MORPHO-DYNAMICS OF RIVER TLAWNG, MIZORAM

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

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CERTIFICATE

This is to certify that David A Lalramchulloa, registered under MZU/Ph.D./746 of 19.05.2015 is a research scholar working under my supervision on a thesis entitled "Morpho-Dynamics Of River Tlawng, Mizoram". He has fulfilled all the requirements laid down in the Ph.D. regulations of Mizoram University. I further certified that the thesis in this form is the result of the research scholar's original work. Neither the thesis as a whole nor any part of it was ever submitted to any other university for any research degree.

I recommended the thesis for due evaluation and recommendation.

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DECLARATION

I, David A Lalramchulloa, hereby declare that the subject matter of this thesis is the record of research work done by me, that the content of this thesis did not form the basis of the award of any previous degree to me or to do the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other University or Institute.

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(DAVID A LALRAMCHULLOA)

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Rivers have been the focus of human activity since the early civilizations. So important to humanity are the benefits obtained from rivers, and so necessary is the protection against floods and other river disasters, that pursuit for knowledge of riverine systems has advanced in leaps and bounds (Garde 2006). Even in modern times a large number of activities of the engineers such as water supply, irrigation, water quality control, power generation, flood control, river regulation, navigation and recreation are centered on rivers. Hence considerable interest has been evinced in the society about various aspects of rivers such as their formation, hydraulics and sediment transport, erosion and sedimentation, and effect of natural and human interferences on rivers (Garde 2006). River processes are largely controlled by the topography of the drainage basin. A river tends to shift towards the position of topographic minimum. Such topographic minimum occurs commonly due to subsidence or base level changes.

River channels exhibit a remarkable similarity, regardless of size. There is a neat progression of shapes and dimensions from the smallest rill to the biggest rivers like Mississippi or the Amazon. There are, of course, differences among rivers in various climates and geological settings, but such differences seem overshadowed by similarities (Leopold 1994).

The term fluvial morphology or river morphology can be defined as a science dealing with forms as those produced by river action. Fluvial morphology deals with streams and stream systems as produced by the action of flowing water.

Rivers are dynamic landscape elements whose primary functions are to drain the landscape and transport sediment. Morpho-dynamics is the study of the evolution of landscapes and seascapes in response to the erosion and deposition of sediment (Vuren 2005). River morpho-dynamics is the study of river forms in response of erosion and sedimentation. The understanding of river morpho-dynamics is functional to the correct management and prediction of important erosion and sedimentation processes involved in river activities, such as bank erosion, overflows, sediment balance in dam regulation, sediment wave propagation, interactions with anthropic structures (bridges, weirs), silting up of reservoirs, renaturalization, sediment mining, degradation/aggradation, planform changes, regulation of equilibrium, setting of slope and hydraulic geometry, renaturalization issues (Vuren 2005).

Rivers in nature display a variety of forms, from meandering to braiding, as a result of feedback processes among water flow, sediment transport, and vegetation. Many of these phenomena are relatively poorly understood, requiring the integration of mathematical, experimental and field techniques. The interaction of human activities with the environment can severely modify these processes often resulting in undesired and unexpected consequences at a variety of spatial and temporal scales. This leads to safety problems, environmental hazards, as well as to environmental degradation, with huge resources and economic losses for the whole society. The study of river morpho-dynamics is therefore crucial to understand how these feedback processes operate in order to support decision-making at multiple levels that can promote economically effective and environmentally friendly river basin and land management

The morphology of river channel is governed by the significant driving forces such as tectonic processes, climate and local lithology that influence the river system over a range of timescales (Schumm, 2005). .

In morphological studies, it is necessary to consider the different types of rivers. Only after sufficiently studying the different types of rivers it is only logical to classify a river. Depending upon the perspective of the investigator, a classification of rivers will depend upon the variable of most significance. For example, the classic braided, meandering and straight tripart division of rivers (Leopold and Wolman, 1957) is based upon pattern with boundaries among the three patterns based upon discharge and gradient. Brice (1982, 1983) added an anabranched or anastomosing channel pattern to the triad and distinguished between two types of meandering channels. The passive equiwidth meandering channel is very stable as compared to the wide-bend point-bar meandering channel. This is a very important practical distinction between active and passive meandering channels (Thorne 1997). A highly sinuous equiwidth channel gives the impression of great activity whereas, in fact, it can be relatively stable. Brice (1982) also indicates how width, gradient, and sinuosity, as well as type of sediment load and bank stability varies with pattern

As there are no surface bodies for intensive agriculture in the study area, farmers choose the areas adjacent to the main river channel. In addition, the area is composed of loose and friable sedimentary formations with high topographic relief which are prone to high erosion added by torrential rains during monsoon period. Hence, it is necessary to understand the dynamics of the river in order to identify sites which are prone to erosion and deposition.

Understanding the morpho-dynamics of river Tlawng will help in designing successful schemes against flooding, bank erosion, channel instability and effects of anthropogenic and environmental changes without having much undesirable effects. For the present study river Tlawng has been divided into upper, middle and lower course where detailed morphological studies like channel geometry, hydraulic properties and channel fluid dynamics have been conducted. Hypsometric analysis of River Tlawng basin and its sub basin was also carried out to know the stage of the river and erosional intensity of the basin.

It has long been recognized that water transport is comparatively much cheaper than road or rail transport. Making the river navigable year around involves construction of dams, locks, channel widening, channel straightening and channel contraction using spurs or jetties and bank stabilization. It may also involve dredging and releasing additional water during low flows. These changes affect the stability of the river and hence executions of such changes need consideration from hydraulic and morphologic points of view.

1.2 Location and extent

The river Tlawng is the longest river in Mizoram which measures about 320 km (Up to its confluence with Barak river in Katakhal). The river runs for a length of about 234 kilometres in Mizoram. It originates from Zopui hill (22°51´N-92°48´E), at about 8 kilometres east of Lunglei town at an elevation of about 4576ft (1395 metres). Its elevation is about 63ft (17metres) in Katakhal (24°49´N-92°38´E), where it joins the Barak river. The areal extent of Tlawng river basin is about 5846 km^2. It passes through five districts of the state namely (Lunglei, Aizawl, Serchhip, Mamit and Kolasib).During the course of its run, several tributaries joins laterally. It flows in northern direction just opposite to the De river on the west and the Mat river on the east. After flowing for about 50 km, it enters Aizawl district near Khawlek village (23°21´N 92°43´E) (Pachuau 2003). The river Tut is the main tributary to the river Tlawng. The river Teirei flows in parallel with the river Tlawng for about 40 km respectively before joining the main river Tlawng (Pachuau 1994). After the confluence with tributaries Tut and Teirei from western bank, it merges with Barak valley in Cachar district of Assam where it is known as river Dhaleswari and river Katakhal. Chhangte , Serlui A ,Tuithum, Kurung and Dur are important tributaries of river Tlawng in Aizawl district. The river is navigable (in some reaches) by small boat up to Sairang. It is regarded as one of the most important channels of water transport in Mizoram. It is also the main source of water supply for Aizawl city.

The Tlawng river basin is characterized by undulating hill ranges with steep slopes in the upper course and moderate to low slope in the lower course. The Tlawng river basin is characterized by tropical humid climate with heavy monsoon rainfall. The average annual rainfall in the study area is about 2449.6 mm. Soils are generally of sedimentary nature which is sandy, immature and high in acidity (Pachuau 2003). The average annual temperature is around 21℃.

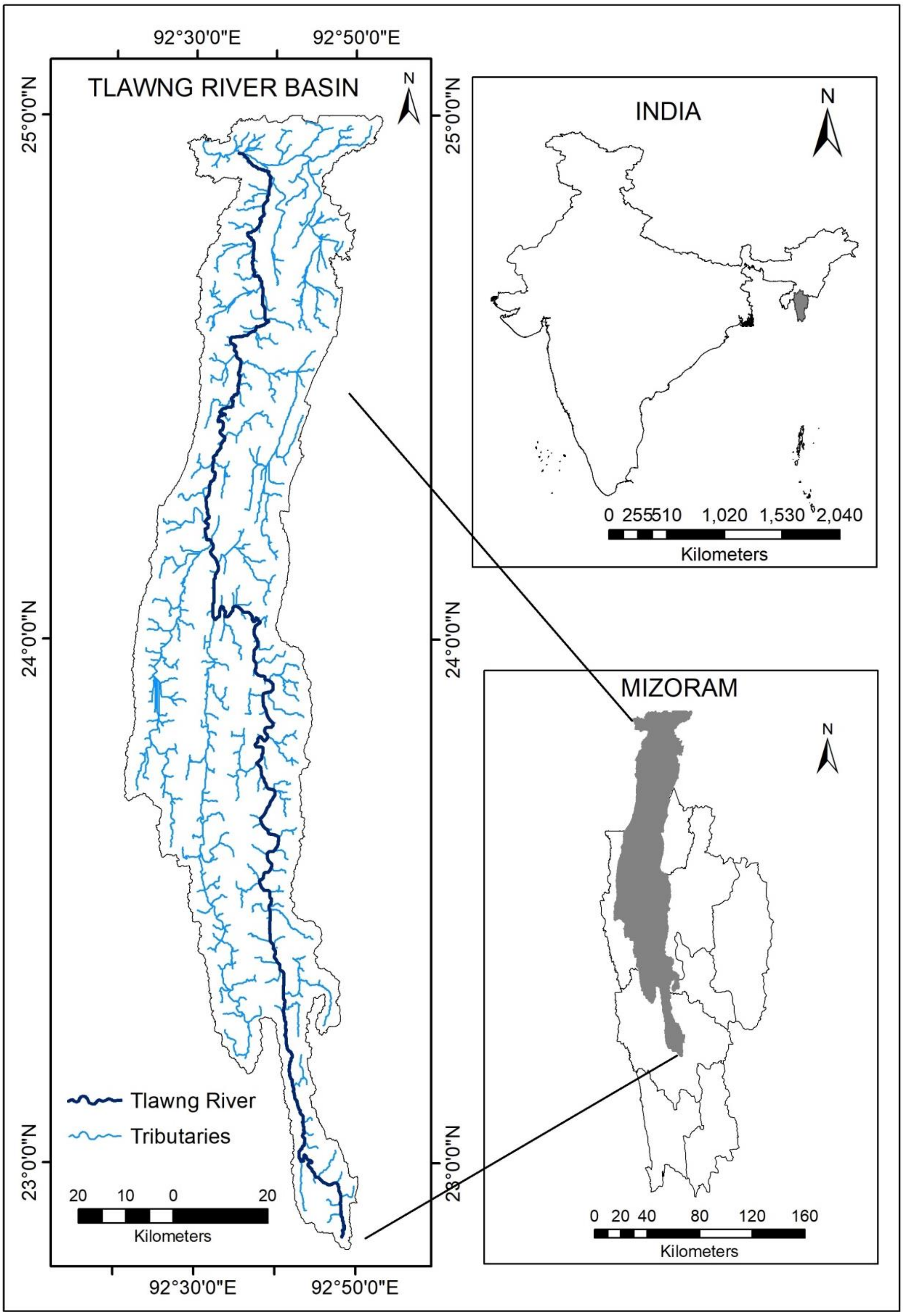

Fig 1.1: Location map of the study area

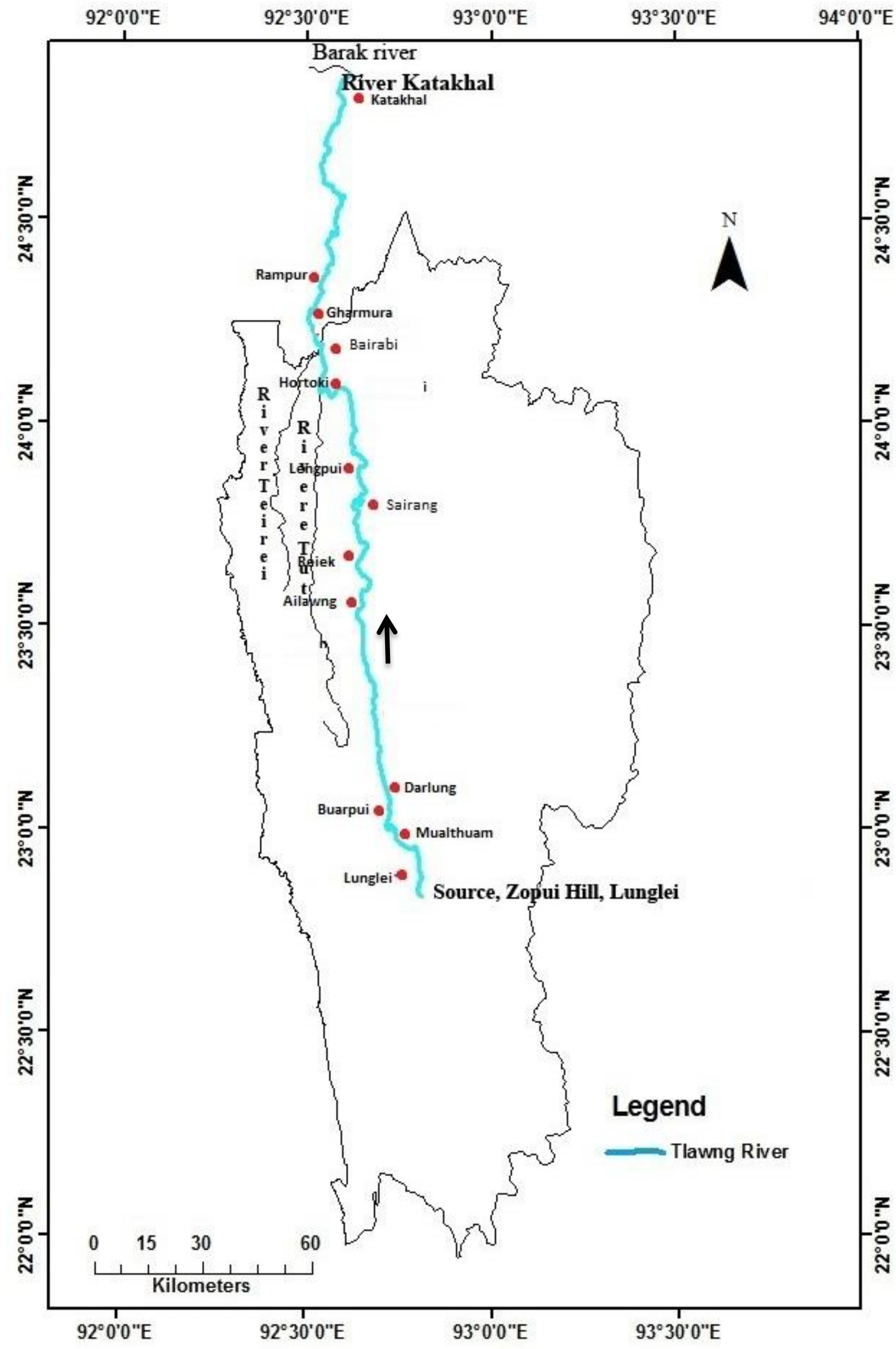

Fig 1.2: Location map of the study area

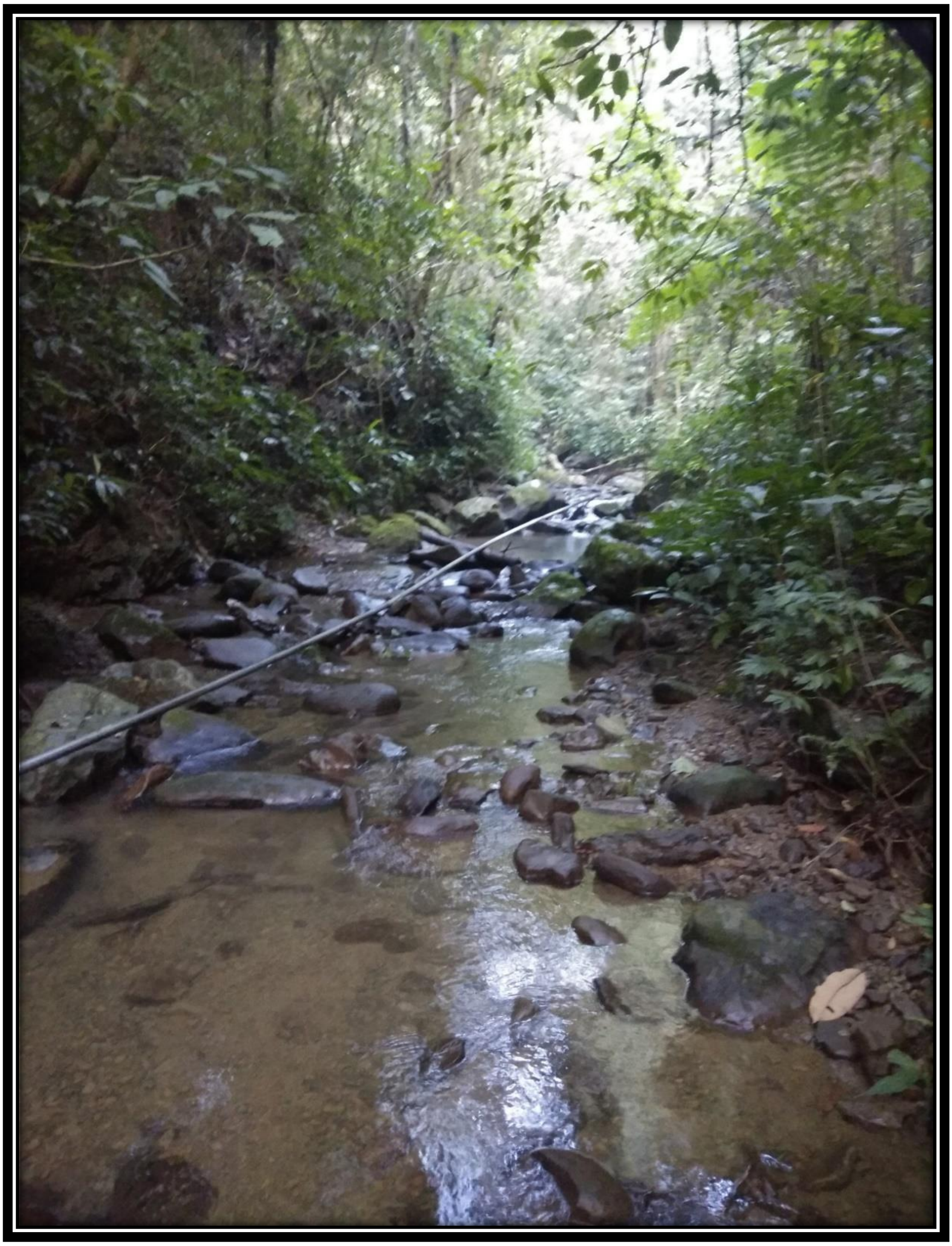

Plate 1.1: Source of Tlawng river at Zopui hill at about 1395 m above MSL in Lunglei district.

1.3 Scope of the study

Rivers and their valleys have been attracting human activity since the early times. In order to understand the morpho-dynamics of a river Tlawng the river has been divided into upper, middle and lower course and from each river course the following fluvio-geomorphic characteristics like channel geometry or channel cross-sectional characteristics (channel length, channel width, channel depth, , channel bends or meandering), channel fluid dynamics (discharge, velocity, roughness, channel gradient), hydraulic properties, channel types, channel bed topography or channel bed configuration, channel pattern, stage of river (youth, mature, old) are studied. Morphometric and drainage parameters such as bifurcation ratio, Rho coefficient, drainage density, stream frequency, stream length, mean steam length, drainage texture, relief aspects and sinuosity index have been studied. Hypsometric analysis has been carried out to understand the stage and erosional status of Tlawng river basin.

Furthermore, the fluvial system is a physical system, it follows an evolutionary development, and it changes through time. Therefore, there are a great variety of rivers in space, and they change through time in response to upstream and downstream controls.

Continuous mining of sand and gravel from the river bed to meet the ever increasing demand of the construction industry might degrade the river downstream creating many problems in the reach. When sediment is reduced, the channels actively incised and the channel morphology is changed.

Burning off their agricultural lands in the catchment areas by the farmers increases the rate of surface runoff during rainy season. This results in large scale erosion and eventually led to an increase in sediment load of the river which can cause flooding, drainage pattern alteration, water quality change and navigation difficulties. As no significant study has so far been carried out in Mizoram, a detailed morphological analysis of Tlawng river has been carried out to understand the morpho-dynamics of the river.

1.4 Research Questions

i) How river morphology affects morpho-dynamics of Tlawng River.

ii) What is the influence of rainfall on the changes of river morphology.

iii) How erosion affects the channel morphology.

iv) Is channel erosion proportional to river discharge.

v) What is the effect of degree of slope on the morpho-dynamics of the Tlawng River.

1.5 Objectives

i) To study the channel geometry and hydraulic properties of river Tlawng.

ii) To study the channel pattern of river Tlawng.

iii) To examine the influence of seasonal variation of weather conditions on the dynamics of the river.

1.6 Design of the study

Chapter - 1 deals with the introductory aspect of the study such as importance of the study, location extent, scope and objectives of the study.

Chapter - 2 explains the physical set up of the area like geology, topography, climate, temperature, rainfall, slope, aspect and drainage.

Chapter – 3 describes the different materials and methods used in the study.

Chapter – 4 is concerned with different studies of literatures which have been reviewed from various international, national and regional journals and books.

Chapter – 5 elucidates the different parameters necessary for morphological analysis of River Tlawng.

Chapter – 6 enlightens the different drainage properties such as linear and textural analysis. It also presents a hypsometric analysis of the Tlawng river basin.

Chapter – 7 provides a brief summary and conclusion of the research work.

Bibliography is presented at the end of the thesis.

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CHAPTER II

PHYSICAL SETTINGS

2.1 Geology

Mizoram is geologically considered as a part of Tripura-Mizoram depositional basin (Evans 1964). It is referred to as the southern extension of the Surma basin. It evolved after the regional uplift of Barail succession and thus, was related with the plate behavior of subduction zone west of Arakan-Yoma, after the spreading of Indian Ocean (Evans 1964). The sedimentary succession of Mizoram considerably differs from that of the typical Surma valley in their lithology, mineralogy, primary -sedimentary structures and degree of compaction (Sarkar and Nandy 1976). The entire sedimentary column of the area is a repetitive succession of arenaceous and argillaceous rocks of Paleogene and Neogene ages. It comprises mainly of sandstone, silty-sandstone, siltstone, shale, mudstone ant their admixture of varying proportions along with a few shell-limestone, calcareous sand stone and intraformational conglomerates. The rocks are thrown into a series of approximately N-S trending, longitudinally plunging anticlines and synclines (Ganju 1975 and Ganguly 1983). The general strike direction of the rock formation is N-S with dip amount varying from 20º-50º either towards east or west. The rocks of Mizoram as a whole comprises of Tertiary rocks of Oligocene to Pliocene age and the rock structures are complexly folded, faulted and uplifted. The Tertiary rocks of Mizoram have been grouped sequentially into the Barail, the Surma and the Tipam Group in the ascending order. Surma group has been sub divided into Bhuban and Bokabil formations. Bhuban formation is further sub divided into lower, middle and upper Bhuban units. The stratigraphic succession of the state and lithological of each litho unit is worked out by Karunakaran (1974) and Ganju (1975). The rocks of the study area fall under Bokabil, Tipam and Bhuban.

The rocks of Mizoram are the continuation of rocks forming Patkai range and Cachar hills. Marine fossils of tertiary age have been found near Lunglei which were embedded in nodular dark grey sandstone (Pachuau 1994). The rocks of the Surma group are mostly found in the eastern part of the state while rocks of Barail group are found in the eastern part of the state. In the north eastern corner along the border areas of Myanmar, rocks are aligned in a north south linear trend and represent a sub parallel mountain ranges and valley type of topography. This can be attributed to the alteration of hardcore and soft shale beds, which are grouped under the Barail group (Pachuau 1994). Lithology of Tlawng river basin is mainly composed of sandstone, clayey sand, gravel, siltstone and shale (Fig 2.1). Sandstone and siltstone covers majority of the area of the river basin.

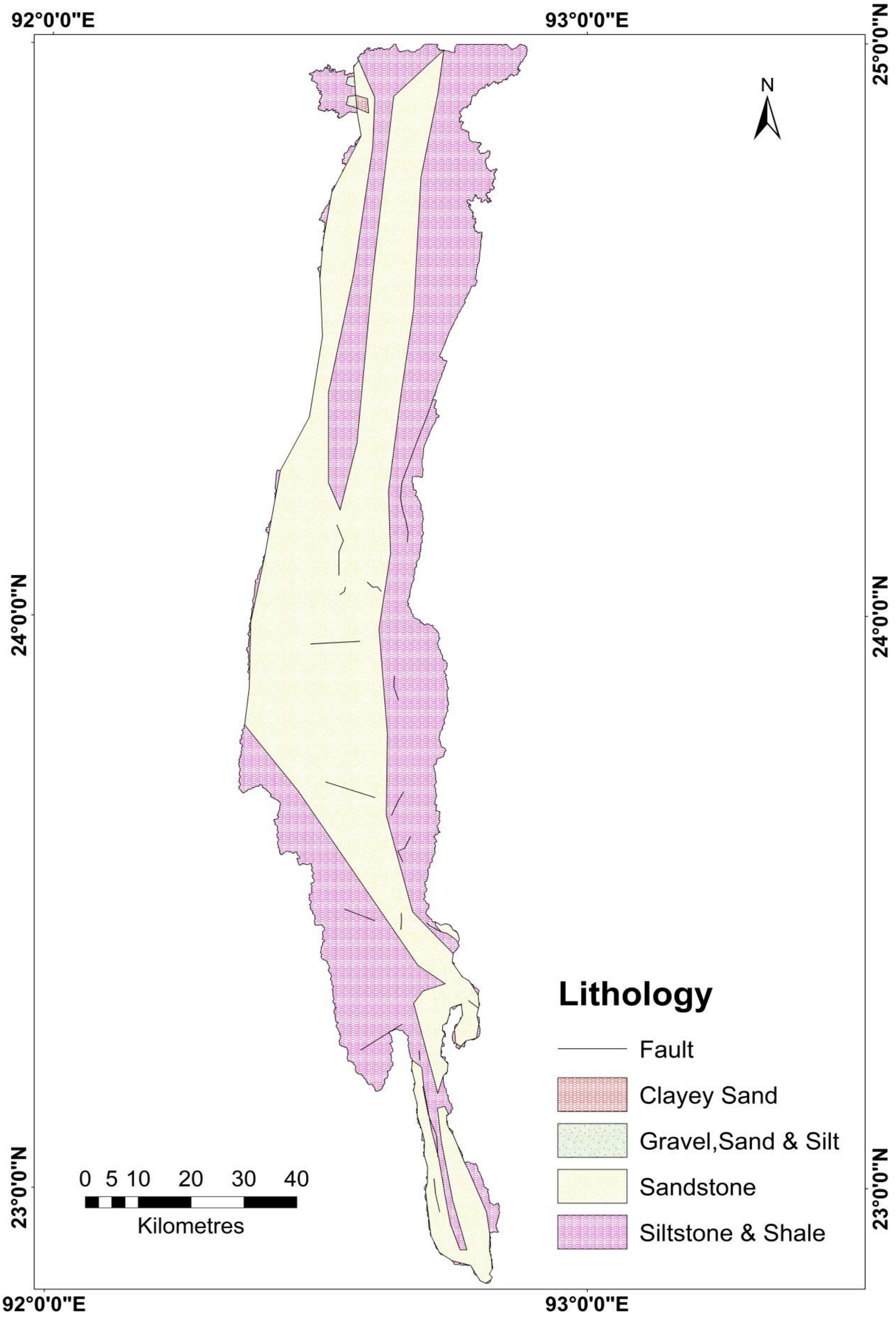

Fig 2.1: Lithology Map of Tlawng river Basin (Source: Geological Survey of India)

2.2 Topography

Mizoram is chracterised by rugged mountains of Tertiary formations. The mountain ranges are inclined north to south direction and runs in a parallel series which are separated by narrow deep valleys. Only small patches of flat lands are found and are mostly intermontane plains. Most of the landforms observed are erosional in nature .The terrain of Mizoram is still undergoing denudation due to various exogenetic process (Pachuau 1994). The study area exhibits undulating terrain or a rugged topography. The area is occupied by steep parallel ridges and deep valleys. Most of the ridges are narrow crest and elongated. Valleys are mostly filled with rivers and are oriented north to south and east to west. The elevation ranges between 6 metres to 1598 metres. The mean elevation is 802 metres above mean sea level. There is a great change of relief from the South towards the northern part of the study area. In general the western parts are higher than the eastern parts. Low hillocks are found in the southern part.

The geomorphic features in the Tlawng river basin are formed mainly by denudation, fluvial and structural process (Fig 2.2). Denudation landforms include highly dissected hills and valleys, pediment and pediplain complex and are mostly located in the northern part of the basin (lower course of the river). Active flood plains, older flood plains and piedmont alluvial plains in the study area are formed by fluvial process. High, low and moderate dissected hills and valleys of structural origin occupies majority of the Tlawng river basin. Structural hills, ridges, escarpments, structural valleys are other geomorphic features identified in the area. Structural hills separated by deep narrow valleys occupy the largest area. High structural hills and valleys cover about 76% of the area. On the other hand other geomorphic features occupy about 24% of the area respectively.

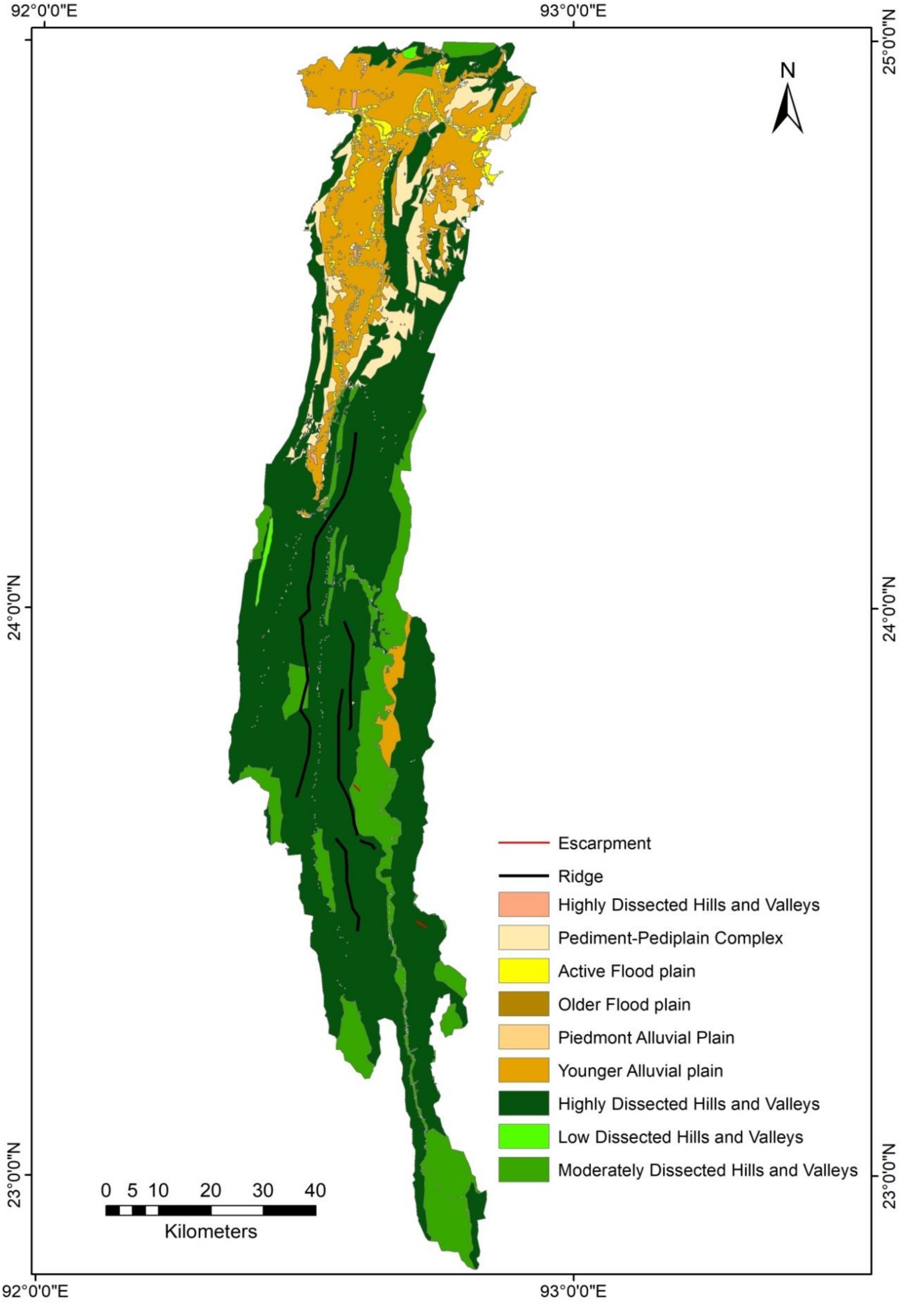

Fig 2.2: Geomorphic map of Tlawng River Basin (Source Geological Survey of India).

2.3 Slope of the Study Area

The Tlawng river basin has been divided into four categories on the basis of degree slope (Fig 2.3). Slope map highlights the regions with high potential runoff with high erosion rate; these potentials decreases from high slope degree to lower slope degree. The area shows irregular distribution of slope in the southern part. The northern part has a more even distribution of slope. The drainage system of the study area is mainly controlled by topography and slope. Therefore river Tlawng can be considered as a consequent stream.

Slope class-

1) **Gentle slope (0°-15°)**: It covers 57.09% of the area which is 3337.95 km^2. Half of the basin area is under gentle slope. It includes lower valleys and flood plain areas in the lower course of the river.
2) **Moderate slope (15° - 30°):** 32.27% of the area falls under moderate slope. It occupies 1889.57 km^2 of the basin. It is associated mostly with the upper structural valley portions.
3) **Steep slope (30° – 45°):** Steep slope covers 586.21 km^2 (10.2%) of the area. They comprise mainly of structural hills and ridges with steep slope.
4) **Very steep slope (> 45°):** It occupies the smallest portion 35.72 km^2 which is only 0.6% of the area. They are mostly located in the eastern part of the basin.

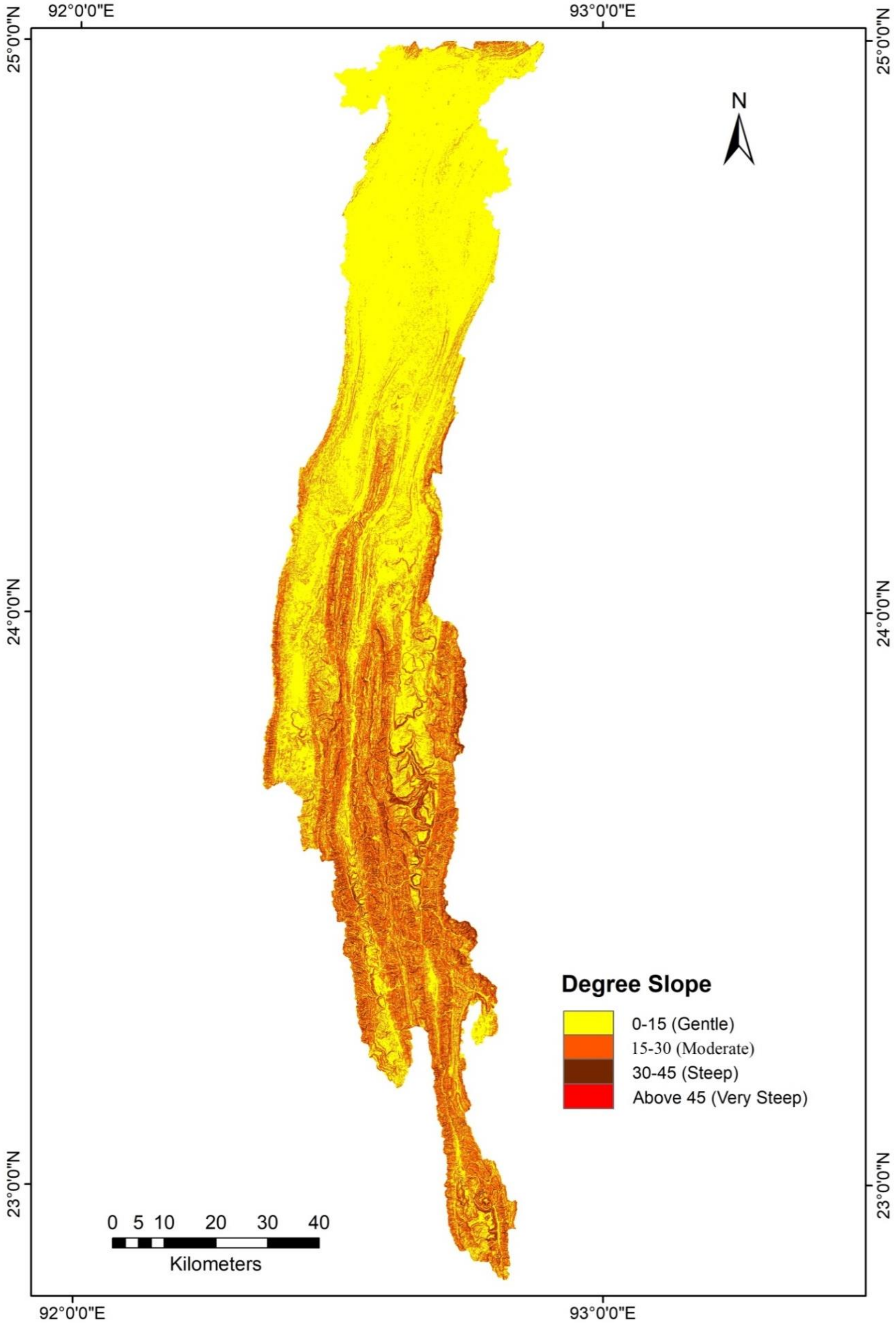

Fig 2.3: Slope map of Tlawng river basin

2.4 Slope Aspect

Aspect is the orientation of slope, measured clockwise in degrees from 0 to 360, where 0 is north-facing, 90 is east-facing, 180 is south-facing, and 270 is west-facing. Majority of the slopes are oriented towards the east and west. Next come the south, north and north-west facing slope. Only a few patches of flat land are located in the area. As sun's rays are in the west during the hottest time of the day the east facing slope, located in the western and middle part of the basin will mostly be in the shadow area of the sun. Hence evaporation will be lower and moisture rate will be much higher than the west facing slope.

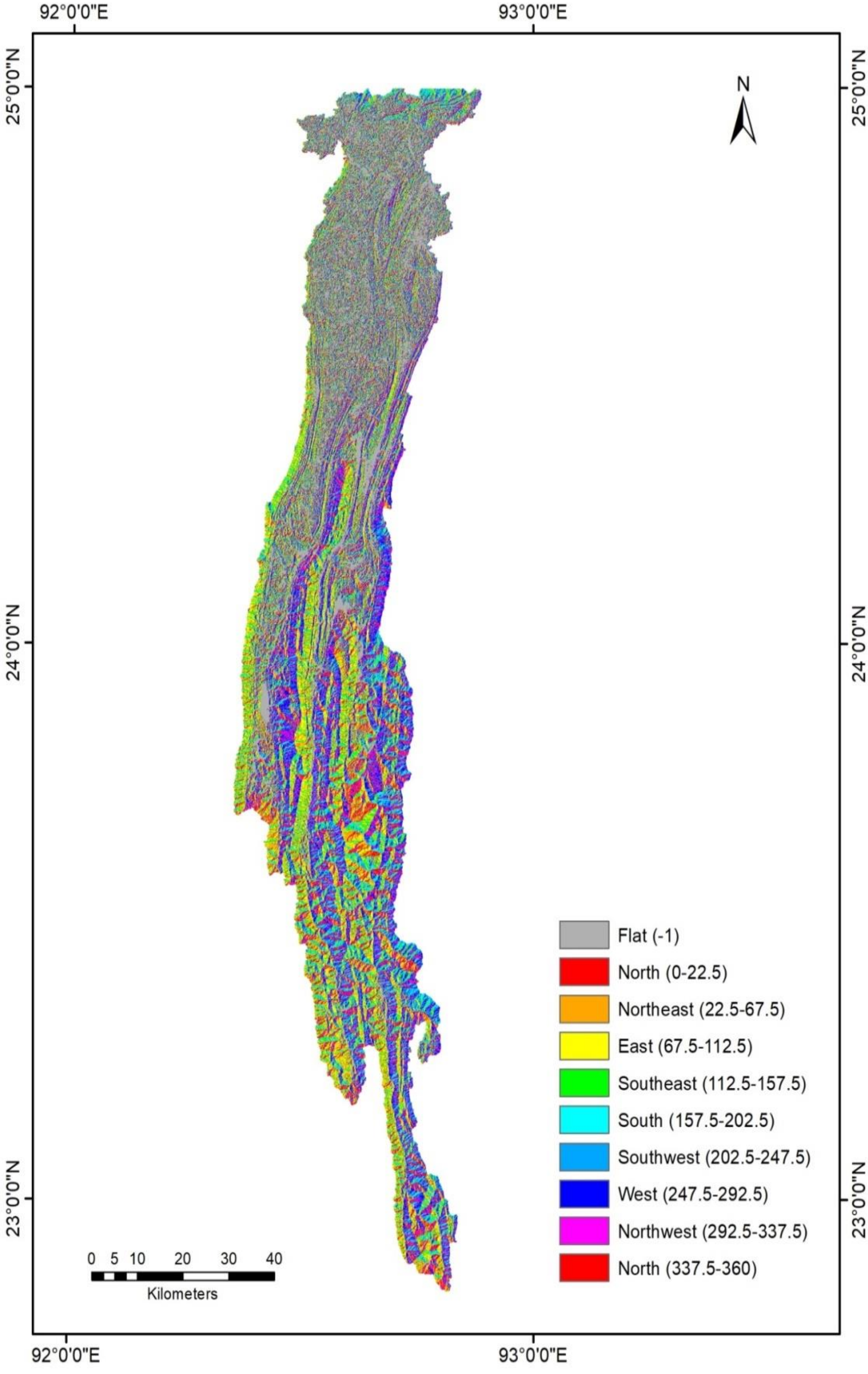

Fig 2.4: Aspect map of Tlawng river basin

2.5 Climate

Mizoram experience a moderate climate throughout the year i.e. neither too hot nor cold during the course of the year. This may be attributed to its tropical location. Mizoram can be assumed as having a tropical humid climate with a short winter and a long summer accompanied by heavy rainfall. According to Pachuau (1994) Mizoram can be broadly classified into three different types of seasons namely- 1) The Cold Season or winter starts from November and ends in February. Temperature can drop below 10℃ during this period. 2) The Warm Season or spring starting from May and merges with the Rainy Season. Temperature can rise above 30 ℃. 3) The Rainy Season or summer is the longest season in the state and last up to six months till the end of October. Greater part of the rainfall is received during this season.

Climate is the most significant factor which determines river hydrology and type. Depending upon amount of precipitation, rivers will be ephemeral, intermittent, or perennial, and, of course, as the hydraulic geometry relations indicate, the more water the larger the channel. It is assumed that hydrology is determined by upstream climatic conditions (Schumm 2006).

2.6 Temperature

Mizoram is characterized by high humidity almost throughout the year. The temperature of the study area doesn't fluctuate much throughout the year. The average annual temperature of the study area is about 22℃ and temperature starts to drop from the latter part of November. January is the coldest month in the study area with an average temperature of about 17℃. The average maximum summer temperature is 31℃ while the average minimum summer temperature stands at 18.6℃. Winters are more severe at the upper course of the study area when compared with lower course. This may be attributed to the excessive difference in elevation between the upper course (1598 m highest) and the lower course (6m lowest) of the basin.

2.7 Rainfall

Mizoram is under the direct influence of South West Monsoon. Hence, the study area receives ample amount of rainfall during monsoon seasons i.e. between

June and September. Rainfall is the single most important driving factor influencing the dynamics of a river as there are no other significant independent factors that can abruptly increase the river discharge in the study area. The average annual rainfall from 2010- 2018 is shown in Table- 2.1. The highest total annual rainfall of 2712.2 mm was recorded in the year 2017, while the lowest was recorded as 1821.2mm in the year 2014. On the other hand, the highest monthly rainfall was recorded in August in the year 2011 with 547.9 mm, which was 21.7 per cent of the total annual rainfall. The average annual rainfall of a given place in the study area is very useful for studying the relationship between rainfall and river discharge as it is considered as an important parameter in river morphological studies.

Table 2.1: Average annual rainfall (mm) of Mizoram (2010- 2018).

Sl. No.	Month	2010	2011	2012	2013	2014	2015	2016	2017	2018
1	January	0	13.7	11.5	0	0	10.2	3.4	0	6.1
2	February	3.3	2.1	17.6	1.46	21.8	6.3	26.7	5.7	20
3	March	102.5	83.4	19.2	4.7	23.9	31.5	84.3	124.4	27.8
4	April	191.3	105.3	302.3	65.6	22.7	281	161.4	289.9	114.8
5	May	356	422.3	209.7	499.3	304.3	146.3	359.9	237.3	268.4
6	June	429	439	456.7	293.1	381.7	298.2	407.6	534.1	604.4
7	July	400	372.9	264	351.9	307.8	481.9	323.3	394.2	363.4
8	August	537	547.9	401.8	519.9	297.9	444.2	371.2	441	365.4
9	September	454.7	374.2	355	476	325.6	296.2	398.8	344.7	460.9
10	October	245	165.8	195	209.2	130.9	175.4	175.6	269.1	121.4
11	November	12.5	0.4	54.8	1.3	4.4	7	70.4	13	2.7
12	December	51.2	0.1	0	0	0.2	1.5	0	58.8	6.5
TOTAL		2782.5	2527.1	2287.6	2422	1821.2	2179.7	2383	2712.2	2362
AVERAGE		231.88	210.59	190.63	201.9	165.56	181.64	198.6	226.02	196.8

2.8 Drainage System

Mizoram is drained by a number of rivers and streams having varying patterns and length. The channel pattern of the study area is influenced by factors such as lithology, tectonic, relief and slope. The area receives ample amount of monsoonal rainfall and as such many ephemeral streams flow during the monsoon season which runs through the rills and gullies and act as a tributary for a larger streams. Much of these small streams get dried up during the winter season.

Most of the large rivers have their source in the central part of the state and flows towards either north or south directed by the north-south trending ridges (Pachuau 1994). As the drainage system of the study area is mainly controlled by topography and slope trellis, parallel to sub-parallel and sub-dendritic drainage patterns are found. Due to the presence of varying resistance folded bedrock trellis and sub-dendritic drainage pattern are most common in the study area.

River Tlawng and its tributaries (Tut and Teirei) drain the northern portion of the state. Tuivawl, Tuirial, Langkaih, Tuivai flows northward and drains into river Barak in Assam. Chhimtuipui on the East along with its tributaries – Mat,Tuichawng,Tiau and Tuipui draines the Southern hills. Khawthlangtuipui with its tributaries Kawrpui, Tuichawng, Phairuang, Kau and De drain the western part of the state (Pachuau 1994).

River Tlawng being the longest river in Mizoram has many tributaries from both banks of the river. The river has sixteen tributaries (minor and major) from the western flank such as Tut and Teirei (major) and other minor tributaries from source to mouth are Khawiva lui, Selin lui, Chawm lui, Nghalvawm lui, Tuisek lui, Tuikual lui, Tuizo lui, Phun lui, Tuichhun lui, Chal lui, Reiek lui, Dialdawk lui, Lunghmul lui and Saiphai lui. The tributaries which join from the eastern side (source to mouth) are – Chite lui, Kaikuang lui, Saipui lui, Zobawh lui, Arbawh lui, Thingva lui, Tuihnial lui, Lik lui, Chhangte lui, Tuithau lui, Saipui lui, Tulsik lui, Uaithlak lui, Ser lui, Tuithum lui, Sairang lui, Dur lui, Khuai lui, Tuikaul lui, Damdia lui, Meidum lui and Vankhuma lui.

2.9 Drainage Pattern

Rivers often follow structural lows or major geo fracture systems. Melton (1959) estimated that between 25 percent and 75 percent of all continental drainage in unglaciated regions has been tectonically influenced or controlled. While Potter (1978) concluded that some large rivers have persisted in essentially their present locations for hundreds of millions of years, because they occupy major tectonic zones. Drainage patterns may reflect original slope and original structure or the successive episodes by which the surface has been modified, including uplift, depression, tilting, warping, folding, faulting, and jointing. A single drainage pattern may be the result of one or of several of these factors. Since drainage patterns are the reflection of so many factors, it is evident that they are of real significance. They form one of the most immediate approaches to an understanding of geologic structure (Zernitz 1932).

Being a consequent stream river Tlawng and its tributaries forms a trellis, parallel to sub-parallel and sub-dendritic drainage patterns (Fig: 2.5). It forms a parallel pattern with River Tut and Terei both flanking Tlawng from the western part and gradually joining it. Trellis pattern is the main pattern because of the presence of resistant folded bed rock in the area. Major tributaries from SE and NE side like Ser lui, Sairang lui, Khuai lui etc. form a sub-dendritic or pinnate pattern before joining the river.

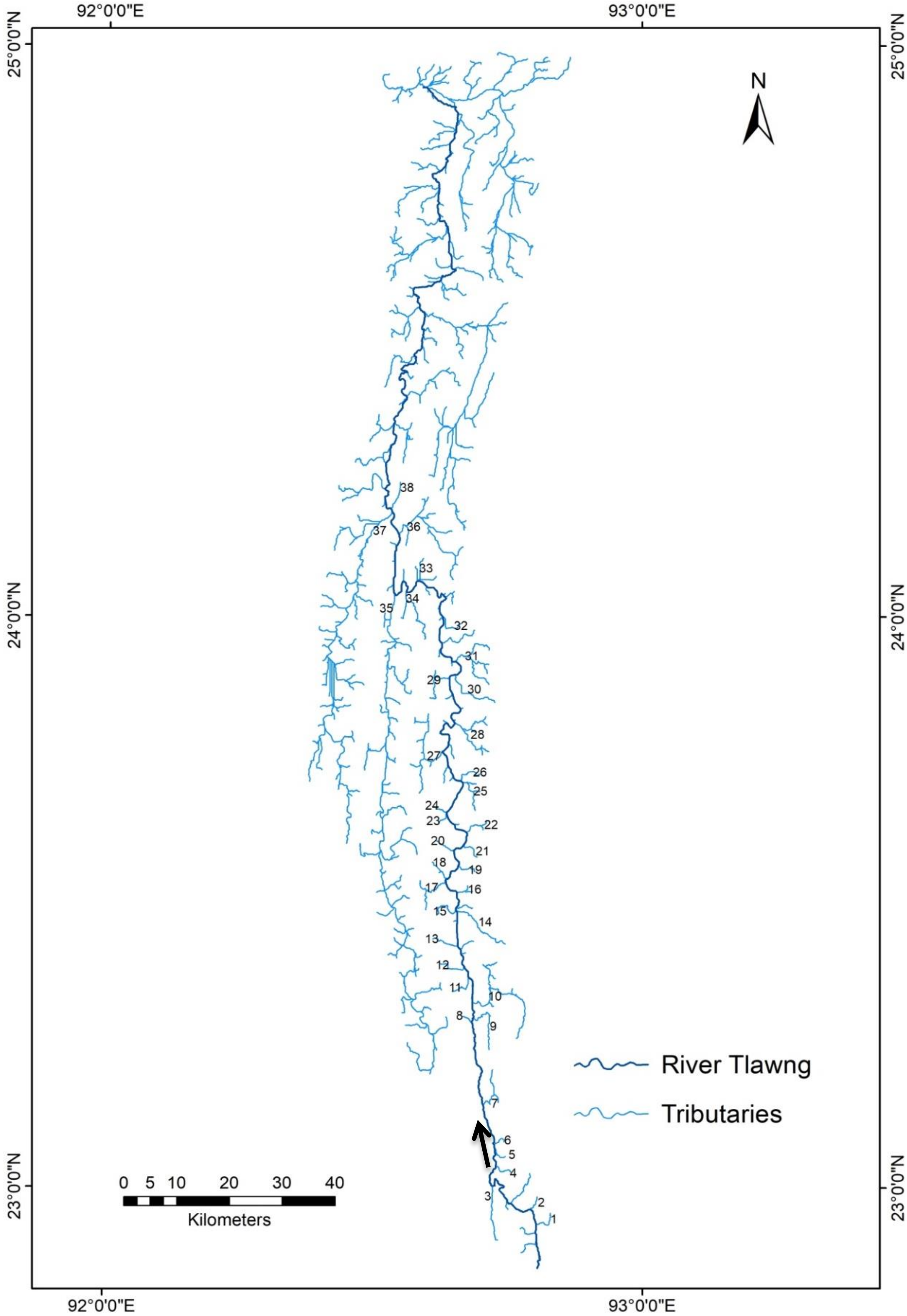

Fig 2.5: Major tributaries of Tlawng river within Mizoram (Source to Mouth).

Table 2.2: Major tributaries of Tlawng river from source to mouth.

West	East
	1. Chite lui
	2. Kaikuang lui
3. Khawiva lui	
	4. Saipui lui
	5. Zobawh lui
	6. Arbawh lui
	7. Thingva lui
8. Selin lui	
	9. Tuihnial lui
	10. Lik lui
11. Chawm lui	
12. Nghalvawm lui	
13. Tuisek lui	
	14. Chhangte lui
15. Tuikual lui	
	16. Tuithau lui
17. Tuizo lui	
18. Phun lui	
	19. Saipui lui
20. Tuichhun lui	
	21. Tulsik lui
	22. Uaithlak lui
23. Chal lui	
24. Reiek lui	
	25. Ser lui
	26. Tuithum lui
27. Dialdawk lui	

	28. Sairang lui
29. Lunghmul lui	
	30. Dur lui
	31. Khuai lui
	32. Tuikual lui
	33. Damdiai lui
34. Saiphai lui	
35. Tut lui	
	36. Medium lui
37. Teirei lui	
	38. Vankhuma lui

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CHAPTER III

METHODOLOGY

For the study primary as well as secondary data has been collected and used for fulfilling different objectives of the study. Remote Sensing and Geographical Information System techniques proved to be an effective tool for hydrological studies. Most of the analysis of the study is based on intensive field work, data collection and empirical observations in terms of- (i) pre-field (ii) field and (iii) post field methods with an application of advanced techniques of measurement and analysis.

3.1 Materials

For generating and preparing maps required for the study three types of data sets have been used.

1. Survey of India (SoI) toposheets No. 83D/11, 83D/12, 84A/9, 84A/10, 84A/11, 84 A/12 with a scale of 1:50,000.
2. Advanced Spaceborne Thermal Emission and Reflection Radiometre (ASTER) GDEM with a 30 m resolution data. (NRSC Bhuvan)
3. Landsat 8 imagery – radiometrically corrected and orthorectified using ground control point. (USGS Earth Explorer)

Monthly rainfall data, humidity and temperature (2010-2018) have been collected from State Meteorological Centre, Directorate of Science and Technology, Aizawl and Directorate of Agriculture, Aizawl.

3.2 Methods

To achieve the objectives of the study the following methods have been carried out:

1. Topographic maps and geospatial data have been pre- processed and geo rectified using advanced techniques of remote sensing and GIS and are again processed for further analyses.
2. Field survey is conducted in selected stations at the upper, middle and lower courses of the river for data collection (identifying river forms) and performing ground truth.
3. Longitudinal profile has been extracted drawn from DEM to identify knick points in order to understand the possible causes for base level change of the river.
4. The channel geometry and channel fluid dynamics is studied and analyzed based on field investigations and satellite image interpretation.
5. Channel gradient is measured from elevation data obtained from digital elevation model (NRSC Bhuvan) by using 'Rise over Run' formula and with the help of the advanced techniques of GIS.
6. Channel flow velocity is measured with the help of float method. Traditional measuring method like level staff and a tape measure is used for measuring purpose depending upon the width and depth of the river.
7. River discharge has been measured in selected stations by using Area Velocity Method,

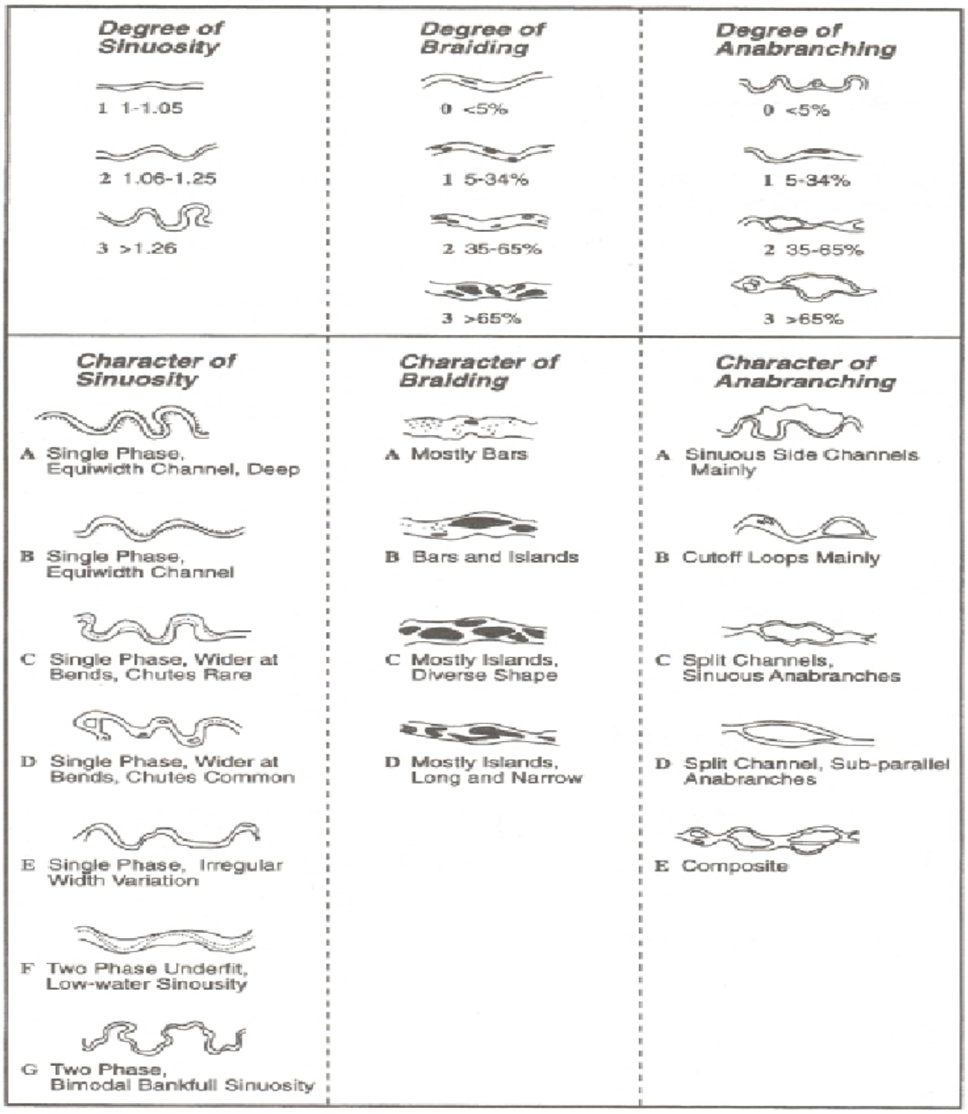
   $Q = w \times d \times v$

where,

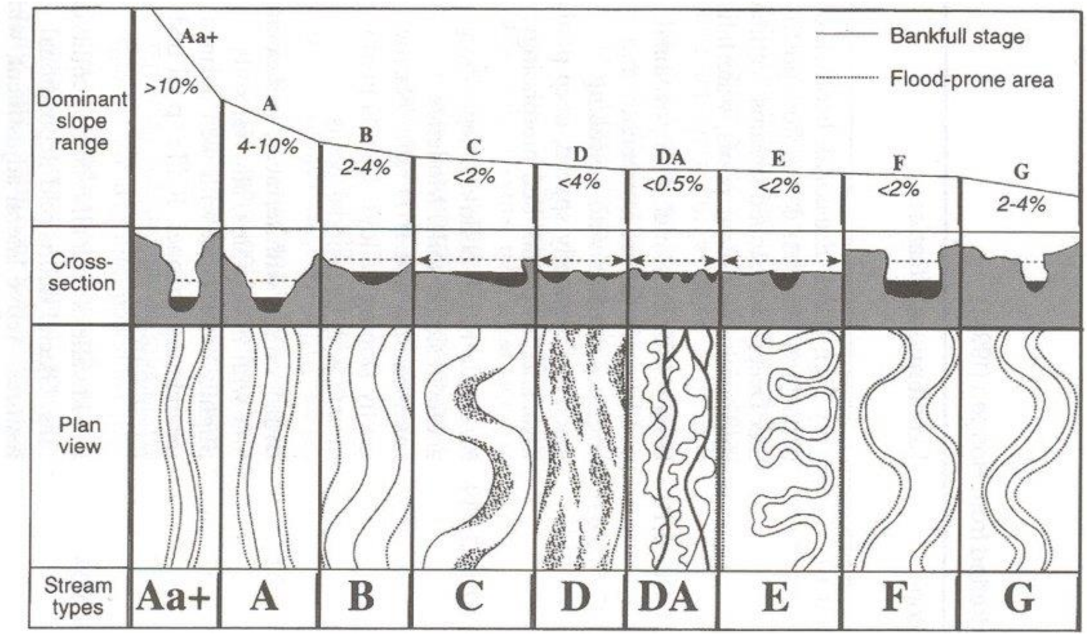
Area (a) = w x d (average)
Q = discharge
w = width
d = depth
v = velocity

8. Channel classification is made from upstream to downstream (Rosgen 1994 & Brice 1975). Channel sinuosity index is measured by using formula proposed by Mueller (1968).

Brice (1975)



Rosgen (1994)

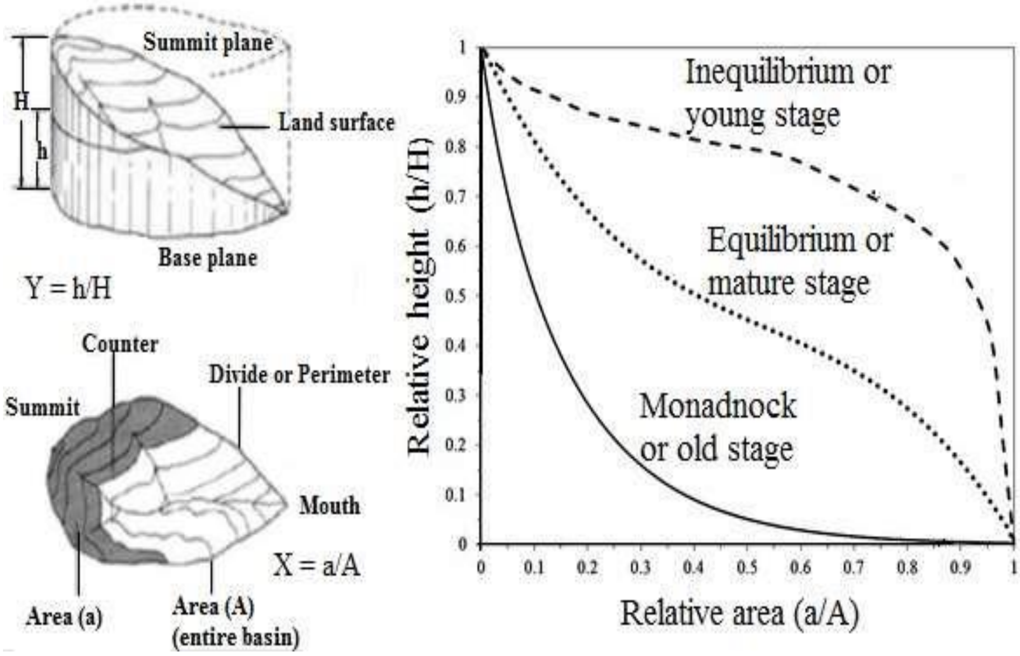


9. Hypsometric analysis has been carried out using Strahler (1952) method to know the stages of the river at different courses.

   For generating these curves the following ratios are used. The curve is created by plotting the proportion of total basin height (h/H = relative height) against the proportion of total basin area (a/A = relative area). The total height (H) is the relief within the basin (the maximum elevation minus the minimum elevation).The total surface area of the basin (A) is the sum of the areas between each pair of adjacent contour lines. The area (a) is the surface area within the basin above a given line of elevation (/z).The value of relative area {a/A) always varies from 1.0 at the lowest point in the basin (where h/H - 0.0) to 0.0 at the highest point in the basin (where h/H - 1.0) (Keller et.al 2002).

   (a) Relative height or h/H; where 'h' is the highest elevation between each pair of contours above the base and 'H' is the total basin height, represented on the ordinate and

   (b) Relative area or a/A; where 'a' is the area enclosed by a pair of contours and 'A ' is the total basin area which is represented on the abscissa.



Hypsometric Integral-

$$H_i = \frac{\text{mean elevation - minimum elevation}}{\text{maximum elevation - minimum elevation}}$$

10. Seasonal variations in weather conditions and its influence on the river morphology have been studied by analyzing rainfall and river discharge during lean and rainy seasons.
11. The watershed boundary, sub-watersheds boundaries and stream networks were delineated and digitized using Arc Map.
12. Slope map, relief, aspect map have been generated and prepared from DEM using spatial analysis tool in Arc Map.
13. The river and channel networks have been digitized from SoI topographical maps and updated with satellite imagery using ArcMap. ASTER DEM data is used to extract river profiles in GIS platform.
14. Geological map of the study area has been prepared based on the data collected from Geological Survey of India.

15. Landsat imagery, Survey of India topographical map, DEM and ground truth verification have been used to extract and prepare geomorphic map of Tlawng river basin.
16. River landforms have been identified and investigated using satellite imagery and extensive field work.
17. Statistical Package for Social Sciences (SPSS) has been used to analyse different hydraulic parameters.
18. Linear, relief and textural drainage properties such as stream ordering, stream number, stream length, mean stream length, stream length ratio, Rho coefficient, bi-furcation ratio, drainage density, stream frequency, drainage texture, etc. is studied to understand the terrain characteristics.

Sl.no	Drainage properties	Formula	Reference
1.	Stream order	Heirarchial rank	Strahler (1964)
2.	Stream length (Lu)	Length of the stream	Horton (1945)
3.	Mean stream length (Lsm)	Lsm = Lu/ Nu	Strahler (1964)
4.	Stream length ratio (Rl)	Rl = Lu/ Lu -1	Horton (1945)
5.	Bifurcation ratio (Rb)	Rb = Nu/ Nu + 1	Schumm (1956)
6.	Mean bifurcation ratio (Rbm)	Rbm = Average of Rb ratios of all orders	Strahler(1957)
7.	Rho coefficient (ρ)	ρ = Rl/ Rb	Horton (1945)
8.	Drainage density (Dd)	Dd = Lu/ A	Horton (1932)
9.	Stream frequency (Fs)	Fs = Nu/ A	Horton (1945)
10.	Drainage texture (Rt)	Rt = Dd x Fs	Smith (1950)
11.	Relief Ratio (Rh)	Rh = H/Lb	Schumm(1956)
12.	Relative Relief(Rhp)	Rhp = (H *100)/ P	Melton(1957)
13	Ruggedness number(Rn)	Rn = Dd*(H/1000)	Patton & Baker (1976)
14.	Channel sinuosity (S)	S = Sl/ Vl	Muller (1968)

Table 3.1: Formulae for calculation of drainage properties.

where,

Nu = Total number of streams of order 'u'
Lu = Total stream length of order 'u'
Nu+1 = Number of stream segments of the next higher order
Lu-1 = Total stream length of its next lower order
Cl = Channel length
Vl= Valley length P = Perimetre of Basin in metres

CHAPTER IV

REVIEW OF LITERATURE

According to Strahler (1952) the percentage hypsometric curve (area-altitude curve) relates horizontal cross-sectional area of a drainage basin to relative elevation above basin mouth. By use of dimensionless parameters, curves can be described and compared irrespective of true scale. Stages of youth, maturity, and old age in regions of homogeneous rock give a distinctive series of hypsometric forms, but mature and old stages give identical curves unless monadnock masses are present.

(Archana *et al*., 2012) have conducted a study which aimed at quantifying the actual bank erosion/deposition along the Brahmaputra River within India for a period of eighteen years (1990-2000) using an integrated approach of Remote Sensing and Geographical Information Sys- tem (GIS). The channel configuration of the Brahmaputra River has been mapped for the years 1990 and 2008 using IRS 1A LISS-I, and IRS-P6 LISS-III satellite imagery respectively. The analysis of satellite data has provided not only the information on the channel configuration of the river system on repetitive basis but also has brought out several significant facts about the changes in river morphology, stable and unstable reaches of the river banks and changes in the main channel. The results provide latest and reliable information on the dynamic fluvio-geomorphology of the Brahmaputra River for designing and implementation of drainage development programmes and erosion control schemes in the north eastern region of the country.

Arulbalaji and Gurugnanam (2017) studied the morphometric parameters of Sarabanga watershed using SRTM 30 metres resolution. Both Strahler’s and Horton’s method were used by them to study drainage parameters. They identified that the river is having a dendritic pattern which indicates that lithology and gentle slope is controlling the study area. The basin relief expressed that the watershed has relatively high denudation rates. Their overall study will be very useful to plan watershed management.

(Babu *et al*., 2012) conducted a study of Hypsometry and Geomorphic Development of a Watershed: A Case Study from South India. They estimate the hypsometric integral values of the Chalakudy river basin located in Kerala state of south India where they identify two stages of erosional cycle development namely youthful to mature stage. They found that development of stream segment is effected by slope and local relief and these factors produce differences in values of drainage density among the sub basins. The morphometric parameters such as drainage density and constant channel maintenance were also computed and relative extent of erosion in different sub basins is estimated. The estimation of erosion status of sub basins helps in the water shed prioritization for taking up soil and water conservation measures in watershed systems.

Crosby and Whipple (2006) conducted a study on knick point initiation and distribution within fluvial networks: 236 waterfalls in the Waipaoa River, North Island, New Zealand using observations from field work, aerial photo analysis and a digital elevation model (DEM). In order to determine how a pulse of incision distributes itself throughout a fluvial network, they develop two simple, end-member models and compare their behavior to the observed knick point distribution in the Waipaoa. In the first model, they propose that a knick point initiated at the basin outlet retreats upstream and distributes the signal throughout the network at a rate that is a power law function of drainage area. In the second model, they propose that knick points form near a threshold drainage area, below which channels cannot incise with the same efficiency as possible in downstream reaches

(Farhan *et al*., 2016) assess the regional pattern of hypsometric curves (HCs) and hypsometric integrals (HIs) for the watersheds draining into the Jordan Rift (River Jordan, the Dead Sea, and Wadi Araba watersheds). The highest hypsometric values are found for the Dead Sea (x = 0.87) and River Jordan (x = 0.77) watersheds. Whereas the lowest values (x = 0.51) characterized Wadi Araba catchments, except Wadi Nukhaileh (lower Wadi Araba) which yields an HI value of 0.26. They identified that seventeen HCs pertained to the River Jordan and the Dead Sea watersheds evince remarkably upward convex shapes indicating that such drainage basins are less eroded, and at the youth-stage of the geomorphic cycle of erosion.

(Iqbal *et al*., 2013) uses Geographic Information System to carry out Morphometric Analysis of Shaliganga Sub Catchment, Kashmir Valley, India. Various linear parameters (Stream order, Stream number, Stream length, stream length ratio, Bifurcation ratio, Drainage density, Texture ratio, Stream frequency) and shape factors (Compactness coefficient, Circularity ratio, Elongation ratio, Form factor) of the Sub catchment were computed at watershed level. Their study demonstrates the usefulness of GIS for morphometric analysis and prioritization of the watersheds of Shaliganga Sub catchment. Quantitative analysis of morphometric parameters is found to be of immense utility in river basin evaluation, watershed prioritization for soil and water conservation, and natural resources management at micro level.

According to Leopold (1954) measurements of parameters such as the discharge, suspended load, bed material, velocity of flow, channel slope, and channel shape indicate that many river channels are characterized by an orderly, progressive change of these variables from their headwaters to their mouths. The interaction of the variables and the establishment of a stable channel suggest that the morphology of the stream is controlled by a kind of equilibrium.

Fuzal and Rao (2016) performed a hypsometric analysis of Tuirini drainage basin to differentiate between erosional landforms at different stages during their evolution. They divided the area into 22 sub basins. They identified that the hypsometric curve of the whole Tuirini basin reflects the mature geomorphic terrain whereas hypsometric integral indicates that the drainage basin has already eroded 58 per cent of land masses. The overall hypsometric results suggest that the sub-basins are in the mature stages of geologic development with moderately eroded landscapes and the entire basin is progressively approaching towards the monadnock phase of erosion.

(Ghosh *et al*., 2012) in their study of Hydro geomorphic Significance of Sinuosity Index in relation to River Instability of Damodar river, West Bengal uses satellite images and Geographic Information System to measure temporal pattern (1943 – 2006) of river plan-form with the help of Mueller's Sinuosity Indexes to unfold the magnitude of river instability, contributing factors of sinuosity and the chances of flood with a probability of changing course.

According to Hack (1960) fluvial or river morphology deals with streams and stream systems as produced by the action of flowing water. The features produced on the land surface by flowing water can be aptly called fluvial landscapes. As the erosion cycle precedes the morphology of streams also changes and the streams pass through the three stages of development as the earth’s surface namely youth, maturity and old age. Although the stage reached by the stream usually corresponds to that of the surrounding topography, this is not necessarily the case. Usually the stream is less youthful in character near its mouth than in the vicinity of its head waters.

Krishnanu (2015) performed a sinuosity analysis in the fifteen sub watersheds of Bharathapuzha river basin by measuring the sinuosity parameters such as channel length, valley length and air length from the toposheets using ArcGIS. Hydraulic sinuosity index (HSI), topographic sinuosity index (TSI) have been used in understanding the topographical and hydrologic characteristics of the sub watersheds. Based on this river channel has been classified into straight, sinuous, meandering and braided depending on the SSI.

According to Mueller (1968) Stream sinuosity indexes are usually derived by dividing the length of a reach as measured along a channel by the length of a reach as measured along a valley. This method restricts stream sinuosity to those rivers which have down cut sufficiently to allow the formation of a floodplain. Therefore, all stream-occupied valleys in the youthful stage of erosion cannot provide a sinuosity value greater than unity, for during youth the valley and channel are coincident.

(Han *et al.*, 2019) studied the impact of the channel geometry on water quantity and quality simulation of the soil and Water Assessment Tool(SWAT) for the Andong Dam watershed. SWAT was modified to consider the various channel cross-sectional shapes. The results of this study suggest that the channel geometry information for the water quantity and quality estimation should be carefully applied, which could improve the model performance regarding stream flow and water quality simulations.

(Gabale *et al*., 2015) studied the morphometric characteristics of AmbilOdha (rivulet) watershed which is a part of Mutha river basin in Pune. Digital Elevation Model (DEM) of the area and Geographical Information System (GIS) were used for the assessment of the linear, areal and relief aspects of morphometric parameters. Such studies can be used for the future planning and management of drainage basin.

Graf (1983) conducted a study on downstream changes in stream power in the Henry Mountains, Utah where he examined that total stream power does not necessarily increase systematically in the downstream direction because of the conflicting influences of channel slope, width, and depth. Comparison of historical and modern conditions shows that mutual adjustment is unlikely to occur in the discontinuous operation of semi-arid fluvial systems.

Hooke (1986), in his study mentioned four practical problems associated with river channel processes and the human use of rivers. He outlined the following four topics on which geomorphologists can provide valuable information: (i) the assessment of the effects of floods, (ii) analysis of the processes and distribution of bank erosion, (iii) identification of the locations and characteristics of channel instability, and (iv) prediction of the effects of human interference with the river system.

(Keller *et al*., 2002) defined that the hypsometric curve describes the distribution of elevations across an area of land, ranging in scale from one drainage basin to the entire planet. According to him a useful attribute of the hypsometric curve is that drainage basins of different sizes can be compared with each other because area and elevation are plotted as functions of total area and total elevation and a simple way to characterize the shape of the hypsometric curve for a given drainage basin is to calculate its hypsometric integral (Hi). The relationship between the hypsometric integral and degree of dissection permits its use as an indicator of a landscape's stage in the Cycle of Erosion.

(Khadri *et al*., 2103) in their study of hypsometric analysis of the Morna River basin, Akola District, Maharashtra, India highlight that hypsometric curves and hypsometric integrals are important indicators of watershed conditions Differences in the shape of the curve and hypsometric integral values are related to the degree of disequilibria in the balance of erosive and tectonic forces. They identified that the slope of the hypsometric curve changes with the stage of watershed development, which controls the erosion characteristics of watershed and it, is indicative of cycle of erosion. The hypsometric integral (Hsi) is found to be an indication of the cycle of erosion in the study area.

Pareta (2011) studied the detail morphometric characteristics of Karawan watershed in Dhasan basin, which itself is part of the mega Yamuna basin in Sagar district, Madhya Pradesh. ASTER data have been used for preparing digital elevation model (DEM), and geographical information system (GIS) was used in evaluation of linear, areal and relief aspects of morphometric parameters. Based on all morphometric parameters analysis; the erosional development of the area by the streams has progressed well beyond maturity and that lithology has had an influence in the drainage development. The studies will be very useful for planning rainwater harvesting and watershed management.

(Plabita *et al*., 2015) in their study of Dhansiri River, evaluated its Sinuosity Index using satellite imageries of 1999 and 2008 which varies from 1.22 to 4.91. The river acquires a meandering course as it flows through the alluvial plains of Assam and is responsible for frequent course change and shifting of bank lines due to consistent bank erosion. The progressive gradual change of the meander bends has been observed by superimposing the river layers of 1999 and 2008 in GIS platform. It has been found that the total area lost as a result of erosion is 13.13834 km^2 and the total area gained as a result of sediment deposition along its bank is 15.15894 km^2.

Rubey (1991) proposed a concept of stream channel development with channel gradient and channel form as dependent variables that mutually adjust to conditions of sediment load, sediment size, and water discharge. A similar channel development model is formulated using multiple equations and tested against a data set for 252 stream sites in the Missouri River Basin, USA. The results strongly support mutual adjustment among the gradient, form, width, and depth aspects of the stream channel system. The relation between channel form and grain size in the bed is shown to have opposite signs in the structural and reduced forms of the model. This provides the basis for an explanation of a puzzling aspect of Rubey's conception of the adjustment process. The results suggest that channel form is more dependent on the process of mutual adjustment of morphologic elements than is channel gradient.

(Sivakumar *et al*., 2011) carry out a hypsometric analysis of Varattaru river basin of Harur taluk, Dharmapuri district, Tamilnadu using remote sensing and GIS technologies. Hypsometric data were derived and analyzed for each of the divided sub zone of Varattaru river basin from the 30 metre ASTER DEM. It was found that high-medium hypsometric integrals/elevation relief ratios indicating a youthful to mature stage landscape, medium to complex denudational processes, the linear river morphological changes of this river basin and remote sensing data and open source tools it becomes less tedious to make hypsometric integrals and curves.

According to Lane (1995) a channel's width, depth and velocity are assumed to increase as discharge increases. Temporal variation in discharge at a particular cross-section implies variation in width, depth and velocity without any necessary change in channel morphology, although bank erosion may occur.

(Long *et al*., 2012), in their study of channel morphology applied the Rosgen's (1994, 1996) classification system to collect geomorphic data at 138 locations on the UVR between 1997 and 2000. The results showed that this segment of the river is dominated by gravel-bedded alluvial channels (B-, C-, and E-types) across a continuum of entrenchment. While channel typing is not a sufficient basis for evaluating channel stability, the lack of braided channels (D-type) is consistent with more detailed studies that describe the UVR as hydrogeomorphically stable.

Kusimi (2000) made a study on stream process and dynamics in the morphology of the Densu River channel in Ghana. The study reveals the current fluvial processes and landforms and the dynamics in the river morphology since the 1960s. This was done by analyzing existing survey maps and air photographs. In this study air photo interpretation and digitization of old topographic maps which were overlaid on each other to identify changes in the river's course. These analyses were backed by field studies to verify findings from these secondary data sources.

(Hartshorn *et al.*, 2002) conducted a study on climate driven bedrock incision in an active mountain belt. Measurements of fluvial bedrock incision were made with submillimetre precision in the East Central Range of Taiwan where long term exhumation rates and precipitation driven discharge are independently known. They examined that valley lowering is driven by relatively frequent flows of moderate intensity, abrasion by suspended sediment is an important fluvial wear process, and channel bed geometry and the presence of widely spaced planes in the rock mass influence erosion style and rate.

(Omvir *et al.*, 2008) carried out estimation of hypsometric integral from the graphical plot of the measured contour elevation and encompassed area and by using empirical formulae in North-Western Lesser Himalayan Watersheds. It was revealed that the hypsometric integral calculated by elevation–relief ratio method was accurate, less cumbersome and easy to calculate within GIS environment. Also comparison of these hypsometric integral values revealed that the Sainj watershed (0.51) was more prone to erosion than the Tirthan watershed (0.41). Further, the validation of these results with the recorded sediment yield data of 24 years (1981–2004) corroborated that the average annual sediment yield during this period for Sainj watershed (0.53 Mt) was more than that of the Tirthan watershed (0.3 Mt).

(Pradeep *et al.*, 2016) performed a GIS and Hypsometry based Analysis on the Evolution of Sub Basins of Ponnaiyar River, Krishnagiri District, Tamil Nadu. Their study shows that the hypsometric integral values range between 0.45 and 0.56 indicating mature stage development for all the river basins. However, the values of 0.55 and 0.56 obtained for Veppanapalli basin and Marakandanadhi basin are close to the lower limit of the youthful stage value range which reveals that these two basins are in the early mature stage. The hypsometric shapes for Chinnar basin–B2 and Marakandanadhi basins are slightly convex indicating that they have just completed the youth stage and presently at the early mature stage.

(Coe *et al*.,2010), conducted a study on the effects of deforestation and climate variability on the stream flow of the Araguaia River, Brazil where they examined that deforestation changes the hydrological, geomorphological, and biochemical states of streams by decreasing evapotranspiration on the land surface and increasing run off, river discharge, erosion and sediment fluxes from the land surface. Deforestation has removed about 55% of the native vegetation and significantly altered the hydrological and morphological characteristics of an 82,632 km2w watershed of the Araguaia River in east-central Brazil. Observed discharge increased by 25% from the 1970s to the 1990s and computer simulations suggest that about 2/3 of the increase is from deforestation, the remaining 1/3from climate variability.

Chase (2002) in her report presents channel-morphology data for five sites on the main stream Tongue River and four sites on its tributaries. Bankfull, water-surface, and thalweg elevations, channel sections, and streambed-particle sizes were measured along reaches near stream flow-gaging stations. At each site, the channel was classified using methods described by Rosgen. For six sites, bankfull discharge was determined from the stage discharge relation at the gauge for the stage corresponding to the bankfull elevation. For three sites, the step-backwater computer model Hydrologic Engineering Centre's River Analysis System(HEC-RAS) was used to estimate bankfull discharge. Recurrence intervals for the bankfull discharge also were estimated for eight of the nine sites. She presented Channel-morphology data for each site in the form of maps, tables, graphs, and photographs.

According to Matsuda, (2004) river morphology is explained by channel patterns and channel forms, and is decided by such factors as discharge, water surface slope, water velocity, depth and width of the channel, and river bed materials, etc. These factors are not independent but inter-related to each other.

(Sapkal *et al*., 2016) in their study of River in Planform and Variation in Sinuosity Index : A Study of Dhamni River, Kolhapur (Maharashtra), argued that Channel in planform (pattern) means, the channel patterns with straight, sinuous, meandering and braided. Planform of the river studies provide the relationship of the differentiate processes acting in the river channel, also shows the inter-relationship between hydrological parameter and river material. Continuous variation in the sinuosity index in the channel gives the signs of changing characteristic and behavior of the river.

Schumm (1993) in his study of, ‘ River Response to Base level Change: Implications for Sequence Stratigraphy’ mentioned that the effect of base level change depends upon many factors, such as rate of change, amount of change, direction of change, river character, and dynamics and erodibility of the sediment source area. In most cases the effects of base level change will be moderate, and they can be accommodated by changes of channel pattern, width, depth, and roughness. Therefore, the delivery of large amounts of sediment to a shoreline or continental shelf probably reflects not only base level lowering, but significant uplift of the sediment-source area and perhaps climate change.

Schumm (2005) inferred in his study that rivers differ among themselves and through time. An individual river can vary significantly downstream, changing its dimensions and pattern dramatically over a short distance. If hydrology and hydraulics were the primary controls on the morphology and behavior of large rivers, we would expect long reaches of rivers to maintain characteristic and relatively uniform morphologies. In fact, this is not the case-the variability of large rivers indicates that other important factors are involved.

River variability and complexity presents a new approach to the understanding of river variability. It provides examples of river variability and explains the reasons for them, including fluvial response to human activities. Understanding the mechanisms of variability is important for geomorphologist, geologist, river engineers and sedimentologist as they attempt to interpret ancient fluvial deposits or anticipate river behavior at different locations and through time. This book provides an excellent background for researchers and professionals.

(Suresh *et al*., 2019) carried out a study on identification of artificial groundwater recharge sites on Neyyar basin using Remote Sensing and GIS. The study showed that GIS techniques have efficient tools in delineation of the drainage pattern in understanding various terrain parameters such as nature of bedrock, infiltration capacity, surface run off etc., which helps in better understanding the land form and their characteristics. Their study can be useful for natural resources management at micro level of any terrain for sustainable development by planners and decision makers.

Ham (2005) has established relationship between sediment transport and channel deformation on a 70 km long wandering reach of lower Fraser River, British Columbia and noticed that changes to reach morphology are dominated by the transfer of coarse alluvial sediments. Small gravel sheets are attached to existing lateral and mid-channel bars, forcing compensating erosion across the channel and propagating instability downstream. Over periods of several decades, entire bars and bar / island complexes migrate downstream in association with the riffles.

(VanLooy *et al*., 2005) examined that rivers are dynamic features on the landscape that respond rapidly to changes in environmental factors such as climatic and anthropogenic change. Channel morphology is especially sensitive to climate and anthropogenic change (Knox 1977; Huckleberry 1994; Lane 1995; James 1997; Waters and Haynes 2001; Urban and Rhoads 2003). Moreover, a change in one or both of these factors has an impact on other variables, such as the riparian vegetation cover, sediment load and type, and hydrologic variables, all of which have the potential to alter channel morphology.

(Vipin *et al*., 2011) performed a hypsometric analysis of Kali River Basin, Karnataka, India, using geographic information system for which hypsometric parameters have been evaluated and curves are prepared for all the 20 sub-basins of Kali River. Thirteen sub-basins are found to be under younger geomorphic stages with high hypsometric integral (Ea) values and subjected to recent tectonic activities. The remaining seven sub-basins are approaching mature stage and subjected to more erosion and less impacted by recent tectonic activities.

According to Gogoi (2006) fluvial morphology, hydrology and the channel forms and process are the basic studies in fluvial geomorphology or river morphology. Based on these parameters he conducted a fluvial geomorphic studies study on the Noa-Dihang River.

(Allan *et al*., 2007) stated that a central theme in fluvial geomorphology is that alluvial rivers determine the location and shape of their channels through complex interactions among hydrology, geology, topography, and vegetation. The development of stream channels and entire drainage networks, and the existence of various regular patterns in the shape of channels, indicates that rivers are in dynamic equilibrium between erosion and deposition, and governed by common hydraulic processes. However, because channel geometry is three dimensional with a long profile, a cross section, and a plan view, and because these mutually adjust over a timescale of years to centuries, cause and effect are difficult to establish.

Leopold and Bull (1979), in their study entitled, 'Base level, aggradation and grade' described that base levels of a river, whether ultimate base level (the ocean) or local (lake, dam, or resistant bedrock in the channel) affect the vertical position of the longitudinal profile only locally. The master stream as base level has an effect only locally and has an influence that extends only a short distance up the tributary.

Mohammadi (2008) has employed GIS techniques to study the morphological changes of Gorgan river north of Iran where he examined that the Gorgan river morphology has changed in the last century, due to the geological, topographical and climatologically conditions, as well as due to the human impact. Further on, some morphological parameters like sinuosity length, meander length, width of meander belt, average curve radius, amplitude and sinuosity coefficient were also calculated. Finally, by means of the t test (Spss software), for some of the morphological parameters in the selected river reach, significant changes have been proved.

(Moore *et al*., 2011) conducted a study on five lower Mississippi River islands in 2007 and 2008 to examine short-term morphological changes and variables controlling this change. Results indicated that morphological change during the study period but only in width. Changes in morphological characteristics were consistent with intensity of river flow around the islands, with the highest velocity and sediment load observed near the island head and to a lesser degree the thalweg side of islands. In reference to islands present in the late 1 890s, contemporary islands appear to be more elongated and have a greater surface slope. Since these islands provide beneficial habitat for flora and fauna, it is crucial to understand the dynamic nature of these landscape features.

(Heritage *et al*., 2011) have carried out studies on the morphological composition of the bedrock influenced Sabie River, Mpumalanga Province, South Africa, mapping of a 25 km long river channel at the scale of individual morphological units. From their studies it is clear that the bedrock-dominated channel types are characterized by energy levels in excess of those accepted for alluvial systems, and an extended river classification is presented for the Sabie River that includes these bedrock channels. The mixed anastomosing channel type on the Sabie River is characterized by higher available energy levels than braided or alluvial single-thread reaches. As such, it appears to be a higher-energy example of an anabranched system, probably formed as a result of sediment accumulation on top of a high-energy bedrock anastomosed channel template.

Legleiter (2011) in his study, evaluated the potential to measure the morphology and dynamics of a large, complex river system such as the Snake using optical image data. Initially, he made use of existing, publicly available images and basic digital aerial photography acquired in August 2010. Analysis to date has focused on estimating flow depths from these data, and preliminary results indicate that remote bathymetric mapping is feasible but not highly accurate, with important constraints related to the limited radiometric resolution of these data sets. In addition, more sophisticated hyperspectral data are scheduled for collection in 2011, along with further field work.

(Ibisate *et al*., 2011) examined that river morphology is conditioned by three basic elements: such as flow regime, sediment yield and valley characteristics. These elements are controlled by factors operating at different spatial and time scales, within and outside of the basin. Moreover, the great influence of human activities has to be considered as they presently constitute one of the main hydromorphological factors. An understanding of the factors that affect channel morphology is of primary importance for assessing river habitat condition, considering that river reach characteristics are the result of the interaction between upstream and downstream catchment and local conditions.

(Rinaldi *et al*., 2015) devised a procedure for classification of river morphology and hydrology to support management and restoration in Europe. Channel morphology is classified at a first level by a basic river typology interpreted using remotely sensed images, and at a second level by an extended river typology that integrates information from field observations. Floodplains are classified by adopting the Nanson and Croke typology with specific reference to the types of floodplain that are most likely to be encountered widely across Europe. Nine flow regime types has been identified using a series of hydrological indicators. Within the REFORM project, the river typology has been tested using case studies representative of a wide variety of European catchment conditions.

According to Selander (2012) material eroded through hill slope processes and bedrock channel incision is eventually transported by alluvial (transport-limited) channels. The morphology of these channels is governed by a number of drivers including tectonic processes, climate, and local lithology that influence the river system over a range of timescales.

(Delai *et al*., 2014) have carried out a study which aimed at improving channel surface models without having available bathymetric sensors, by deriving dry areas elevations from LiDAR data and water depth of wetted areas from aerial photos through a predictive depth-colour relationship in two different sub-reaches of the Piave river, a gravel-bed river which suffered severe flood events in 2010.Erosion and deposition patterns were identified through DEM differencing, showing a predominance of scour processes which can lead to channel instability situations. They have also compared bathymetric output to other previously-derived models confirming the accuracy of the in-channel elevation estimates.

Miller and Leopold (1956), in their study entitled simple measurements of morphological changes in river channels and hill slopes described that some relatively simple techniques like monumented cross-sections, chain for indicating bed sour, pins for measuring rates of bed recession, depth of flow, movement of individual rocks, rock movement in headwater ephemeral rills, pins to measure rates of erosion, form and gradient of deposition behind barriers and stakes for the measurement of soil creek and mass movement are found to be very useful in observing morphological changes on slopes and in channels.

(Moges *et al*., 2015) conducted a study on Morphometric Characteristics and the Relation of Stream Orders to Hydraulic Parameters of River Goro: An Ephemeral River in Dire-dawa, Ethiopia. The study assessed the relation of stream orders to selected channel hydraulic parameters (width, depth, channel bed slope, velocity and discharge) at bank full flow condition. Analysis of morphometric parameters indicate that pattern of stream networks is less controlled by structural condition though the area is situated in the rim of the great east African rift valley; and its geomorphic development is at late youth stage. They ascertain that depth, velocity and bed slope of the channel are less explained by stream order, which may indicate that these hydraulic parameters are rather affected by other local channel factors.

Nandeshwar (1998) conducted a hypsometric analyses of some selected river basins of the Western Ghats where he examined that denudation has a significant influence on the landscape development which subsequently effects on man's activities. His study of hypsometric integral helps to understand the denudation chronology of an area.

According to Singh (1998) the geological works of fluvial processes of rivers are called three-phased-work comprising erosion, transportation and deposition. The fluvial landforms are divided into two major groups e.g. erosional and depositional landforms. The landforms resulting from progressive removal of the bedrock mass are called erosional landforms e.g. various types of valley, pot holes, rapids and waterfalls, structural benches, terraces, meanders etc. The landforms shaped by the deposition of different types of eroded materials become depositional landforms such as alluvial fans and cones, natural levees, flood plains, terraces, deltas etc.

Singh (2003) emphasize Hydraulic geometry as fundamentally important in planning, design, and management of river engineering and training works. The survey of literature made in this study suggests that there is plenty of data available for different rivers in different countries but efforts to archive these data and organize them into a database have not been reported. Despite all the work done and new theories developed during the past half a century, the classic work of Leopold and Maddock (1953) still remains the benchmark contribution.

Sarker (2008) examined that morphological changes in the Jamuna-Padma-Lower Meghna system have occurred in response to disturbance of the fluvial system by the Assam earthquake of 1950 where he used a time-series of remotely-sensed imagery together with hydrological, hydraulic, sedimentary and morphometric data to study dynamic process-response and morphological changes in the Jamuna-Padma-Lower Meghna river system within Bangladesh.

(Rao *et al*., 2010) have employed spatial information technology to analyze the morphometry of Gostani River Basin in Andhra Pradesh and reveals that the area is 7^{th} order drainage basin and drainage pattern mainly in sub dendritic to dendritic type. It is observed that the drainage density value is low which indicates the basin is composed of highly permeable subsoil and with thick vegetative cover. The circularity ratio value reveals that the basin is strongly elongated and highly permeable homogenous geologic materials. This study would help the local people to utilize the resources for sustainable development of the basin area.

Ganguly (2010) conducted study on the morphometric analysis of Garua basin in which he infered that basin geometry is affected by the structure and environmental controlling factors.

(Ghosh *et al*., 2012) have conducted a study on hydrogeomorphic significance of sinuosity index in relation to river instability in the flood prone Damodar river of West Bengal which provides a sound basis for predicting future changes of river dynamics, especially those taking place after dam constructions by Damodar Valley Corporation (DVC).Toposheets, satellite images and geographic information system (GIS) were used to measure the temporal pattern (1943 – 2006) of river plan-form with the help of Mueller's sinuosity indexes which unfold the magnitude of river instability, contributing factors of sinuosity and the chances of flood with a probability of changing course.

(Magesh *et al*., 2012) have developed extraction tool through the model builder technique in ArcGIS environment to delineate the basin morphometry which helped the users to select the range of stream delineation. This technique is very useful for those who work in the field of terrain analysis, hydrology, and watershed analysis to generate a reliable database for morphometric analysis.

Sivasamandy and Ramesh (2014) have conducted a granulometric studies of sediments in Kolakkudi lake, Tamil Nadu. In their study they classify textural and geostatistical parameters as mean, sorting, skewness and kurtosis which has been carried out with significance in lake sedimentological aspects. They also record some applications related to sediment types and bottom dynamics. Their studies revealed thatinlet part is dominated by fine sand. Central part is dominated by medium sand and outlet part is dominated by coarse sand.

Rao (2011) conducted a drainage morphometric study of lower Tlawng sub watershed in Aizawl district with an attempt to understand the nature of ongoing tectonic activity in the area. He analyzed the computed drainage parameter's such as stream length ratio (RL), bifurcation ratio (Rb), stream frequency (FS), drainage density (Dd), drainage texture (Rt), constant of channel maintenance (C), circulatory ratio (Rc), elongation ratio (Re), drainage basin asymmetry factor (Af), relief ratio (Rh), and ruggedness number (Rn), which revealed the history of ongoing tectonic activity in addition to nature of terrain and climate. He has inferred based on the computed parameter of drainage parameters as well as the analysis of satellite imagery that the area is tectonically active due to presence of structurally controlled valleys and river channels.

According to Tinkler (1970) the channel shape is controlled by mean flow conditions of the fluid phase, although basically an independent variable, must partly adjust to channel shape. Hence, velocity distribution and energy losses of the fluid phase are to some degree controlled by the channel shape.

Zernitz (1932) in his study presented a more detailed classification of drainage patterns in the belief that clearer conceptions regarding the various types will increase their usefulness in interpreting structural controls of drainage evolution.

According to him it is evident that drainage patterns may reflect original slope and original structure or the successive episodes by which the surface has been modified, including uplift, depression, tilting, warping, folding, faulting, and jointing, as well as deposition by the sea, glaciers, volcanoes, winds, and rivers.

CHAPTER V

MORPHOLOGICAL ANALYSIS

5.1 Channel Morphology

Drainage network is a natural flow system developed on slopes. Rain water flowing down slopes comes together to form a stream flow. The space where a stream flow runs is a channel. A river is the general term for a channel typically with water. The area supplying water into a channel is a drainage basin. A river system consists of the main stream and many tributaries (Matsuda 2004). A drainage pattern is a plan of a river system with spatial arrangement of channels. Channel morphology is concerned with the structure or forms of a channel. It can be either static or dynamic. River Tlawng develops various landforms through dynamic channel processes. Erosion, transportation and sedimentation are the main fluvial channel processes. Erosion prevails in the upper reach area of Tlawng drainage basin as the terrain is steep and composed of sedimentary rocks. The materials are brought to the lower reaches from the upper reaches where erosion is prevalent due to high degree of gradient and erosion caused by severe channel incision.

There are two factors controlling channel morphology independent and dependent variables. Geology, climate and human variables are independent variables that changes or influences the channel morphology. Dependent variables such as velocity, river discharge, river landforms etc. depend on independent variable or they respond and adjust to the independent variables.

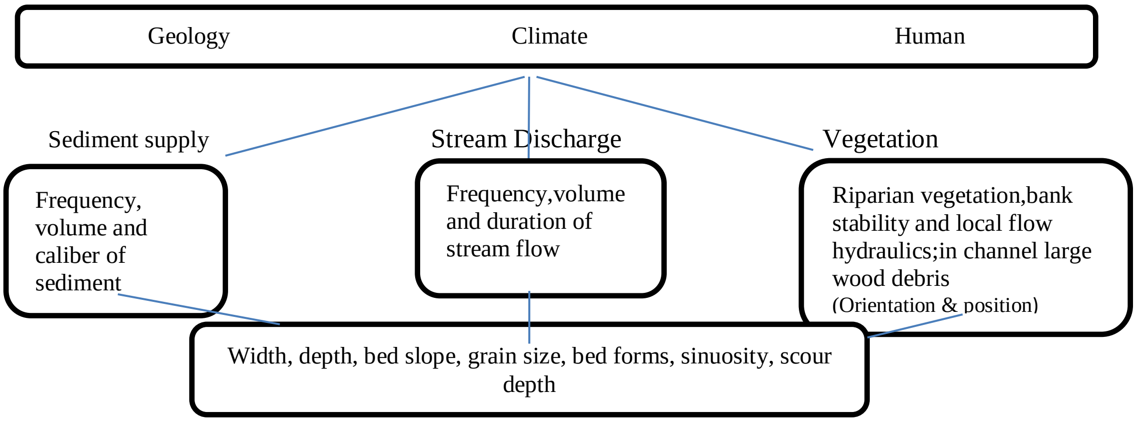


Fig 5.1: Independent and dependent variables controlling channel morphology.

5.2 Channel Types and Patterns

Classification of river channels depends upon the perspective of investigators based on the most significant variables. For instance, the classic braided, meandering and straight tripart division of rivers (Leopold and Wolman 1957) is based upon pattern with boundaries among the three patterns based upon discharge and gradient. Brice (1982, 1983) added an anabranched or anastomosing channel pattern (Figure 5.3) to the triad and distinguished between two types of meandering channels. The passive equiwidth meandering channel is very stable as compared to the wide-bend point-bar meandering channel. This is a very important practical distinction between active and passive meandering channels (Thorne 1997). A highly sinuous equiwidth channel gives the impression of great activity, in fact, it can be relatively stable. Brice (1982) also indicates how width, gradient, and sinuosity, as well as type of sediment load and bank stability varies with pattern.

A channel may be defined as the path of a river or a stream outlined by its bed and banks. Channel pattern represents a mode of channel-form adjustment in horizontal plan. Channel-form means the configuration of a river as it would appear from the airplane. Channel pattern is a mode of adjustment to changing channel morphology. A river may exhibit different channel patterns in its course based upon channel gradient and also nature of the terrain. River morphology is explained by channel patterns and channel forms, and is decided by such factors as discharge, water surface slope, water velocity, depth and width of the channel, and river bed materials, etc. These factors are not independent but inter-related to each other (Matsuda 2004).

River landforms can be categorized into two different ways. They can be classified either by the processes such as erosion, deposition, erosion and deposition that made them or the location like upper, middle and lower at which there are found.

Upper Course	Middle Course	Lower Course
• Waterfalls • Rapids • Gorges • V-shaped valleys • Interlocking spurs	• Meander • Ox-bow lake • Levees • Braided rivers	• Deltas • Floodplains • Meanders • Oxbow lakes

Table 5.2.1 : General classification of river landforms on basis of location

Erosional Landforms	Depositional Landforms	Erosional and depositional Landforms
• Waterfalls • Gorges • Rapids • Potholes • V-shaped valleys • Interlocking spurs	• Deltas • Levees • Braided Rivers	• Meanders • Ox –bow lake • Flood plains

Table 5.2.2: General classification of river landforms on the basis of process that made them

For the analysis of channel morphology the river Tlawng has been divided into upper, middle and lower course (Fig 5.2.1). The landforms along the upper course of the river are mostly erosional landforms. Due to high gradient and lithological characteristics, head ward erosion or down cutting is prominent. As such the river valleys resemble V- Shape steep sides. Here, erosion is greater than deposition. Small point bars are present where the river tends to bend or meander. The middle course shows signs of valley widening. The rate of erosion is still very high channel is active in incision. As the channel gradient is declining the river started to deposit its sediment load as it does not have enough velocity to carry its entire load downstream. Erosional landforms such as pot holes and river cliffs are the prominent landforms in this section. The valleys are almost flat in the latter middle and lower course. The erosive capability of the river flow velocity is decreasing and deposition prevails. Most of the erosional works are lateral erosion. Depositional landforms like flood plain, shoals, point bars are prominent along the lower course. Ox – Bow Lake resulting from river cut off is also identified. The local people in the middle and lower course are deeply engaged in sand extraction. Large scale sand excavation can change the channel morphology and dynamics in the long run.

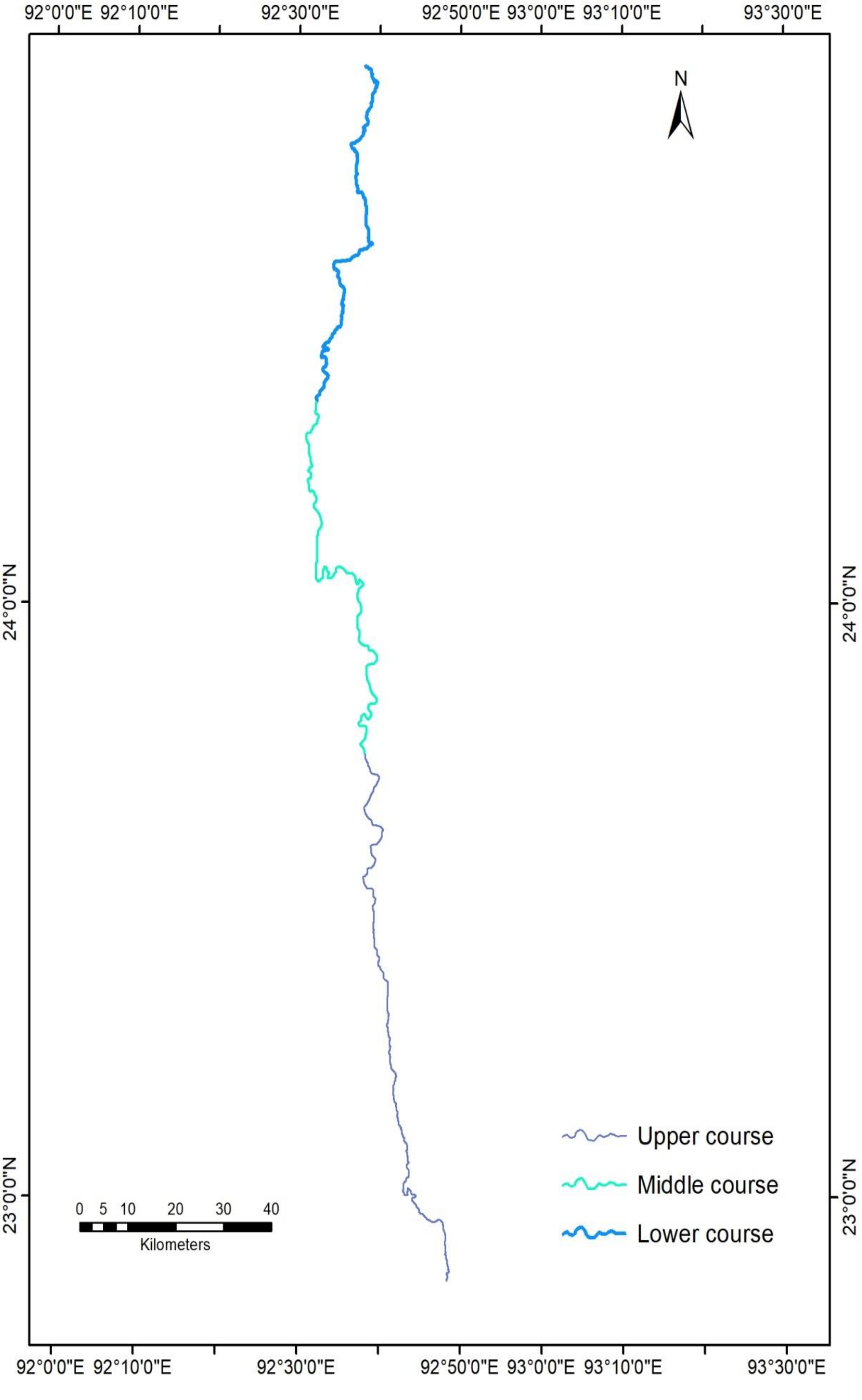


Fig 5.2.1: Tlawng river course map.

a.

b.

Plate 5.2.1 a and b: Erosional landforms -10 to 50 cm diameter sized pot hole at Ailawng village and 5 m steep river cliff at Bairabi town.

Plate 5.2.2 : Extensive Flood Plain along the left bank of Tlawng River at Sairang town.

Plate 5.2.3: Ox – Bow lake at Rangaba (as indicated with red arrow), neck cut-off(as indicated with green arrow) and a series of chute-cut-offs (as indicated with blue arrow) can be seen in this photograph.

Regime (Graded) channels	Non-regime channels
Patterns : i) Straight ii) Meandering iii) Wandering iv) Braided v) Anastomosing(can be of any of the above patterns)	Bedrock : i) Confined ii) Constrained
Hydrology: i) Ephemeral ii) Intermittent iii) Perennial iv) Interrupted	Unstable: i) Aggrading (transport limited) ii) Degrading (supply limited) iii) Avulsing

Table 5.2.3: Channel Types (after Schumm, 2005).

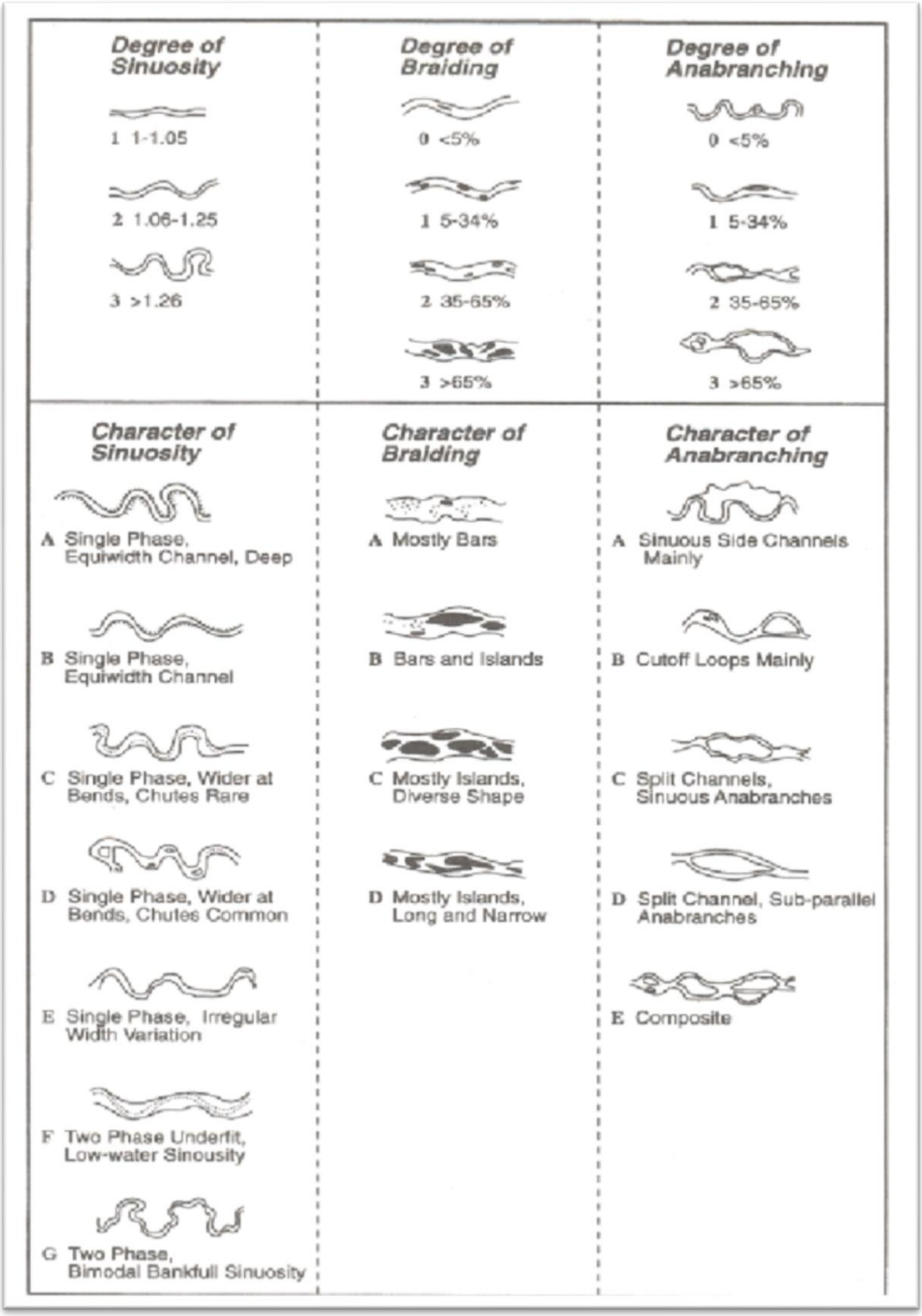


Fig 5.2.2: Channel planfom classification according to Brice (1975)

Channel type and pattern can also be classified under two basic phenomena or structure-1) Gradient 2) Lithological characteristics. Lithological characteristics can be further classified into Bedrock/load and Alluvium.

Low	High	Gradient %
• Straight (rare)	Riffle Pool :	1-2%
• Meandering	Rapids :	5%
• Braided channel	Step pools :	5-20%
• Anastomosing	Cascade/waterfall :	> 20%
• Wandering channel		

Table 5.2.4: Channel Type on the basis of gradient

The patterns which streams form are determined by inequalities of surface slope and inequalities of rock resistance. Rivers and streams continuously shape and reform their channels through erosion of the channel boundary (bed and banks) and the reworking and deposition of sediments. According to the classification made by Brice (1975) River Tlawng follows a Single Phase Equiwidth Channel in the upper course and migrates to Single Phase Irregular Wide Variations downstream. The River Tlawng is meandering to some extent at the upper course of the river because of the lithological characteristic and interlocking spurs (Plate: 5.2.4). As the river cuts its deep V-shaped valley (Plate: 5.2.5) in its upper course, it follows the path of the easiest rock to erode. Thus it tends to wind its way along, leaving the more resistant areas of rock as interlocking spurs. V- Shape valleys are formed at the upper course of the river. In the upper course of Tlawng river, the river cuts rapidly downwards, as the river puts almost all of its energy towards cutting down to base level. This causes the most distinctive river feature, the V-shaped valley. Rocks and other material are washed into the river from the steep valley sides during times of heavy rainfall, adding to the material being carried by the river. River Tlawng exhibit different channel patterns in its course. According to the classification made by Tinkler and Wohl (1998), Schumm (2005) River Tlawng can be considered as a non-regime (bed rock) channel at the upper and initial middle course of the river as more than 50% of the bed and bank material exposed is composed of rocks. In a bedrock channel, driving forces exceed resisting forces so that the channel incises over time. It is a mixture of bedrock and alluvial channel having gravel bed in the lower middle course and regime (alluvial channel) in the lower course. River reach of Pool riffle (Fig: 5.3.1 a,b) sequence is observed in the upper course of the river due to high gradient and high erosive power of the river.

Plate 5.2.4: River meandering in the upper course. Interlocking spurs can be seen in this photograph)

Plate 5.2.5: Formation of V-Shaped valley in the upper course due to active down cutting by river.

Plate 5.2.6: Confined (Non-regime) channel at Ailawng village in the middle course.

Plate 5.2.7: Gravel bed in the upper course at Lunglei town.

Plate 5.2.8: Regime (Alluvial Channel) at Bairabi town.

Plate 5.2.9: Regime (Alluvial Channel) at Bairabi town. Boats are used to collect extracted sands from the river channel.

Gravel and boulder-bed rivers are those rivers that flow through predominantly gravelly and boulder materials respectively. The River Tlawng in the upper and middle course flow through much coarser material having a much wide spectrum of sediment sizes–from cobbles to fine sand. All the fractions of bed material move only at a few flows in a year. As regards to plan-form River Tlawng is transitional form straight to braided at few reaches and starts to meander in the lower course of the river due to widening of the channel and change in lithology from gravel to sand bed. The river change from one plan-form to another as the rate of discharge changes in the lower course. It is rare to find reaches that meander significantly in the upper and middle course as the higher degree of bank stability permits the maintenance of narrow- deep straight channel.

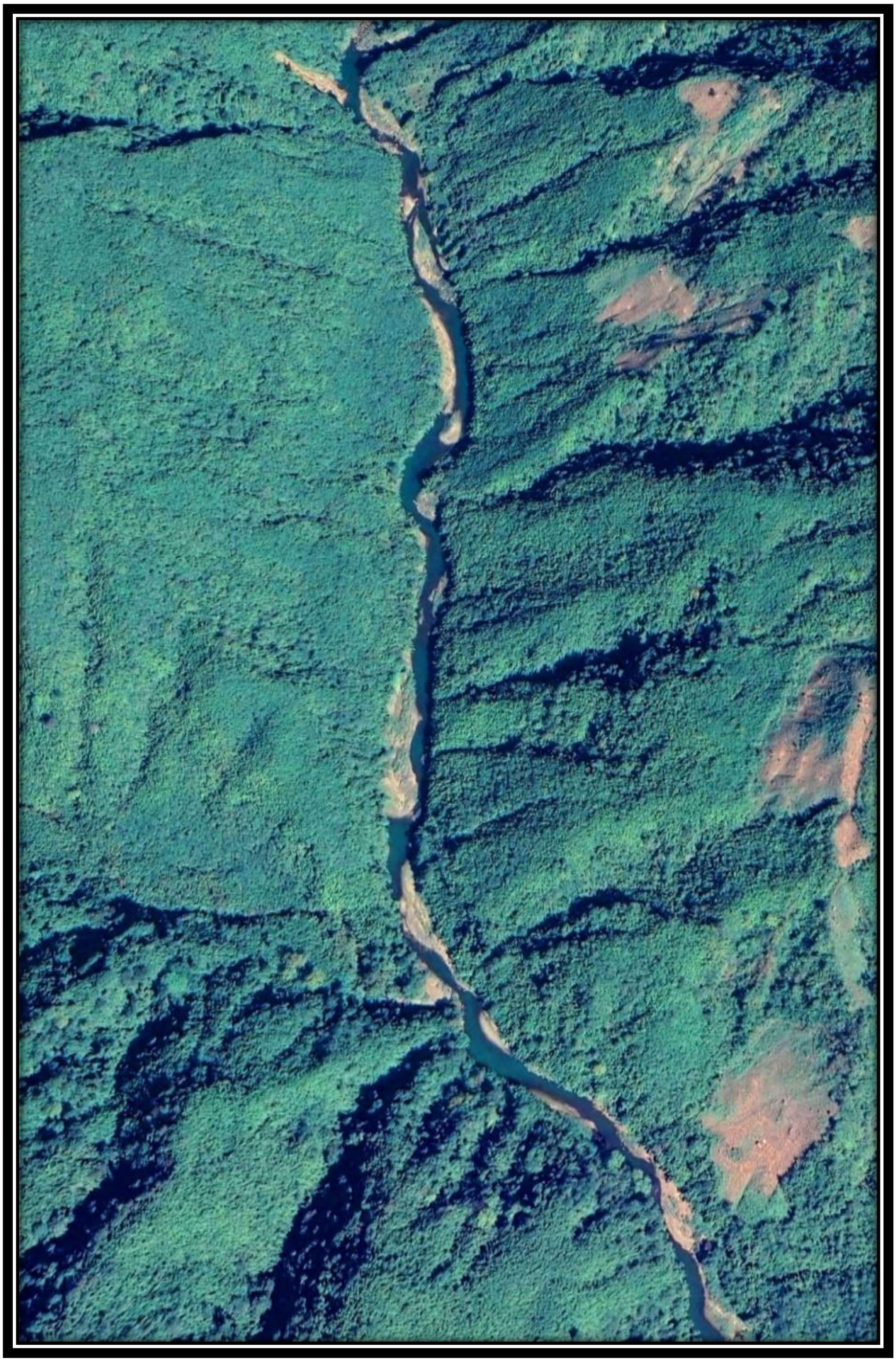


Plate 5.2.10: Braided river course in the middle reach .The straight course here indicates the fault control direction in south-north.

5.3 Channel bed topography

Large bed features known as bars, transverse and diagonal bars, riffles and pools, rapids, step pool, cascade waterfall and transverse ribs of coarse material are common features in gravel bed rivers. These bed features not only offer resistance to flow but also act as sediment storage spaces. Pools and riffles are important bed forms that are one of the most recognized features in rivers having 1-2% gradient. Pools are classified as deep areas with low velocities at low stage, whereas riffles exhibit higher water-surface slopes and faster velocities. Pools and riffles exist in both alluvial and bedrock channels, but are best developed in gravel-bed substrates and meandering channels. The channel bed topography or river bed structure of River Tlawng is characterized by a Pool Riffle sequence in the upper course of the river. This can be attributed to the high erosive capability of the river upstream. Riffle which is shallower than Pools occurs on the straight stretch of the river where erosion is evenly stretched while Pools are located on the bends where erosion is concentrated on the outside of the bends. Sediments or bed loads are much coarser in Riffles than in Pools. Step Pool reaches and low rapids of rough turbulent (white water) are also identified in the upper course of the river where there is a layering of hard and soft rocks. In some reaches of the middle course the river is having a Pane bed channel which according to Montgomery and Buffington (1997) is a channel lacking well-defined bed forms and instead displaying long, and commonly channel-wide, reaches of uniform “riffles” or “glides having a relatively uniform grain size, typically of cobbly gravel.

According to Schumm (2005) rivers differ among themselves and through time and an individual river can vary significantly downstream, changing its dimensions and pattern dramatically over a short distance. River Tlawng migrated from being a bed rock channel in the upper and early middle course to sand bed or alluvial channel in its lower course. This is because of the change in lithological characteristics in its lower course from gravel to sand.

a **b**

Plate 5.3.1: a, b: Pool Riffle Sequence in the late upper course.

Fig 5.3.2: Low Rapids in the upper course

Fig 5.3.3: Pool Riffle in the middle course at Sairang. Steep sided right bank and steeply dipping bedding plane can be seen in this photograph. (Arrow indicates flow direction of the river in south-north)

5.4 Channel Geometry

Channel geometry is concerned with the description of the size and shape of the channels in which water flows. The average width or perimeter, depth of flow or the hydraulic radius, flow area at the bankful discharge, and the slope, describe the hydraulic geometry of the rivers. Channel geometry and characteristics of stream flow are inherently related. Changes in the geometry of the channel can impact stream velocity and discharge. The controlling influence of discharge upon channel form, resistance to flow, and flow velocity is explored in the concept of hydraulic geometry.

Channel geometry can be further classified into two types- cross section study and longitudinal channel study. Parameters such as Thalweg, Channel, Sinuosity, Radius of Curvature and Channel Gradient are important in understanding the channel geometry.

5.4.1 Cross profile

The River Tlawng has been divided into Upper, Middle and Lower Course for the purpose of the study. From each course cross sectional area has been extracted from DEM and through field work at various reaches in order to understand the channel geometry at a point and for the channel. In the upper course of the river the cross section area is representing a V- Shape structure with 0.46m depth due to prominent vertical erosion by the river and gradually flattens out downstream where channel is at its widest stretch of 110 m. This is due to the increase in discharge about 10.3 cubic metres per second (cumecs) and changing of channel type from bedrock to alluvial channel in the lower course. The channel cross-section is characteristically irregular in outline and is locally highly variable in nature.

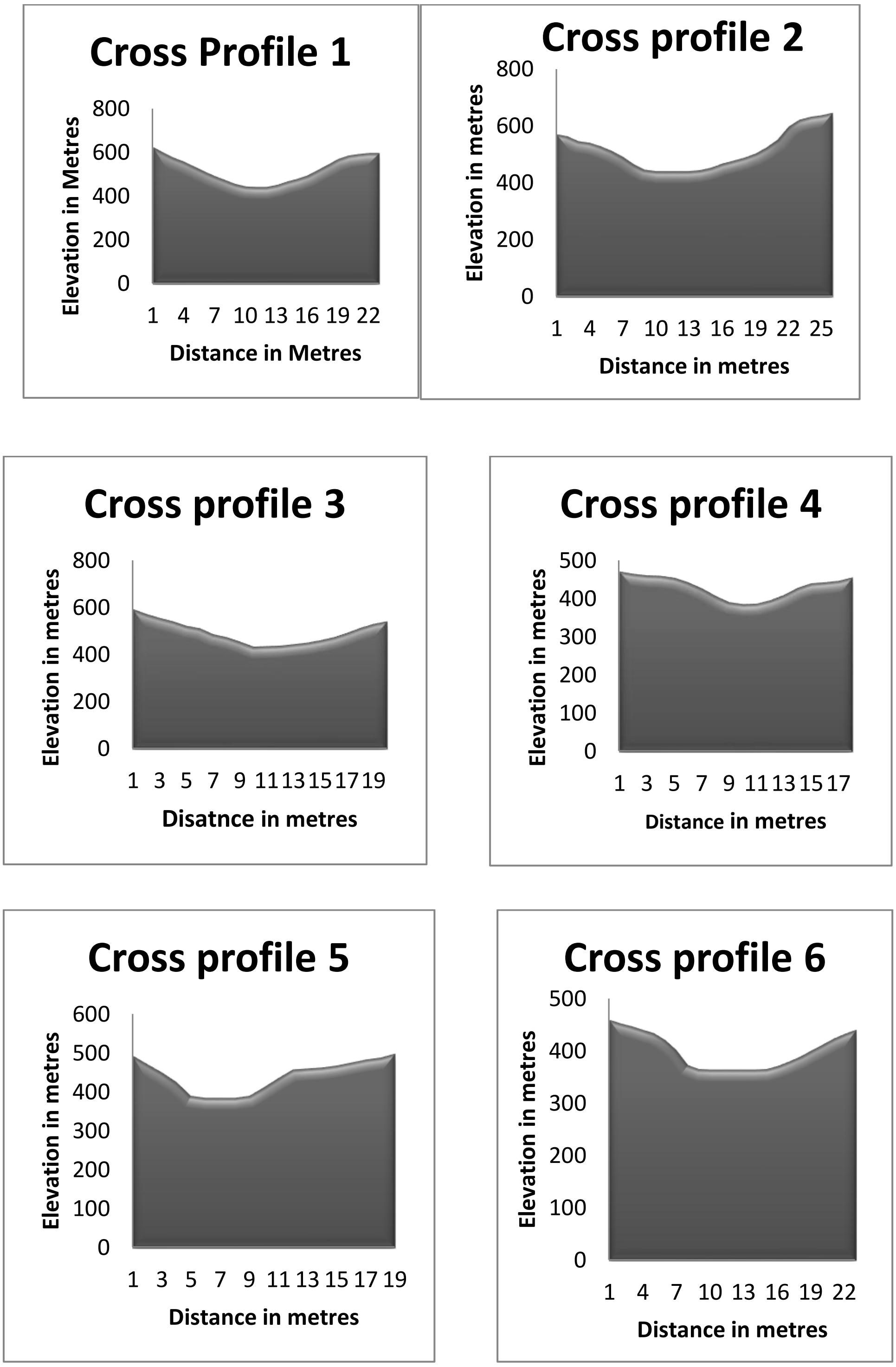


Fig 5.4.1.1: Cross profile

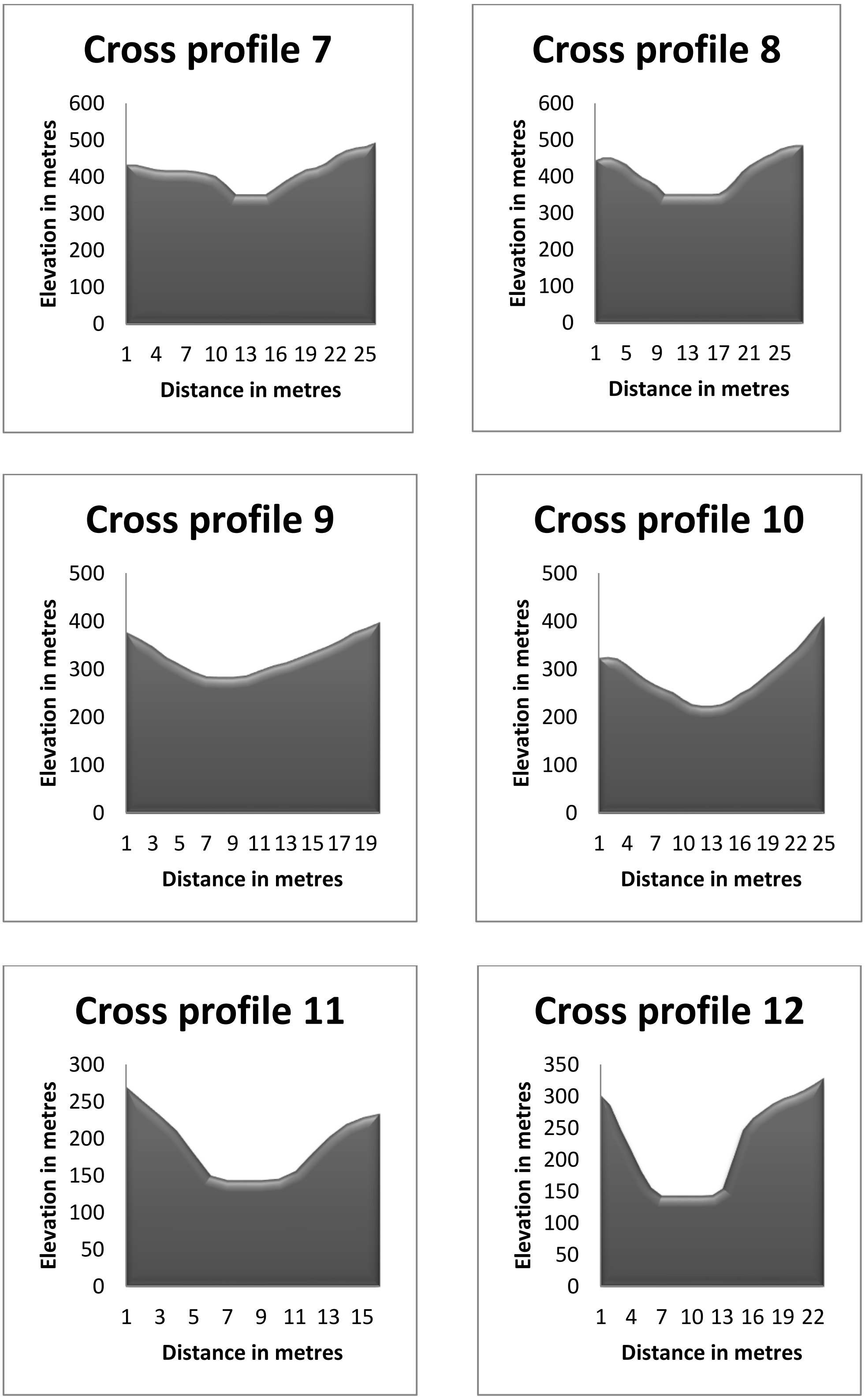


Fig 5.4.1.2: Cross profile

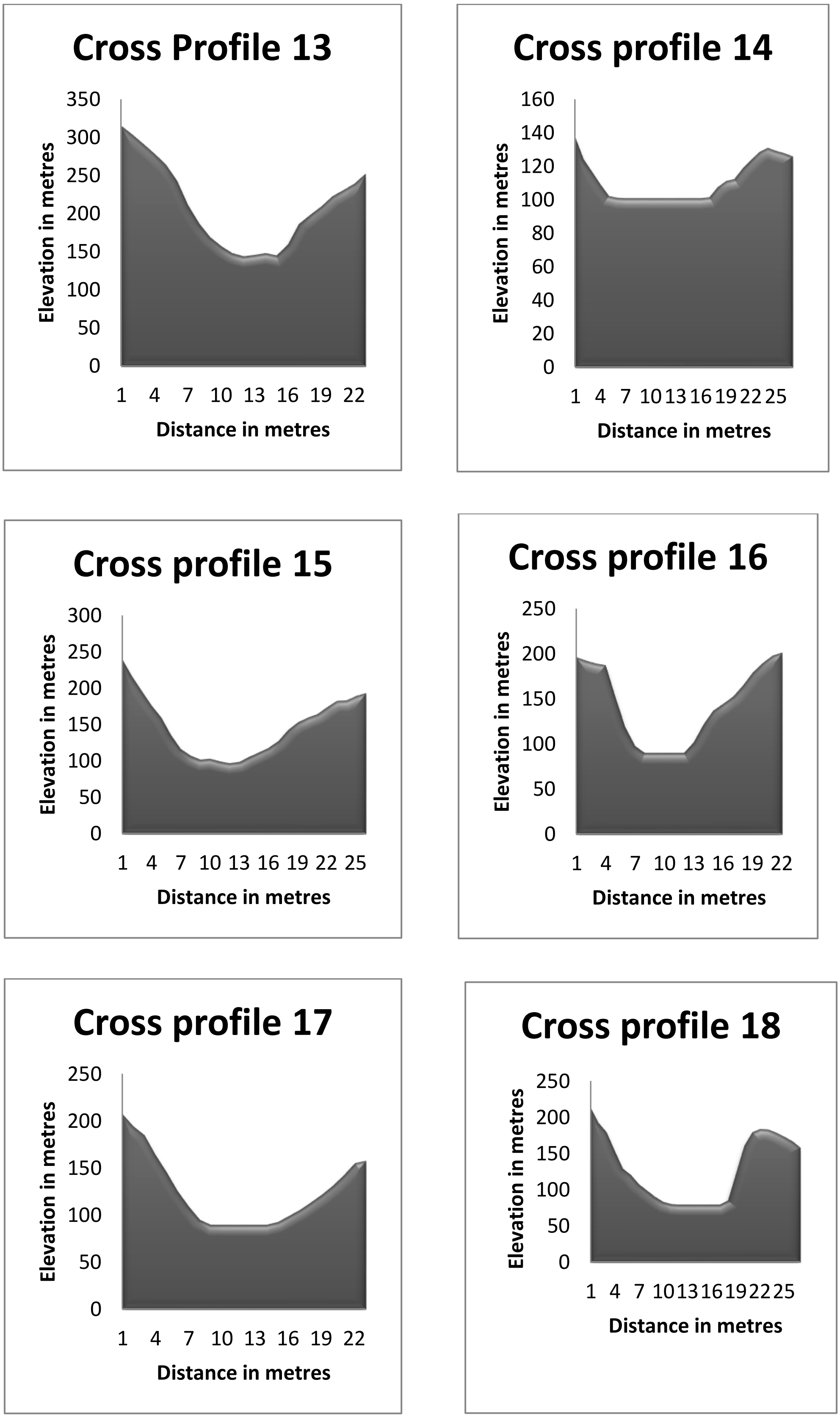
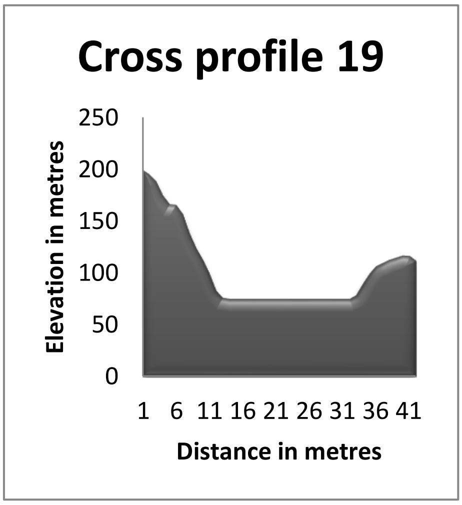
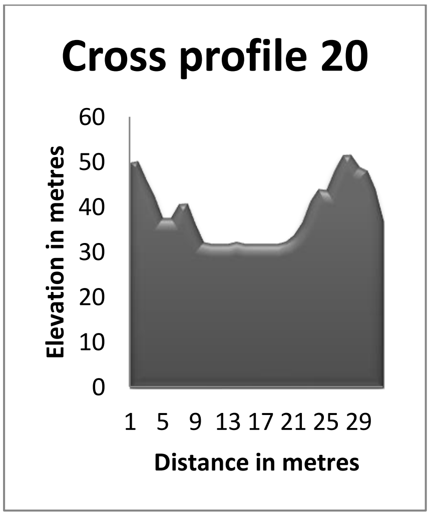
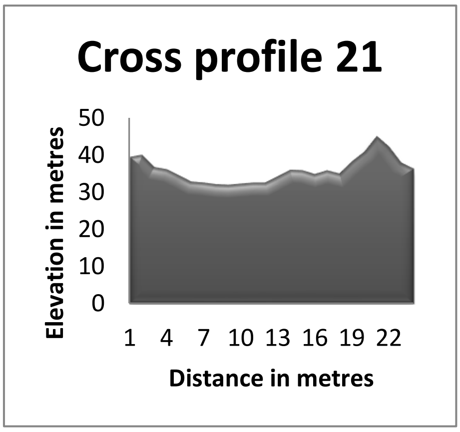
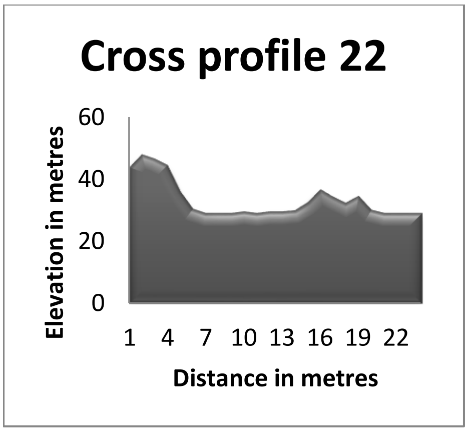


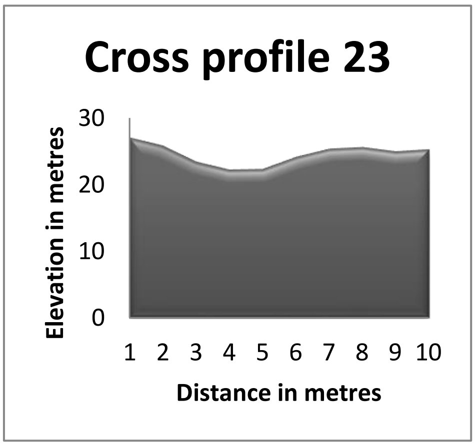
Fig 5.4.1.3: Cross profile











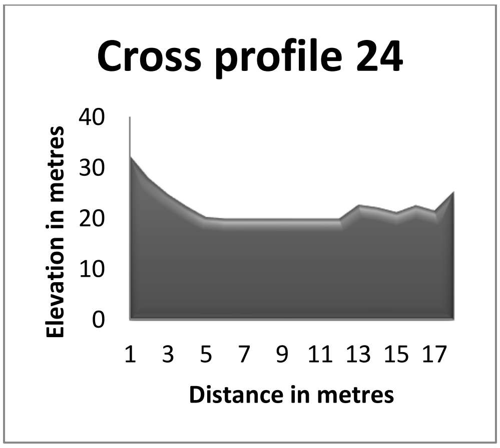


Fig 5.4.1.4: Cross profile

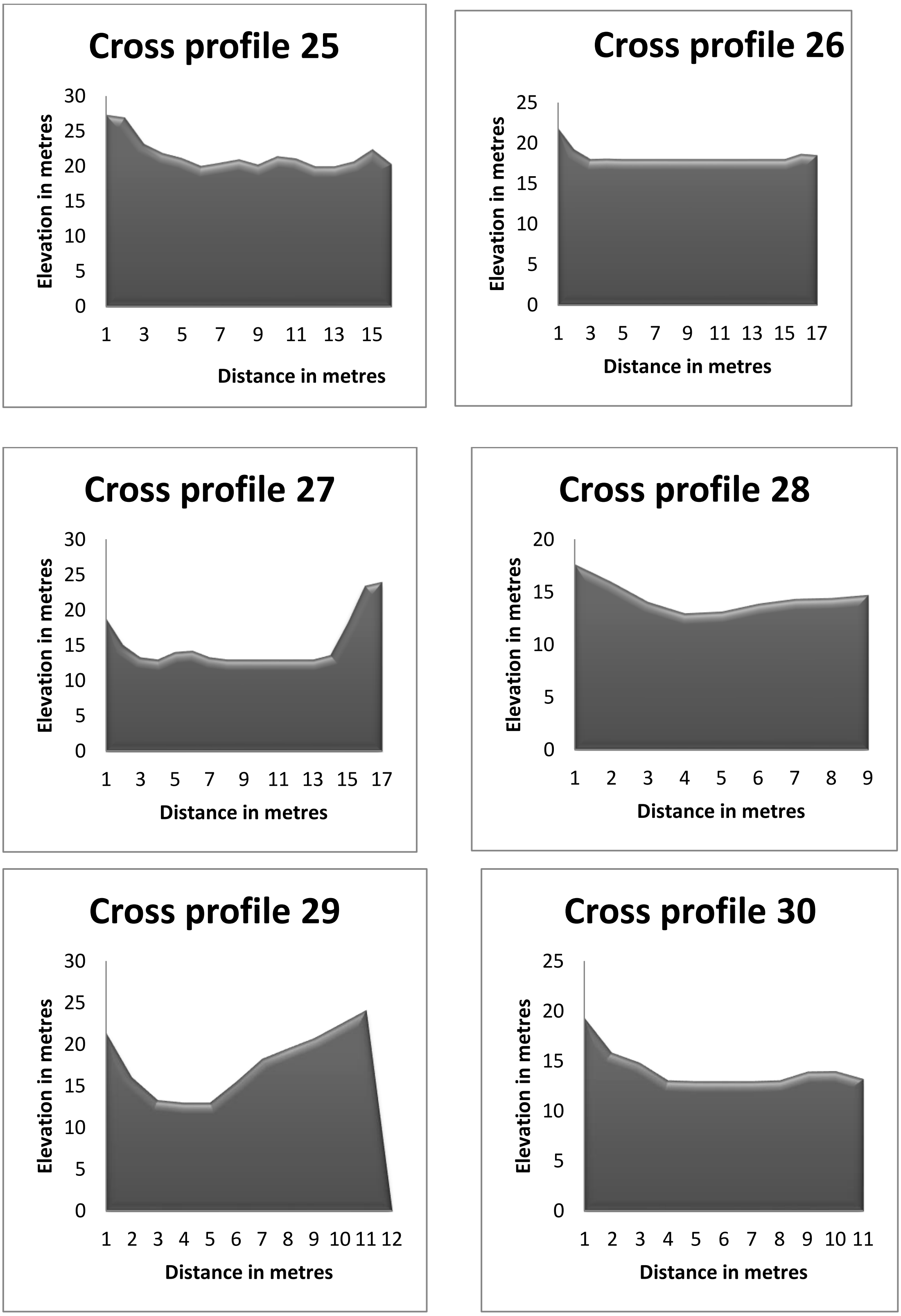


Fig 5.4.1.5: Cross profile

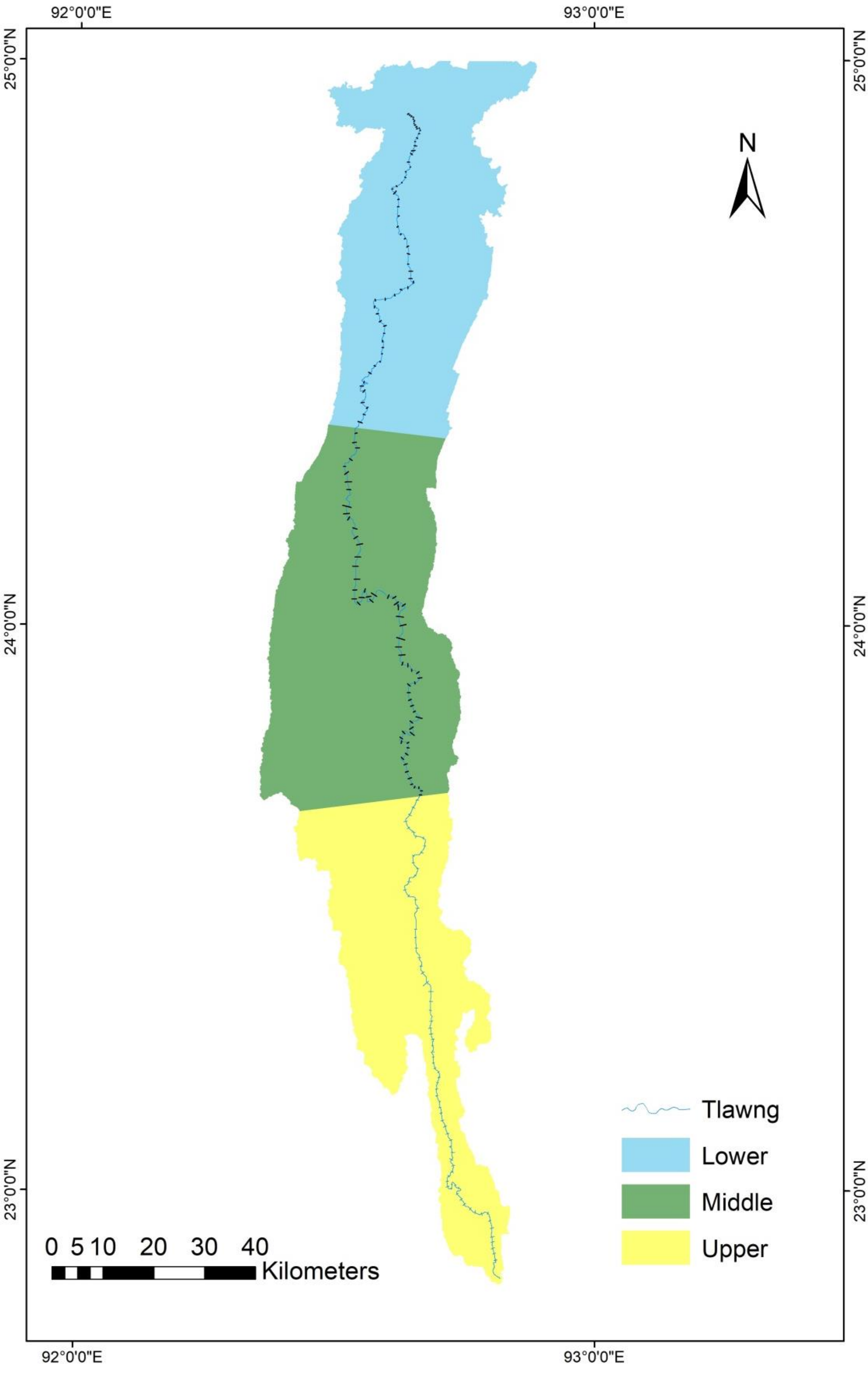


Fig 5.4.1.6: Map showing location of cross profiles.

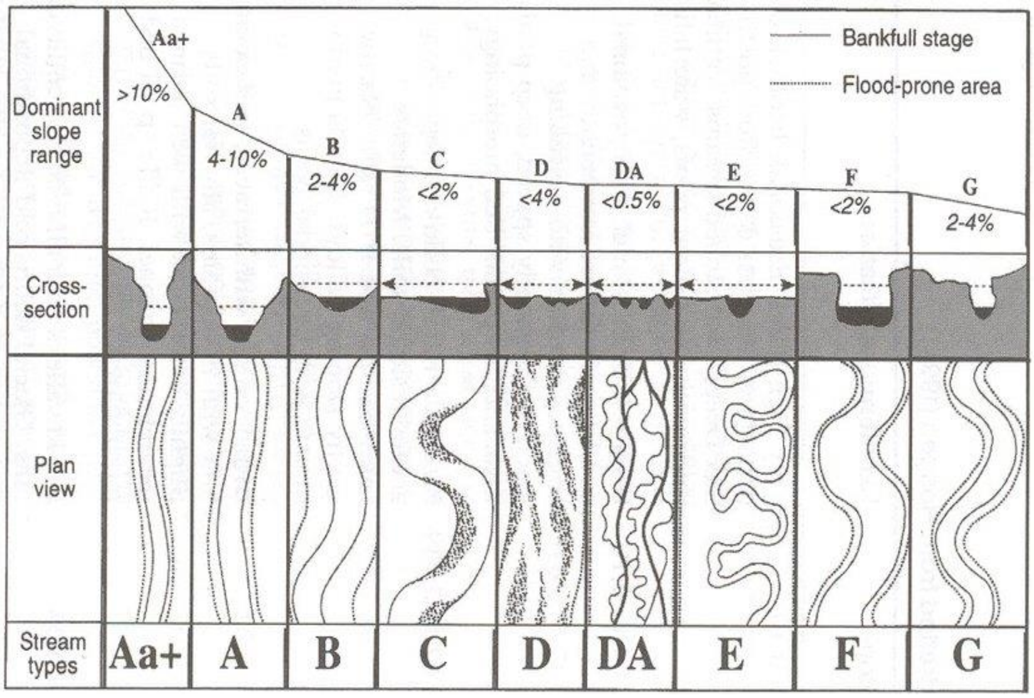


Fig 5.4.1.7: Longitudinal-cross-sectional-and-planform-views of major channel types (after Rosgen 1994)

Cross profile 1-10 are extracted from the upper course of River Tlawng. According to the classification made by Rosgen the cross profile of the upper course of River Tlawng represents an Aa+ and A stream type where valleys are narrow (15m) and vertical erosion is prominent. The average stream velocity is about 0.2.m/s. The valleys are mostly V-Shaped due to resistant bank material which results in active down cutting by the river fueled by higher velocity of the river and high gradient in the upper course of the river. The middle course-cross profile 11 to 20 represents B stream type. Here valleys are 30-40 m wide and depth is about 2-4.m. Here valleys started to open up due to increase in river discharge and gradual change in bed and bank material. As river discharge increases lateral erosion is in progress and the channel started to widen. The lower course-21 to 30 cross profile is characterized by C in the initial lower course and E stream type at the lower reaches of the river. The channel type migrates from a gravel bed to alluvial channel. The valleys are almost flat and the channel is at its widest. The average channel width and depths are about 70 -110 and 2-3m respectively. The river started to meander due to low gradient of the channel.

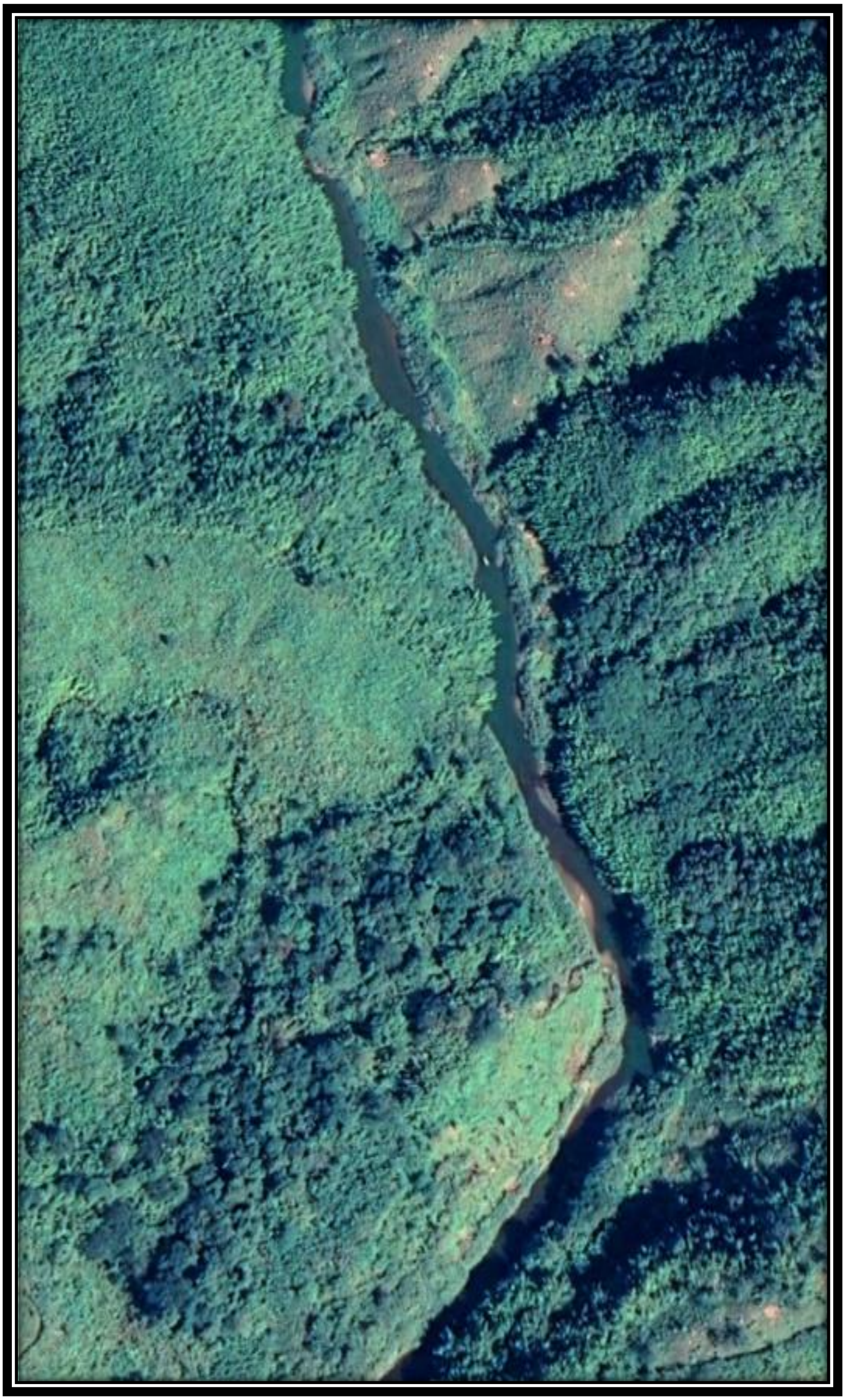


Plate 5.4.1.1: A type Channel at Lunglei (Upper course).

Fig 5.4.1.2: B type Channel at Khamrang (Middle course).

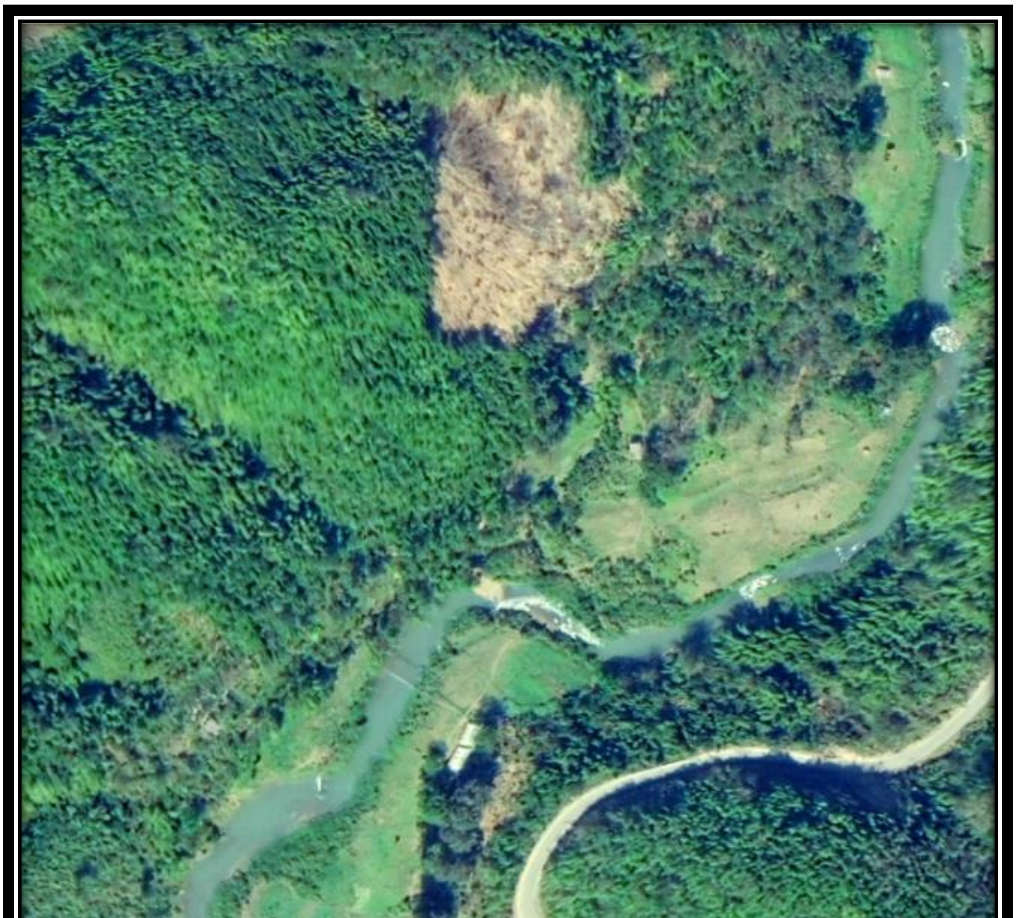


Fig 5.4.1.3: Aa+ type channel at Lunglei (World Bank Road Bridge)

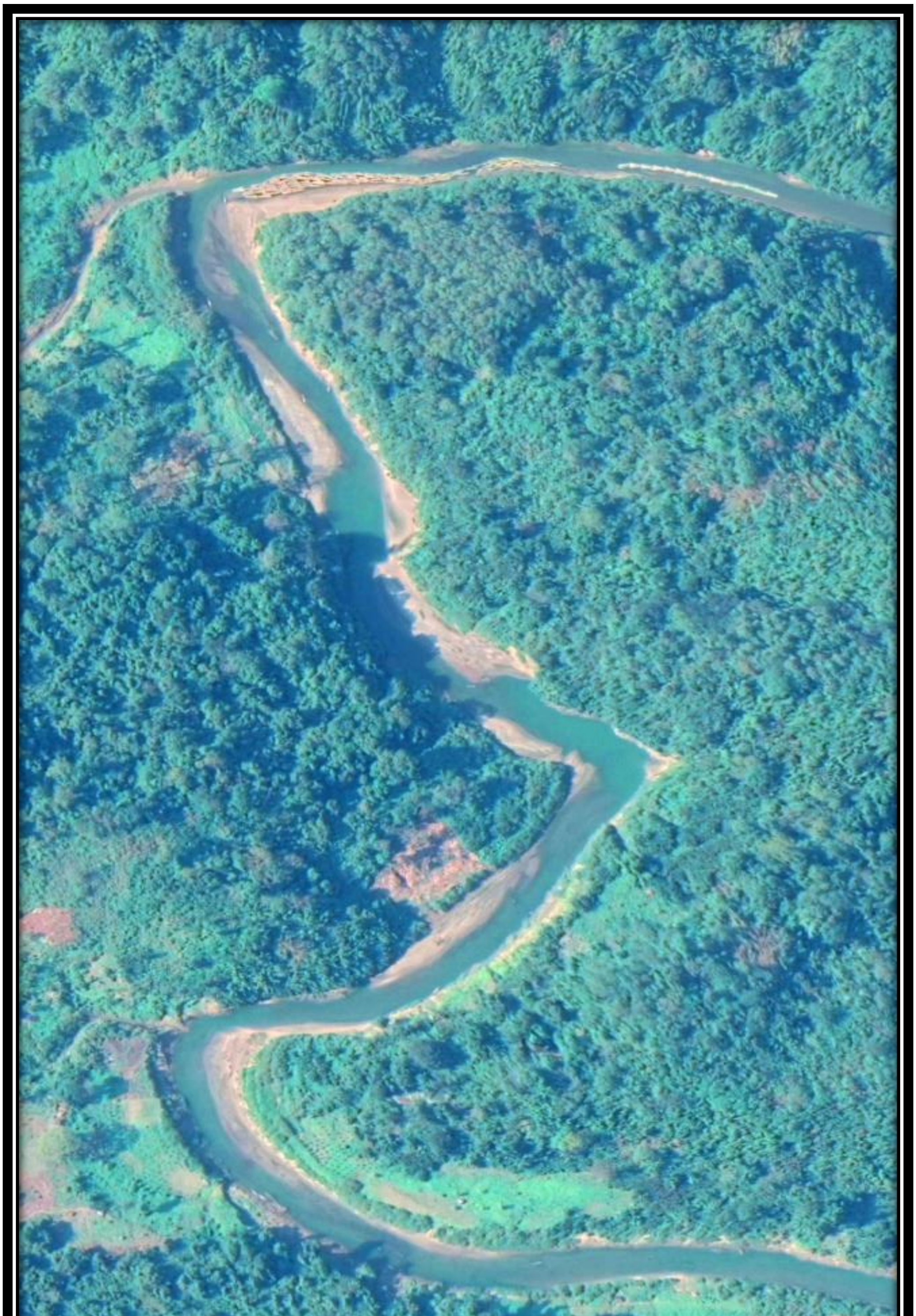


Fig 5.4.1.4: C type channel near Bairabi town.

Fig 5.4.1.5: E type channel at Rangaba (Lower course).

5.4.2 Longitudinal profile

Longitudinal profile provide a powerful platform with which to analyse interactions among many attributes of river systems. The longitudinal profile of a river depicts the change in channel gradient from its headwaters to its mouth, thereby showing the rate of change of slope (or gradient) with distance downstream. The longitudinal profile of a stream is a cross-sectional plot of its elevation from its headwaters downstream to its mouth. Longitudinal profiles of rivers provide clues to underlying materials as well as insights into geologic processes and geomorphic history of an area (Hack 1960).

The longitudinal profile of River Tlawng displays a sharp drop in elevation from 1200 metres to 600 metres within a distance of about 20 kilometres in the upper course of the river. From here the profile descends gradually at a low gradient towards the mouth of the river. In the middle course the profile drops slightly from 135 kilometres to 140 kilometres. The river profile declines smoothly at a low rate in the lower course. Local perturbations in the longitudinal profile, such as a local steepening, are caused by variations in the geologic substrate, water and sediment input from tributaries. No major knick points are identified along the profile from its source to mouth.

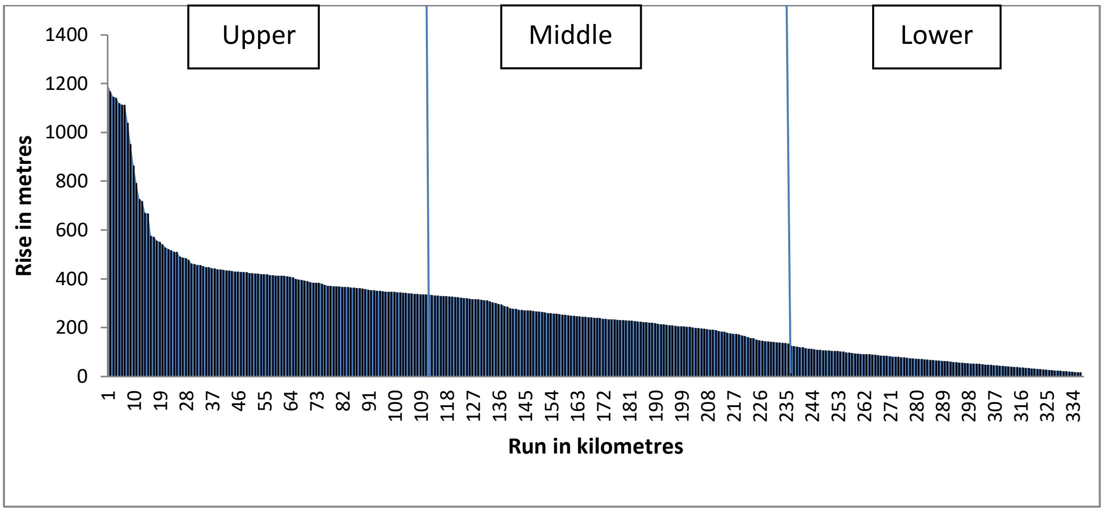


Fig 5.4.2.1: Longitudinal profile of Tlawng river.

5.4.3 Sinuosity

Sinuosity is the ratio between channel length and valley length. Rivers meander in order to maintain a channel slope in equilibrium with discharge and sediment load. On a meandering river, sinuosity is the ratio of channel length to valley length. A river meanders when the straight-line slope of the valley is too steep for equilibrium—the sinuous path of the meanders reduces the slope of the channel. Any tectonic deformation that changes the slope of a river valley may result in a corresponding change in sinuosity to maintain the equilibrium channel slope (Pinter 2002).

Muller (1968), defined channel sinuosity (S) as the ratio between the stream length (Sl) to the valley length (Vl), which is expressed as S = Sl/ Vl. Sinuosity index can be computed as the ratio of the length of channel to length of valley axis (Brice, 1964). According to the Brice, if the sinuosity index of a reach is 1.3 or greater, the reach is considered as meandering, a straight reach has a sinuosity index of 1 and reaches which is having sinuosity indices between 1.05 and 1.3 are defined as sinuous.

Type	Sinuosity
Straight	< 1.05
Sinuous	> 1.05
Meandering	> 1.5
Braided	> 1.3
Anastomosing	> 2.0

Table 5.4.3.1: Classification of Channel Pattern in terms of Sinuosity Index (after Morisawa 1985).

The channel length (CL) of River Tlawng is 320 kilometres from source to mouth while the valley length or air length (VL) is calculated as 230.2 kilometres. Sinuosity index has been computed as the ratio of the length of channel to length of valley axis - CL/VL. The river is having a sinuosity index value of 1.39 which according to Morisawa, is a sinuous channel. The upper course of the river has a channel length (CL) of 102.77 kilometres and a valley length (VL) 99.8 kilometres. It can be considered as a sinuous channel with 1.03 sinuosity index value. With a sinuosity index value of 1.9 and a channel length (CL) and value length (VL) of 125.742 and 66.51 kilometres the middle course can be said as a meandering channel. The channel length (CL) and valley length (VL) of the lower course is 89.689 kilometres and 67.96 kilometres respectively. Its sinuosity index value is 1.31. Low sinuosity is imposed by valley alignment.

Section (Course)	Channel length (km)	Valley length (km)	Sinuosity Index
Upper	102.77	99.8	1.03
Middle	125.742	66.51	1.9
Lower	89.689	67.96	1.31
River Tlawng (source to mouth)	320	230.2	1.39

Table 5.4.3.2: Sinuosity indices of Tlawng river.

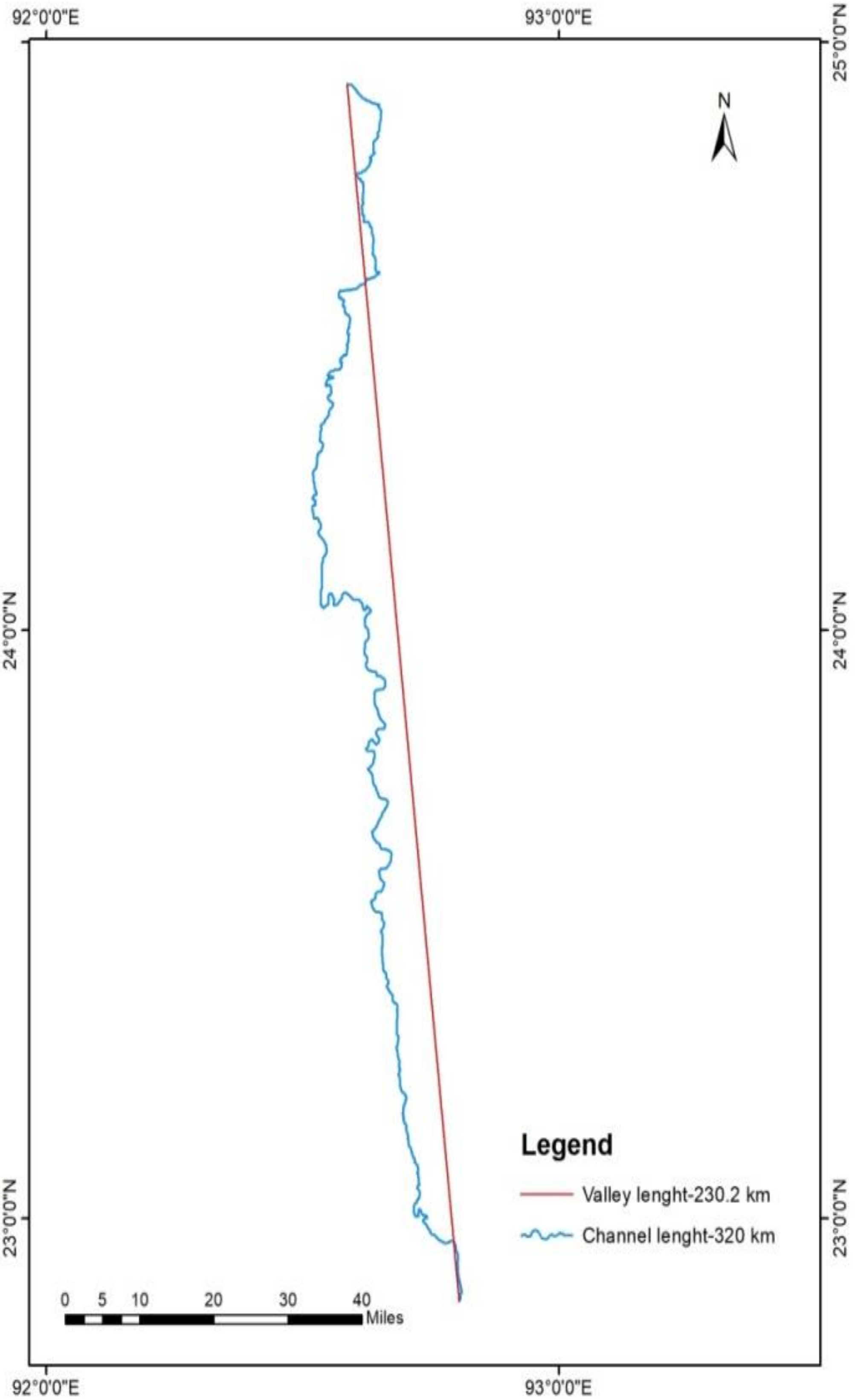


Fig 5.4.3.1: Sinuosity index map of Tlawng River.

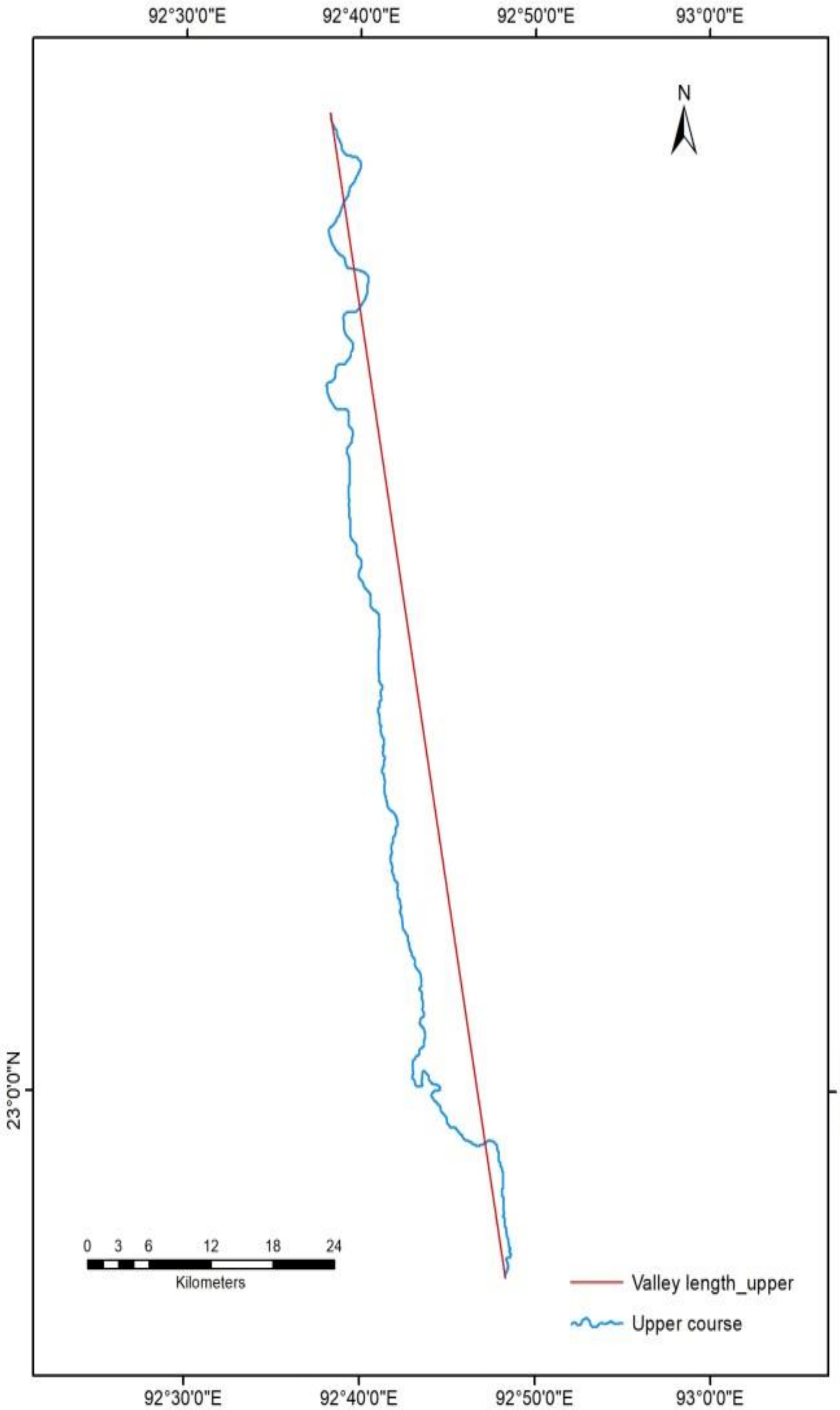


Fig 5.4.3.2: Sinuosity in the upper course

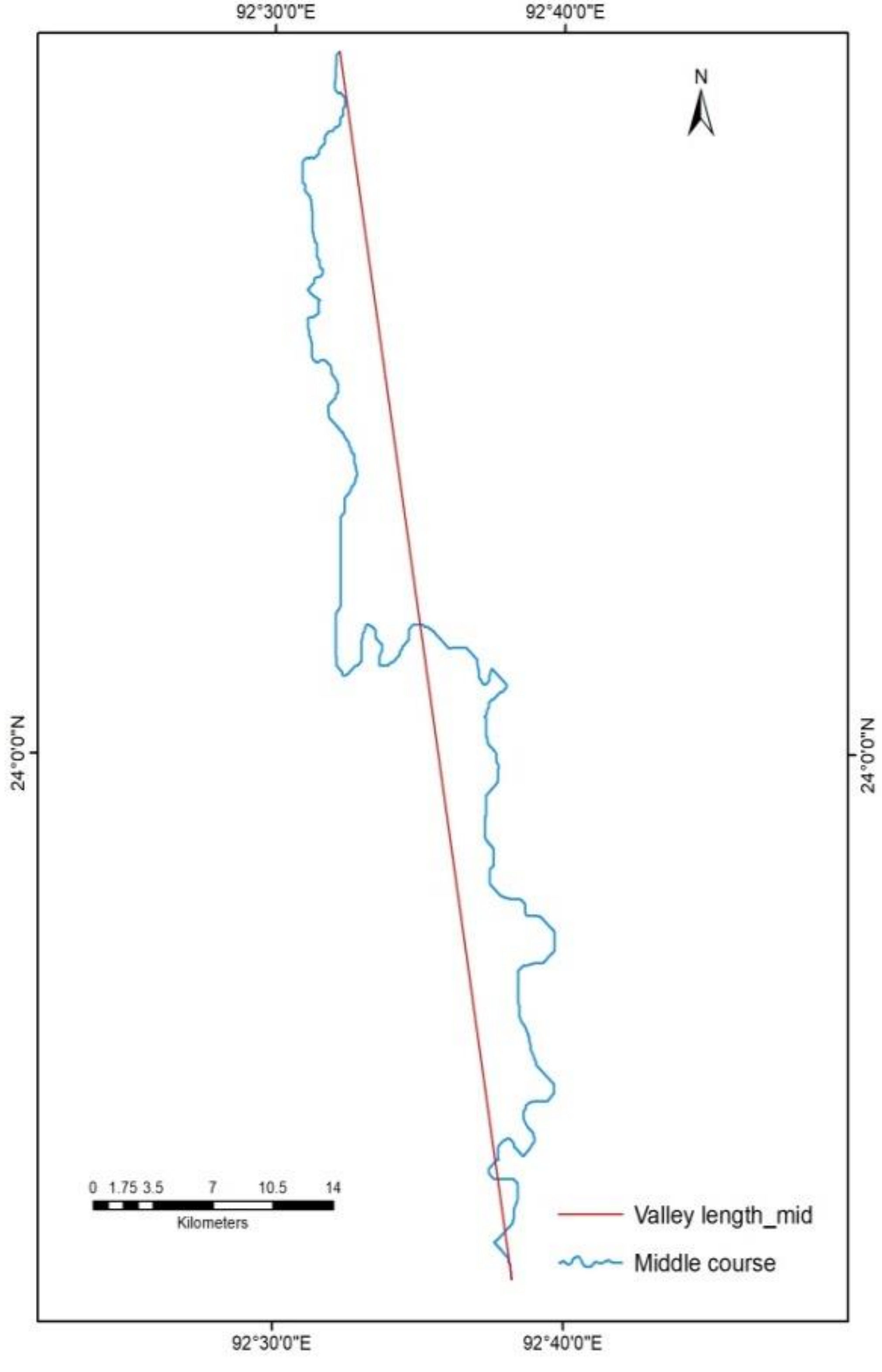


Fig 5.4.3.3: Sinuosity in the middle course

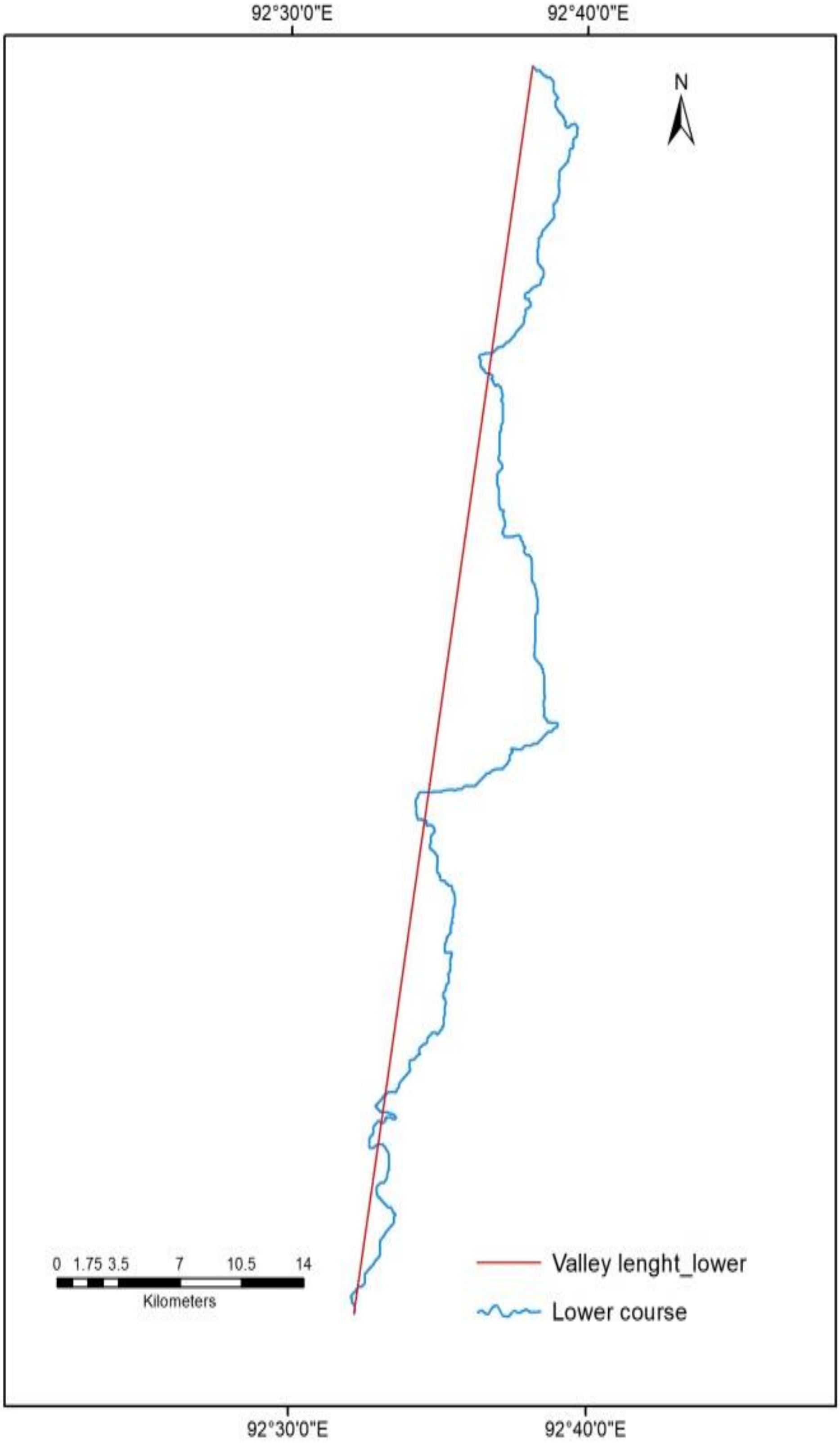


Fig 5.4.3.4: Sinuosity in the lower course

5.4.4 Channel Gradient

Gradient is the slope of the stream and is measured by the difference in elevation between two points on a stream divided by the distance between the two points that the water actually flows. Gradient is usually expressed as a drop in elevation over a given lateral distance, in feet per mile or a drop of metres per kilometre. The gradient influences the velocity of the stream. The steeper the gradient, the higher will be the velocity if all other factors are held constant. For calculating the channel gradient of River Tlawng 'rise over run' formula has been used. River Tlawng rises up to 1200 metres in its source and have a flow length of 320 kilometres from source to mouth. The channel gradient of River Tlawng is 0.004% or 1: 0.004 which means that the river channel descends by 0.004 metre for every 1 metre of run.

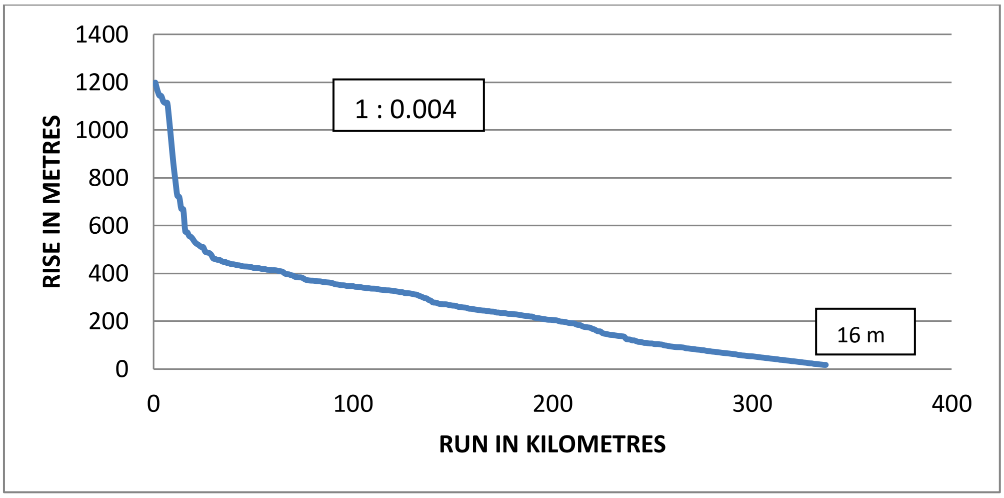


Fig 5.4.4.1: Channel gradient of Tlawng river.

A steep gradient would be closer to a 1:1 ratio of elevation to distance, whereas a lesser gradient would be .5:1 ratio, or less. With a channel gradient of 1: 0.004 River Tlawng may be considered as having a medium to steep gradient. From Fig 5.4.4.1 it can be ascertained that there is a rapid change of elevation in the upper reach of the river. This rapid change of elevation can be attributed as the main reason for the steep channel gradient of the river as the river slopes gently in the middle and lower course of the river.

5.5 Channel Fluid Dynamics

Channel fluid dynamics may be defined as the movement of river water in its channel from source to mouth. It is influenced by factors such as gradient, width and confinement, roughness, discharge and sediment. Rivers with early or youth stage are at a higher gradient as compared to rivers in the later stage. As the upper course of River Tlawng is in an early or youthful stage (Fig 6.11.3.2) the channel gradient is steeper than the middle and lower course. This results in higher velocity of river water (0.20 mps average) in the upper course of the river and leads to the formation various erosional landforms along the channel. The velocity is reduced to 0.08 mps (average) with increased in roughness because of the presence of heavy bed load and resistant rocks along the bed and bank of the river (Plate 5.5.1). The kind of sediments that are moving across the channel also governs the flow. Higher bed load decreases the velocity of the river water.

As the wide of the channel increases downstream to about 70-100m the River Tlawng becomes shallower at some reaches. Because of shallower depth most of the river water is in contact with the bed and bank. This results in more friction with channel bed and bank and as such the velocity of the river is reduced.

River discharge governs how fast or slow the river flows. Regions with higher discharge have higher flow of water and have lesser contact with the river bed which increases the river velocity. With an increase in discharge in the initial lower course (Bairabi) the river velocity increases with an average velocity of 0.33 mps. Having a uniform and steady channel the River Tlawng is unlikely to change its pattern with time as the river velocity does not fluctuate much throughout the river channel.

Station	Average Velocity (mps)
Lunglei	0.20
Sairang	0.10
Ailawng	0.08
Bairabi	0.31

Table 5.5.1: Average velocity of River Tlawng at different stations

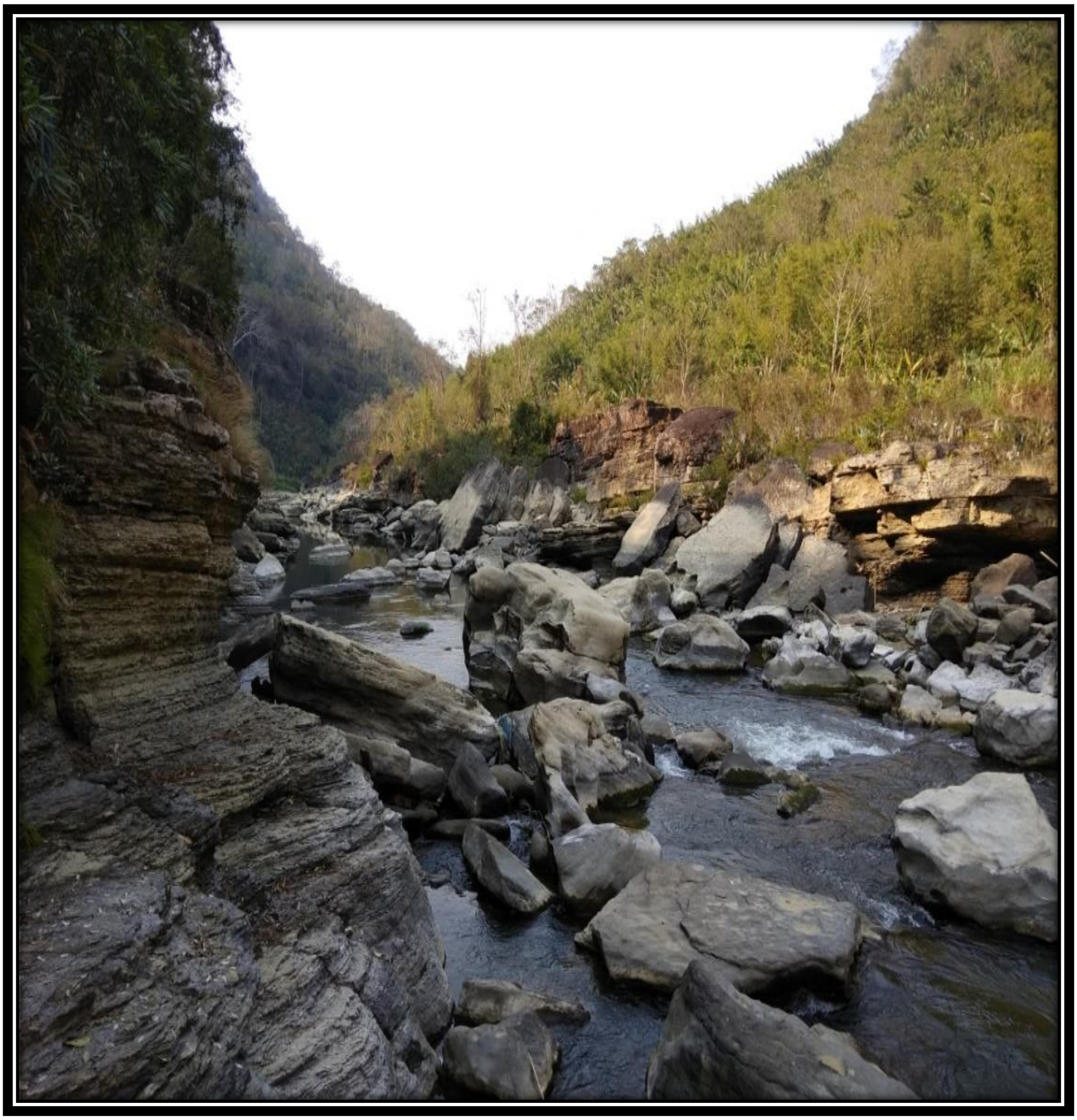


Plate 5.5.1: High roughness level in bed and bank of Tlawng river at Ailawng.

Plate 5.5.2: Tlawng river measurement by float method at Ailawng.

Plate 5.5.3: Tlawng river measurement by float method at Bairabi town.

5.6 Hydraulic Geometry

The hydraulic geometry of a river is totally governed by its flow or discharge. The channel discharge is the volume of water flowing through a given channel cross-section in a given time. These can be grouped into instantaneous measurements, where discharge is measured at a particular point in time, and continuous measurements for a record of discharge variations through time. The size of a river channel at a given point is largely determined by the discharge supplied from upstream. This is the volume of water that passes through a given channel cross-section in a given period of time. In the upper reaches of a river, the area drained – and hence the discharge – is relatively small. As you move downstream, discharge and channel size generally increase with the upstream drainage area.

The discharge of River Tlawng is measured by using- Area Velocity Method:

$$Q = w.d.v$$

where, Q is stream discharge (m3/s), w is the stream width (m), d is the mean depth of the stream in a cross section (m), and v is the mean flow velocity in the cross-section (m/s).As a rule of thumb, the mean velocity and width–depth ratio (w/d) both increase downstream along alluvial channels as discharge increases (Huggett 2007). River discharge has been measured at Lunglei (Pukpui), Sairang, Ailawng and Bairabi. In Sairang, Ailawng and Bairabi town river discharge has been measured at three different points or stations i.e. three stations each at Sairang, Ailawng and Bairabi and two stations at Lunglei town. In order to examine the influence of seasonal variation of weather conditions on the dynamics of the river, discharge has been measured in both lean and rainy season.

	DISCHARGE (Dihmunzawl)		
YEAR	MONTH	DISCHARGE 'Q' ML/D	REMARKS
2010	1st March	182.3	Area-velocity method
	20th March	127.01	
	27th March	125.28	Water level rises due to rainfall
	24th April	224.64	
	Total	659.23	
2011	8th Feb	202.95	Area-velocity method
	15th Feb	187.17	
	8th March	174.53	After 15th March water level again rises
	15th March	173.66	due to rainfall
	Total	738.31	
2012	11th Feb	123.43	Area-velocity method
	17th Feb	115	Discharge is lower than previous years
	25th Feb	76.5	Discharge increases after rainfall
	Total	314.93	
2013	18th March	132.72	Area-velocity method
	23rd March	124	Average discharge recorded
	28th March	121.4	
	Total	378.12	

	DISCHARGE (Dihmunzawl)		
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2010	1st March	182.3	Area-velocity method
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	15th Feb	187.17	
	8th March	174.53	After 15th March water level again rises

	15th March	173.66	due to rainfall
	Total	738.31	
2012	11th Feb	123.43	Area-velocity method
	17th Feb	115	Discharge is lower than previous years
	25th Feb	76.5	Discharge increases after rainfall
	Total	314.93	
2013	18th March	132.72	Area-velocity method
	23rd March	124	Average discharge recorded
	28th March	121.4	
	Total	378.12	

Table 5.6.1: River discharge at Dihmunzawl (source PHE Department)

Lunglei	Cross Section Area (in square metre)	Discharge in cumecs (6th Oct 2018)	Million liters per day (mld)
Station 1	34.2	1.035	89.4
Station 2	10.54	0.695	60
		May 2018	
Station 1	25.7	8.8	760

Table 5.6.2: River discharge at Lunglei town.

Sairang	Cross Section Area (in square metre)	Discharge in cumecs (6^{th} Feb 2017)	Million liters per day (mld)
Station 1	10.41	1.8	155
Station 2	19.9	2.1	181
Station 3	28.64	2.5	216
		August 2017	
Station 3	118.7	17.8	1538

Table 5.6.3: River discharge at Sairang.

Ailawng	Cross Section Area (in square metre)	Discharge in cumecs (3^{rd} March 2017)	Million liters per day (mld)
Station 1	26.4	1.42	122
Station 2	53.3	4.3	371
Station 3	45.98	4.1	354
		Sept 2017	
Station 2	127.7	178.8	15646

Table 5.6.4: River discharge at Ailawng.

Bairabi	Cross Section Area (in square metre)	Discharge in cumecs (1^{st} Feb 2017)	Million liters per day (mld)
Station 1	49.04	11.27	973
Station 2	25.63	8.20	708
Station 3	29.06	11.33	978
		Sept 2017	
Station 1	198	1251.4	108086

Table 5.6.5: River discharge at Bairabi town.

In Lunglei the average river discharge during lean season is 0.865 cubic metre per second (cumecs) while it is 8.8 cumecs during rainy season. The average river discharge at Sairang in dry season is 2.13 cumecs and 17.8 during rainy season. In Ailawng average discharge in lean season is 3.3 cumecs and leaped to 178.8 cumecs in rainy season. While in Bairabi the average discharge is 10.3 cumecs during lean season and rapidly rises to 1251 cumecs during rainy season. The discharge of River Tlawng increases downstream as shown in table (5.6.6 & 5.6.7) The river discharge also changes at a point and along the channel with the change in season. An important factor for this change is increase in rainfall. It can be said that discharge has a direct relationship with rainfall, the more the rainfall greater is the river discharge.

River Tlawng has been experiencing the worst possible flood within the last five decades during the year 2016, 2017 and 2018. Higher rainfall has been experienced in the month of March to September during these three years when compared with the previous years (Tab 2.1). Hundreds of houses located on the bank of the river have been completely submerged and evacuated. Continuous rains have caused extensive damage in many districts within the study area. The worst hit areas are Sairang, Hortoki and Bairabi town as valleys are wider and flatter than other areas. This results in an increase in the wetted perimeter during high floods. Clearing of forest cover in the catchment areas of the river for cultivation of crops increases the run off rate. This greatly contributes to a surge in the river discharge. People lost their home, their possession because of the sudden natural occurrence.

Station	Rainfall(in mm)	Discharge (in cumecs)
Lunglei (Sept 2018)	121.4	0.865
Sairang (Feb 2017)	5.7	2.13
Ailawng (March 2017)	124.4	3.3
Bairabi(Feb 2017)	5.7	10.3

Table 5.6.6: Rainfall discharge comparison during lean Season.

Plate 5.6.1: Flood in Sairang town in the year 2017.

Plate 5.6.2: Food in Bairabi town leading to evacuation of houses.

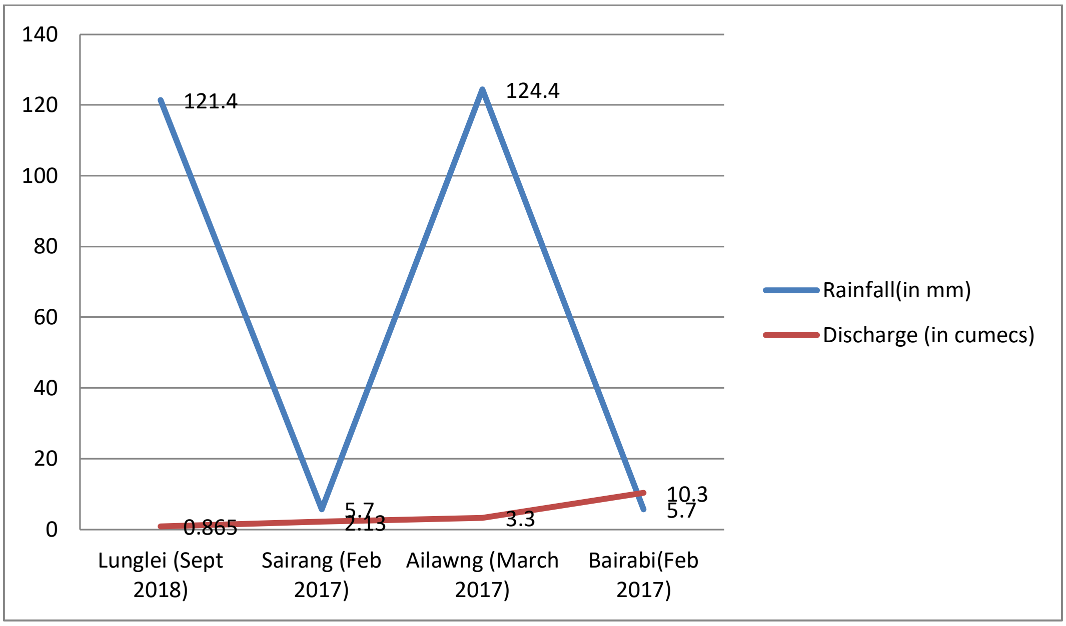

Fig 5.6.1: Rainfall discharge comparison during lean Season.

Station	Rainfall(in mm)	Discharge (in cumecs)
Lunglei (July 2018)	363.4	8.8
Sairang (Aug 2017)	441	17.8
Ailawng (Sept 2017)	344.7	178.8
Bairabi(Sept 2017)	344.7	1251

Table 5.6.7: Rainfall discharge comparison during rainy season.

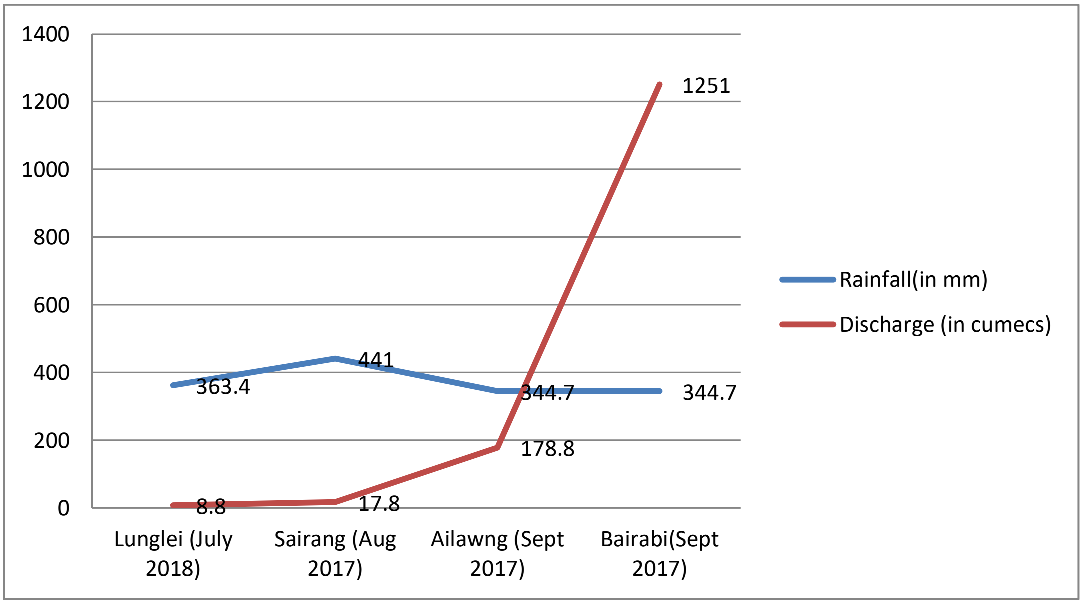

Fig 5.6.2: Rainfall discharge comparison during rainy season.

Year	Month	Rainfall	Discharge(Mld)
2010	March	102.5	144.8
	April	191.3	224.64
2011	Feb	1.3	195.06
	March	54.7	174
2012	Feb	15.4	104.9
2013	March	3.6	126.04

Table 5.6.8: Rainfall and discharge comparison at PHE site Dihmunzawl.

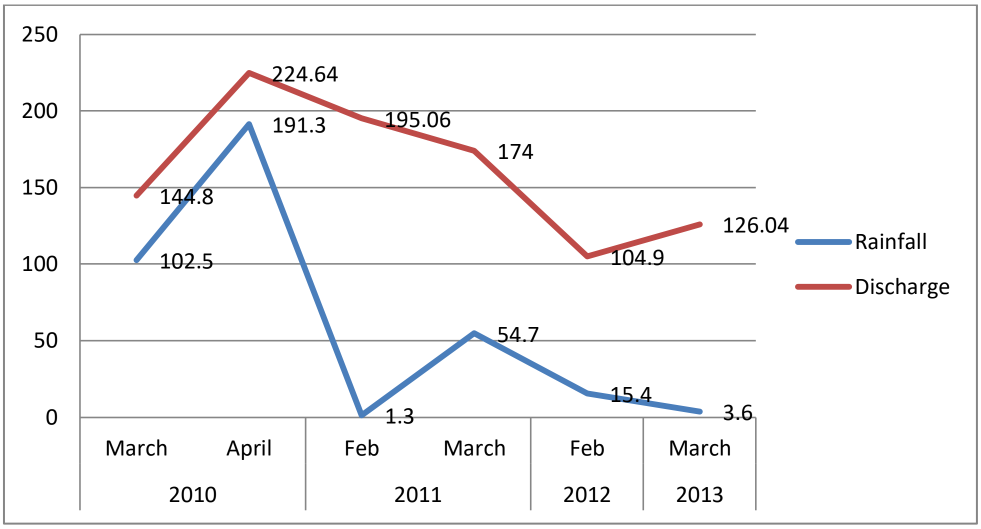

Fig 5.6.3: Rainfall (mm) and discharge (cumecs) comparison at PHE site Dihmunzawl.

From tables above it can be ascertained that the discharge of River Tlawng upsurges with an increase in rainfall at a point and along the channel. As the number of tributaries rises along the river channel discharge also increase downstream. Despite of low rainfall, stations with large cross section area and higher velocity have greater discharge than stations with high rainfall, low velocity and small cross section area (Tab 5.6.9). As a rule of thumb larger the cross section area greater is the river discharge, if velocity being the same.

Station	Area(in sqm)	Rainfall (in mm)	Velocity(mps)	Discharge(cumecs)
Lunglei	22.7	121.4	0.2	0.86
Sairang	19.65	5.7	0.1	2.13
Ailawng	41.89	124.4	0.08	3.3
Bairabi	34.57	5.7	0.33	10.3

Table 5.6.9: Hydraulic parameters during lean season.

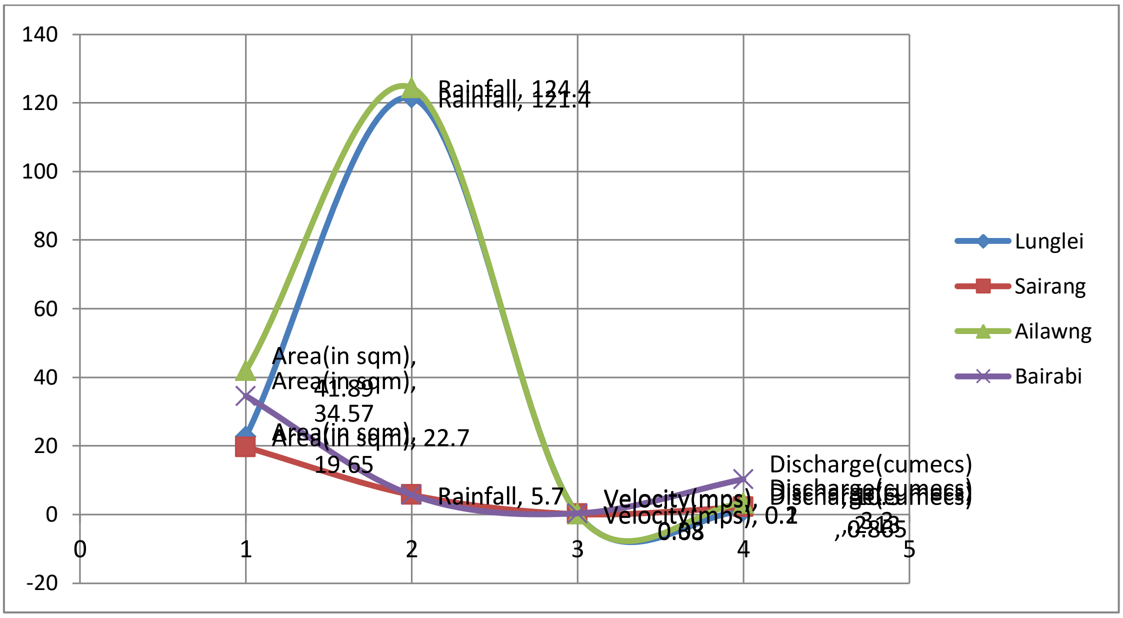

Fig 5.6.4: Relationship between different hydraulic parameters during lean season.

Station	Area(sqm)	Rainfall(in mm)	Velocity(mps)	Discharge (in cumecs)
Lunglei (July 2018)	28.27	363.4	0.31	8.8
Sairang (Aug 2017)	118.7	441	0.5	17.8
Ailawng (Sept 2017)	127.7	344.7	1.4	178.8
Bairabi(Sept 2017)	198	344.7	6.32	1251

Table 5.6.10: Hydraulic parameters during rainy season.

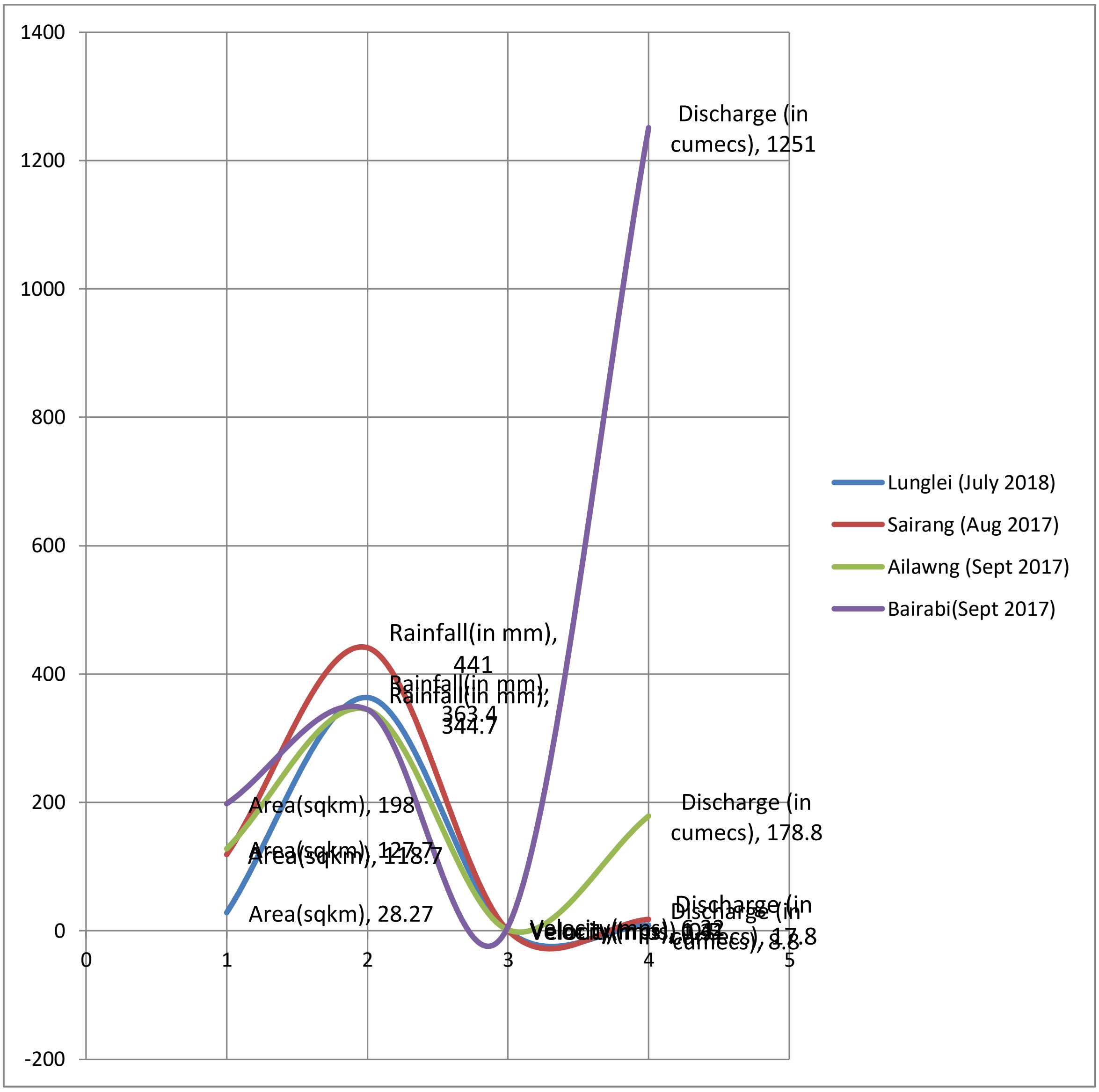

Fig 5.6.5: Relationship between different hydraulic parameters during rainy season.

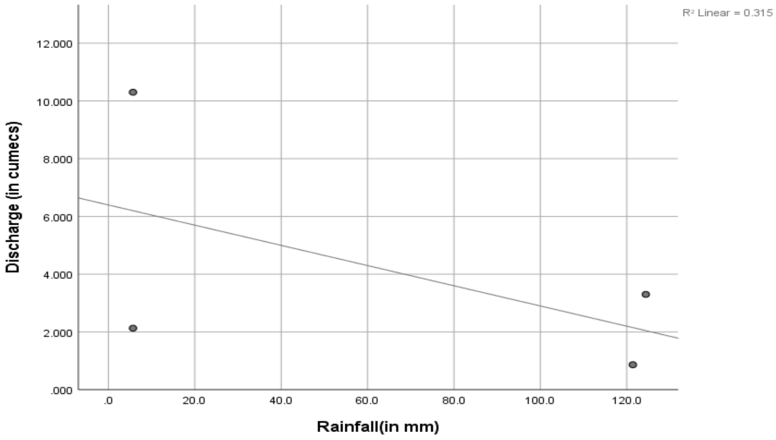

Fig 5.6.6: Simple Scatter plot with Fit Line of Discharge (in cumecs) by Rainfall (in mm).

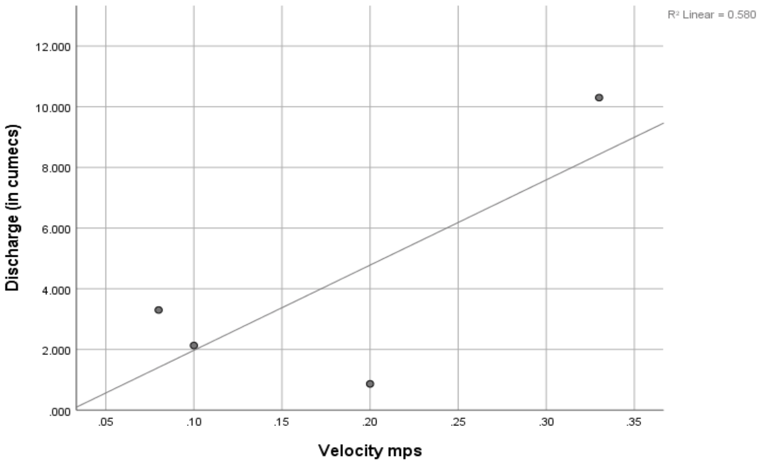

Fig 5.6.7: Simple Scatter plot with Fit Line of Discharge (in cumecs) by Velocity mps.

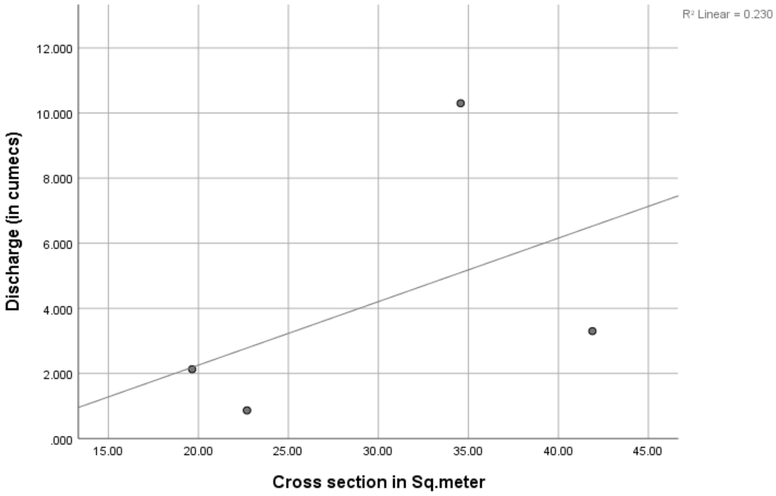

Fig 5.6.8: Simple Scatter plot with Fit Line of Discharge (in cumecs) by Cross section in km^2

When calculating the impact of rainfall and river velocity on river discharge (regression analysis) the value of R square is .664 which means that river velocity and rainfall have 66% contribution in river discharge. Rainfall and cross section area have an R square value of .778. This indicates that rainfall and cross section area have 77% contribution on the volume river discharge. While cross section area and river velocity has an R square value of .776. Thus cross section area and river velocity again have 77% impact on the volume river discharge.

Variables		R Square value
Rainfall and Velocity	River Discharge	.664
Rainfall and Cross section		.778
Velocity and Cross section		.776

Table 5.6.11: Comparison of rainfall, velocity, cross section with river discharge

5.7 References

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CHAPTER VI

DRAINAGE PROPERTIES

Drainage morphometric parameters are important indicators to understand the terrain condition, hydrological and morphological characteristics of a region. Morphometric analysis provides a quantitative description of a drainage network in a basin. Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface including shape and dimensions of the landforms (Clarke 1966). Further, the morphological characteristics of drainage network provide very important clues as it discharges voluminous water along its course which influences the morphology of a drainage basin. The morphometric analysis includes the study of different linear, areal and relief aspects such as stream ordering, stream number, stream length, mean stream length, stream length ratio, Rho coefficient, bi-furcation ratio, drainage density, stream frequency, drainage texture and relief aspects like basin relief, relief ratio, relative ratio and ruggedness number, which give impetus in understanding morpho-dynamics of the river Tlawng. The techniques of Remote Sensing and Geographical Information Systems have been used as efficient tools in delineating and analyzing different drainage properties.

6.1 Stream order

Stream order provides a measure of the relative size and pattern of channels within a drainage network. This exerts a significant influence upon the relative discharge of streams at any point of a drainage network. In any drainage network analysis, the streams are classified into different orders according to the number of bifurcations. Various methods of stream ordering were suggested by earlier workers. Davis (1930) proposed a genetic approach to drainage pattern. However, the most important quantitative approach to drainage analysis was proposed by Horton (1945) and Strahler (1952). According to Strahler (1952) perennial streams without tributaries are termed first-order. When two streams of equal order come together, the downstream reach is increased by one order. The trunk stream or the main stream through which all the discharge of the water is carried out is the stream of the highest order. The study area is a 6th order drainage basin. A total of 7638 streams are identified in Tlawng river basin out of which only 3847 are 1st order streams. There are 1848 2nd order streams, 874 3rd order streams, 443 4th order, 474 5th order streams and 148 streams in the 6th order. According to Zaidi (2011), the topography is still undergoing erosion if the number of stream is more, whereas less number of streams indicates matured topography.

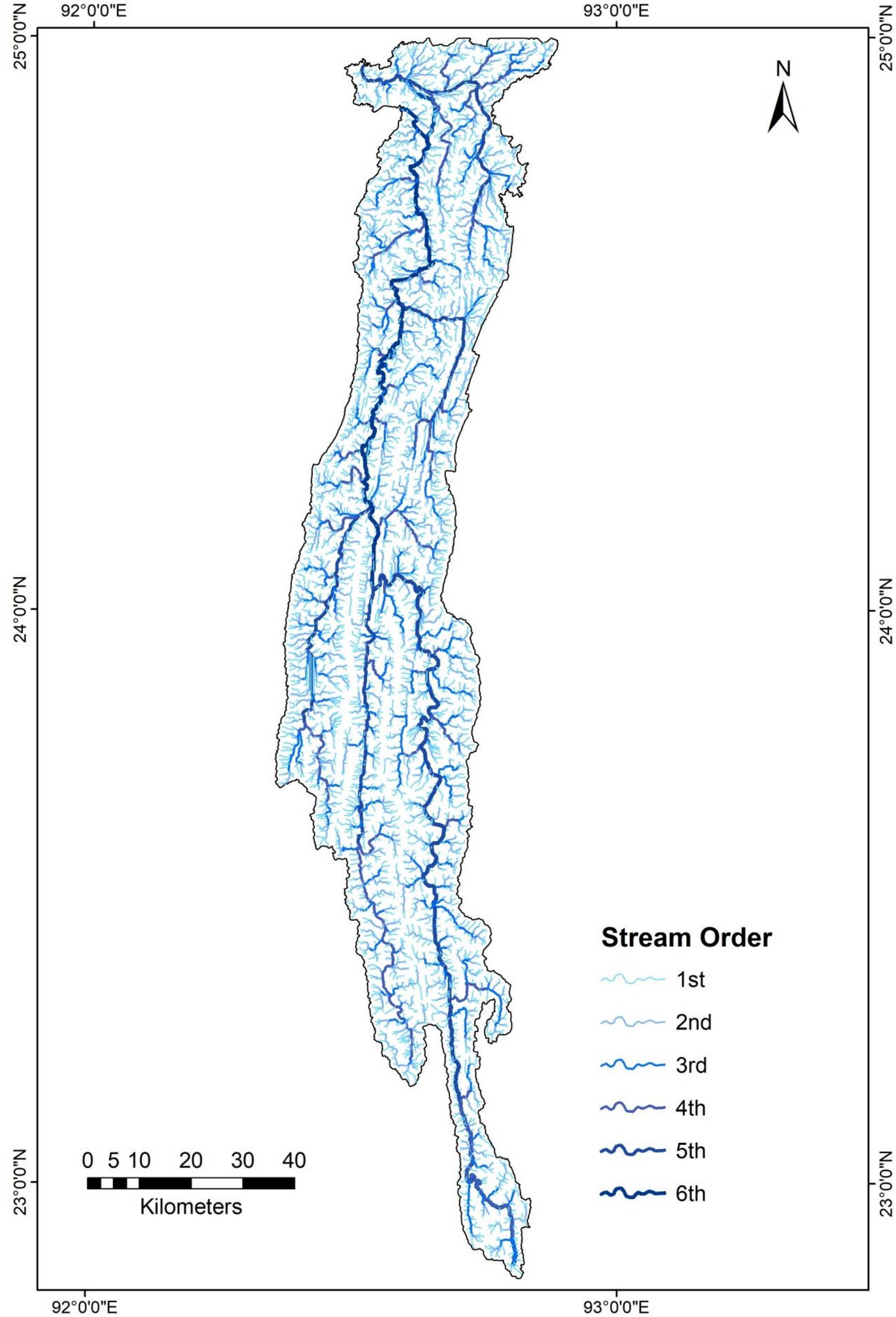

Fig 6.1.1: Stream ordering of Tlawng River Basin

6.2 Stream Number

The number of stream segments (Nu) present in each order is known as stream number. According to Horton (1945), the number of stream segments of each order forms an inverse geometric relationship with order number. A total of 6736 streams are present in the drainage basin (Table 6.2.1). From table 6.2.1, it is clear that the number of streams decreases with an increased stream order. The presence of more number of streams in the basin is expected to change the morphology of the channels at many sections influenced by the local topography and high discharge as observed.

6.3 Stream length

Stream length (Lu) is measured from the mouth to the drainage divide. The total length of all streams in the basin is 2156.45 km. The 1st order streams have a length of 3484 km and the stream length of the 2nd order is 1678 km. The length of 3rd order streams is 737 km and 4th order streams have a stream length of 359km. Fifth order and sixth order streams have a length of 352 and 126 km, respectively (Table.6.2.1) The length of the main channel is about 320 km. The total stream length of first order streams is by far greater than the second, third, fourth fifth and sixth order streams. As proclaimed by Horton (1945) the total stream length of respective orders decreases with increasing order of streams. As more number of streams is present in higher orders it influences the channel morphology of the lower orders in the downstream sections.

Stream Order	Stream Number (Nu)	Stream Length (Lu) (in km)	Mean Stream Length(Lum)	Stream Length Ratio (RL)	Rho co efficient(For Basin)
1	3487	3848	1.10	1.79	
2	1848	1678	1.97	0.42	
3	878	737	0.84	0.96	0.50
4	443	359	0.81	0.88	
5	474	352	0.72	1.18	
6	148	126	0.85		
	Total - 7638	*Total*- 6736			

Table 6.2.1: Stream order, Stream number, Stream length, Mean stream length, Stream length ratio, Rho co-efficient

6.4 Mean Stream Length

According to Strahler (1964) mean stream length (Lsm) is a dimensional property revealing the characteristic size of components of a drainage network and its contributing watershed surfaces. From table 6.2.1 it is observed that the mean stream length ranges from 0.85-1.97. Normally mean stream length increases with increasing stream order, but the deviation observed may be due to slope and topographic variation in the different segments of the stream.

6.5 Stream Length Ratio

Stream length ratio (Rl) is the mean length of the one order to the next lower order of the stream segments (Das *et.al*. 2012). A variation in the stream length ratio from one order to another order indicates the development of the late youth stage of streams. The stream length ratio in the study area varies from 0.42 – 1.79.

6.6 Bifurcation ratio

The bifurcation ratio (Rb) is the ratio of the number of streams in a given order to the number in the next higher order (Horton, 1945). Horton (1945) considered the bifurcation ratio as the index of relief and dissection. The lower value of bifurcation ratio is the characteristic feature of the drainage basin which have flat or rolling plain while the higher values of bifurcation ratio indicates strong structural control on the drainage pattern and have well-dissected drainage basins (Horton 1945; Fryirs and Brierley 2013). The bifurcation ratio of Tlawng drainage basin ranges from 0.93 to 3.20. The mean bifurcation ratio of the basin is 2.05. The higher the bifurcation ratio, the shorter will be the time taken for discharge to reach the outlet, hence there will be higher peak discharge. This will lead to greater probability of flooding. Hence, Tlawng river has a low chance of flooding as it has a low bifurcation ratio.

Stream Order	Number of Streams	Bifurcation Ratio (Rb)	Mean Bifurcation ratio	Mean RL	Rho coefficient
1	3487	2.08	2.05	1.04	0.50
2	1848	2.10			
3	878	1.98			
4	443	0.93			
5	474	3.20			
6	148				

Table 6.6.1: Bifurcation ratio of streams in different orders

6.7 Rho coefficient

The Rho coefficient is an important parameter relating drainage density to physiographic development of a drainage basin which facilitate the evaluation of storage capacity of drainage network and hence, a determinant of ultimate degree of drainage development in a given watershed (Horton 1945). The Rho value of the Tlawng river basin is 0.50 which indicates low to moderate hydrologic storage during floods. This might have some effect on the morphological changes of the lower order channels like from 3^{rd} order streams up to the main channel.

6.8 Drainage Density

Drainage density is the stream length per unit area in a region of watershed (Horton 1945; Goudie, 2004; Selvan *et.al*., 2011). Drainage density is one of the most important linear aspects of the drainage basin. High drainage density reflects the highly dissected drainage basin and rapid hydrological response to the rainfall events while low drainage density shows slow hydrological response (Selvan 2011; Hajam *et.al*., 2013). The study area is divided into four classes of drainage density (Fig. 6.8.1), such as high drainage density (> 5 km/km^2) with an areal extent of 27 km^2, moderate drainage density (3-5 km/km^2) with an areal extent of 735 $km^{2,}$ low drainage density (1.5-3 km/km^2) of 2474 km^2 and very low drainage density (<1 km/km^2) occupies an area of about 2622 km^2. The major part of the Tlawng drainage basin has a low drainage density of 1.15 km/ km^2 covering an area of about 2474 km^2 which indicate that basin area has a resistant permeable subsurface material and a moderate to thick vegetation cover. Also it is noticed that many tributary streams dried up during lean season. According to Dingman (2009) low value of drainage density is one of the characteristics of the humid region. Due to major extent of the low and very low drainage density, river Tlawng can be considered as a uniform and steady channel where velocity is almost constant and stream pattern does not change much with time.

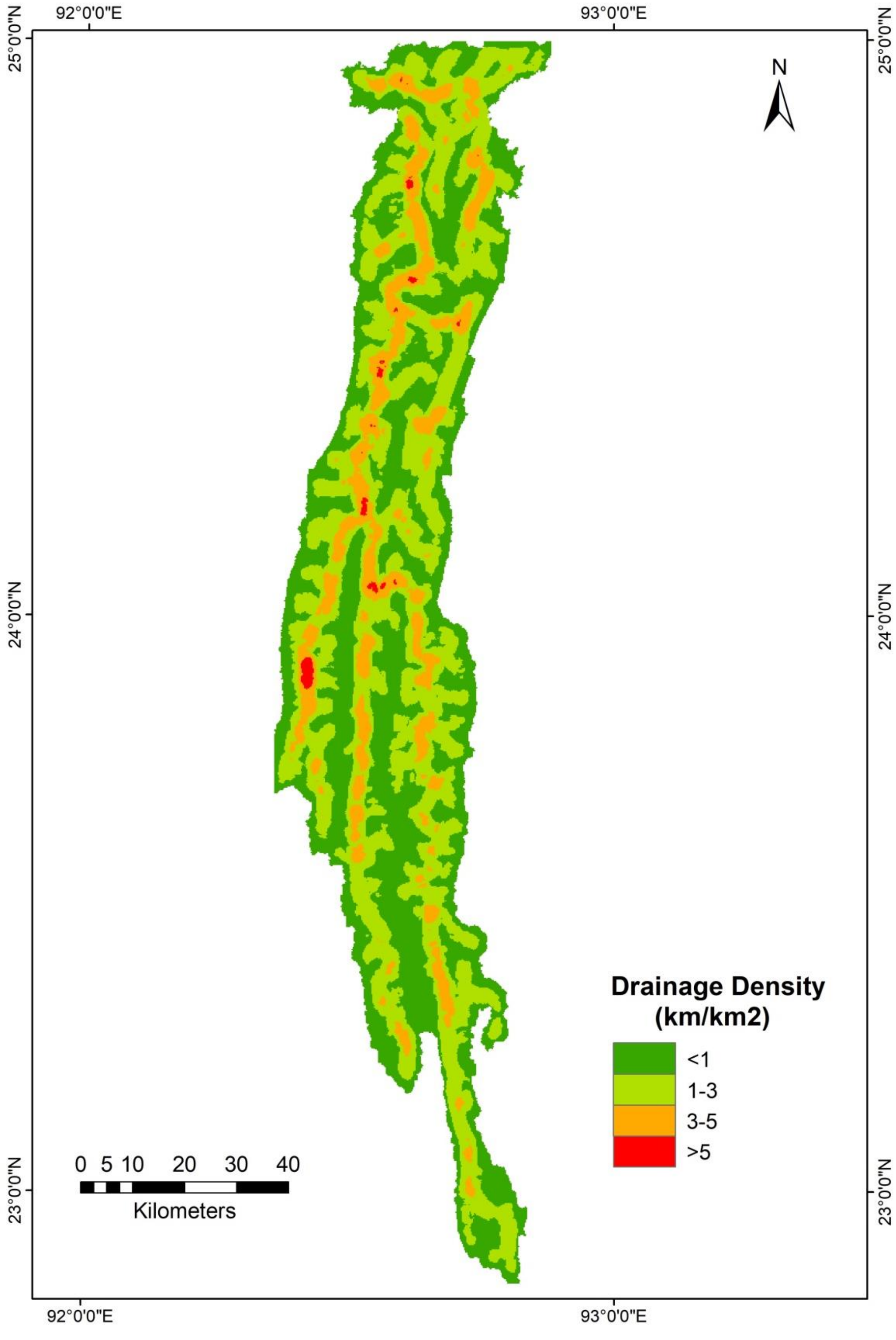

Fig. 6.8.1: Drainage density

6.9 Stream frequency

Stream frequency (Sf) is the total number of stream segments of all orders per unit area (Horton 1932). The stream frequency value of the Tlawng river basin is 1.30 streams / km^2 which shows a positive relation with drainage density. Stream frequency generally depends on the lithology of the drainage basin. The study area is divided into three frequency classes (Fig. 6.9.1), such as high stream frequency (> 5 streams/km^2) with an areal extent of 24 km^2, moderate stream frequency (2-5 streams/km^2) with an areal extent of km2, low stream frequency (<2 streams/km^2) of 3259 km^2. (Reddy *et al.*, 2004) stated that low stream frequency values indicate the presence of a permeable subsurface material and low relief. As the area is composed of permeable rocks like sandstones with an average relief of 377 m the Tlawng river basin shows low stream frequency.

Drainage Density (km/km^2)	Area (km^2)	Stream Frequency(no/km^2)	Area (km^2)	Drainage texture
<1	2622	<2	3259	
1.5-3	2474	2-5	2575	0.88
3-5	735	>5	24	
>5	27			

Table 6.9.1: Drainage density, Stream frequency, Drainage texture

6.10 Drainage texture

Drainage texture (Dt) is the total number of stream segments of all orders per perimeter of that area (Das *et.al.*, 2012). Drainage texture of any drainage basin depends on climate, rainfall, vegetation, soil and rock types, infiltration rate, relief and the stage of development (Horton 1945; Smith 1950). Smith (1950) has classified drainage texture into five different textures i.e., very coarse (<2), coarse (2 to 4), moderate (4 to 6), fine (6 to 8) and very fine (>8). Areas having low drainage density have coarse texture while areas with high drainage density have fine drainage

texture. The drainage texture of Tlawng river basin is 0.88, which falls under vey coarse drainage texture according to Smith. According to Horton (1945) the more drainage texture more will be dissection and leads more erosion which might affect the channel morphology at places.

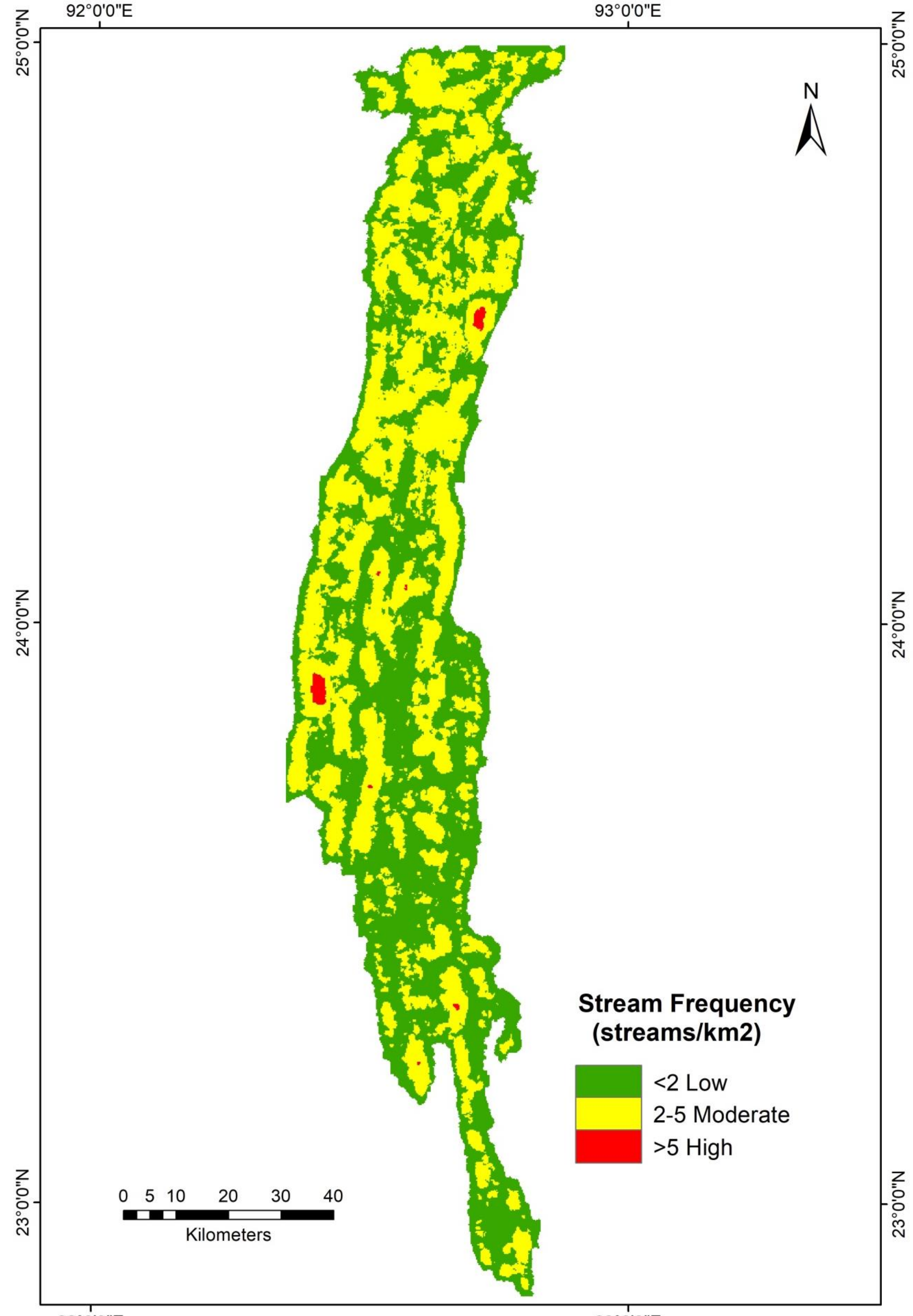

Fig 6.9.1: Stream frequency

6.11 Basin Relief

Relief may be defined as the difference in elevation of any part of the earth's surface or relative vertical inequality of land surface. Relief is commonly regarded as the range in altitude (Smith 1935). The difference in elevation between the highest point of a basin (H) and the lowest point on the valley floor (h) is called basin relief (Strahler 1957). The lowest point is 6 m, and highest point is 1598 m and moderate slope and moderate runoff. The relief values have been grouped into three categories such as 6-500 m (low), 500-1000 m (moderate) and above 1000 m (high). The relief value 6- 500m zone occupies about 4456 $km^2$of the basin area, moderate relief region of 500 to 1000 m covers maximum area of about 1239 $km^2$and above 1000 m high relief zone occupies about 60.3 $km^2$of the total basin area. Major portion of the basin area falls under low relief followed by moderate relief and high relief zone covers the smallest area in the basin

Relief Ratio (R_r)	Relative Relief (Rhp)	Ruggedness number(Rn)
4.75	0.19	1.83

Table 6.11.1: Relief ratio, Relative relief and Ruggedness number.

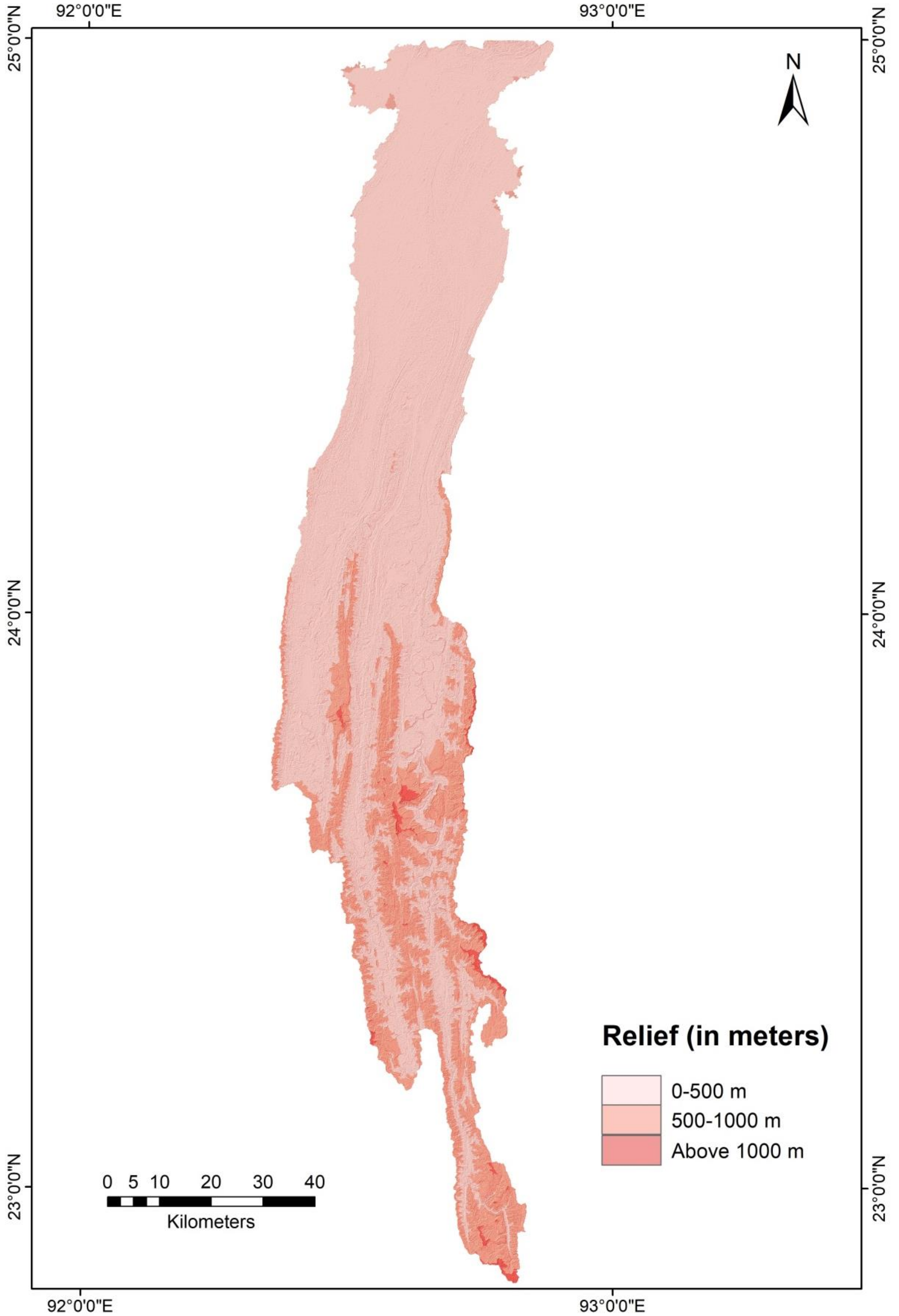

Fig 6.11.1: Relief map of the Tlawng River basin.

6.12 Relief Ratio

The relief ratio (R_r) may be defined as the ratio between the total relief of a basin and the longest dimension of the basin parallel to the main drainage line (Schumm 1956). If the values of relief ratio are high it indicates hilly region and low ratio indicates pediplain and valley region (Kumar *et al.*, 2011). Relief ratio measures the overall steepness of a drainage basin and is an indicator of the intensity of erosion process operating on slope of the basin (Schumm 1956). Relief ratio of Tlawng river basin is 4.75 indicating moderate relief and moderate slope which might affect channel morphology to some extent particularly, in the lower sections.

6.13 Relative Relief

Relative relief (Rhp), introduced by Melton (1957) is the ratio between the relief and perimeter of the watershed. Relative relief has been calculated by using perimeter and total basin relief introduced by Melton (1957) which is 0.19. This signifies that the land surface has low to moderate slopes. Relative relief is considered to be the most reliable potential predictor of denudation rates (Ahnert 1970; Summerfeld and Hulton 1994; Gunnel 1998). On account of the direct relationship between relative relief and denudation rates, it can be inferred that major denudational landforms are found in the northern part (lower course) of the basin (Fig 2.2).Denudation landforms in the northern part might affect the channel morphology from 3rd order streams.

6.14 Ruggedness number

Ruggedness number (Rn) is the product of the basin relief and the drainage density and usefully combines slope steepness with its length (Strahler 1957). Extremely high values of ruggedness number occur when slopes of the basin are not only steeper but long, as well (Chow 1964). The ruggedness number (Rn) of Tlawng river basin is 1.83. Ruggedness number is found to be directly proportional to relative peak discharge (Patton, 1988).

6.15 Hypsometric analysis

Mizoram is geologically considered as a part of Tripura-Mizoram depositional basin (Evans 1964). It is referred to as the southern extension of the Surma basin. It evolved after the regional uplift of Barail succession and thus, was related with the plate behaviour of subduction zone west of Arakan-Yoma, after the spreading of Indian Ocean (Evans 1964). Mizoram is drained by a number of rivers, streams and rivulets of different patterns and length (Pachuau 1994).The catchment areas of river Tlawng are prone to erosion due to intense monsoon and pre monsoon storms. Running water plays an important role in sculpturing landforms as large areas of land are exposed directly to rainfall as the land in the catchment areas are cleared for cultivation.

Hypsometric analysis was first time introduced by Langbein (1947) to express the overall slope and the forms of drainage basin. The hypsometric integral (Hi) is also an indication of the 'cycle of erosion' Strahler (1952); Garg (1983). Hypsometric analysis has been used to differentiate between erosional landforms at different stages during their evolution (Strahler 1952, Schumm 1956). Due to advent of remote sensing data (including derived digital elevation models) and open source GIS tools, the estimation process becomes easier than conventional method. Comparison of hypsometric curve (HC) shapes for different catchments developed under similar geologic, geomorphic and climatic conditions provide a relative insight into the erosional history and degradation processes of drainage basins. Furthermore, the shape of a hypsometric curve is an important indicator to recognize the landform erosion stage and evolution process with respect to the fluvial cycle of erosion, or the geological time needed to reduce terrain elevation to the base level (Farhan *et.al* ., 2006). Hypsometric analysis is useful for understanding the geomorphic stages of a river basin. Difference in HC shapes and deviation in HI values are often attributed to the degree of disequilibria in the balance of erosive and tectonic force.

6.15.1 Percentage Hypsometric Curve

Percentage hypsometric method, expressing the ratio of relative area and relative height with respect to the total height and total area of a drainage basin has been used on the study. For generating these curves the following ratios are used. The curve is created by plotting the proportion of total basin height (h/H = relative height) against the proportion of total basin area (a/A = relative area) (Figure 6.15.1.1). The total height (H) is the relief within the basin (the maximum elevation minus the minimum elevation).The total surface area of the basin (A) is the sum of the areas between each pair of adjacent contour lines. The area (a) is the surface area within the basin above a given line of elevation (/z).The value of relative area {a/A) always varies from 1.0 at the lowest point in the basin (where h/H - 0.0) to 0.0 at the highest point in the basin (where h/H - 1.0) (Keller *et.al.*, 2002).

(a) Relative height or h/H; where 'h' is the highest elevation between each pair of contours above the base and 'H' is the total basin height, represented on the ordinate and

(b) Relative area or a/A; where 'a' is the area enclosed by a pair of contours and 'A ' is the total basin area which is represented on the abscissa.

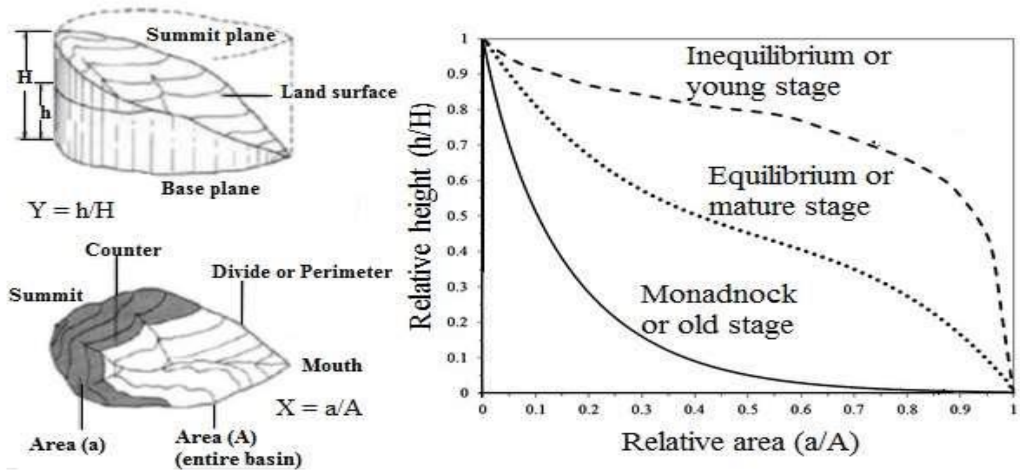

Figure 6.15.1.1: The concept of hypsometric analysis and the model hypsometric curves (Strahler, 1952; Ritter et al. 2002)

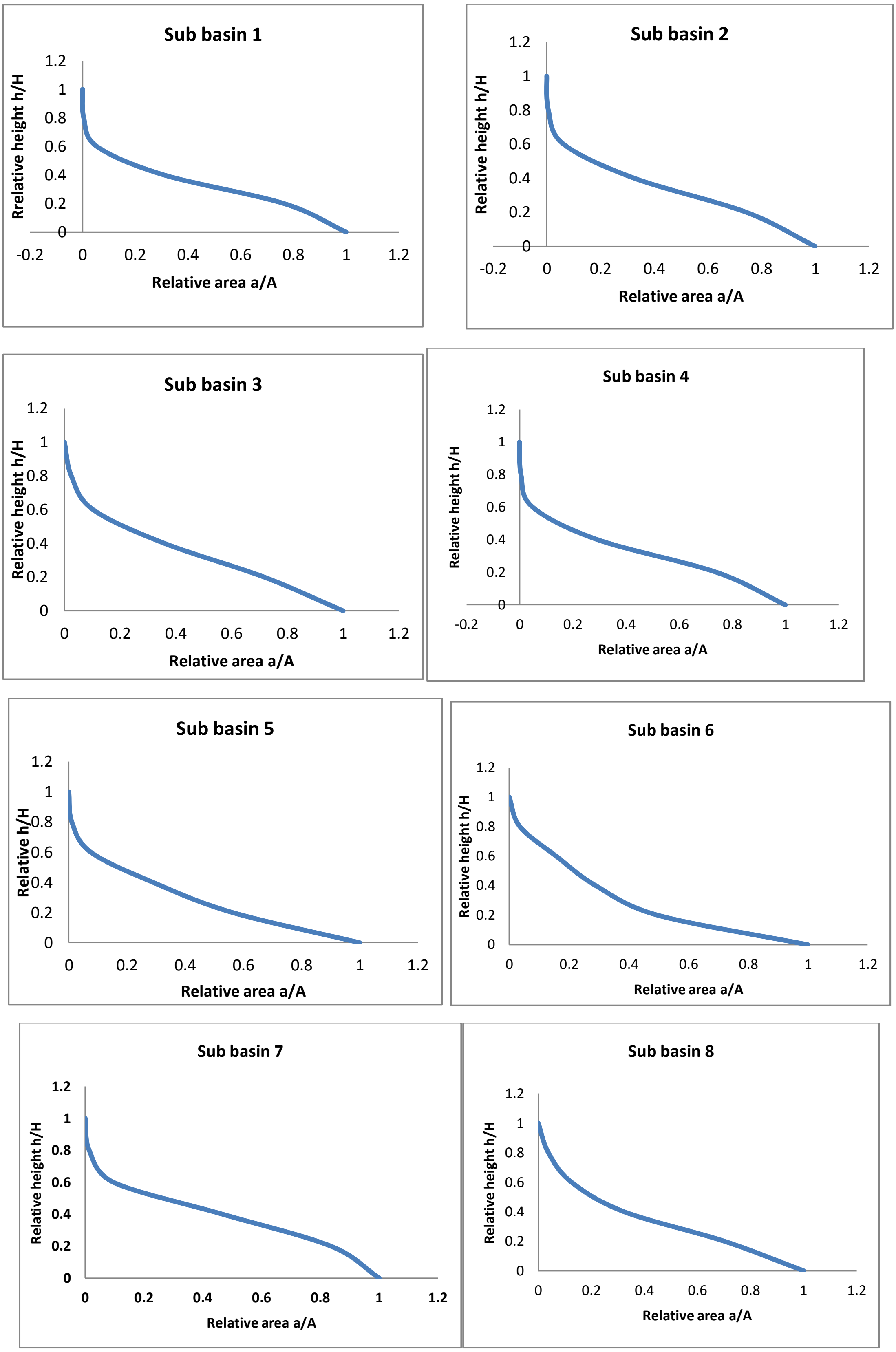

Figure 6.15.1.2: Hypsometric curves of Tlawng River sub-basins

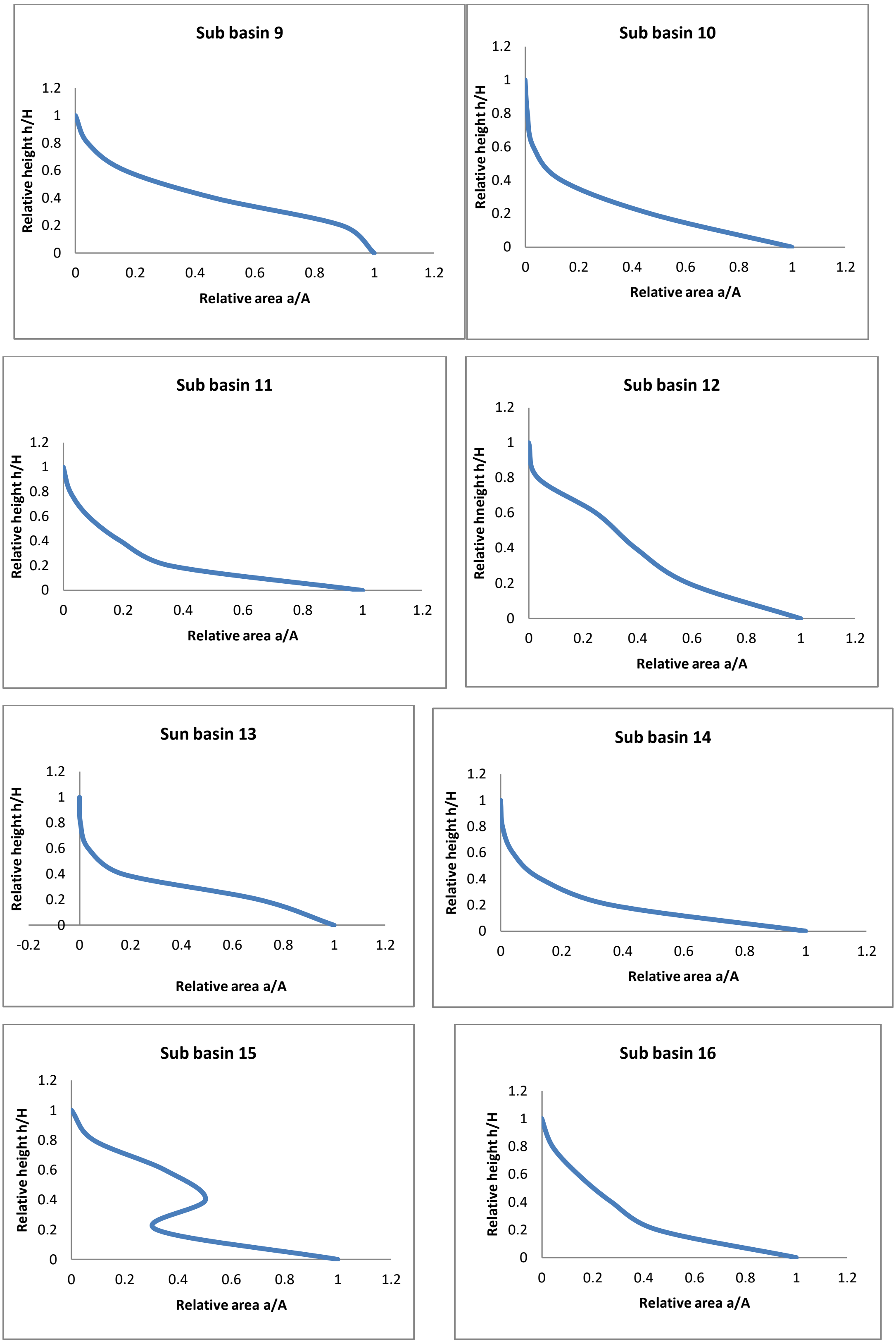

Figure 6.15.1.3: Hypsometric curves of Tlawng River sub-basins.

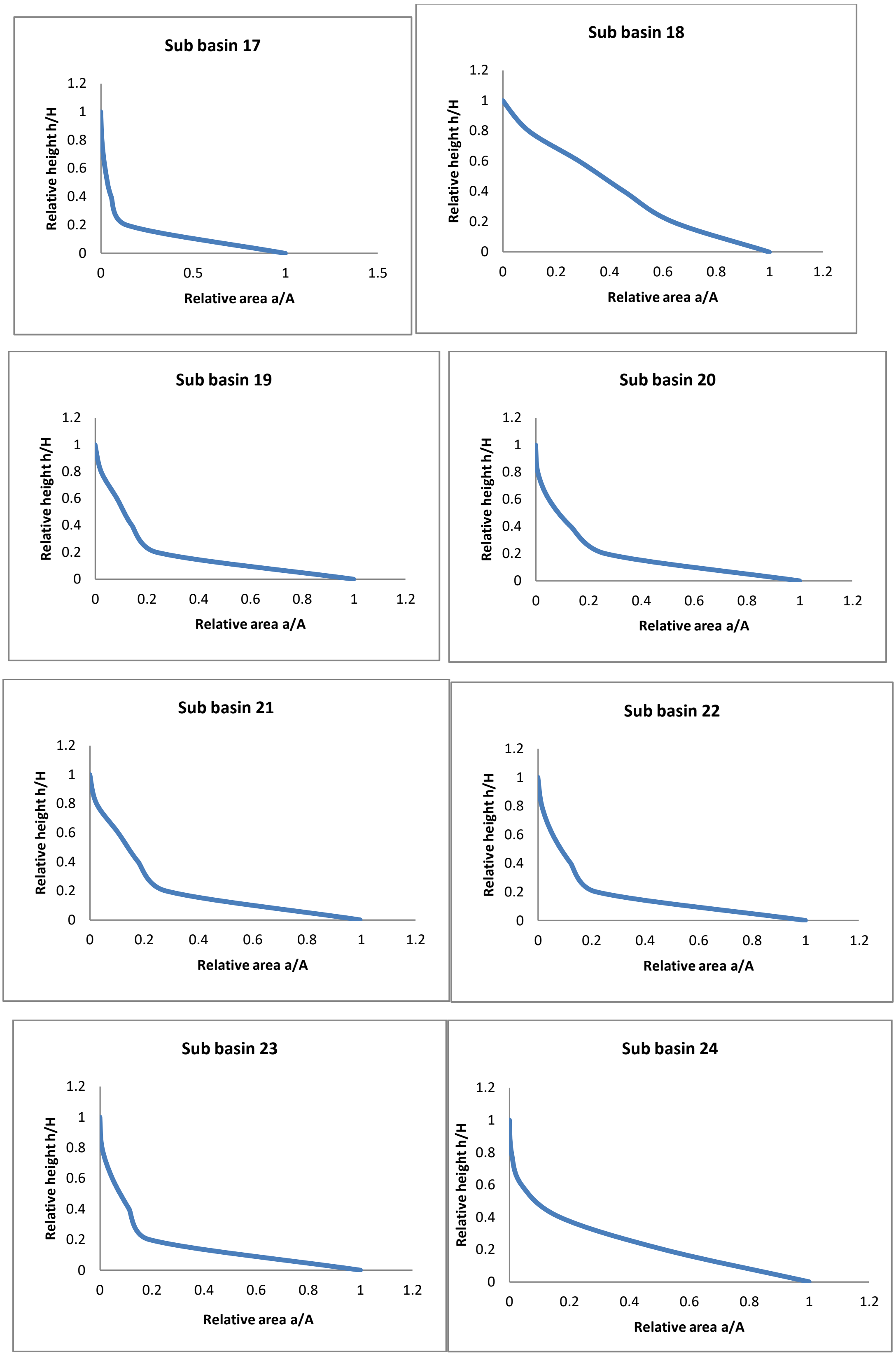

Figure 6.15.1.4: Hypsometric curves of River Tlawng sub-basins.

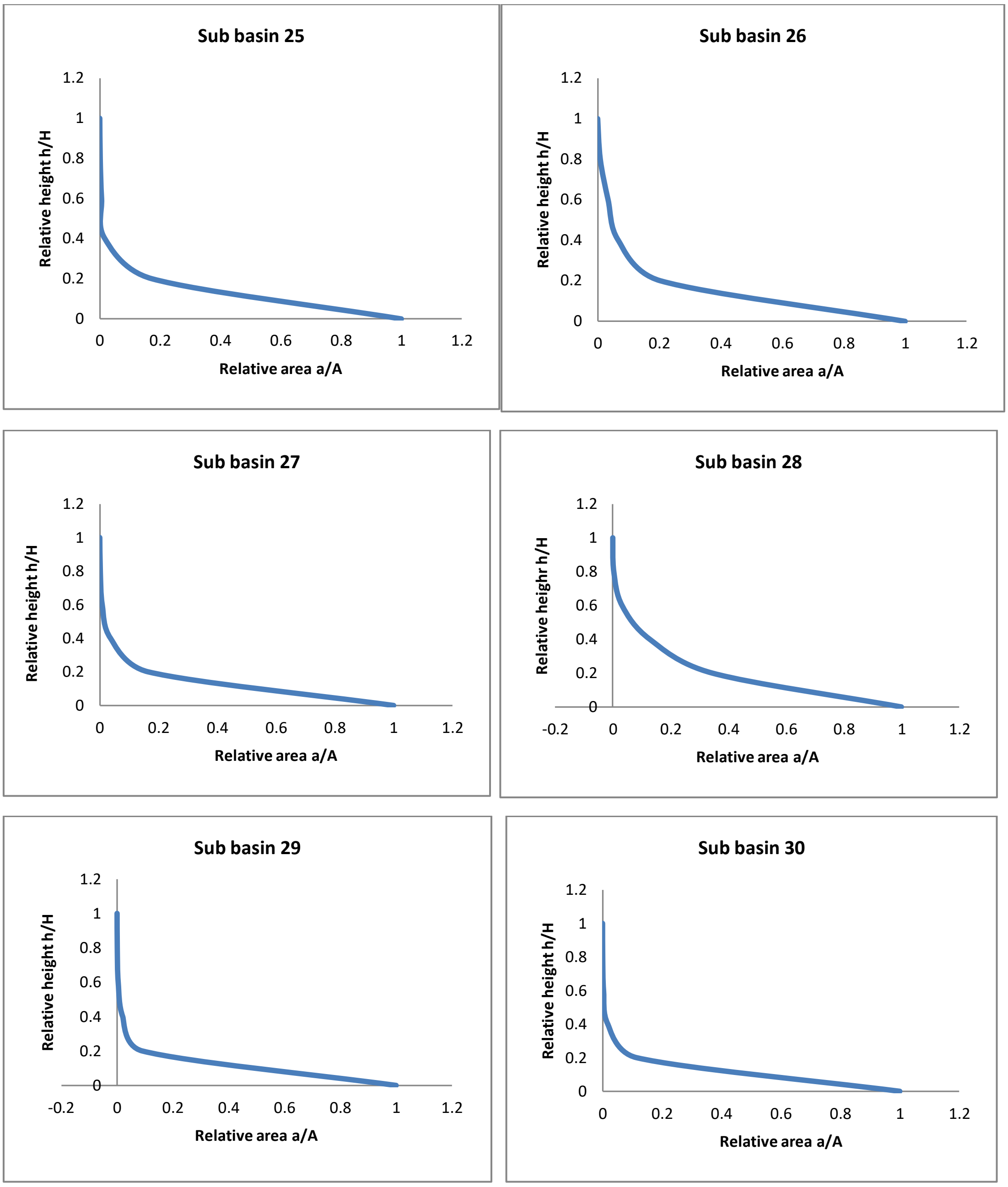

Figure 6.15.1.5: Hypsometric curves of Tlawng River sub-basins.

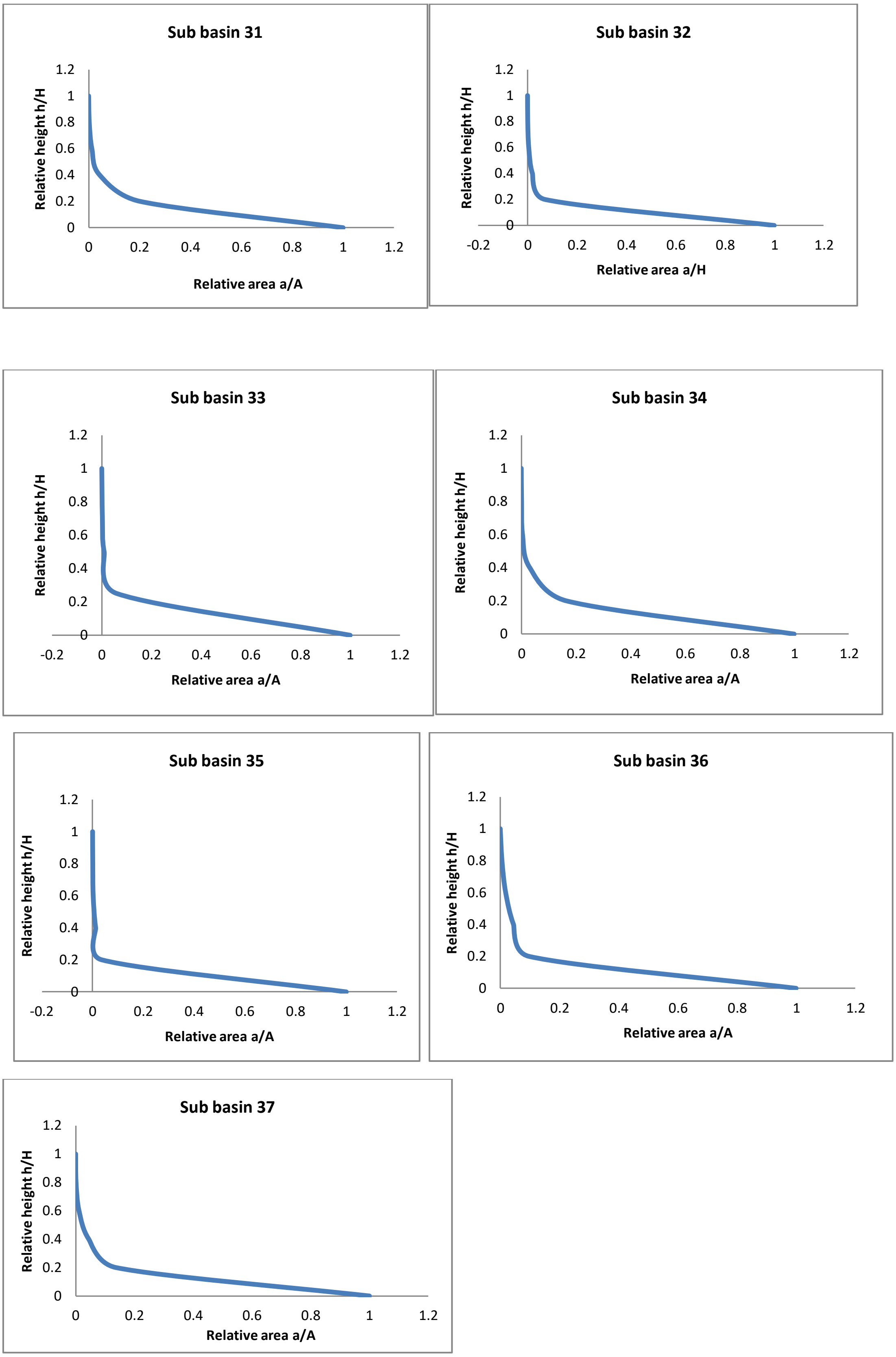

Figure 6.15.1.6: Hypsometric curves of Tlawng River sub-basins.

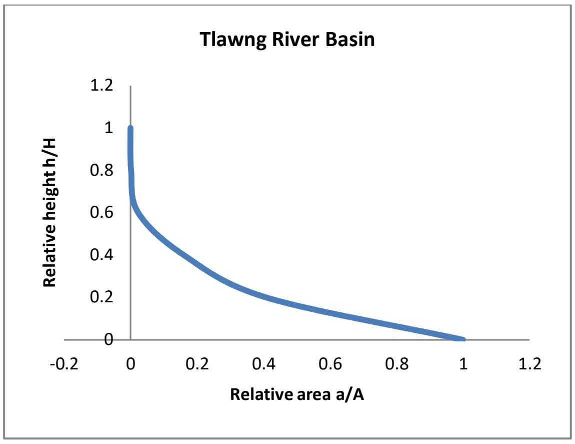

Figure 6.15.1.7: Hypsometric curve of Tlawng river basin.

For the study river Tlawng Basin have been divided into thirty seven (37) sub basins or catchment area hypsometric curve of River Tlawng Basin along with thirty seven (37) hypsometric curves for sub basins have been drawn from a DEM. The hypsometric curve of River Tlawng basin almost represents almost a S-shaped curve which signifies moving towards monadnock stage of development of a landscape (Fig 6.15.1.7). The hypsometric curves of the sub basins (Fig 6.15.1.2-6.15.1.6) ranges from convex to S-shape which indicates that the landscape is moving towards old or monadnock stage of erosion. This can be attributed to difference in lithology, incision of bed rock, down slope movement of eroded materials and removal of the sediments from the basin.

6.15.2 Hypsometric Integral

A simple way to characterize the shape of the hypsometric curve for a given drainage basin is to calculate its hypsometric integral (Hi).The integral is defined as the area under the hypsometric curve. The following formula has been used to compute hypsometric integral.

$$H_i = \frac{\text{mean elevation - minimum elevation}}{\text{maximum elevation - minimum elevation}}$$

Thus only three values, two of them easily obtained from a topographic map, are necessary to calculate the integral. Maximum and minimum elevations are read directly from the map. Mean elevation can be obtained by point sampling (on a grid) of at least 50 values of elevation in the basin and calculating the mean, or by analysis of Digital Elevation Models (DEMs). High values of the hypsometric integral indicate that most of the topography is high relative to the mean, such as a smooth upland surface cut by deeply incised streams. Intermediate to low values of the integral are associated with more evenly dissected drainage basins.

The relationship between the hypsometric integral and degree of dissection permits its use as an indicator of a landscape's stage in the Cycle of Erosion. The Cycle of Erosion describes the theoretical evolution of a landscape through several stages: a "youthful" stage characterized by deep incision and rugged relief, a "mature" stage where many geomorphic processes operate in approximate equilibrium, and an "old age" stage characterized by a landscape near base level with very subdued relief. A high hypsometric integral indicates a youthful topography. An intermediate value of the hypsometric integral and a sigmoidal-shaped hypsometric curve indicate a mature stage of development. Further development to the old-age stage will not change the value of the integral, unless high-standing erosional remnants are preserved. However, more sophisticated numerical descriptions of the hypsometric curve that are sensitive to continued evolution of the topography are available. In summary, hypsometric analysis remains a powerful tool for differentiating tectonically active from inactive regions.

Strahler (1952) categorized drainage basins with reference to three stages of geomorphic evolution 1) youth stage (convex upward curves, where $HI \geq 0.60$), where basins in this category are highly susceptible to erosion and land sliding; 2) mature stage or equilibrium (S-shaped hypsometric curve which concave upward at high elevations and convex downward at low elevations, where $0.35 \leq Hi \leq 0.60$); and 3) old (monadnock) or peneplain stage (concave upward curve, where $HI \leq 0.35$).

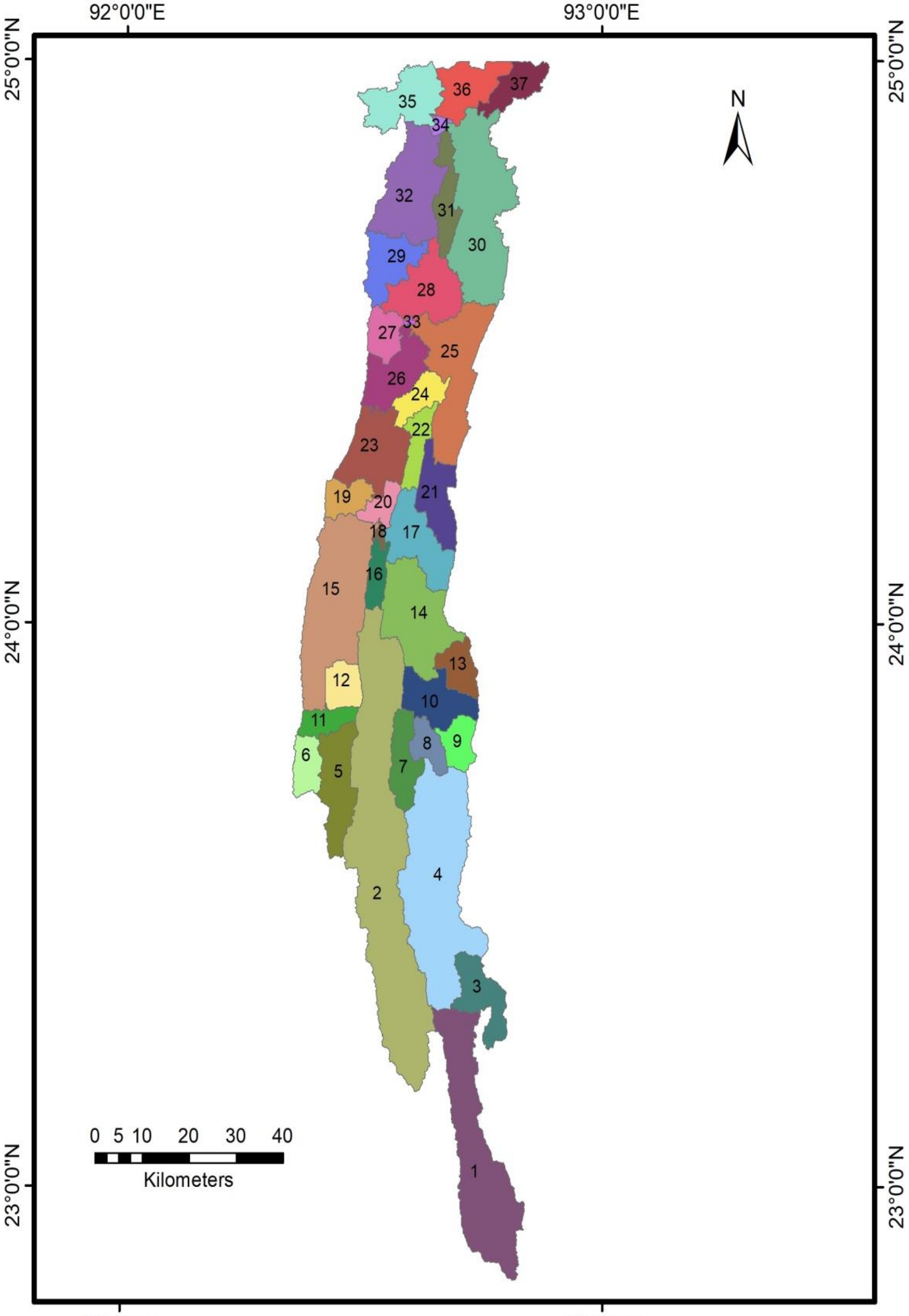

Fig 6.15.2.1: Tlawng river sub basins.

Sub-Basins	Area in Km^2	Min Elevation	Max Elevation	Mean Elevation	Hypsometric Integral (HI)	Geological Stage
Upper Course						
1	425.035	256	1521	687.789	0.341	Early old or monadnock stage
2	862.782	75	1348	463.546	0.305	Early old or monadnock stage
3	111.979	144	1598	637.719	0.339	Early old or monadnock stage
4	546.014	144	1469	580.714	0.329	Early old or monadnock stage
5	149.444	147	1259	486.963	0.305	Early old or monadnock stage
6	62.485	147	929	343.274	0.250	Middle old or monadnock stage
7	93.13	101	985	349.656	0.281	Early old or monadnock stage
8	55.189	101	1392	497.308	0.306	Early old or monadnock stage

9	61.784	90	1516	568.242	0.335	Early old or monadnock stage
10	121.192	102	997	305.801	0.227	Middle old or monadnock stage
11	52.821	102	1239	428.133	0.286	Middle old or monadnock stage
12	65.63	90	1502	594.920	0.357	Late maturity
13	66.744	75	1349	489.176	0.325	Early old or monadnock stage
			Middle Course			
14	242.585	75	1017	376.325	0.319	Early old or monadnock stage
15	385.615	75	810	255.741	0.245	Middle old or monadnock stage
16	47.552	75	1104	438.970	0.353	Late maturity
17	150.97	44	374	116.481	0.219	Middle old or monadnock stage
18	8.369	44	988	338.033	0.311	Early old or monadnock

						stage
19	61.589	40	565	201.767	0.308	Early old or monadnock stage
20	43.57	40	626	209.357	0.289	Middle old or monadnock stage
21	115.061	69	862	286.410	0.274	Middle old or monadnock stage
22	65.049	69	619	236.578	0.304	Early old or monadnock stage
23	176.698	32	616	216.865	0.316	Early old or monadnock stage
24	64.597	32	214	91.318	0.325	Early old or monadnock stage
25	267.797	22	325	124.647	0.338	Early old or monadnock stage
			Lower Course			
26	130.413	22	583	244.461	0.396	Late Maturity
27	64.113	22	66	38.857	0.383	Late Maturity
28	161.362	22	225	97.959	0.374	Late Maturity

29	113.67	18	122	59.493	0.398	Late Maturity
30	390.715	18	109	46.989	0.318	Early old or monadnock stage
31	82.962	13	130	56.080	0.368	Late Maturity
32	239.305	13	175	78.723	0.405	Middle maturity
33	3.018	13	42	23.885	0.375	Late Maturity
34	11.157	13	194	85.673	0.401	Middle maturity
35	148.942	13	626	236.409	0.364	Late Maturity
36	115.978	6	498	215.589	0.425	Middle maturity
37	77.821	13	588	228.879	0.375	Late Maturity
Tlawng Basin	**5846.884**	**6**	**1598**	**512.08**	**0.317**	**Early old or monadnock stage**

Table 6.15.2.1: Estimated hypsometric integral values of Tlawng River basin and its sub-basins

It was claimed that hypsometric integral controls the shape of a hypsometric curve, and thereby offers an indicator for geomorphic evolution of drainage basins (Farhan *et.al.*, 2016). There are thirteen sub-basins in the upper course, thirteen sub-basins in the middle course and eleven sub-basins in the lower course. The HI value of Tlawng river basin is calculated to be 0.317 indicates that only about 31% of the landmass remains and 79% of the landmass was eroded. This indicates that the basin as a whole is under a monadnock or old stage of erosion cycle. The hypsometric integral values of the sub-basins vary from 0.22- 0.42 (Table 6.15.2.1). Sixteen (16) sub basins fall under the early old or monadnock stage, seven (7) sub basins fall under middle old or monadnock stage, three (3) sub basins fall under middle maturity and nine (9) sub basins comes under late maturity stage of erosion (Fig.6.15.2.3) About 35% (2084 km^2) of the basin area in under mature stage of development and 65% (3762 km^2) of the basin is composed of old stage of landscape development.

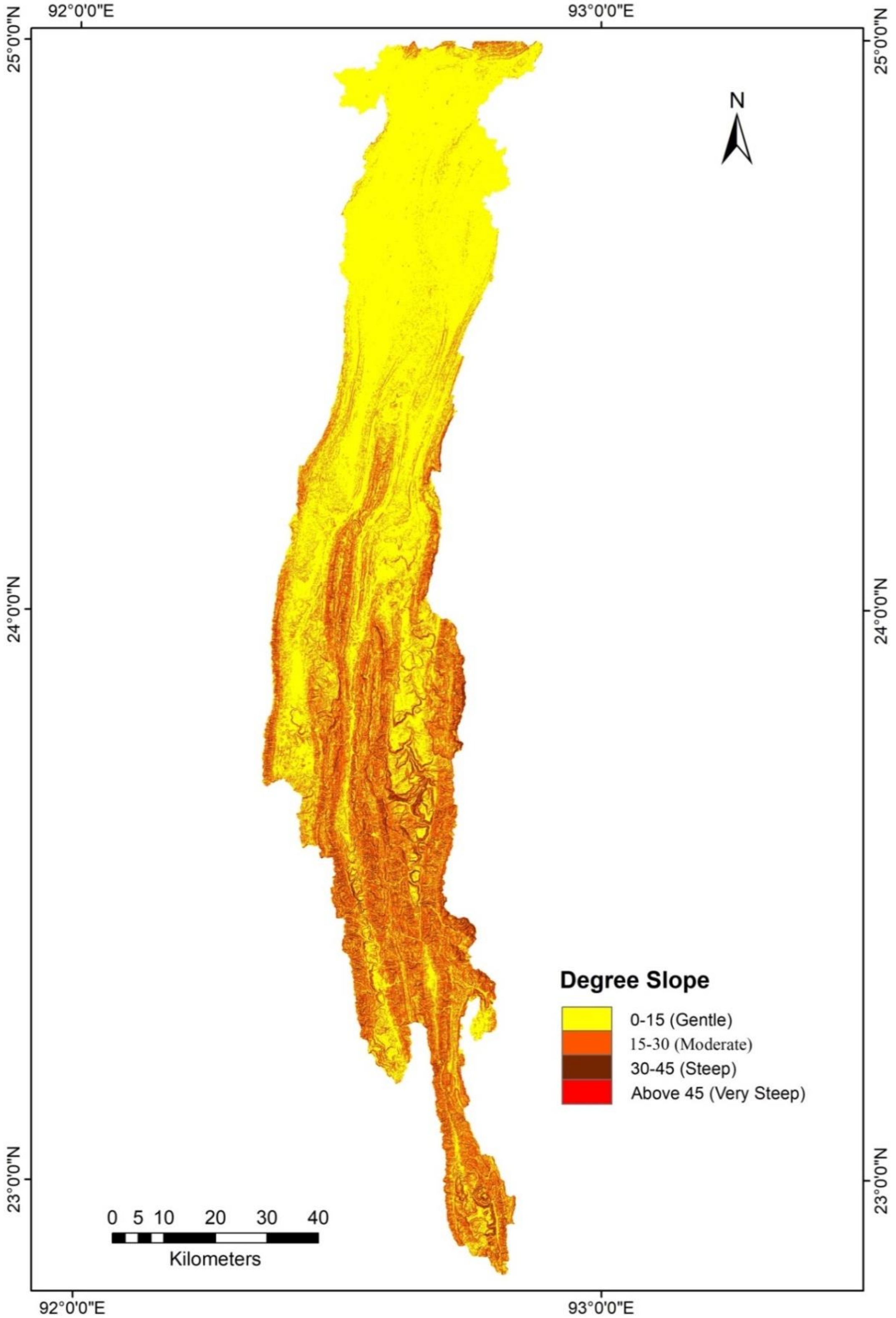

Fig: 6.15.2.2: Slope Map of Tlawng River basin

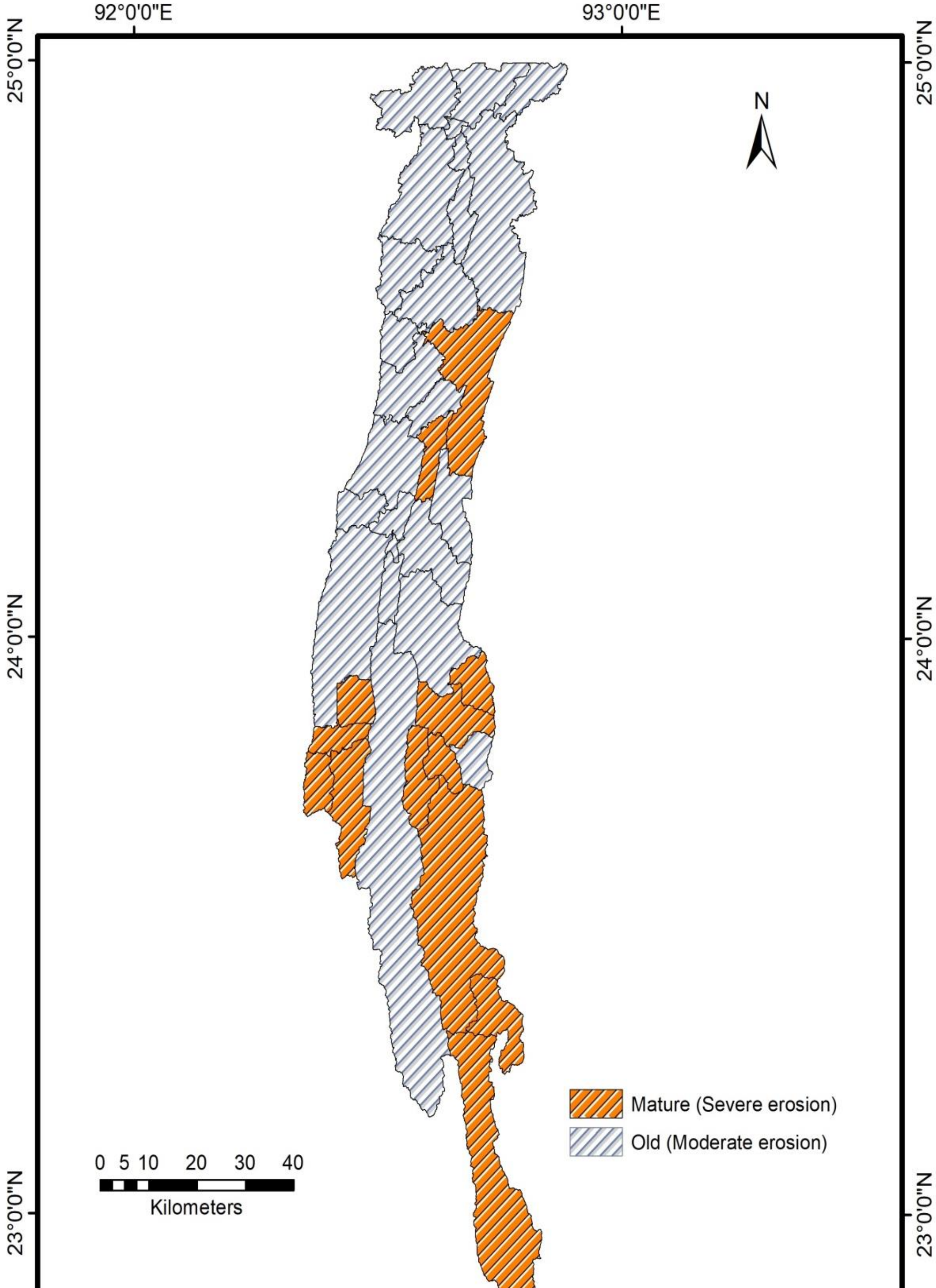

Figure 6.15.2.3: Hypsometric Integral map of Tlawng River basin

The integrated slope and stages of landform development layers reveal the erosion status of the Tlawng river basin (Fig.6.15.2.4). About 1282.31 km^2 area (22%) which attained mature stage along with 13% (746.56 km^2) under middle or late mature stage is prone to moderate to severe erosion mostly along the slope which ranges from 15^o to 45^o and above (Table 6.15.2.3 and Fig.6.15.2.4). Low intensity of erosion is also observed at some places where slope is within 15^o. Erosion of low to very low intensity has been observed in the landscape with old or monadnock stage of development particularly, in the lower reaches where slope is below 10^o or even less.

Sl.No.	Erosion Intensity Class	Areal extent in km^2	Percentage of areal extent	Stage of Landscape development
1	Severe	4.89	0.08	Mature
2	High	195.52	3.34	Mature
3	Moderate	1081.90	18.51	Mature
4	Low	1921.79	32.87	Middle/Late mature and Old
5	Very Low	2641.90	45.19	Old
	Total	5846	100	

Table 6.15.2.2: Soil erosion intensity zones of Tlawng river basin.

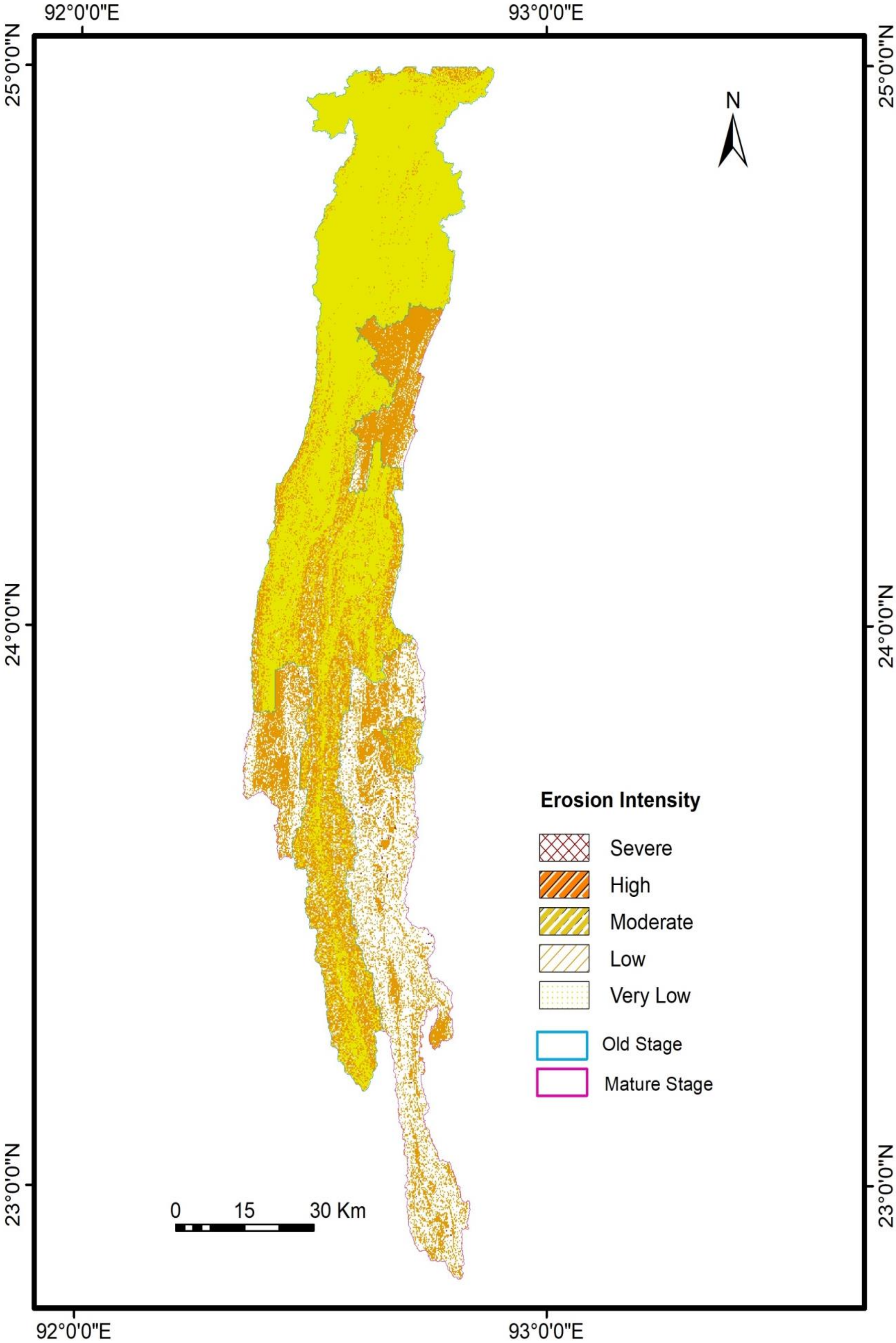

Fig 6.15.2.4: Erosion intensity zones of Tlawng river basin.

It is revealed that the area is under the influence of the unfavorable topographic conditions such as soft sedimentary rocks with steep slopes and heavy rainfall. A number factors and processes are responsible for erosion in bedrocks and subsequent siltation along the river channels (Whipple *et al.*, 2000). Channel width and slope play major role in sediment dynamics and erosion. Moreover, the area is tectonically active, results in the formation of faults and fractures which are expected to enhance erosion at many sections in this area Proper soil conservation measures should be adopted particularly, over steep slopes in order to prevent severe soil loss from the basin thereby to minimize sedimentation in reservoirs and river channels causing floods and other hazards in the area.

Hypsometric analysis of Tlawng river basin reveals the stage and rate of erosion of landforms and ascertains the type of geomorphic processes acting over the sub-basins of Tlawng river basin. From the hypsometric study of Tlawng river basin and its sub basins it is concluded that the landscape is changing towards old monadnock stage of development from maturity stage as twenty five sub basins from the total thirty seven basins fall under old stage of landscape development. Majority of the sub-basins in the Tlawng river basin covering an area of about 2028.87 km^2 are prone to moderate to severe erosion which needs proper conservation measures as the area is under the influence of unfavorable physiographical conditions with steep slopes which may lead to siltation in reservoirs and river channels causing floods and hazards in this sedimentary terrain.

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CHAPTER VII

CONCLUSION

River morpho-dynamics became a science with Leonardo da Vinci, who annotated and sketched several morpho-dynamic phenomena, such as river bed erosion and deposit formation, generated by flow disturbances due to obstacles, channel constrictions and river bend (Crosato 2007). The study of river morpho-dynamics has gained popularity in the past three decades among many researchers for conducting channel restoration, modeling and monitoring. As no significant study has so far been carried out in Mizoram, a detailed morphological analysis of Tlawng river has been carried out to understand the morpho-dynamics of the river.

The drainage area of the Tlawng river basin selected for the study of morpho-dynamics is located between 92°38´ - 92°48´ longitudes and 24°49´- 22°51´ latitudes. Tlawng river, the longest river in Mizoram originates from Zopui hill at about 8 km east of Lunglei town at an elevation of about 1598 m above MSL. The lowest elevation point is about 6m above MSL located in Katakhal. The mean elevation of the basin is 802 m. The drainage basin area is 5846 km^2. It is the main source of water supply to Aizawl city. The Tlawng river basin is characterized by undulating terrain of high hill ranges with steep slopes in the upper course and moderate to low slope in the lower course.

The Tlawng river basin is characterized by tropical humid climate with heavy monsoon rainfall. The mean annual rainfall in the study area is 2449.6 mm. The temperature of the study area doesn‘t fluctuate much throughout the year. The average annual temperature of the study area is about 22℃ and temperature starts to drop from the latter part of November. January is the coldest month in the study area with an average temperature of about 17℃. The average maximum summer temperature is 31℃ while the average minimum summer temperature stands at 18.6℃. Winters are more severe at the upper course of the study area when compared with lower course with minimum and maximum temperatures 8 ^{o}C and 20 ^{o}C respectively.. This may be attributed to the extreme difference in elevation.

The study area is geologically considered as the southern extension of the Surma basin. Rocks in the study area are of sedimentary which are composed of sandstone, silty-sandstone, siltstone, shale, mudstone and their admixture of varying proportions along with a few shell-limestones, calcareous sandstone and intraformational conglomerates. They mostly belong to upper and middle Bhuban formations of Tertiary age. The rocks are thrown into a series of approximately N-S trending, longitudinally plunging anticlines and synclines.

The mountain ranges of the study area are inclined from north to south and run parallel to each other. The area is occupied by steep parallel ridges and narrow deep valleys. Most of the ridges are narrow crested and elongated in a linear to curvilinear shape. The rivers fallow the existing structurally controlled valleys and are oriented from north to south and east to west. The elevation in the Tlawng basin ranges between 1598 m and 6 m above MSL. The mean elevation of the basin is 802 m above mean sea level. Denudational landforms such as pediment and pediplain complex and are mostly located in the northern part of the basin (lower course of the river). Active flood plains, older flood plains and piedmont alluvial plains in the study area are formed by fluvial process. High, low and moderate dissected hills and valleys of structural origin occupies majority of the Tlawng river basin. Structural hills, ridges, escarpments, structural valleys are other geomorphic features identified in the area. The area shows an irregular distribution of slope in the southern part. The northern part has a more even distribution of slope. The area is dived into four slope types ranging from gentle to very steep slope (0^{o} to above 45o). River Tlawng and its tributaries form a trellis, parallel to sub-parallel and sub-dendritic drainage patterns. Trellis pattern is the main pattern because of the presence of resistant folded bedrock in the area. Major tributaries which flow from SE and NE side are Ser lui, Sairang lui, Khuai lui and a few unnamed streams form a sub-dendritic or pinnate pattern before joining the main river.

Detailed morphological analysis has been done by analyzing various parameters such as channel type and patterns, channel bed topography, channel geometry, channel fluid dynamics and hydraulic geometry. River Tlawng develops various remarkable landforms through the channel processes. Erosion, transportation and deposition are the main channel or fluvial processes in the area. River Tlawng has been divided into upper, middle and lower course for the purpose of understanding morpho-dynamics at various sections. The landforms along the upper and middle courses of the river are mostly erosional type like V-shape valley, pod holes etc. while the landforms in the lower course sections are depositional which include shoals, point bars ,flood plains etc. Channel classification has been done on the basis of classification made by Brice (1975). The river follows a Single Phase Equiwidth Channel in the upper course and migrates to Single Phase Irregular Wide Variations downstream.

Based on the classification of Tinkler and Wohl (1998) River Tlawng can be considered as a non- regime (bedrock) channel at the upper and initial middle course of the river. It is a mixture of bedrock and alluvial channels having gravel bed in the lower middle course and regime (alluvial channel) in the lower course. The river changes from one plan-form to another as the discharge changes at various sections particularly, in the lower course. The higher degree of bank stability due to presence of hard sandstones with steep gradient permits the maintenance of narrow to deep straight channels in the upper course.

The river exhibits a pool riffle sequence in the upper course of the river. Riffle occurs on the straight stretch of the river where erosion is evenly stretched while Pools are located on the bends where erosion is concentrated on the outside of the bends. Step Pool reaches and low rapids are also identified in the upper course of the river where there is a sequence of alternate hard and soft rocks.

A total of thirty cross profiles, ten each from the upper, middle and lower course has been extracted in order to study the morphology of the cross-sectional area of the stream valleys. The cross profiles are depicting a mostly V-shape in the upper course which indicates the dominance of head ward erosion or down cutting by the river due to base level change. The cross profiles gradually started to flatten in the lower course. This is due to the increase in discharge and changing of channel type from bedrock to alluvial in the lower course. Based on the classification made by Rosgen (1994) the cross profile of the upper course of the river Tlawng represents an Aa+ and A stream type. The middle course-cross represents B stream type and the cross profile lower course is characterized by C in the initial lower course and E stream type at the lower reaches of the river.

The longitudinal profile of the river Tlawng shows a sharp drop of elevation within a distance of about 20 km from the source of the river. The profile shows decline in gradient gently from the middle course towards the lower course. With a sinuosity index value of 1.39 the river can be considered as having a sinuous channel. Rise over run formula has been used to calculate the channel gradient of River Tlawng. With a channel gradient of 1: 0.004 River Tlawng may be considered as having a medium to steep gradient.

The velocity of the river changes with gradient, discharge, roughness, bed configuration and bed load. Due to high channel gradient the average velocity in the upper course is 0.20 metres per second (mps). The velocity is reduced in the middle course due lo decrease in channel gradient to 0.10 mps and friction caused by heavier bed load and rough bed materials. The velocity is again increasing downstream (0.30 mps) as the river discharge upsurges and a much smoother bed and bank material.

The river discharge is influenced by factors such as river velocity, rainfall and cross section area. Discharge has been calculated by using 'area velocity method'. River discharge increases downstream as the number of tributaries and cross section area increase. Discharge also upsurges with an increased velocity and rainfall. This clearly indicates that the dynamics of river Tlawng changes with the change of season also. As the area falls under the direct influence of south west monsoon, discharge tremendously upsurges during the rainy season. As an impact factor the contribution of rainfall, velocity and cross section in the quantity of river discharge is more than 60%.

The different drainage properties of linear, areal, relief and textural analysis has been carried out based on -Horton (1932 & 1945), Schumm (1956), Strahler (1964), Smith (1950), Muller (1968). The stream ordering was carried out using Strahler's (1964) technique of stream ranking. A total of 7638 streams are identified in Tlawng river basin out of which 3487 are alone 1st order streams. There are 1848 2nd order streams, 878 3rd order and 443 4^{th} order streams. Number of streams in the 5^{th} and 6^{th} order streams is 474 and 148 respectively. As the total length of the streams from 3^{rd} order up to the higher order like the main river is about 6263 km. Longer the stream courses are likely to be prone to frequent changes depending upon the local topography and lithology. The presence of large number of streams indicates that the area is still undergoing erosion and the channel morphology is changed frequently. The total stream length of respective orders decreases as the stream order increases. Drainage density gives a rough estimate of the areas where the severe changes in the morphology of the channels occurs along with the presence of soft sedimentary rocks and local topography.

The stream length ratio in the study area varies from 0.08 – 1.3 which indicates the development of late youth stage of streams. The mean stream length increases with increasing stream order. The bifurcation ratio of Tlawng drainage basin ranges from 1.06 - 2.29 with a mean bifurcation ratio of 1.62. The bifurcation ratio values show lithological variations, and structural control of the basin due to ongoing tectonic activity. The river Tlawng has low chance of flooding as it has a low bifurcation ratio.

The textural parameters like drainage density, stream frequency, drainage texture, have been calculated. The major part of the Tlawng drainage basin has a low drainage density of 1.15 km/ km^2 covering an area of about 2474 km^2 which indicate that basin area has a resistant permeable subsurface material and a moderate to thick vegetation cover. The stream frequency value of the Tlawng river basin is 1.30 streams / km^2 which shows a positive relation with drainage density. Stream frequency is controlled by the lithology and also the tectonic influence on the area.

The drainage density and stream frequency show that the basin area has a resistant permeable sub-surface material and a moderate to thick vegetation cover which is a characteristic of humid region. The area falls under coarse texture based on classification made by Smith (1950) which indicates less dissection and lower rate of erosion. As drainage texture decreases downstream erosion rate also declines in the lower course of the river.

The relief values of the drainage basin have been grouped into three categories such as 6- 500 metres (low), 500-1000 metres (moderate) and above 1000 metres (high). Major portion of the basin area falls under low relief followed by moderate relief and high relief zone covers the smallest area in the basin. The lowest point is 6 m, and highest point is 1598 m and moderate slope and moderate runoff. Relief ratio of Tlawng river basin is 4.75 indicating moderate relief and moderate slope. The relative relief of the study area is 0.19 as a result of which numerous denudational landforms have been found in the northern part (lower course) of the basin. The ruggedness number (Rn) of Tlawng river basin is 1.83 which reveals that slopes of the basin are not only steep but long, as well which have a great impact on the peak discharge of the river.

The hypsometric curves of the Tlawng river basin and sub-basins range from convex to S-shape which indicate that the landscape is changing towards old or monadnock stage of erosion at the middle and lower reaches of the river. The difference can be attributed to variation in lithology. The HI value of Tlawng river basin and thirty seven sub-basins shows that more than half of the landmass had so far been eroded. Erosion in the catchment areas is extremely propelled by high rate of surface run-off during monsoon season. High rate of erosion is the cumulative effect of unscientific cultivation practiced in the catchment areas of the river Tlawng.

The study has shown different morphological parameters of the river Tlawng and the controlling forces in the dynamics of the river channel morphology. The energy that drives channel processes comes from the valley gradient which is the product of historic geological processes. The valley gradient is, therefore, not a product of the modern day river. River Tlawng is considered as stable as it does not exhibits abrupt, episodic, or progressive changes in position, geometry, gradient or pattern that are anomalous or accelerated. The study will help in predicting the change in river morphology and floods. Further, this study is also useful to estimate siltation in future. The channel forms and patterns identified in the present study will help in river restoration and channelization if required.

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Plates

Plate A: Sediment/sand extraction at Sairang.

Plate B: Bridge construction at Bairabi

Plate C: Construction of a small dam by P.H.E at Lunglei District Park.

Plate D: P.H.E site at Dihmunzawl.

Plate E: River cross section measurement by using a bamboo raft at Ailawng.

Plate F: Eroded rocks and pot holes at Ailawng.

Plate G: Measuring depth across the river.

Plate H: Fishing in the rapids

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ABSTRACT

MORPHO-DYNAMICS OF RIVER TLAWNG, MIZORAM

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

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DECLARATION

I, David A Lalramchulloa, hereby declare that the subject matter of this thesis is the record of research work done by me, that the content of this thesis did not form the basis of the award of any previous degree to me or to do the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other University or Institute.

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MORPHO-DYNAMICS OF RIVER TLAWNG, MIZORAM

River morpho-dynamics became a science with Leonardo da Vinci, who annotated and sketched several morpho-dynamic phenomena, such as river bed erosion and deposit formation, generated by flow disturbances due to obstacles, channel constrictions and river bend (Crosato 2007). The study of river morpho-dynamics has gained popularity in the past three decades among many researchers for conducting channel restoration, modeling and monitoring. As no significant study has so far been carried out in Mizoram, a detailed morphological analysis of Tlawng river has been carried out to understand the morpho-dynamics of the river.

In order to understand the morpho-dynamics of a river Tlawng the river has been divided into upper, middle and lower course and from each river course the following fluvio-geomorphic characteristics like channel geometry or channel cross-sectional characteristics (channel length, channel width, channel depth, , channel bends or meandering), channel fluid dynamics (discharge, velocity, roughness, channel gradient), hydraulic properties, channel types, channel bed topography or channel bed configuration, channel pattern, stage of river (youth, mature, old) are studied. Morphometric and drainage parameters such as bifurcation ratio, Rho coefficient, drainage density, stream frequency, stream length, mean steam length, drainage texture, relief aspects and sinuosity index have been studied. Hypsometric analysis has been carried out to understand the stage and erosional status of Tlawng river basin.

The present study is aimed at achieving the following objectives:

i) To study the channel geometry and hydraulic properties of river Tlawng.
ii) To study the channel pattern of river Tlawng.
iii) To examine the influence of seasonal variation of weather conditions on the dynamics of the river.

The drainage area of the Tlawng river basin selected for the study of morpho-dynamics is located between 92°38´ - 92°48´ longitudes and 24°49´- 22°51´ latitudes. Tlawng river, the longest river in Mizoram originates from Zopui hill at about 8 km east of Lunglei town at an elevation of about 1598 m above MSL. The lowest elevation point is about 6m above MSL located in Katakhal. The mean elevation of the basin is 802 m. The drainage basin area is 5846 km^2. It is the main source of water supply to Aizawl city. The Tlawng river basin is characterized by undulating terrain of high hill ranges with steep slopes in the upper course and moderate to low slope in the lower course.

The Tlawng river basin is characterized by tropical humid climate with heavy monsoon rainfall. The mean annual rainfall in the study area is 2449.6 mm. The temperature of the study area doesn‘t fluctuate much throughout the year. The average annual temperature of the study area is about 22°C and temperature starts to drop from the latter part of November. January is the coldest month in the study area with an average temperature of about 17°C. The average maximum summer temperature is 31°C while the average minimum summer temperature stands at 18.6°C. Winters are more severe at the upper course of the study area when compared with lower course with minimum and maximum temperatures 8 ^{o}C and 20 ^{o}C respectively.. This may be attributed to the extreme difference in elevation.

The study area is geologically considered as the southern extension of the Surma basin. Rocks in the study area are of sedimentary which are composed of sandstone, silty-sandstone, siltstone, shale, mudstone and their admixture of varying proportions along with a few shell-limestones, calcareous sandstone and intraformational conglomerates. They mostly belong to upper and middle Bhuban formations of Tertiary age. The rocks are thrown into a series of approximately N-S trending, longitudinally plunging anticlines and synclines.

The mountain ranges of the study area are inclined from north to south and run parallel to each other. The area is occupied by steep parallel ridges and narrow deep valleys. Most of the ridges are narrow crested and elongated in a linear to curvilinear shape. The rivers fallow the existing structurally controlled valleys and are oriented from north to south and east to west. The elevation in the Tlawng basin ranges between 1598 m and 6 m above MSL. The mean elevation of the basin is 802 m above mean sea level. Denudational landforms such as pediment and pediplain complex and are mostly located in the northern part of the basin (lower course of the river). Active flood plains, older flood plains and piedmont alluvial plains in the study area are formed by fluvial process. High, low and moderate dissected hills and valleys of structural origin occupies majority of the Tlawng river basin. Structural hills, ridges, escarpments, structural valleys are other geomorphic features identified in the area. The area shows an irregular distribution of slope in the southern part. The northern part has a more even distribution of slope. The area is dived into four slope types ranging from gentle to very steep slope (0^{o} to above 45o). River Tlawng and its tributaries form a trellis, parallel to sub-parallel and sub-dendritic drainage patterns. Trellis pattern is the main pattern because of the presence of resistant folded bedrock in the area. Major tributaries which flow from SE and NE side are Ser lui, Sairang lui, Khuai lui and a few unnamed streams form a sub-dendritic or pinnate pattern before joining the main river.

Detailed morphological analysis has been done by analyzing various parameters such as channel type and patterns, channel bed topography, channel geometry, channel fluid dynamics and hydraulic geometry. River Tlawng develops various remarkable landforms through the channel processes. Erosion, transportation and deposition are the main channel or fluvial processes in the area. River Tlawng has been divided into upper, middle and lower course for the purpose of understanding morpho-dynamics at various sections. The landforms along the upper and middle courses of the river are mostly erosional type like V-shape valley, pod holes etc. while the landforms in the lower course sections are depositional which include shoals, point bars ,flood plains etc. Channel classification has been done on the basis of classification made by Brice (1975). The river follows a Single Phase Equiwidth Channel in the upper course and migrates to Single Phase Irregular Wide Variations downstream.

Based on the classification of Tinkler and Wohl (1998) River Tlawng can be considered as a non- regime (bedrock) channel at the upper and initial middle course of the river. It is a mixture of bedrock and alluvial channels having gravel bed in the lower middle course and regime (alluvial channel) in the lower course. The river changes from one plan-form to another as the discharge changes at various sections particularly, in the lower course. The higher degree of bank stability due to presence of hard sandstones with steep gradient permits the maintenance of narrow to deep straight channels in the upper course.

The river exhibits a pool riffle sequence in the upper course of the river. Riffle occurs on the straight stretch of the river where erosion is evenly stretched while Pools are located on the bends where erosion is concentrated on the outside of the bends. Step Pool reaches and low rapids are also identified in the upper course of the river where there is a sequence of alternate hard and soft rocks.

A total of thirty cross profiles, ten each from the upper, middle and lower course has been extracted in order to study the morphology of the cross-sectional area of the stream valleys. The cross profiles are depicting a mostly V-shape in the upper course which indicates the dominance of head ward erosion or down cutting by the river due to base level change. The cross profiles gradually started to flatten in the lower course. This is due to the increase in discharge and changing of channel type from bedrock to alluvial in the lower course. Based on the classification made by Rosgen (1994) the cross profile of the upper course of the river Tlawng represents an Aa+ and A stream type. The middle course-cross represents B stream type and the cross profile lower course is characterized by C in the initial lower course and E stream type at the lower reaches of the river.

The longitudinal profile of the river Tlawng shows a sharp drop of elevation within a distance of about 20 km from the source of the river. The profile shows decline in gradient gently from the middle course towards the lower course. With a sinuosity index value of 1.39 the river can be considered as having a sinuous channel. Rise over run formula has been used to calculate the channel gradient of River Tlawng. With a channel gradient of 1: 0.004 River Tlawng may be considered as having a medium to steep gradient.

The velocity of the river changes with gradient, discharge, roughness, bed configuration and bed load. Due to high channel gradient the average velocity in the upper course is 0.20 meters per second (mps). The velocity is reduced in the middle course due lo decrease in channel gradient to 0.10 mps and friction caused by heavier bed load and rough bed materials. The velocity is again increasing downstream (0.30 mps) as the river discharge upsurges and a much smoother bed and bank material.

The river discharge is influenced by factors such as river velocity, rainfall and cross section area. Discharge has been calculated by using 'area velocity method'. River discharge increases downstream as the number of tributaries and cross section area increase. Discharge also upsurges with an increase in velocity and rainfall. This clearly indicates that the dynamics of river Tlawng changes with the change of season also. As the area falls under the direct influence of south west monsoon, discharge tremendously upsurges during the rainy season. As an impact factor the contribution of rainfall, velocity and cross section in the quantity of river discharge is more than 60%.

The different drainage properties of linear, areal, relief and textural analysis has been carried out based on -Horton (1932 & 1945), Schumm (1956), Strahler (1964), Smith (1950), Muller (1968). The stream ordering was carried out using Strahler's (1964) technique of stream ranking. A total of 7638 streams are identified in Tlawng river basin out of which 3487 are alone 1st order streams. There are 1848 2nd order streams, 878 3rd order and 443 4th order streams. Number of streams in the 5th and 6th order streams is 474 and 148 respectively. As the total length of the streams from 3rd order up to the higher order like the main river is about 6263 km. Longer the stream courses are likely to be prone to frequent changes depending upon the local topography and lithology. The presence of large number of streams indicates that the area is still undergoing erosion and the channel morphology is changed frequently. The total stream length of respective orders decreases as the stream order increases. Drainage density gives a rough estimate of the areas where the severe changes in the morphology of the channels occurs along with the presence of soft sedimentary rocks and local topography.

The stream length ratio in the study area varies from 0.08 – 1.3 which indicates the development of late youth stage of streams. The mean stream length increases with increasing stream order. The bifurcation ratio of Tlawng drainage basin ranges from 1.06 - 2.29 with a mean bifurcation ratio of 1.62. The bifurcation ratio values show lithological variations, and structural control of the basin due to on going tectonic activity. The river Tlawng has low chance of flooding as it has a low bifurcation ratio.

The textural parameters like drainage density, stream frequency, drainage texture, have been calculated. The major part of the Tlawng drainage basin has a low drainage density of 1.15 km/ km^2 covering an area of about 2622 km^2 which indicate that basin area has a resistant permeable subsurface material and a moderate to thick vegetation cover. The stream frequency value of the Tlawng river basin is 1.30 streams / km^2 which shows a positive relation with drainage density. The drainage density and stream frequency show that the basin area has a resistant permeable sub-surface material and a moderate to thick vegetation cover which is a characteristic of humid region. Stream frequency is controlled by the lithology and also the tectonic influence on the area. Due to major extent of the low and very low drainage density, river Tlawng can be considered as a uniform and steady channel where velocity is almost constant and stream pattern does not change much with time. The area falls under coarse texture based on classification made by Smith (1950) which indicates less dissection and lower rate of erosion. As drainage texture decreases downstream erosion rate also declines in the lower course of the river.

The relief values of the drainage basin have been grouped into three categories such as 6- 500 meters (low), 500-1000 meters (moderate) and above 1000 meters (high). Major portion of the basin area falls under low relief followed by moderate relief and high relief zone covers the smallest area in the basin. The lowest point is 6 m, and highest point is 1598 m and moderate slope and moderate runoff. Relief ratio of Tlawng river basin is 4.75 indicating moderate relief and moderate slope. The relative relief of the study area is 0.19 as a result of which numerous denudational landforms have been found in the northern part (lower course) of the basin. The ruggedness number (Rn) of Tlawng river basin is 1.83 which reveals that slopes of the basin are not only steep but long, as well which have a great impact on the peak discharge of the river.

The hypsometric curves of the Tlawng river basin and sub-basins range from convex to S-shape which indicate that the landscape is changing towards old or monadnock stage of erosion at the middle and lower reaches of the river. The difference can be attributed to variation in lithology. The HI value of Tlawng river basin and thirty seven sub-basins shows that more than half of the landmass had so far been eroded. Erosion in the catchment areas is extremely propelled by high rate of surface run-off during monsoon season. High rate of erosion is the cumulative effect of unscientific cultivation practiced in the catchment areas of the river Tlawng.

The study has shown different morphological parameters of the river Tlawng and the controlling forces in the dynamics of the river channel morphology. The energy that drives channel processes comes from the valley gradient which is the product of historic geological processes. The valley gradient is, therefore, not a product of the modern day river. River Tlawng is considered as stable as it does not exhibits abrupt, episodic, or progressive changes in position, geometry, gradient or pattern that are anomalous or accelerated. The study will help in predicting the change in river morphology and floods. Further, this study is also useful to estimate siltation in future. The channel forms and patterns identified in the present study will help in river restoration and channelization if required.