The coalescence of fans can be observed in this segment due to flood depositions which joins the fans. Braided rivers are depositing mainly finer grained silts and sands. Soil texture of this segment is fine, fine loamy and patches of coarse loamy with pH 5.8-6.7.

<table>
<thead>
<tr>
<th>Fan segment</th>
<th>Average Sand %</th>
<th>Average Silt %</th>
<th>Slope %</th>
<th>Runoff/sq.km.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper fan</td>
<td>86.97</td>
<td>7.55</td>
<td>$&gt; 5^\circ &amp; 3^\circ - 5$</td>
<td>0.14 cum.</td>
</tr>
<tr>
<td>Middle fan</td>
<td>74.75</td>
<td>11.15</td>
<td>$1^\circ - 3^\circ$</td>
<td>0.135 cum.</td>
</tr>
<tr>
<td>Lower fan</td>
<td>64.03</td>
<td>24.46</td>
<td>$&lt; 1^\circ$</td>
<td>0.125 cum.</td>
</tr>
</tbody>
</table>

Table 6.3: Interrelationship between Slope%, Average Sand% Silt % and Runoff/sq.km.
Figure 6.1: Graphical representation of alluvial fan segment wise runoff differences

Reference: Appendix Table 6.1

Figure 6.2: Graphical representation of alluvial fan segment wise sand% and silt% differences

Reference: Appendix Table 6.1
We can also establish the correlation between Rainfall and runoff by using Rational method which is the most widely used for the estimation of discharge for small watersheds for its ease applicability. It is expressed by the equation:

$$Q = \frac{CIA}{360}$$

Here,

$Q$ = Peak rate of runoff in cumec for given frequency of rainfall.

$C$ = Rational runoff coefficient having values ranging zero to one, depending upon condition of the study area. (Appendix-II)

$I$ = Rainfall intensity (mm/hr.)

$A$ = Area in km$^2$

Constant value = 360.

<table>
<thead>
<tr>
<th>Fan Segment</th>
<th>Area in sq.km.</th>
<th>Rainfall intensity (mm/hr.)</th>
<th>$Q = \frac{CIA}{360}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Fan</td>
<td>140.2</td>
<td>125</td>
<td>17.53 cum.</td>
</tr>
<tr>
<td>Middle Fan</td>
<td>158.34</td>
<td>120</td>
<td>19.01 cum.</td>
</tr>
<tr>
<td>Lower Fan</td>
<td>590.36</td>
<td>115</td>
<td>67.99 cum.</td>
</tr>
</tbody>
</table>

**Table 6.4: Alluvial fan segment wise runoff calculation**

Reference: Appendix B Figure 6.1


In the present study area soils of the upper fan segment, in contrary to the higher amount of rainfall, are having less moisture due to slope, high percentage of sand, low percentage of silt and heavy surface runoff (Table 6.3).
**Figure 6.3**: Correlation (Negative) between altitude and silt percentage

**Reference**: Appendix Table 6.2

In the upper fan segment the slope percentage, surface runoff is high with higher sand percentage and less silt percentage (Table 6.3) in soil indicates that the available moisture is low. Consequently, the landuse in this segment is a reflection of this available moisture condition as the agricultural landuse occupied only 4.60% (Table 5.1) land of the whole upper Fan segment.

Subsequent interrelationships in upper fan segment may be stated as:

In the middle fan segment the slope percentage and surface runoff is lesser that that of the upper fan segment. The sand percentage is relatively lower, whereas the silt percentage is slightly high in comparison with the upper fan (Appendix Table 6.1). Hence, the available soil moisture is a bit high as the agricultural landuse occupancy raised with 6.54% of the total middle fan area (Table 5.1).
Finally, the Lower fan segment is monotonously flat with $< 1^\circ$ of slope percentage and the surface runoff is pretty low. Here the sand percentage is less with higher silt percentage (Figure 6.2) ultimately increases the adsorption capacity of soil (Table 6.1). Hence, in this area, the available soil moisture is indicatively higher than that of the upper and middle fan segment as reflected by the agricultural landuse occupancy of 21.22% of the total lower fan area (Table 5.1).

The correlation of the present landuse with the pedo-geomorphic characteristics in different fan segments depicts mentionable features. In the upper fan segment the major landuses are Forests (100.23 sq.km.) and Tea gardens (27.89 sq.km.) (Table 5.1) with some patches of other economic landuses like settlements, agricultural lands and naked lands. This landuse is quite adjustable and relates with the pedo-geomorphic setup of this segment as the forest cover holds the vulnerable hill slopes and the slopes are also favourable for tea cultivation.

\[ y = 0.0989x + 52.951 \]
\[ R^2 = 0.8493 \]
**Figure 6.5:** Presence of sand, silt, clay and nitrogen in the collected samples

**Reference:** Appendix Table 6.2

**Figure 6.6:** Presence of potassium and sodium in the collected samples

**Reference:** Appendix Table 6.2
In the middle fan segment the major landuse types are Forests, Teagardens, linear and scattered settlements, patches of semi-fertile agricultural lands. The gradient of slope and agricultural land with settlement observed inversely proportionate. Hence, it can be assumed that with the changing character of slope and soil agricultural landuse positively increased along with settlements. However, forests and tea gardens are dominating landuse in this region also.

6.4 Land Suitability Classification

Land suitability is the capability of a certain land category for a specific use. Generally, the lands are considered in its existing situation or after developments. The method of land suitability classification is the assessment and federation of particular zones of land according to their suitability for any particular uses. Guidelines of Food and Agriculture Organization (FAO) on the land suitability analysis system are mostly accepted. A land suitability study based on FAO guidelines has been initiated with some modifications in the present research work.

<table>
<thead>
<tr>
<th>Suitability orders</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Order S (Suitable)</strong></td>
<td>Land on which sustained use of the kind under consideration is expected to yield benefits which justify the inputs, without unacceptable risk of damage to land resources.</td>
</tr>
<tr>
<td><strong>Order N (Not suitable)</strong></td>
<td>Land which has qualities that appear to preclude sustained use of the kind under consideration.</td>
</tr>
</tbody>
</table>

**Table 6.5: FAO land suitability orders with definition**


<table>
<thead>
<tr>
<th>Suitability orders</th>
<th>Degrees of limitation</th>
<th>Scale of Limitation</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class S1, Highly Suitable:</td>
<td>None</td>
<td>85-100</td>
<td>Land having no substantial restrictions to sustained application of a particular practice, or only minor limitations that will not significantly decrease productivity or profits and will not increase inputs above a tolerable level.</td>
</tr>
<tr>
<td>Suitability orders</td>
<td>Degrees of limitation</td>
<td>Scale of Limitation</td>
<td>Explanation</td>
</tr>
<tr>
<td>-------------------</td>
<td>-----------------------</td>
<td>---------------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Class S2</td>
<td>Slight</td>
<td>60-85</td>
<td>Land having limitations which in cumulative are moderately severe for sustained application of a given use; the limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use, although still attractive, will be appreciably inferior to that expected on Class S1 land.</td>
</tr>
<tr>
<td>Class S3</td>
<td>Moderate</td>
<td>40-60</td>
<td>Land having limitations which in aggregate are severe for sustained application of a given use and will so reduce productivity or benefits, or increase required inputs, that this expenditure will be only marginally justified.</td>
</tr>
<tr>
<td>Class N1</td>
<td>Strong</td>
<td>25-40</td>
<td>Land having limitations which may be surmountable in time but which cannot be corrected with existing knowledge at currently acceptable cost; the limitations are so severe as to preclude successful sustained use of the land in the given manner.</td>
</tr>
<tr>
<td>Class N2</td>
<td>Very strong</td>
<td>0-25</td>
<td>Land having limitations which appear as severe as to preclude any possibilities of successful sustained use of the land in the given manner.</td>
</tr>
</tbody>
</table>

**Table 6.6:** Explanation of Suitability classes with limitation indicators

Figure 6.7: Land suitability map of the study area with arability perspective

In the lower fan segment Arable farming, small tea gardens, cultivable waste lands, scattered forest and conglomerated pattern of settlement are the major types of landuse. In this section all tea gardens are not synergistic with the present pedo-geomorphic condition with less than 1° slope having considerable siltation and high water holding capacity. Hence, Different soil samples were collected from various places of the study area to analyse some of their physical and chemical properties (Table 4.4 & figure 6.5 & 6.6). While comparing the result with the present landuse pattern of the fan area by generating land suitability map (figure 6.7) on ArcGIS platform by applying weighted sum overlay of the spatial analysis techniques to identify the effectively suitable location for cultivation in the study area. Topography, climate, soil characteristics, drainage density and landuse land cover of the study area were considered as base of the suitability analysis as the flowchart (fig no 6.9) reflects the process at a glance. It is found interesting that, landuse types mainly on the lower fan to some extent is not sustainable in respect to its pedo-geomorphic configuration as describes before.
Figure 6.8: Spatial status of landuse (Tea garden & Agricultural land) with land suitability outcome.

<table>
<thead>
<tr>
<th>Impute layers</th>
<th>Influence level</th>
<th>Suitability value</th>
<th>CR value (CR= CI / RI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil</td>
<td>Very High</td>
<td>9</td>
<td>&gt;0.067</td>
</tr>
<tr>
<td>Rainfall</td>
<td>High</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Drainage</td>
<td>Moderately high</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Slope</td>
<td>Moderate</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Landuse land cover</td>
<td>Average</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

Table 6.7: Impute layers with suitability value and calculated CR value

According to the land suitability map (figure 6.7) the moderately high suitability areas are positively courageous for main course cultivation with favourable agro potentialities, whereas the potential environments are getting limited in the next two suitability classes of moderate suitability and marginal suitability with increasing sandy character of the soil with other indicators involved herewith. The N1 land category may not appropriate presently for agricultural landuse but in future it can be transformed with special treatments for specified agricultural activities.
Hence, land resources must be managed in a suitable method to their nature to obtain the desired results from the particular type of land utilization. The productive land with enormous sedimentation every year is liable for agricultural development, especially the braided rivers and their valleys like Rakti, Rohini, Mahananda, Balasan etc. are vastly used for cultivation.

**Plate 6.1:** A) Fertile cultivable flat surfaced are converted into small tea gardens with artificial drainage  

B) Cultivable lands are encroached by small tea gardens ultimately changed the agricultural landuse pattern on the lower fan segment of the study area.
Figure 6.9: Flow Chart for land suitability classification prepared by researcher.
<table>
<thead>
<tr>
<th>Suitability Classes</th>
<th>Fan segment wise distribution</th>
<th>Land characteristics</th>
<th>Suitability status</th>
</tr>
</thead>
<tbody>
<tr>
<td>(S1) Moderately high suitability</td>
<td>Lower.</td>
<td>Low gentle slope, silt containing fine, fine loamy, coarse loamy soil, sufficient rainfall, drainage and adequate water holding capacity.</td>
<td>Highly suitable for agriculture within the study area.</td>
</tr>
<tr>
<td>(S2) Moderate suitability</td>
<td>Lower, Middle and very few in Upper.</td>
<td>Gentle to gently steep slope, fine loamy, coarse loamy soil, sufficient rainfall, drainage and moderate water holding capacity. Forest cover is mentionable.</td>
<td>Moderately suitable for cultivation with special irrigation facilities. Relatively suitable for tea gardens and afforestation.</td>
</tr>
<tr>
<td>(S3) Marginal suitability</td>
<td>Upper, Middle and minimum in Lower.</td>
<td>Gentle to moderately steep slope, fine loamy, coarse loamy soil with some sandy patches, sufficient rainfall, drainage and low moderate water holding capacity. Forest cover is mentionable.</td>
<td>Marginally suitable for cultivation with special irrigation facilities. Moderately suitable for tea gardens and afforestation.</td>
</tr>
<tr>
<td>(N1) Presently not suitable</td>
<td>Majorly in Upper, scattered patches in Middle.</td>
<td>Moderately steep to steep slope, sandy and coarse loamy patches, sufficient rainfall, drainage and low water holding capacity.</td>
<td>Presently not suitable for cultivation but Mostly suitable for tea gardens and natural forestry.</td>
</tr>
</tbody>
</table>

**Table 6.8:** Land suitability status with sustainable predictions based on land suitability assessment
6.5 Conclusion

From the above findings it can be concluded that the landuse is vastly controlled by the pedo-geomorphic characteristics mainly in the upper fan segment where the slope, altitude, runoff, climate, soil are relevantly synergistic with the landuse and vice-versa. In case of soil sand % and altitude are positively correlated where the silt % is having negative correlation with altitude. The water holding capacity somehow manipulated mainly in the lower fan segment with land conversion and artificial drainage. Hence, the harmony becomes questionable in case of middle and lower fan segment where the landuse land covers to some extent is not adjustable with the pedo-geomorphic scenario of the study area, though further intensive research can be done to formulate more sustainable landuse land cover by determining many other factors which may have correlations with pedo-geomorphology and landuse of the study area.

References


CHAPTER-VII

Conclusions and recommendations

It is already mentioned in chapter-I that the main objectives of this research work are to investigate thoroughly the complex interaction of the fan forming processes and their mode of operation by which fans are being developed and to correlate the pedo-geomorphic characteristics of this region with the landuse pattern existent in present scenario with assessment.

The physical background of the study area as discussed in chapter II reveals that the area is geologically young and mobile which is mostly consisted of sands, gravels & older alluvium. The entire zone is irregularly composed of sandy, fine, coarse and fine loamy soils with uneven monsoonal distribution of high intensity rainfall and seasonal temperature variations (Table 2.2). Rapid decrease in vegetation cover has also been noticed from upper to lower fan segment, which is from north to south (Table 5.1).

The detailed study regarding the development of the alluvial fans discussed in the chapter III reveals that the alluvial fans in the Terai region has been developed by the complex interaction of the fan forming processes and the mode of operation of different factors responsible for fan development. The study area possesses different slopes and debris carried by streams with sudden break of slope at the foothills where the channels contribute detritus with sudden fall of velocity for the formation of alluvial fans. The alluvial fans of the study area are formed by the major rivers like the Balasan, the Mahananda, the Tista and the main tributaries like the Rungsung, the Rakti, the Rohini and the Sukhia. The development of alluvial fans and their morphometry are strongly controlled by several factors including neotectonism, climatic influence, lithological setup, and hydrology and hydraulics of the concerned area. So, on the basis of these dynamic factors of fan development and the morphological characteristics of the fans, it can be said that fan formation process of the study area is still in action.

It can be concluded on the basis of information gathered from the field and from the analysis of morphometric maps, that, the alluvial fans over the study area are divided into three separate segments (Figure 4.11) having different characteristics and pedogenesis. Steep to gently steep gradient, semi-deep trenches and enormous sub angular boulders widely spreading over moderately developed soil are the major features of the upper fan segment. Flash floods, debris
flows and mass wasting are the key stimulators of sedimentation process of this zone. The middle fan segment characterized with moderate gradient with shallow trenching. River’s braided pattern originates mainly from here. Semi large boulders and pebbles are scattering over this portion. Sedimentation in this segment is mainly accelerated by Stream overflow, floods, occasional flash floods etc. The landscape of the lower fan segment is characterized with very low gradient and almost flat topography. Streams with high concentration over this segment are widespread and braided. This area is covered with fine sediments and rounded pebbles. Stream overflow/floods are the major sedimentation processes of this part of study.

The alluvial fans of the study area with three distinct fan segments have been observed with diversified land utilization. The Spatial status of landuse (Tea garden & Agricultural land) with land suitability outcome map (Figure 6.8) shows that the southern and south-western portion of the study area with suitable climatic conditions is having the prospective soil condition for high value agricultural crops. But unfortunately this part is dominated by settlement and small tea gardens. It is considerable that the settlement cover cannot be changed easily but we can readjust our thinking about the small tea gardens being replaced by more profitable crops over this nearly flat area.

Large tea gardens are the governing landuse of this whole study area for a prolonged time. Naturally it has deep impact on local economy. Large tea gardens stimulates the thought process of the local community for growing tea leafs even in small scales. This has created conversion of agricultural lands into tea gardens with a hope of better profit. But if those lands are used for maize, wheat and rabi crops it will be a creative way of mitigating local demands with a prospect of greater profitability and controlling pesticide contamination on the soil and water by the tea gardens.

Hence, on the basis of findings explained in the preceding chapters, the landuse of the study area have been judged through implication of land suitability classification model based on weighted overlay technique. Some suitability classes have been assessed for proposing some recommendations about more sustainable land utilization and better landuse planning in comparison to the existing landuse.

It is also found that the lower fan segment is dominated by silted soil characteristics, more water holding capacity in comparison with the upper and middle fan segment, high rainfall with uneven yearly distribution, stagnation of water in patches, prolong low average
temperature etc. based on which some sustainable land use may also be adopted in the lower fan segment.

Over all the following recommendations have been proposed for the study area:

- Cultivation of high value crops like Gherkin, Baby corn etc. can be practiced on the basis of soil suitability and water potentiality.
- In the lower fan segment agricultural activities can be carried out based on soil characteristics and fertility available as suitable soil cover is changeable as new alluvium covers the surfaces by the river bank side almost every year due to seasonal floods and flash floods.
- Leguminous crops which develop nitrogen capital and soil compactness resisting soil loss like Arhar (*Cajanus cajan. L*) and pulses (*Vignaradieta, Vignamungo* etc.) can make a sustainable approach towards the development of the area.
- Photo and thermo insensitive crop variety can be adopted.
- Submergence tolerant crop variety may be applicable in the patches of water stagnation.
- Deep rooted crops should be avoided.
- Intermittent drought tolerance crops can be cultivated with temporal variations.

About 61% (Table 5.1) of the land surfaces of the study area is occupied by tea gardens and forests. Greater portion of cultivated land is located on the lower fan. Mainly in the upper part of the lower fan segment and lower part of the middle fan segment destruction of forest to meet the demand of land for cultivation and settlement is a regular feature here which initiates soil erosion, landslides, flooding and hinders process of soil found in the upper fan region. On the slope of high gradient step cultivation is a prominent feature the fields of cultivation are found around small villages retracing is done by enormous human labour. Paddy is the single crop and the poor water holding capacity of soil permits only one crop in a year. Such area can be brought under fruit orchard or multipurpose tree species (*Leucaena lanatacephala* etc.) to cope up with the economic as well as nutrition perspective of the dwellers. Such large canopy area can minimize the erodability of the area with mulching effect. During field survey little forest fire evidence was found on the high slopes. Destruction of forest in this way results in mass movements which supply materials to the fans.
The middle fan area may be sustainably conserved through multiple agricultural products, suitable vegetative and mechanical engineering measures along with settlement construction can be easily allowed according to demand considering the buffering zones of the large braided channels as they frequently change their courses with monsoonal floods.

The upper alluvial fan primarily constituted of boulders and coarse grained materials can be better utilized if resistant variety of crops, intensive root spreading plants like Chilaune (Schimawallichii), Gokul (Ailanthusgrandis), Utis (Alnusnepalensis) etc. Commercially useful grasses like Amlisho (ThysanolaenaMaxima), Kash (Saccharamspontaneum) etc. are also helpful to resist slope failure and will effective to involve the local people in this process (Bhattacharya, 2004).

Though agriculture and construction sites are may be targeted away from the fragile zone of the stream bank area with proper planning as this region is formed by diversified alluvial detritus carried by different streams from mountainous tracts. However, Lastly forest management in every fan segment, especially in the upper and middle fan segments is strongly appreciated.

Hence, the current study illustrates that the agricultural and horticultural landuse will be more sustainable landuse than small tea gardens in this part of the lower fan segment supported by prolong winter season and compatible pedo-geomorphic characters. Being situated in the highly susceptible to erosion zone, if, any adverse changes stuck down the monopoly tea based economy, this substitute sustainable high value agricultural and horticultural landuse may control the situation in a positive approach with the support of agriculturally favorable pedo-geomorphic conditions of this segment.
ANTHROPOGENIC ENCROACHMENT OF THE RIVER
Plate 7.1: A) Barren terrace left uncovered and unproductive near the apex of the fan at Marchebong;

B) Anthropogenic encroachment of the river at Sevok;

C) Forest land encroached and converted into human settlement;

D) Unscientific settlement construction on the vulnerable hill slopes on the upper fan segment;
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ABBREVIATION

AHP- Analytical Hierarchy Process
Arc-GIS- Aeronautical Reconnaissance Coverage Geographic Information System
DEM- Digital Elevation Model
FAO- Food and Agriculture Organization
GIS- Geographical Information System
LFS- Lower fan Segment
LISS- Linear Imaging Self-Scanning Sensor
MFS- Middle fan Segment
NBSS&LUP- National Bureau of Soil Survey and Land Use Planning
NPK- Nitrogen (N), Phosphorus (P) and Potassium (K)
SLUSI- Soil and Land Use Survey of India
SOI- Survey of India
SRTM- Shuttle Radar Topography Mission
SWP- Soil Water Potentiality
UFS- Upper fan Segment
USDA- United States Department of Agriculture
APPENDIX A

List of publication:

A Pedo-Geomorphic Study of Landuse on the Alluvial Fans of Terai Region, West Bengal, India.

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&

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Department of Geography & Applied Geography, NBU, West Bengal.

Abstract: From field investigation and data analysis it becomes clear that alluvial fans of the Terai region are the result of slope, fluvial actions, nature of the transportation of debris and mode of deposition by the rivers and their interrelationships. Accordingly, the fans are marked by diversified landuse on the basis of fertility status and necessary soil ingredients. At places the forests have been extended up to middle fans from the apex where rest of the fan area is occupied by tea gardens with small stretches of cultivated, barren lands along with some patches of settlements. All these indicate a close link between distributed materials onto the fan surface having varied constitution as well as nutritional values on the landuse in different parts of the fans. Therefore, it is essential to investigate the pedo-geomorphic significance of the fans to the landuse presently existent over the study area.

Keywords: High School/Introductory Chemistry, Inorganic Chemistry, Symbolic/representational learning, Convergent-Divergent Thinking Topology Mnemonics/Rote Learning, Oxidation/Reduction, Reactions.

Introduction

Geographical study of the alluvial fans of Terai region in the Eastern Himalaya foothill has been carried out with an objective to determine the pedo-geomorphic significance of the fans to the landuse pattern and their suitability to optimum land utilization. Conclusively some management strategies have been framed out for individual landform.

Study Area

The study area extends from 26°15' N to 26°50'N Latitudes and 88°12'45" E to 88°30'15" E Longitudes comprising

Fig-1: Location Map
the whole Terai plains and this includes parts of Darjeeling and Jalpaiguri districts. The Terai (moist undulating land) traverses east-westward along the base of the Darjeeling Himalayas being drained by numerous rivers coming down from the Himalayan hills.

Methods

Before adaptation of any paper method the present researcher did intensive field investigation with previous research works and then collection of soil samples from various parts of the study area executed. After that various morphometric and quantitative techniques based on toposheets, geological maps, satellite images adapted to explain the typical landuse pattern of the study area with reference to the alluvial fans.

Alluvial fans of the study area

The development of the North Bengal alluvial plains at the Himalayan margin has a long drawn historical perspective since the Pleistocene period. During this period of Pleistocene cryoturbation, initial fan materials were deposited at the foothills, which further re-distributed subsequent fluvial processes dominant over this region due to climatic change i.e. the appearance of inter-glacial period (Bhattacharya, S.K. 1993). Tista, Mahananda, Balason, Rakti, Rohini and Mechi, the major streams flowing through the study area along with their tributaries are carrying a great volume of debris which are further redistributed over the fans and deposited accordingly to shapes and sizes and further with pedogenesis reshape the fans. The rivers of the study area i.e. Tista, Mahananda, Balason, Mechi, Rakti, Rohini etc. have formed a thick cover of poorly stratified and unsorted sediments at the base of the foot-hills and formed alluvial fans. These alluvial fans coalesce to form a piedmont zone. The evolution, materials, modes of deposition of debris, stratigraphy, morphology and pedogenesis of the alluvial fans are strongly influenced by factors like tectonics and lithology, local relief, climate and hydrology. Field experiences show that flash floods, stream action, stream floods, debris flow are four notable modes of deposition of alluvial fans. (Basu and Sarkar 1990; Bhattacharya, S.K. 1993, 2004).

i) Fan material

It is thought that during Pleistocene period the rivers from Himalayan tracks brought down a great volume of periglacial debris and solifluxion materials which eventually were deposited as coalescing alluvial fans at the river's outlets (Kar 1962, 1969, Godwin Austin 1968, Basu & Sarkar 1990, Bhattacharya, S.K. 1993). In the area of study, the fan deposits are coarse grained, poorly-sorted and immature sediments. Usually gravels, cobbles and boulders predominate with lesser amount of sand, silt and some clay. The coarsest and the thickest deposits occur near the fan heads i.e. in the proximal or upper fan region. Size of grains and thickness of sediments decrease rapidly from the apex towards the base and the roundness of the materials increases conversely from the apex to the lower portion of the fan. The pedo-geomorphology of the alluvial
fans of the study area can be discussed by segmenting fan into three parts. i.e.

a) Upper Fan.
b) Middle Fan.
c) Lower Fan.

a) Upper Fan

The Northern part or upper fan region is characterized by huge boulders and gravels in association with very fine sands and clay. Mainly the base of the mountains or foot of the hills, from where the alluvial fan originate is characterized by huge amount of boulders of unusually large size. The river beds are almost sucked with such detritus, through which a very thin channel of water is flowing. The boulders are mainly of granitic gneiss, granites and schistose rocks and are stretched out in size, signifying a near source deposition i.e. from surrounding hills during heavy rains (Bhattacharya, S.K., 1993). In the interflo interfluv region such big boulders are not rare lying over the upper fan portion. The average lengths of the boulders are 2.6 m to 4 m and the width is about 2m. The boulders are seen to have been highly weathered and oxidized and obviously the materials found in this upper fan portion are very unsorted and stratified. Due to the deeply incised river valleys in the upper fan region it can be anticipated that the infrequent large boulders in the interfluvues are the fragments of single extensive deposition only.

b) Middle Fan

In the middle fan region medium grained debries are the major deposits instead of big boulders, though sometime large boulders of 1.5 to 2m in length and 1 to 1.5m in width are found scattered over this fan region. Though the boulder size are elongated in this part of fan also but the roundness is higher than that of the upper fan region. The major deposits in the middle fan portion are slackly sandy sediments sprinkled with pebbles and gravels. The pebbles as well as gravels are not much rounded, still, elongated shape with less sharp edges. This poorly stratified and unsorted materials are found in most of the middle fan as experienced during the field survey. Deeply weathered and oxidized boulders are also noticed near tea garden, agricultural field and jungle.

c) Lower Fan

The physical characteristics of the materials which are deposited in this outer most or lower or distal part of the fan largely differ from the upper and middle fan region. Large boulders are significantly absent in this part and the interfluvues are characterized by fine grained sands, silts and clay. The wide river valleys with braided channel pattern shows a somewhat coarser sand and rounded pebbles and gravels.
<table>
<thead>
<tr>
<th>Segments</th>
<th>Contour Limit</th>
<th>Slope</th>
<th>Materials</th>
<th>Process</th>
<th>Pedogenesis</th>
<th>Major Landuse</th>
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<tr>
<td>Upper</td>
<td>300 m.-450 m.</td>
<td>5°-15°</td>
<td>Coarse-gravels, cobbles and</td>
<td>Flash floods, debris-flow, solifluxation and</td>
<td>Moderate</td>
<td>Forests and Tea Gardens, scattered</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>boulders</td>
<td>stream action</td>
<td></td>
<td>settlement</td>
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<tr>
<td>Middle</td>
<td>200 m.-300 m.</td>
<td>1.5°-5°</td>
<td>Medium grained sand-silt with occasional boulders</td>
<td>Stream action and stream floods</td>
<td>Maximum with distinct B horizon between 30 cm below surface</td>
<td>Forests, Tea Gardens, Arable Lands and Settlements</td>
</tr>
<tr>
<td>Lower</td>
<td>100 m.-200 m.</td>
<td>1°-1.5°</td>
<td>Fine grained sand, silt and clay</td>
<td>Stream action and stream floods</td>
<td>Minimum with weakly developed B horizon.</td>
<td>Forests, Tea Gardens, Arable Lands and Settlements</td>
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Table-1: Characterization and Segmentation of alluvial fans

Fig. 4: A Naturally Exposed Soil Profile Near Sevoke.

Pedo-geomorphic Significance and Landuse

Different soil samples were collected from various places of the study area to analyze some of their physical and chemical properties. While comparing the result with the present landuse pattern of the fan area it is found interesting that, land resources must be managed in a suitable method to their nature to obtain the desired results from the particular type of land utilization. The productive land with enormous sedimentation every year is liable for agricultural development, especially the braided rivers and their valleys like Rakti, Rohini, Mahananda, Balasan etc. are vastly used for rice cultivation. The same formula is experienced in where paddy vegetable, Maize and other crops are cultivated on the flat alluvial plains mainly in the middle and lower part. While the upper segment of the fans are being used for forest and tea cultivation. Coarse-loamy soils with sandy loamy and sandy loam textural classes covered almost 70% of the study area. The maximum part of the study area having soils with moderate acidic soils with pH ranges from 4.5 - 5.5. But some portions, mainly the upper and lower fan segments where the forests, Tea gardens and cultivated areas respectively are the major landuse character, the soil pH seems to be strongly acidic (< 4.5). The soils of upper and lower part of the fans are suffering from Boron deficiency with a critical limit of < 0.36 mg/kg, where the
Boron in major middle segment ranges between 0.36 -> 0.75 mg/kg. Interestingly soils of the densely settlement areas are having sufficient Boron content.

**Landuse Pattern of the study area**

The landuse of the study area can be discussed with the following perceptions:

a) **Forest**

At the beginning of the 19th century all the fans of the Terai region were well covered with tropical forests of densely growing Sal (*Shorea robusta*), Segun (*Tectona grandis*), or sturdy sheesham (*Dalbergia sissoo*). (S.R. Basu & S. Sarkar, pp-328). Other than this the study area also have some species like, Champak (*Michelia champaca*), Almond (*Terminalia arjuna*), Gokul (*Ailanthus grandis*) etc with valuable commercial timbers. It is observed during field survey and analyzing remote sensing data that mainly the upper fan segment has the major forest cover with tea gardens than middle and lower. For example Sevok, Upper Rohini, marchebong, Mechi basti etc areas are mostly forest covered than middle fan areas like Sukna, Kharpraill, Samalbong etc. and lower fan areas like 2.5 miles, Matigara, Bagdogra etc. But unfortunately deforestation in different ways making slopes of the upper fan areas and apex areas vulnerable resulting loss of soils from the slop.

b) **Tea Plantation**

With the gradual establishment of tea gardens after 1866 on the undulating terrain having suitable soil and adequate drainage, more and more forests were cut. At present tea gardens cover about 30.7% of the total area under study. Moreover, tea gardens occupying about 4.8% of the region have been deserted by their owners as these were no longer economical. The gently undulating land surface which prevents accumulation of water in this high rainfall areas with permeable acidic soil facilitates the cultivation of the India's high foreign exchange earner tea crop. The whole Terai region has a very rich physio-cultural environment which is very perfect for the tea cultivation. From the very beginning of 1866, the British empires started the process of tea cultivation in this region. They got a pretty good response from the undulating surface of this region. The Terai region fulfilled the basic criterions for the successful cultivation of tea i.e. soil, temperature, rainfall etc.

The tea cultivators were encouraged by this. They started to expand the periphery of tea gardens. As the researcher stated earlier that the major portion of the study area was covered by forests, so the tea merchants overviewed the environmental factors and no other way they started to cut the forests resulting intensive defilement of environment in form of slop failure, soil erosion etc.

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<td><strong>TOTAL</strong></td>
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</table>

Source: Field Survey

![Fig-6 : Present Landuse Map Map (Bhuban)](image-url)
e) Agricultural Land

As per the agricultural zonation made by the West Bengal agricultural department the present study area falls under Terai-Tista agricultural region with alluvial soil cover. In comparison to the upper fan segment the middle and lower fan segments are the ideal option for agriculture. As the diversified debris from different mountainous tract are spreading over and depositing mainly on this part, the middle and lower fan segments get a fertile soil characteristics in the form of flood deposited top soil. The fine and coarse loamy soils with sandy clay makes this foothill landform suitable for agriculture. In the upper part of the fan some semi terrace cultivation and 'Jhum' cultivation may observed. Interesting thing is that, due to the deforestation in the upper and middle fan areas, the rivers started to erode extensively and then they were dumping that detritus on the lower fan areas having gentle or no slope. So, the lower fans are growing as a very rich and fertile land for agriculture. But as this upper part has immature soil cover due to soil slips and high surface runoff due to massive deforestation the arable land are not so fertile for crops. In rest of the segments paddy, vegetables etc. are the main agricultural products.

d) Settlements

In the present study area human settlements have increased with decreasing forest and agricultural areas. With the increasing population the settlements are established encroaching the forests, arable lands and even different stream banks. Transportation networks are developed rapidly with increasing settlements. In many places the forests are smashed to make steps to cultivate as a conventional process, but, after some years the steps are left barren and converted into unscientific built-up areas. It is vary dangerous for the vulnerable hill slopes. Unfortunately, now a days, it is a common practice seen in the upper fan region. The middle and lower fan areas have the conglomerated settlement pattern whereas the upper fan has scattered or clustered settlement pattern. But defilement of environment in the form of mass deforestation, unscientific settlement construction on the vulnerable hill slopes, rapid growth of urbanization and associated phenomenon like, construction of roads, passing of heavy vehicle through these roads have become the triggering factors for severe soil creeping, sheet slides, slips and other types of slope failure, which results in the addition of extra sediment load in the river channels.

Managements and Concluding remarks

From the above discussion it seems that the alluvial fans in the Terai region having three distinct fan segments which are ideal for land utilization. Though agriculture and settlement constructions are may proposed for this study area but this must be done with proper planning as this region is formed by alluvial detritus of varied sizes and textures carried by different streams from mountainous tracts. The upper alluvial fan primarily constituted of boulders and coarse grained materials can
be better utilized if resistant variety of crops, intensive root spreading plants like Chilaune (Schimawallicii), Gokul (Ailanthus grandis), Uitis (Alnus nepalensis) etc. Commercially useful grasses like Amlisho (Thysanolaena Maxima), Kash (Saccharum spontaneum) etc. are also helpful to resist slope failure and will effective to involve the local people in this process (Bhattacharya, S.K., 2003). Settlements may be constructed over this fan segments without rigid restrictions but it must be situated far from the stream banks as flash floods in the rainy season is a very common phenomenon of the study area. Pedogenically rich middle fan area may be utilized for multiple agricultural products. Settlement construction can be easily allowed according to demand but avoiding the buffering zones of the large braided channels as they frequently change their courses with monsoonal floods. In the lower fan segment agricultural activities can be carried out with proper planning, i.e. cultivation based on soil characteristics and fertility as suitable soil cover is not developed everywhere as per need as new alluvium covers the surfaces by the river bank side almost every year due to seasonal floods and flash floods. On the other hand settlements and other activities can be admissible without any specific restrictions. Lastly afforestation in every segment, especially in the upper and middle fan segments is strongly recommended. 

So, it can be said that the materials which are deposited on the alluvial fans have a very significant impact on the landuse since the materials are transported by the rivers from the different parts of the hill areas which are consisted of the substances having different geologic, pedologic and geomorphic origin.

References

APPENDIX B

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<th>Soil pit number</th>
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Table 1: Soil survey and soil sampling sheet

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<th>Angle in degrees</th>
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Table 2: Per cent slope corresponding to degree slope

(Source: Participatory Integrated Watershed Management, A field manual, 2006)

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<th>Slope of degree (%)</th>
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Table 3: Soil textural class in relation with LCC (FAO)

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<td>3549.00</td>
<td>27.30</td>
</tr>
<tr>
<td>1000</td>
<td>37.50</td>
<td>3750.00</td>
<td>28.10</td>
</tr>
<tr>
<td>1125</td>
<td>43.10</td>
<td>4348.00</td>
<td>32.30</td>
</tr>
<tr>
<td>1250</td>
<td>48.00</td>
<td>6100.00</td>
<td>36.60</td>
</tr>
<tr>
<td>1375</td>
<td>54.40</td>
<td>7480.00</td>
<td>40.80</td>
</tr>
<tr>
<td>1500</td>
<td>60.00</td>
<td>9000.00</td>
<td>45.00</td>
</tr>
</tbody>
</table>

**Table 4:** Estimated runoff and yield per ha from catchment area- Strange’s table  
Figure 6.1: Isopleth map based on rainfall intensity per hour for different frequencies in India;

APPENDIX C

<table>
<thead>
<tr>
<th>Months</th>
<th>Upper Fan Region</th>
<th>Middle Fan Region</th>
<th>Lower Fan Region</th>
<th>Whole Fan Region</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rainfall (mm)</td>
<td>Temp (°C)</td>
<td>Rainfall (mm)</td>
<td>Temp (°C)</td>
</tr>
<tr>
<td>January</td>
<td>23.625</td>
<td>10.53</td>
<td>8.25</td>
<td>14.23</td>
</tr>
<tr>
<td>February</td>
<td>27.58</td>
<td>12.09</td>
<td>11.05</td>
<td>18.1</td>
</tr>
<tr>
<td>March</td>
<td>58.88</td>
<td>15.56</td>
<td>24.95</td>
<td>21.3</td>
</tr>
<tr>
<td>April</td>
<td>89.09</td>
<td>18.62</td>
<td>112.65</td>
<td>23.7</td>
</tr>
<tr>
<td>May</td>
<td>255.46</td>
<td>19.5</td>
<td>268.11</td>
<td>25.3</td>
</tr>
<tr>
<td>June</td>
<td>667.765</td>
<td>20.72</td>
<td>563.435</td>
<td>27.5</td>
</tr>
<tr>
<td>July</td>
<td>842.395</td>
<td>21.71</td>
<td>681.44</td>
<td>26.4</td>
</tr>
<tr>
<td>August</td>
<td>695.025</td>
<td>21.88</td>
<td>621.725</td>
<td>26.84</td>
</tr>
<tr>
<td>September</td>
<td>421.32</td>
<td>19.94</td>
<td>639.605</td>
<td>25.6</td>
</tr>
<tr>
<td>October</td>
<td>149.415</td>
<td>18.36</td>
<td>124.35</td>
<td>24.6</td>
</tr>
<tr>
<td>November</td>
<td>29.31</td>
<td>15.23</td>
<td>81.8</td>
<td>21.3</td>
</tr>
<tr>
<td>December</td>
<td>16.95</td>
<td>11.92</td>
<td>6.57</td>
<td>17.9</td>
</tr>
<tr>
<td>Mean</td>
<td>273.068</td>
<td>17.17</td>
<td>261.994</td>
<td>22.7308</td>
</tr>
</tbody>
</table>

(Source: Tea Gardens record collected in 2014-2017)

**Table 2.2** Rainfall and Temperature of the study area

<table>
<thead>
<tr>
<th>Category Name</th>
<th>Slope Limits</th>
<th>Area (sq. km.)</th>
<th>% of the Fan area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderately steep</td>
<td>&gt; 5°</td>
<td>60.45</td>
<td>6.8</td>
</tr>
<tr>
<td>Gently steep</td>
<td>3° - 5°</td>
<td>150.22</td>
<td>16.9</td>
</tr>
<tr>
<td>Gentle</td>
<td>1° - 3°</td>
<td>264.00</td>
<td>29.7</td>
</tr>
<tr>
<td>Low</td>
<td>&lt; 1°</td>
<td>414.23</td>
<td>46.6</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td><strong>888.90</strong></td>
<td>100%</td>
</tr>
</tbody>
</table>

**Table 4.2:** Area Slope Distribution of the Study area
### Table 4.6: The coverage of total area (Sq. Km.) under different major contours

<table>
<thead>
<tr>
<th>Contour</th>
<th>Area in sq.km.</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;300</td>
<td>44.445</td>
</tr>
<tr>
<td>300-200</td>
<td>133.335</td>
</tr>
<tr>
<td>200-100</td>
<td>284.448</td>
</tr>
<tr>
<td>&lt;100</td>
<td>426.672</td>
</tr>
<tr>
<td>Total</td>
<td>888.9</td>
</tr>
</tbody>
</table>

### Table 4.7: Area (in %) of alluvial fans under different amplitude or Relative Relief zones.

<table>
<thead>
<tr>
<th>Relative Relief in m</th>
<th>% of area to the total area</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;300</td>
<td>8.88</td>
</tr>
<tr>
<td>300-200</td>
<td>25.76</td>
</tr>
<tr>
<td>200-100</td>
<td>52.90</td>
</tr>
<tr>
<td>&lt;100</td>
<td>12.46</td>
</tr>
</tbody>
</table>

### Table 5.3: Differences of forest cover and tea garden cover in between year 1959 and 2016

<table>
<thead>
<tr>
<th>Year</th>
<th>1959</th>
<th>2016</th>
<th>difference</th>
<th>Difference in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>FOREST</td>
<td>473.99</td>
<td>342.27</td>
<td>131.72</td>
<td>27.78961581</td>
</tr>
<tr>
<td>TG</td>
<td>84.105</td>
<td>203.3</td>
<td>119.195</td>
<td>141.7216575</td>
</tr>
<tr>
<td>YEAR</td>
<td>landuse type</td>
<td>Upper sq.km.</td>
<td>middle sq.km.</td>
<td>lower sq.km.</td>
</tr>
<tr>
<td>------</td>
<td>--------------</td>
<td>--------------</td>
<td>---------------</td>
<td>--------------</td>
</tr>
<tr>
<td>2017</td>
<td>FOREST</td>
<td>100.23</td>
<td>98.36</td>
<td>143.68</td>
</tr>
<tr>
<td></td>
<td>TG</td>
<td>27.89</td>
<td>41.29</td>
<td>134.12</td>
</tr>
<tr>
<td></td>
<td>AGRI LAND</td>
<td>6.45</td>
<td>9.33</td>
<td>148.51</td>
</tr>
<tr>
<td></td>
<td>SETTLEMENT</td>
<td>2.35</td>
<td>2.75</td>
<td>125.27</td>
</tr>
<tr>
<td></td>
<td>OTHERS</td>
<td>3.28</td>
<td>6.61</td>
<td>38.78</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>140.2</td>
<td>158.34</td>
<td>590.36</td>
</tr>
</tbody>
</table>

**Table 5.4:** Alluvial fan segment wise coverage of landuse type of the study area

<table>
<thead>
<tr>
<th>YEAR</th>
<th>landuse type</th>
<th>Upper %</th>
<th>Upper sq.km.</th>
<th>middle %</th>
<th>middle sq.km.</th>
<th>lower %</th>
<th>lower sq.km.</th>
<th>TOTAL %</th>
<th>TOTAL sq.km.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017</td>
<td>FOREST</td>
<td>71.49</td>
<td>100.23</td>
<td>62.12</td>
<td>98.36</td>
<td>24.34</td>
<td>143.68</td>
<td>38.50</td>
<td>342.27</td>
</tr>
<tr>
<td></td>
<td>TG</td>
<td>19.89</td>
<td>27.89</td>
<td>26.08</td>
<td>41.29</td>
<td>22.72</td>
<td>134.12</td>
<td>22.87</td>
<td>203.3</td>
</tr>
<tr>
<td></td>
<td>AGRI LAND</td>
<td>4.60</td>
<td>6.45</td>
<td>5.89</td>
<td>9.33</td>
<td>21.22</td>
<td>125.27</td>
<td>15.87</td>
<td>141.05</td>
</tr>
<tr>
<td></td>
<td>SETTLEMENT</td>
<td>1.68</td>
<td>2.35</td>
<td>1.74</td>
<td>2.75</td>
<td>25.16</td>
<td>148.51</td>
<td>17.28</td>
<td>153.61</td>
</tr>
<tr>
<td></td>
<td>OTHERS</td>
<td>2.34</td>
<td>3.28</td>
<td>4.17</td>
<td>6.61</td>
<td>6.57</td>
<td>38.78</td>
<td>5.48</td>
<td>48.67</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100</td>
<td>140.2</td>
<td>100</td>
<td>158.34</td>
<td>100</td>
<td>590.36</td>
<td>100</td>
<td>888.9</td>
</tr>
</tbody>
</table>

**Table 5.5:** Diversified landuse occupancy on the different fan segments

<table>
<thead>
<tr>
<th>Fan segment</th>
<th>Average Sand %</th>
<th>Average Silt %</th>
<th>Slope %</th>
<th>Runoff/sq.km.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper fan</td>
<td>86.97</td>
<td>7.55</td>
<td>&gt; 5° &amp; 3° - 5</td>
<td>0.14 cum.</td>
</tr>
<tr>
<td>Middle fan</td>
<td>74.75</td>
<td>11.15</td>
<td>1° - 3°</td>
<td>0.135 cum.</td>
</tr>
<tr>
<td>Lower fan</td>
<td>64.03</td>
<td>24.46</td>
<td>&lt; 1°</td>
<td>0.125 cum.</td>
</tr>
</tbody>
</table>

**Table 6.1:** Alluvial fan segment wise runoff, sand% and silt% differences
<table>
<thead>
<tr>
<th>Soil Pit</th>
<th>SAND %</th>
<th>SILT %</th>
<th>CLAY %</th>
<th>N %</th>
<th>P kg/ha</th>
<th>K kg/ha</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>92</td>
<td>5.2</td>
<td>0</td>
<td>0.25</td>
<td>28.67</td>
<td>80</td>
<td>4.8</td>
</tr>
<tr>
<td>A2</td>
<td>91</td>
<td>6.8</td>
<td>0</td>
<td>0.85</td>
<td>50.17</td>
<td>40</td>
<td>4.6</td>
</tr>
<tr>
<td>A3</td>
<td>84.6</td>
<td>7.2</td>
<td>0</td>
<td>0.11</td>
<td>73.47</td>
<td>200</td>
<td>4.6</td>
</tr>
<tr>
<td>A4</td>
<td>87.2</td>
<td>7.7</td>
<td>8.6</td>
<td>0.14</td>
<td>33.15</td>
<td>480</td>
<td>6.1</td>
</tr>
<tr>
<td>B5</td>
<td>83</td>
<td>9.2</td>
<td>6.8</td>
<td>0.36</td>
<td>41.66</td>
<td>40</td>
<td>5.8</td>
</tr>
<tr>
<td>B6</td>
<td>76.4</td>
<td>12.3</td>
<td>7.7</td>
<td>0.19</td>
<td>48.11</td>
<td>330</td>
<td>5.9</td>
</tr>
<tr>
<td>B7</td>
<td>68</td>
<td>20</td>
<td>8.3</td>
<td>0.55</td>
<td>49.01</td>
<td>230</td>
<td>6.1</td>
</tr>
<tr>
<td>C8</td>
<td>64</td>
<td>22.6</td>
<td>8.6</td>
<td>0.87</td>
<td>49.90</td>
<td>233</td>
<td>6</td>
</tr>
<tr>
<td>C9</td>
<td>59.3</td>
<td>23.1</td>
<td>9.2</td>
<td>0.72</td>
<td>50.80</td>
<td>480</td>
<td>6.2</td>
</tr>
<tr>
<td>C10</td>
<td>58.3</td>
<td>25.3</td>
<td>9.3</td>
<td>0.88</td>
<td>51.70</td>
<td>470</td>
<td>6.2</td>
</tr>
</tbody>
</table>

**Table 6.2:** Physical and chemical properties of the collected soil samples