GEOMORPHOMETRY AND MORPHOTECTONICS OF TUIRINI WATERSHED IN MIZORAM

BY

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DECLARATION

I Fuzal Ahmed, hereby declare that the subject matter of this thesis is the record of research work done by me, that the contents 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.

This is being submitted to the Mizoram University for the degree of Doctor of Philosophy in Geology.

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CERTIFICATE

This is to certify that the thesis entitled **"Geomorphometry and Morphotectonics of Tuirini Watershed in Mizoram"** submitted to the Mizoram University, Aizawl for the award of the degree of Doctor of Philosophy in Geology is the outcome of original research work carried out by Mr. Fuzal Ahmed, bearing Regd. No. *MZU/Ph.D./392/02.06.2011* under my supervision.

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PREFACE

Drainage basin or watershed is an ideal geomorphic unit and is considered to be efficient and appropriate for natural resources management. To prepare a comprehensive development plan of the watershed for optimum use of its resources, it becomes necessary to understand the topography, drainage system, geology, geomorphology, soil and erosional status of the area. The analyses of morphometric and morphotectonic parameters of a drainage basin help to understand the process of landform evolution, geologic structures and hydrological characteristics of rocks as well as tectonic activity of the region. Remote sensing and Geographic Information System (GIS) have played an important role in the drainage basin analysis. Hence, Remote sensing and GIS techniques have been used for the present work. The present work is an attempt to understand the drainage characteristics and ongoing tectonic activity of the terrain on the basis of various morphometric and morphotectonic parameters.

Drainage basin morphometry describes the drainage characteristics and associated geomorphic processes. So, morphometric analysis of the study area has been carried out through the measurement of linear, textural, geometric and relief aspects to understand the basin morphology. Hypsometric curve and integral are used to infer the geomorphic stages of landscape development. Therefore, hypsometric analysis has been carried out to identify the geomorphic stages of the drainage basin evolution. The analyses of different morphotectonic indices such as asymmetry factor, channel sinuosity etc. provide important information about active tectonics in areas undergoing rapid tectonic deformation. Thus, various morphotectonic indices have been estimated to understand the ongoing tectonic activities in the basin area.

Hence, the present work can be used for watershed management and conservation of natural resources for sustainable development of the watershed.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

CHAPTER I

INTRODUCATION

1.1 Importance of the Study

The Mizoram state as a whole comprises of Tertiary rocks of Oligocene to Pliocene in age and the rock sequences are complexly folded, faulted and uplifted. The region is rugged mountainous terrain characterized by a large number of river networks, which plays an important role in agriculture activities in the state. The steep slopes of the mountains are composed of soft sedimentary rocks and a large amount of eroded sediments outflow from the watersheds every year, particularly during the monsoon season. Although the region is dominant in various natural resources like forest, soil etc., most parts of these areas remain inaccessible due to the mountainous nature of the terrain. Therefore, planning and management of these resources are essential for sustainable development.

Watersheds are considered to be appropriate for the natural resources management and implementation of various developmental programmes. Management of natural resources at watershed scale produces multiple benefits in terms of increasing groundwater storage, minimizing land degradation and controlling soil erosion. A watershed is an ideal unit for the management of natural resources like land, water and for mitigation of the impact of natural disasters for achieving sustainable development (Nookaratnam *et al.*, 2005). Watershed or drainage basin is an extent of land area that captures precipitation, snow or dew etc., which drains to common point. It includes both streams and rivers that convey the water downward as well as land surfaces from which water drains into these channels (George, 2005).

The proper watershed management needs utilization of land, water and soil resources for sustainable development.

Morphometry is the measurement and mathematical analysis of the configuration of the earth surface, shape and dimension of its landforms (Clarke, 1966). It can be achieved through the measurement of linear, aerial (Textural and Geometric), relief aspects of the watershed and its slope contribution (Nag and Chakraborty, 2003). The morphometric analysis of a watershed provides valuable information regarding the watershed characteristics, regional topography, drainage pattern, basin geometry, nature of bedrocks and groundwater potential zones etc., which helps for effective planning and management of natural resources of an area. It is also found to be of immense utility in watershed prioritization and conservation of natural resources at watershed level.

Tectonic activity plays vital role in the development of drainage basin morphology. Analysis of a drainage basin in response to the tectonic processes can provide an insight into the past and recent deformational events of the region. Drainage networks are the most active and sensitive elements which can be used as a powerful tool to understand the tectonic activity of an area. Morphotectonic deals with the landscape morphology, which has evolved as a result of the tectonic activity. An analysis of active structures can be done by using morphotectonic indices, which are sensitive to rock resistance, climatic changes and tectonic processes resulting into landscape evolution. The information about tectonic history of an area can be retrieved through analysis of topographic maps, aerial photographs, satellite data and quantification of different morphotectonic indices (Keller, 1986).

Remote sensing and Geographical Information System (GIS) techniques are widely applied for studying the morphometric and morphotectonic aspects of the drainage basin. Remote sensing data with synoptic view of a large area at a time has become a useful tool in identification, mapping, monitoring and conservation of natural resources. GIS has emerged as a powerful tool in morphometric and morphotectonic analyses of the drainage basin. It is a set of tools for collecting, storing, retrieving, and analysing the spatial data from the real world units.

1.2 Study Area

1.2.1 Location and Extent

The study area is a part of the Tuirial catchment. It lies between longitudes 92°49′34″– 92°58′22″E and latitudes 23°28′37″– 23°53′20″N in the Aizawl and Serchhip districts of Mizoram state in the northeast India (Fig. 1.1). The Tuirini watershed is covering an area of about 420.07 sq.km with elongated shape of the watershed. The maximum length of the watershed is 45.30 km from south to north and the maximum width of 11.5 km from east to west. The study area is characterized by rugged topography with steep slopes and narrow gorges (Plate 1A). The Tuirini watershed is surrounded by the Mat, Tuichawng and Tuivawl watersheds in the state of Mizoram. The entire study area is sub-divided into 22 sub-watersheds (Fig. 1.3) based on the name of the major tributaries of the Tuirini river. The important villages are situated in and around the study area are Tuirial, Sesawng, Tualbung, Lailak, Khumtung, Seling, Sihfa, Thingsulthliah, Tlungvel, Darlawng, Baktawng, Buhkangkawn, Tawizo, Keifang, Sailtual and Tuirinikai. The study area is well connected by national highways and other roads.

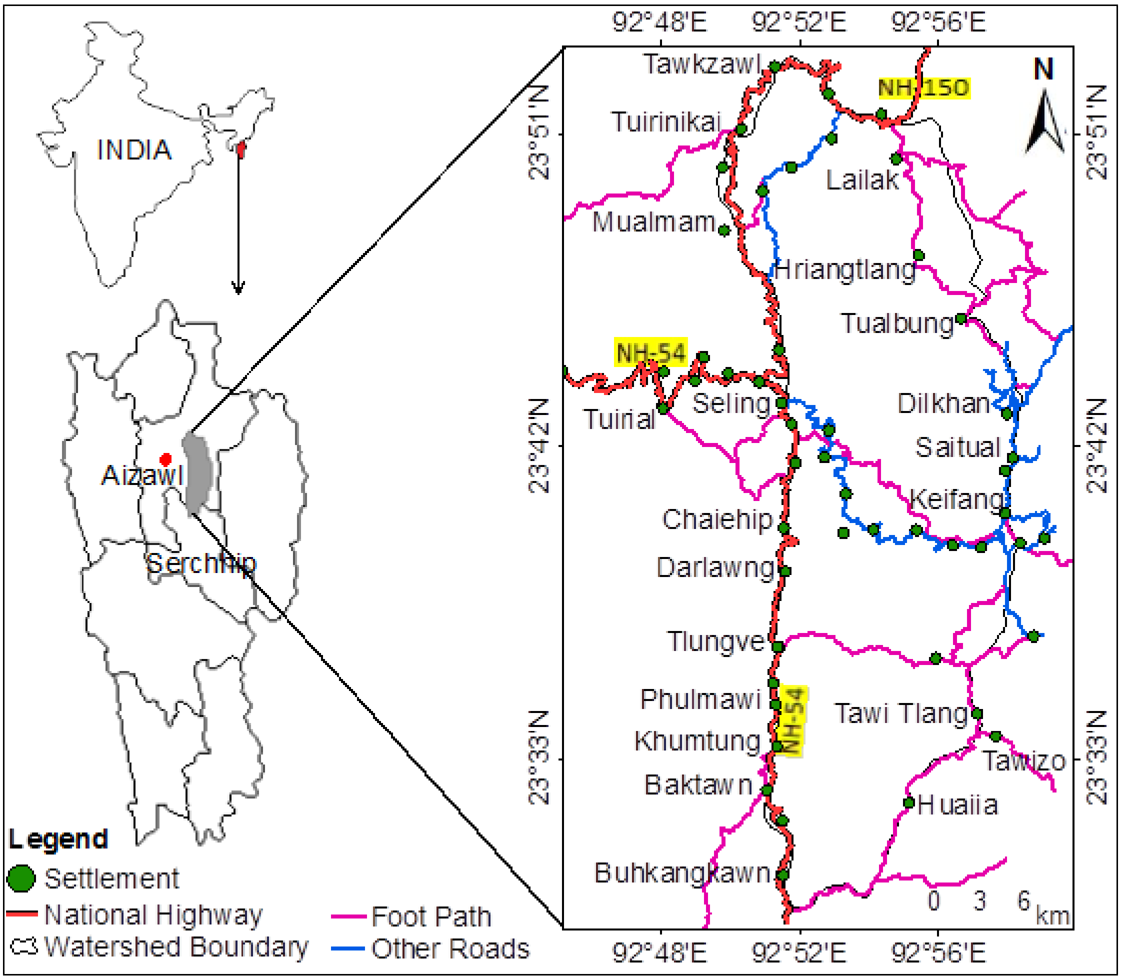


Figure 1.1. Location map of the study area.

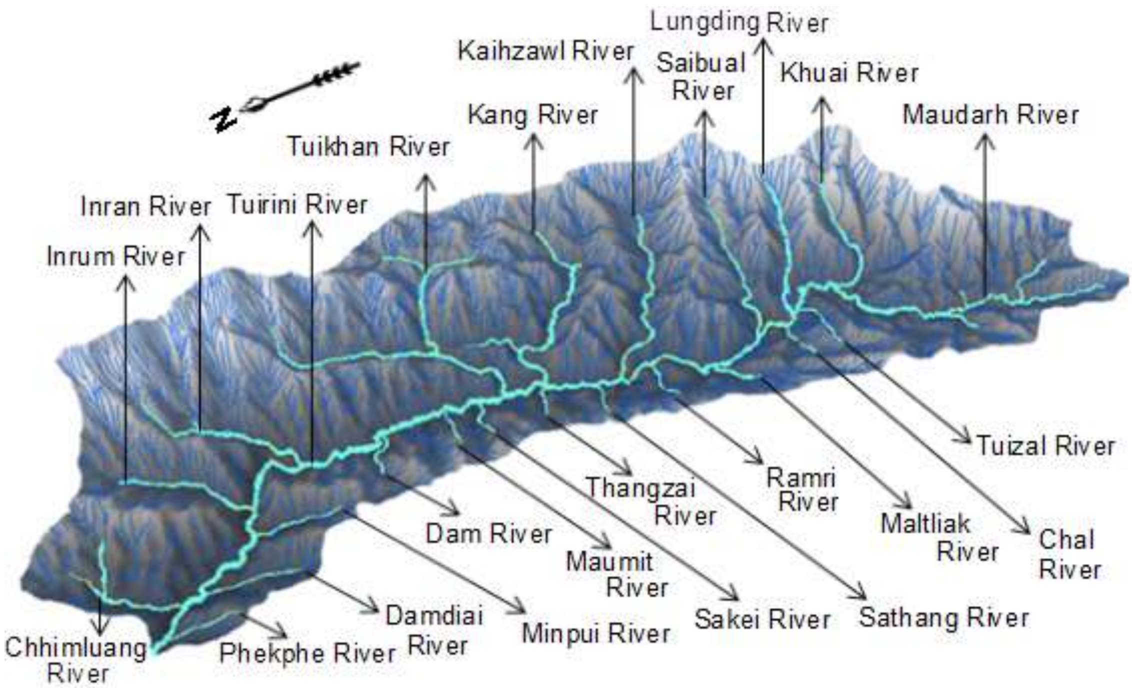


Figure 1.2. 3D view of the Tuirini river networks.

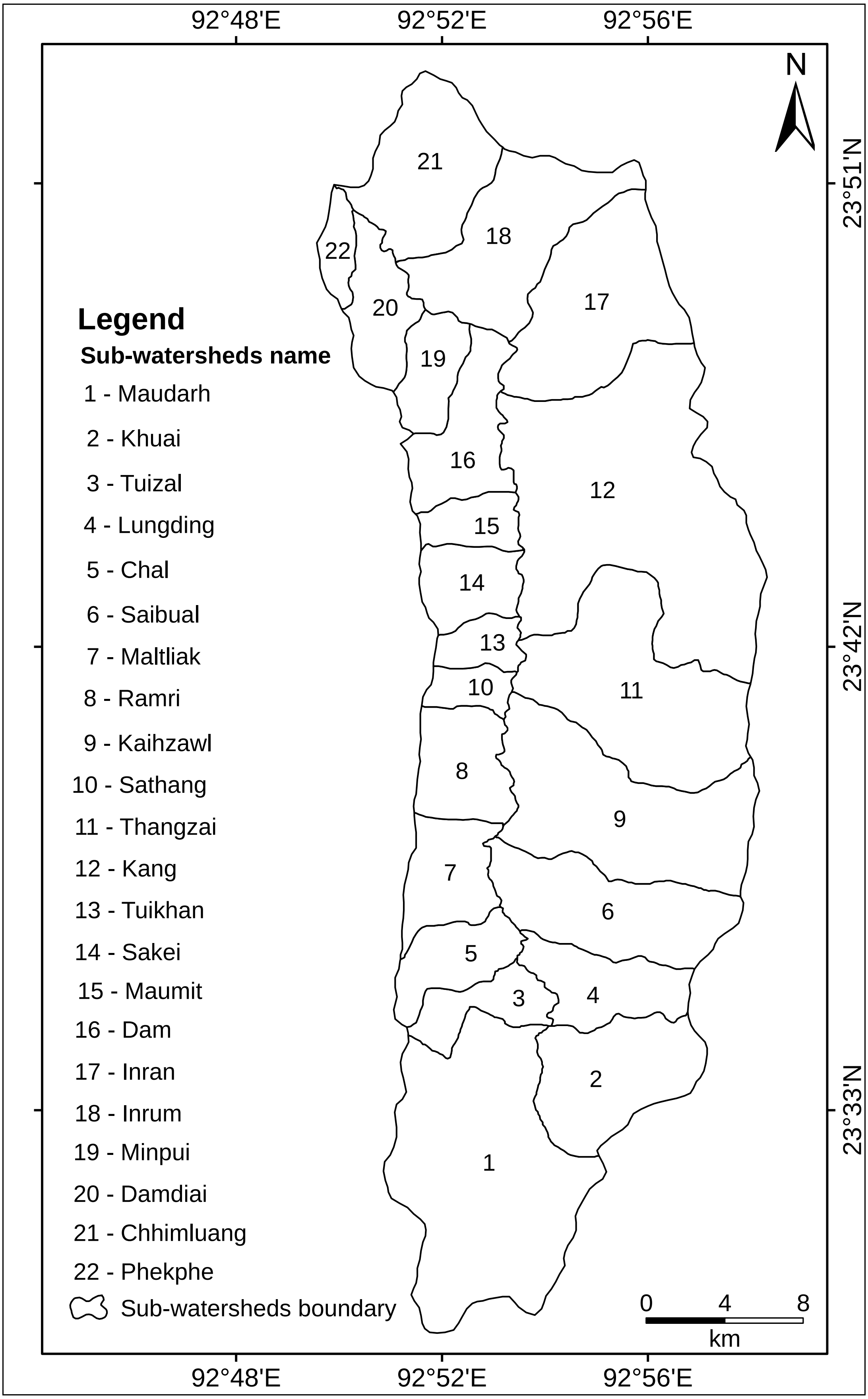


Figure 1.3. Sub-watersheds boundary map of the Tuirini watershed.

1.2.2 Drainage System

The major bifurcation of the drainage in the Mizoram state is mainly from north to south. The Tlawng (Dhaleswari), the Tuirial (Sonai) and the Tuivawl rivers originate from the middle part of the Mizoram state and flowing towards north, finally joining the Barak river in the Cachar district of Assam state. The southern portion of the region is drained by rivers Mat, Tuichawng, Tiau, Tuipui and Khawthlangtuipui.

The Tuirini river is the major river in the study area. It originates from Buhkangkawn hill at an elevation of about 780 m above mean sea level (msl) near the Buhkangkawn village in Serchhip district of Mizoram. The river Tuirini flows northward for a distance of 56.75 km and finally joins the Tuirial river near Tuirinikai village at an elevation 78 m above msl in Aizawl district of Mizoram (Plate 1B). The Tuirini river is a sixth order drainage basin with 22 major tributaries (Table 1.1). Its major tributaries which are joining towards right side of the Tuirini river namely Khuai, Lungding, Saibual, Kaihzawl, Kang, Tuikhan, Inran, Inrum and Chhimluang, and the left side joining tributaries are Tuizal, Chal, Maltliak, Ramri, Sathang, Thangzai, Sakei, Maumit, Dam, Minpui, Damdiai and Phekphe (Fig. 1.2). Most of the tributaries are originate from the higher altitude of about 800 m and some of the tributaries show more or less straight courses.

The study area is characterized by trellis, parallel to sub-parallel and sub-dendritic drainage patterns. Trellis is the most dominant drainage pattern due to the presence of folded bedrock of varying resistance and might be structural influence on streams development. In the NE, SE and SW parts of the study area, some of the streams show the parallel type of drainage pattern due to steep slopes. Sub-dendritic drainage pattern is also observed in the limited part of the study area which might be due to homogeneous lithological development.

Table 1.1. Elevation characteristics and length of the Tuirini river and its major tributaries.

Sl. No.	Tributary names	Order	Source elevation (m)	Confluence elevation (m)	Length of main tributaries (km)
1	Maudarh	5th	780	340	15.93
2	Khuai	4th	1710	340	6.92
3	Tuizal	3rd	840	320	3.7
4	Lungding	3rd	1340	310	6.38
5	Chal	4th	1060	300	7.15
6	Saibual	4th	1020	298	7.36
7	Maltliak	4th	1210	280	5.67
8	Ramri	4th	420	260	1.84
9	Kaihzawl	4th	1180	250	13.9
10	Sathang	3rd	740	245	2.95
11	Thangzai	3rd	480	240	1.67
12	Kang	5th	780	238	11.44
13	Tuikhan	5th	1280	235	13.89
14	Sakei	4th	490	230	2.90
15	Maumit	3rd	420	225	1.91
16	Dam	4th	840	220	5.45
17	Inran	5th	1460	180	9.59
18	Inrum	4th	1380	160	9.15
19	Minpui	3rd	580	135	4.68
20	Damdiai	3rd	425	120	5.49
21	Chhimluang	4th	870	100	7.24
22	Phekphe	3rd	610	80	5.13
Tuirini river		6th	780	78	56.75

1.2.3 Climate

The climate of the Mizoram is neither very hot nor very cold, but moderate throughout the year. The entire state falls under the direct influence of south-west monsoon and receives an adequate amount of rainfall. The climate of the state is humid tropical, characterized by short winter, long summer with heavy rainfall.

As the region falls under the direct influence of south-west monsoon, the study area receives adequate amount of rainfall. The climate of the area is humid tropical in nature and is neither too hot in summer nor too cold during winter. The average annual rainfall in the study area is about 2300 mm and 80% of the rainfall occurs during the monsoon season from June to September. During summer the average temperature of the study area rises to 25°C, which varies between 23°C and 30°C. During winter the average temperature of the study area is 18°C, which varies between 11°C and 21°C. The average annual humidity of the watershed is about 70%.

1.2.4 Vegetation

Mizoram has a rich tropical forest. Vegetation growth in the state is abundant with plenty of trees, plants, bushes, grass and bamboos. The region is characterised by the various types of forest cover such as tropical evergreen forest, Sub-Himalayan semi-ever green forest, sub-tropical pine forest, sub-tropical hill forest and mixed forest.

The study area is characterized by tropical semi evergreen forest. The dominant species of the study area are Khiang (*Schima wailichii*), Tei (*Cedrela toona*), Char (*Tarminalia mycriocarpa*), Zuang (*Duabanga sonneratioides*), Thingdawl (*Tetrameles nudiflora*), Vaiza (*Hibicus macrophyllus*), Kawhtebel (*Samecarpus subpanduriformis*), Zawngtah (*Parkiaroxburghii*), Bil (*Protium serratum*), Thil (*Quercas pachyphyllum*) etc.

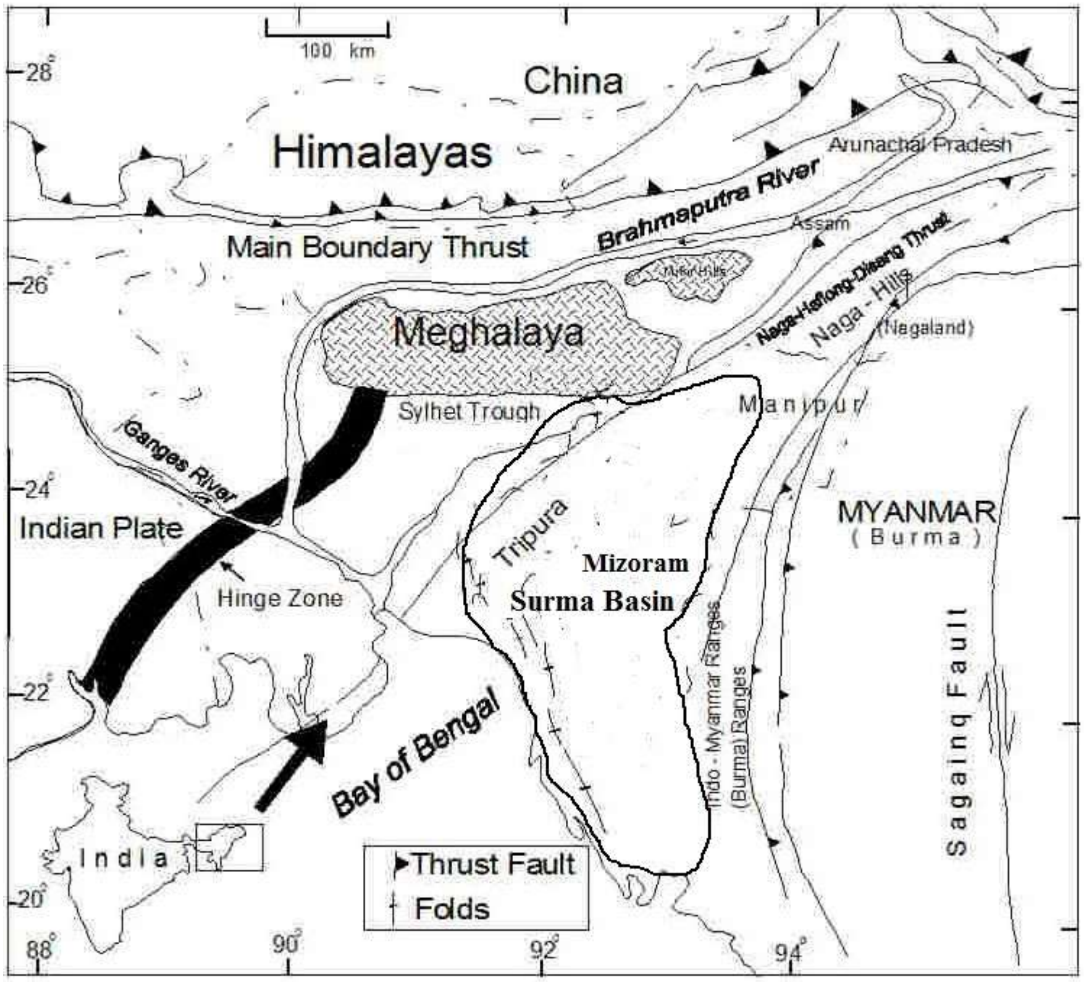


Figure 1.4. Map showing the regional tectonic features of NE India (After Uddin and Lundberg, 1989 a,b).

1.3 Regional Geological Setup

Geologically, Mizoram is a part of Tripura-Mizoram sedimentary basin belongs to Surma Group of Cenozoic age (Evans, 1964), which constitutes a part of Assam - Arakan basin (Fig. 1.4). It evolved after the regional uplift of Barail succession and thus, was related with the plate behaviour in the sub-duction zone west of Arakan - Yoma, after spreading of the Indian Ocean (Evans, 1964). Sarkar and Nandy (1977) opined that in lithological and mineralogical characteristics, primary-sedimentary structures and degree of compaction, rock successions of Mizoram differs considerably from that of the typical Surma Valley. The lithological formations, which are generally trending N-S with varying dips from 20º to 50º either towards east or west (Karunakaran, 1974).

The region is exposed mainly by mollasse sediments of Neogene age, comprising of poorly fossiliferous succession of alternating shales, mudstones, siltstones and sandstones in varying proportions. The generalized stratigraphic succession of the Mizoram state as shown in Table 1.2.

Table 1.2. Stratigraphic succession of Mizoram (Modified after Geological Survey of India, 1974; Karunakaran, 1974; Ganju, 1975; Mandaokar, 2000; Tiwari and Kachhara, 2003).

<table>
<tr><th>Age</th><th>Group</th><th>Formation</th><th>Thickness (m)</th><th>Gross Lithology</th><th>Depositional Environment</th></tr>
<tr><td>Recent</td><td>-</td><td>-</td><td>-</td><td>Gravel, silts and clays</td><td>Fluvial and alluvial</td></tr>
<tr><td colspan="6">---------------------------------Unconformity--------------------------</td></tr>
<tr><td>Early Pliocene to Late Miocene</td><td>TIPAM</td><td>-</td><td>> 900</td><td>Friable sandstone with occasional clay bands</td><td>Fluvial</td></tr>
<tr><td colspan="6">-----------------Conformable and transitional contact ------------------</td></tr>
<tr><td rowspan="7">Miocene to Upper Oligocene</td><td rowspan="7">S U R M A</td><td>BOKABIL</td><td>> 950</td><td>Shale, siltstone and sandstone</td><td>Shallow marine</td></tr>
<tr><td colspan="4">-------------Conformable and transitional contact --------------</td></tr>
<tr><td rowspan="5">B H U B A N</td><td>Upper (>1100)</td><td>Arenaceous predominating with sandstone, shale and siltstone</td><td>Shallow marine, near shore to lagoonal</td></tr>
<tr><td colspan="3">--------Conformable and transitional contact ------</td></tr>
<tr><td>Middle (>1000)</td><td>Argillaceous predominating with shale alterations and sandstone</td><td>Deltaic</td></tr>
<tr><td colspan="3">------Conformable and transitional contact --------</td></tr>
<tr><td>Lower (>900)</td><td>Arenaceous predominating with sandstone, silty shale</td><td>Shallow marine</td></tr>
<tr><td colspan="6">----------------------Unconformity----------------------</td></tr>
<tr><td>Oligocene</td><td>BARAIL</td><td>-</td><td>(> 3000)</td><td>Shale, siltstone and sandstone</td><td>Shallow marine</td></tr>
<tr><td colspan="6">---------------- Lower contact not exposed ------------------</td></tr>
</table>

Structurally, the Mizo Hills are considered to be forming an integral part of the mobile belt constituted of very tight, sub-parallel, elongated asymmetrical, doubly plunging folds. The fold are slightly arcuate in shape with westward convexity and comprises a series of strongly folded anticlines and synclines arranged en-echelon (Ganguly, 1975; Srivastava *et al.*, 1979). These anticlines and synclines are commonly dislocated by numerous longitudinal faults and thrusts (Ram and Venkataraman, 1984). The hill ranges mainly comprise of compact and resistant older rock units exposed in the anticlinal crests, whereas the valleys are composed of younger and softer formations exposed in the synclinal troughs (Ganguli, 1983). There are around 15 major long and arcuate anticlines and corresponding synclines in the region (Nandy *et al.*, 1983).

1.4 Geology of the Study Area

Geologically, the study area consists of Surma Group of rocks belongs to Middle - Upper Bhuban Formations of Lower to Middle Miocene in age. The sedimentary rocks exposed in the study area are thickly bedded sandstones, shales and siltstones and there various admixtures in varying proportions (Fig. 1.5 & Plate 2A). The Middle Bhuban Formation is conformably overlain by the Upper Bhuban Formation with transitional contact. Middle Bhuban Formation is mainly argillaceous with shale as the dominant rock type. It is having the assemblages of shale, siltstone, sandy-shale and silty-shale with subordinate amount of sandstones. Upper Bhuban Formation is mainly arenaceous which consists of sandstone as the dominant rock type. This unit comprises of sandstones with subordinate amount of shale and siltstones alternations. Most dominant rocks in the study area are shales and siltstones covering an area of 274.03 sq.km (65.24 %) and the sandstones occupied by 146.04 sq.km (34.76 %) area.

The study area is structurally very complex due to folding and faulting. The rocks have been folded and formed as a series of longitudinal en-echelon anticlines and synclines. The anticlines are very tight, asymmetric in nature while the synclines are narrow valleys. Most of the anticlines and synclines are doubly plunging. The eastern limbs of the anticlines are steeper than the western limbs with approximately north-south orientation. The prominent folds have been noted in the study area are Thingsulthliah Anticline, Keifang Anticline and Tuirini Syncline (Plate 3A). There are several transverse faults which present in the study area having NW-SE and NE-SW orientation (Fig. 1.5). The major course of the Tuirini river and its tributaries are controlled by lineaments or faults.

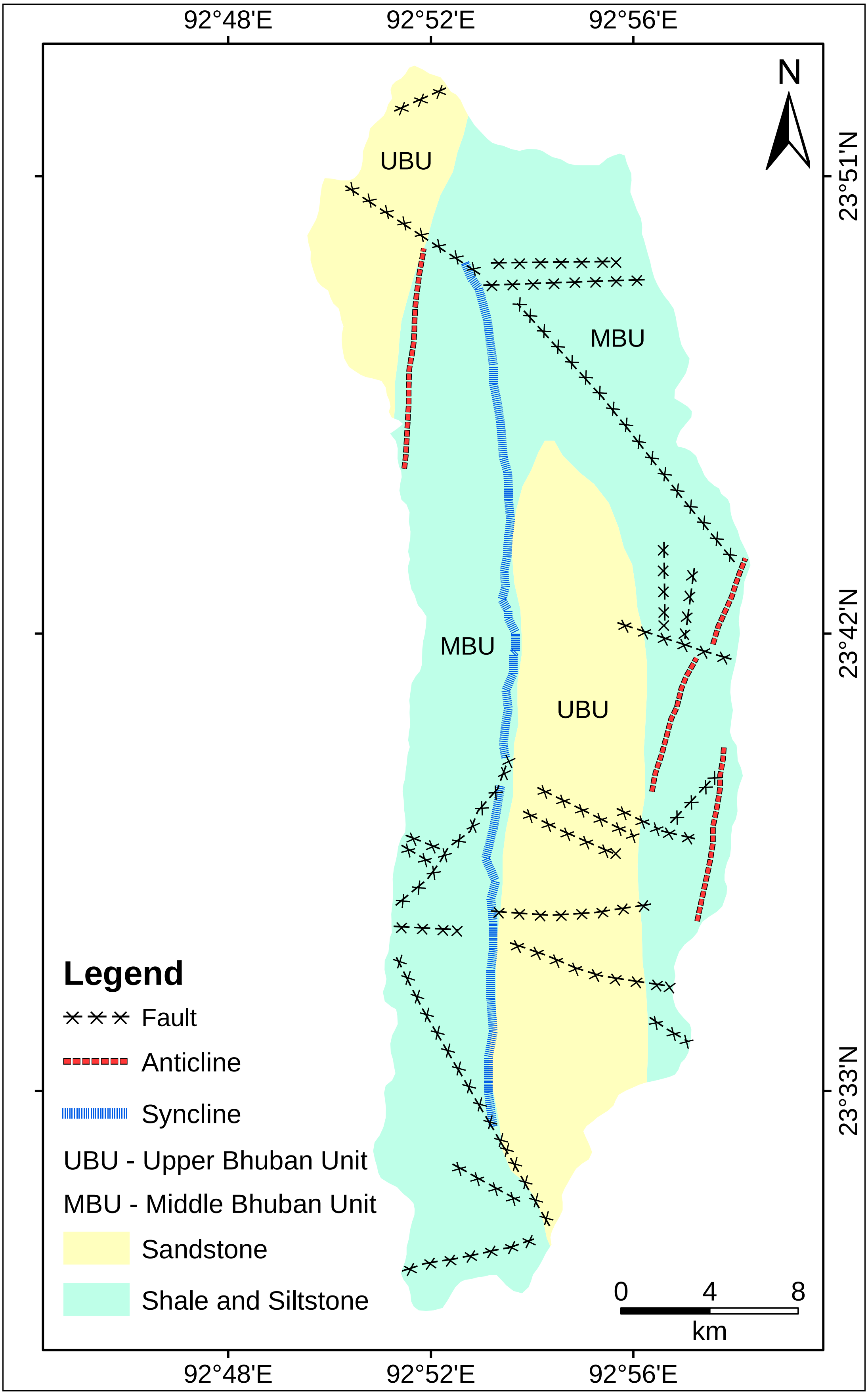


Figure 1.5. Geological map of the study area (after Ganju, 1975).

1.5 Geomorphology of the Area

The state of Mizoram is characterized by rugged undulating mountainous terrain with steep slopes. The mountain ranges in the state are oriented in north to south direction in parallel series and the hills are separated from one another by narrow deep gorges.

The study area is characterized by rugged nature of topography. It is noticed that the ruggedness of the right bank topography is high due to steep slopes and high relief. The geomorphology of the terrain is controlled by the folding and faulting activities in the study area. Geomorphologically, the area is occupied by a series of the ridges and deep valleys (Plate 1A & 2B). Most of ridges are elongated and narrow crested, though a few of these are also broad crest types. Valleys are occupied by the streams, which oriented in all directions running parallel to the strike ridges. Some of the hillocks are highly dissected with steep slopes, whereas the other areas are characterized by moderate and low dissected hillocks. The major alignments of hillocks are north to south direction in parallel series. The elevation ranges from 1905 m to 78 m above mean sea level (msl) and the average elevation of the study area is about 830 m above msl. The relief is low in the western part and increases towards the east.

The geomorphic features observed in the study area are linear ridges, escarpments, structural valleys, structural hills and valley fills (Fig. 1.6). The structural hills are the prominent landforms in the study area and are separated by narrow and steep valleys. The structural hills are classified into three categories viz. high structural hills (>1200 m), medium structural hills (1200 m - 800 m) and low structural hills (<800 m). The high structural hills are found in the northeastern and southeastern parts of the study area, which occupies 70.83 sq.km (16.87 %) area while the maximum area is covered by medium structural

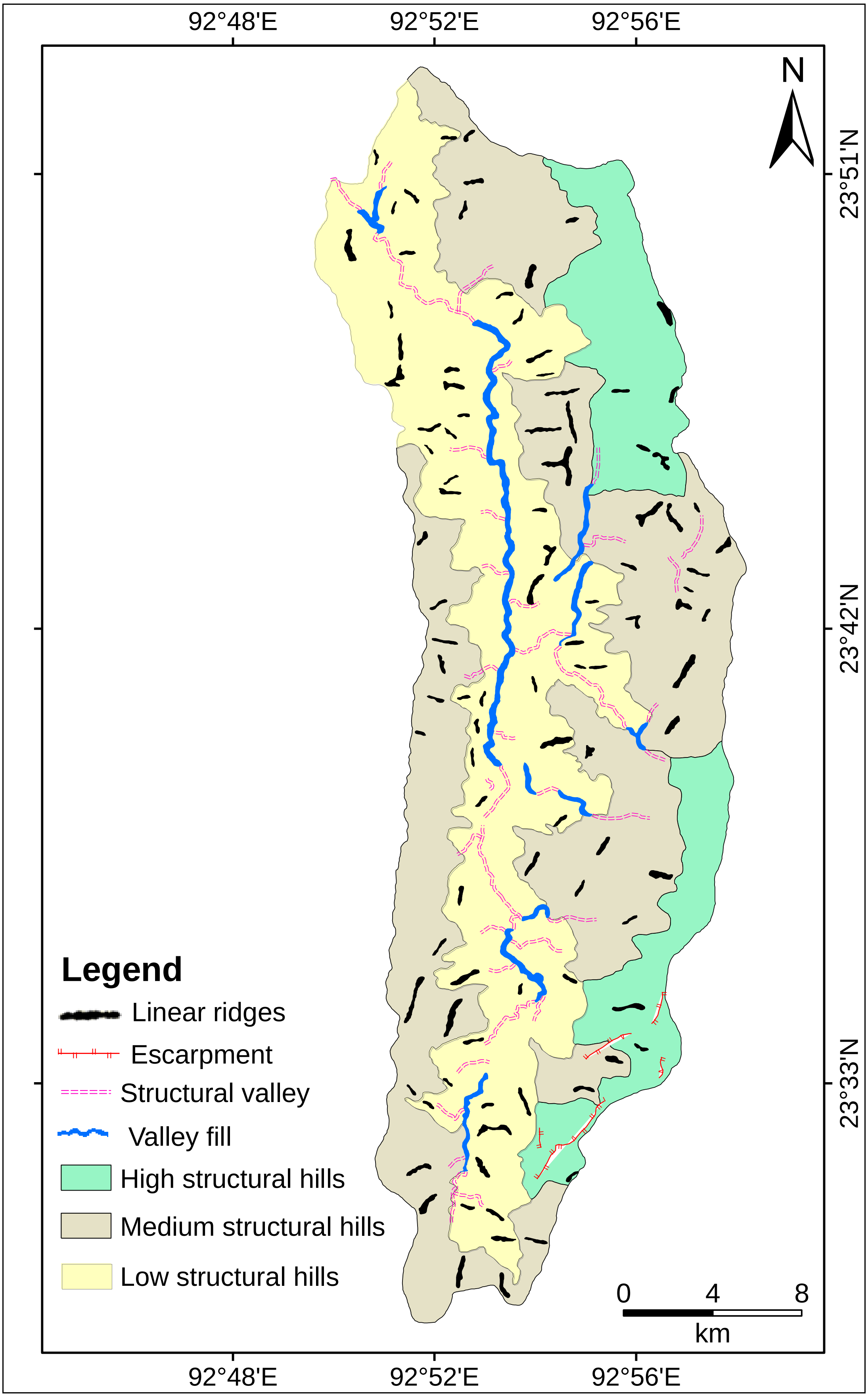


Figure 1.6. Geomorphological map of the study area.

hills comprises of 183.75 sq.km (43.75 %) area. The middle portion of the study area is covered by low structural hills and the areal extent of this unit is estimated as 165.43 sq.km (39.38 %). The structural hills with moderate to steep slopes are prone to weathering and erosion. Structural valleys are also prominent features in the area and are controlled by structure and lithology (Plate 3A & B). These show linear to curvilinear pattern with narrow and steep valleys sides. The other geomorphic feature such as valley fills deposits (Plates 4A, 4B &5A) are also noticed in the study area, which are composed of medium to coarse grained sands along the major river. There are numerous escarpments having general trends of N-S and NE-SW also observed in the study area.

1.6 Slope of the Area

The slopes of the study area are mentioned in terms of degrees and are classified into four categories such as gentle, moderate, steep and very steep (Fig. 1.7). Right side of the study area shows more irregular distribution of slope than the left side, which are described below.

1. **Gentle slope:** $< 10^0$ slope is under gentle slope class, which is observed along the lower portions of the river valleys occupies an area of about 61.75 sq.km (14.71 %).
2. **Moderate slope:** 10^0 **-** 20^0 is moderate slope category covering an area of about 125.23 sq.km (29.81 %) of the basin area. This slope type is associated with the upper valley portions.
3. **Steep slope:** Major part of the basin area of about 167.75 sq.km (39.94 %) falls under steep slope category of 20^0 **-** 30^0. Almost all the sub-basins of the study area are characterized by steep slopes.
4. **Very steep slope:** About 65.35 sq.km (15.54 %) of the study area comes under the very steep slope class of above 35^0 and mostly covered in the northeastern and southeastern parts of the basin.

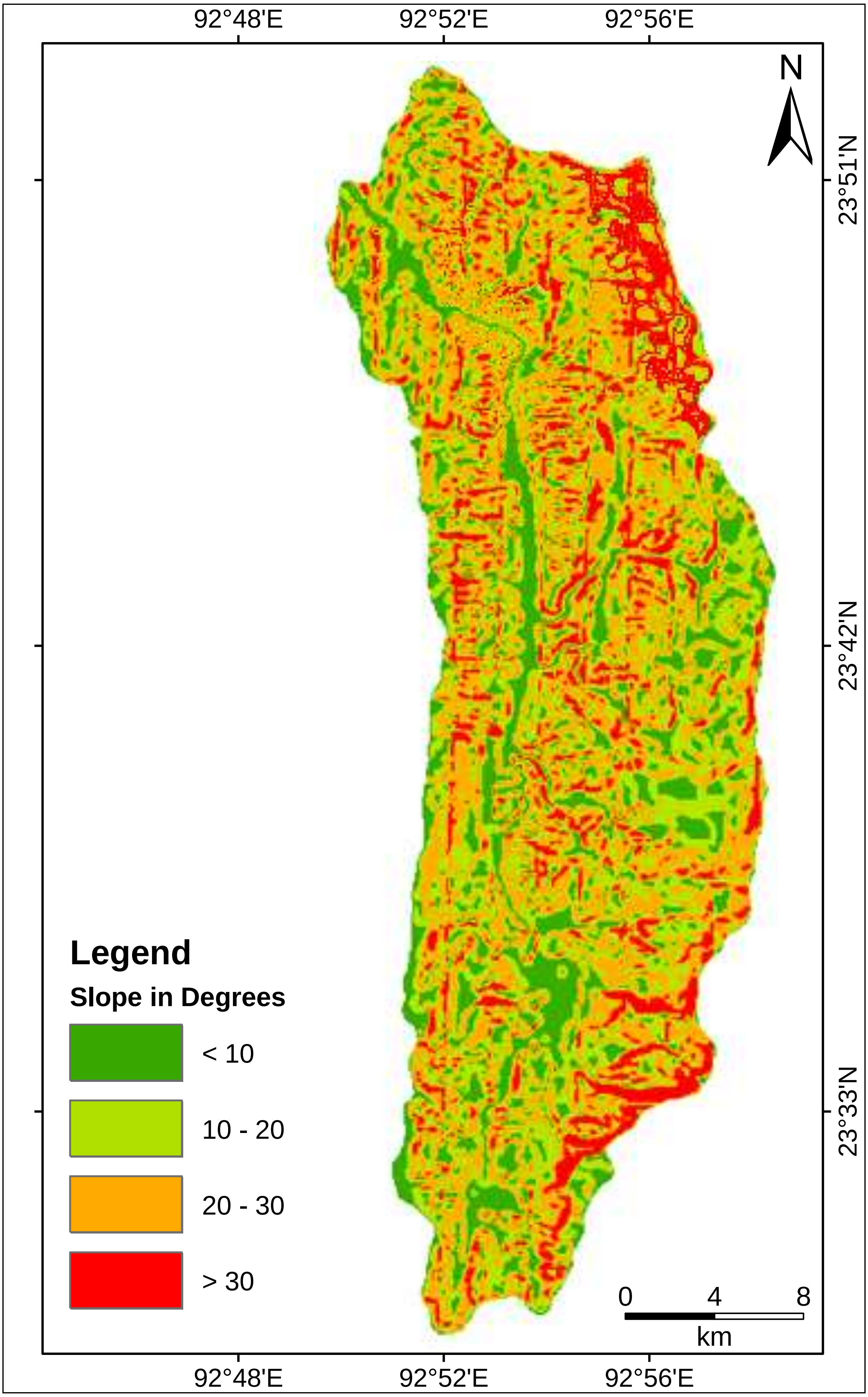


Figure 1.7. Slope map of the study area.

1.7 Slope Aspect

Aspect indicates the maximum slope direction of a terrain to which it faces. The aspect of a slope plays a significant role on its local climate because the sun’s rays are in the west at the hottest time of day in the afternoon and in most cases, a west-facing slope will be warmer than sheltered east-facing slope (Magesh *et al.*, 2011). Generally, aspect is used in hilly region, because shadows play a major role in the hilly terrain for determining the soil moisture regime. The present study area is mostly covered by hills and there is very minor flat area. From the figure 1.8, it can be seen that east facing slopes mainly occur in the western part of the basin, whereas west facing slopes are seen in the eastern part of the basin. Therefore, east facing slopes have higher moisture content and lower evaporation rate then the west facing slopes.

1.8 Objectives

The main objectives of the present study are:

1. To prepare the thematic maps of the Tuirini watershed
2. To understand the drainage morphometry
3. To evaluate the morphotectonic indices

1.9 Scope of the Work

In the present study an attempt is made to evaluate the morphometric and morphotectonic attributes of the Tuirini watershed in order to understand the evolution of landforms with reference to the tectonic activity. There are considerable works have been done by the different workers on various aspects of morphometric and morphotectonic of watersheds in the state of Mizoram. Remote sensing and Geographic Information System (GIS) are the most advanced techniques for the drainage basin analysis. Hence, the present study is carried out by using remote sensing and GIS tools.

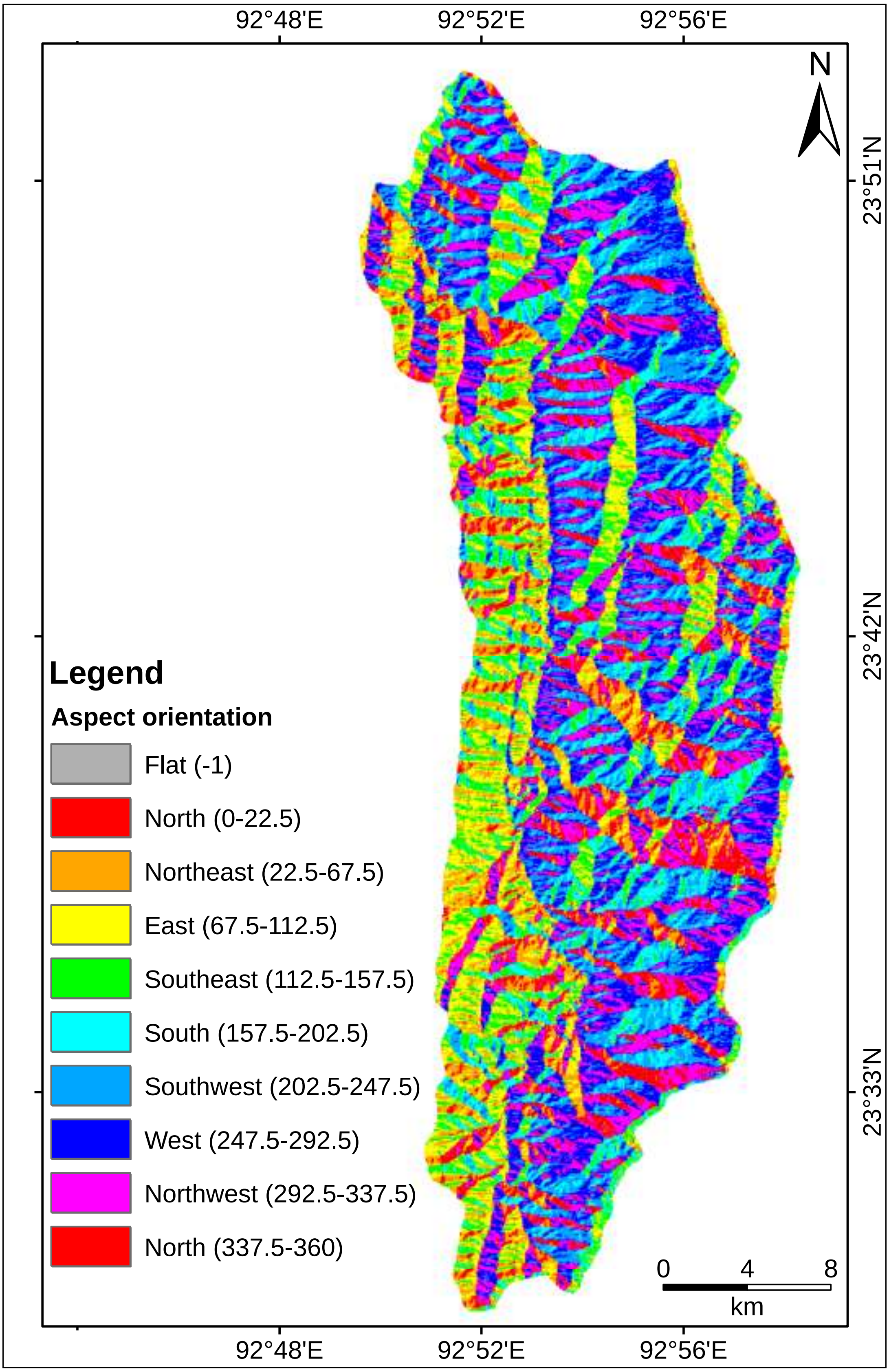


Figure 1.8. Aspect map of the study area.

Many researchers have applied the empirical formulae derived by Horton (1932 & 1945), Strahler (1952 & 1964), Schumm (1956), Smith (1950), Bull and McFadden (1977), Hack (1973) and Cox (1994) in the study of drainage basin morphometry and tectonic geomorphology. Different morphometric parameters such as bifurcation ratio, Rho coefficient, drainage density, stream frequency, drainage texture, form factor, circularity ratio, compactness coefficient, constant of channel maintenance, length of overland flow, basin relief, relief ratio, relative relief, dissection index, gradient ratio, ruggedness number, and morphotectonic indices like basin elongation ratio, asymmetry factor, transverse topographic symmetry factor, channel sinuosity, valley floor width to valley height ratio, mountain front sinuosity, stream length gradient index proposed by eminent workers is used to quantify and to understand the drainage characteristics and ongoing tectonic changes of the terrain. Hypsometric analysis is carried out to identify the stage reached by the drainage basin in the present cycle of erosion and to evaluate the erosional status of the basin. Analysis of river profiles and lineaments are carried out to better understand the influence of tectonics on drainage development in the area. Generation of thematic maps such as geological, geomorphological, slope, aspect, drainage and lineament maps etc. by using topographical maps published by the Survey of India and satellite imagery followed by field observations. The study helps to understand the terrain conditions and is more useful for management of natural resources for sustainable development, and further implementation of the developmental activities in the watershed.

1.10 Design of the Study

The present research work is organized into six chapters and all the aspects of the work undertaken in the present study are presented in their respective chapters.

Chapter-1

This chapter deals with the introductory aspects of the topic, importance of the study, scope, objectives, location and extent including drainage, climate, vegetation, geology, geomorphology, slope and aspect of the study area. This chapter also describes the organization of the work.

Chapter-2

The second chapter provides the various methods and materials applied for the present research work.

Chapter-3

This chapter gives idea about the review of the literatures carried out at international, national and regional levels.

Chapter-4

This chapter describes morphometric analysis of the Tuirini watershed as well as sub-watersheds. This chapter also elaborates on the hypsometric analysis of the Tuirini watershed and its sub-watersheds.

Chapter-5

This chapter presents morphotectonic aspects of the Tuirini watershed as well as sub-watersheds; lineament analysis includes azimuth, frequency and length of lineaments. The chapter also describes about the various river profiles of the Tuirini river and its major tributaries.

Chapter-6

This chapter deals with the summary and conclusions of the present research work.

It is followed by references as quoted in this work and filed photos are presented at the end of the thesis.

CHAPTER II

RESEARCH METHODOLOGY

The remote sensing and GIS techniques have become effective tools to overcome most of the problems of land and waters resources. During the recent years many researchers have been used satellite data and analyzed them on GIS platform for understanding the morphometric and morphotectonic characteristics of the watersheds. The following methodological framework (Fig. 2.0) has been adopted for attaining the objectives of the present study.

2.1 Materials

Three types of data sets have been used in the present study:

(i) Survey of India (SoI) toposheets No. 84A/13, 84A/14 and 84A/15 on 1:50,000 scale,

(ii) Cloud free remote sensing data in the form of Standard Geocoded False Colour Composite (FCC) of IRS-1D, LISS III satellite imagery having a spatial resolution of 23.5 m acquired on 04^{th} February, 2001 with path: 113/ row: 055 and

(iii) Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) GDEM 30 m data.

All the data were geometrically rectified and projected into Universal Transverse Mercator (UTM), WGS 1984 datum, 46 N zone projection system, so that errors can be minimized in GIS platform. ERDAS Imagine - 9.2 has been used for the digital analysis of remotely sensed data and was geometrically corrected and resampled taking toposheets as reference. The information pertaining to climatic conditions such as humidity, temperature and rainfall of the study area has been obtained from Meteorological data of Mizoram, Directorate of Economics & Statistics, Govt. of Mizoram, Aizawl, 2015.

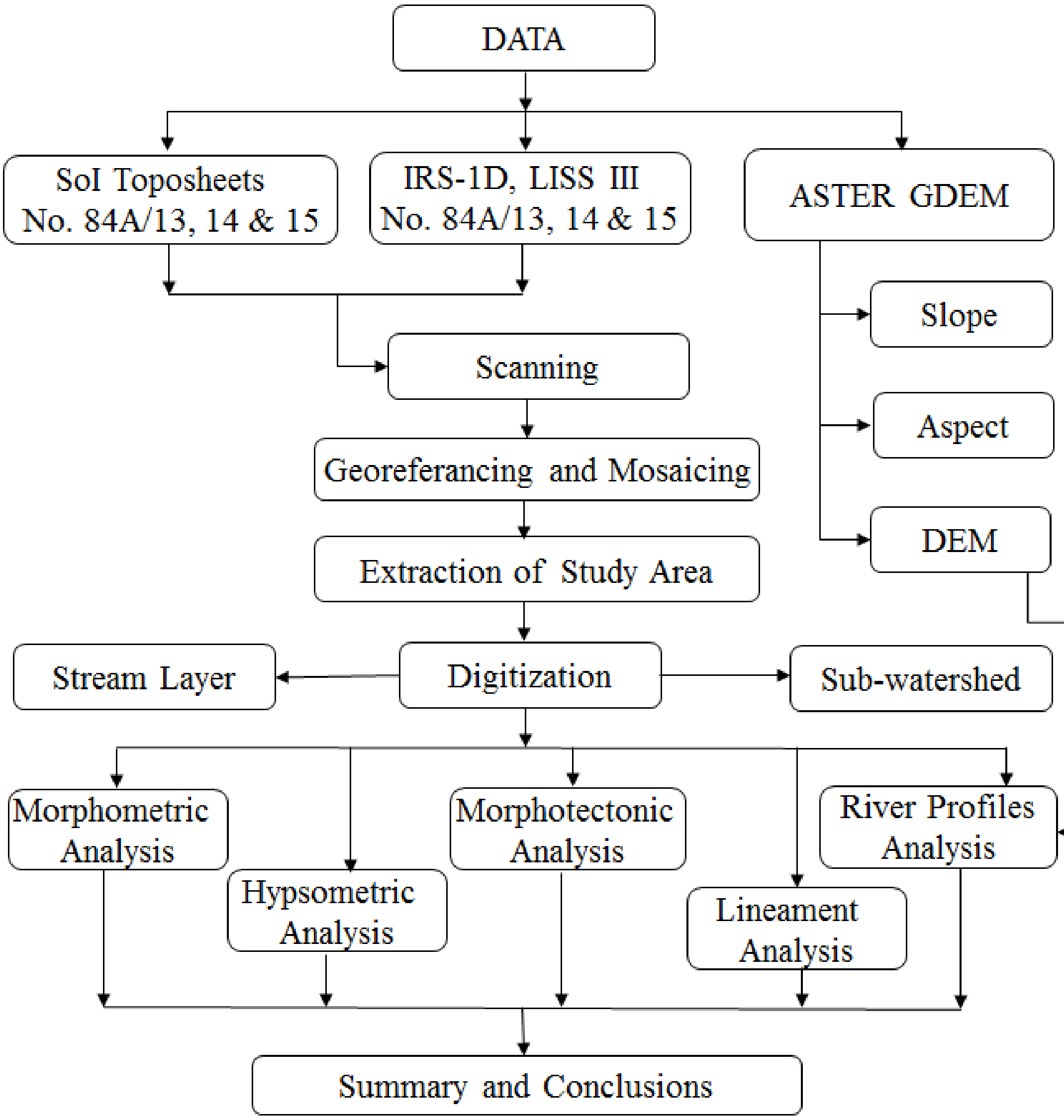


Figure 2.0. Flow chart of methodology.

2.2 Methods

The various methods have been used in this study are as follows:

1. Standard digital image processing and image enhancement techniques have been applied to extract the drainage layer from FCC (False Colour Composite) for better visualization and interpretation of the streams order.
2. The watershed boundary, sub-watersheds boundaries and stream networks were delineated and digitized from SoI toposheets, which was later updated from satellite data at scale of 1:50,000.

Table 2.1. Methods for computing morphometric parameters.

Sl. No.	Morphometric parameter	Formula	Reference
Linear Aspects			
1	Stream order (u)	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, 1964)
7	Rho coefficient (ρ)	ρ = Rl/ Rb	Horton (1945)
Textural Aspects			
8	Drainage density (Dd)	Dd = Lu/ A	Horton (1932, 1945)
9	Stream frequency (Fs)	Fs = Nu/ A	Horton (1932, 1945)
10	Drainage texture (Rt)	Rt = Dd x Fs	Smith (1950)
11	Length of overland flow (Lg)	Lg = 1/ 2Dd	Horton (1945)
12	Constant of channel maintenance (Cm)	Cm = 1/ Dd	Schumm (1956)
Geometric Aspects			
13	Form factor (Ff)	$Ff = A/ Lb^2$	Horton (1932)
14	Circularity ratio (Rc)	$Rc = 4 \pi A/ P^2$	Miller (1953)
15	Compactness coefficient (Cc)	$Cc = 0.2821 P/ A^{0.5}$	Gravelius (1914)
Relief Aspects			
16	Basin relief (R)	R = (H – h)	Schumm (1956)
17	Relief ratio (Rr)	Rr = R/ Lb	Schumm (1963)
18	Relative relief (Rhp)	Rhp = (R *100)/ P	Melton (1957)
19	Dissection index (Di)	Di= R/ Ra	Singh & Dubey (1994)
20	Gradient ratio (Gr)	Gr = (a-b)/ Ls	Sreedevi *et al.* (2005)
21	Ruggedness number (Rn)	Rn = R x Dd	Schumm (1956)

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, A = Area of the basin, P = Perimeter, Lb = Maximum length of the basin, Ls = Length of the main channel, H = Maximum elevation of the basin, h = Minimum elevation of the basin, Ra = Absolute relief, a = Elevation at source, b = Elevation at confluence, $\pi = 3.141$

3. The stream ordering was carried out using the Strahler (1964) method and the stream length has been computed as per the laws of Horton (1945).
4. The different morphometric parameters namely linear, textural, geometric and relief aspects of the sub-watersheds were computed using standard methods and formulae are presented in Table 2.1 and are also elaborated in their respective chapter.
5. All the measurements have been carried out in GIS platform using ArcGIS-10.2 version.
6. The various morphotectonic indices were estimated based on mathematical formulae proposed by Muller (1968), Hack (1973), Bull and McFadden (1977) and Cox (1994) are given in Table 2.2 and are also discussed in their respective chapter.
7. The thematic maps such as base map, sub-watershed map and drainage network map etc. are derived from SoI topographic maps together with satellite data in GIS environment.
8. Geological map of the study area has been prepared from the previously published map (Ganju, 1975) and followed by field verifications.

9. The geomorphological map of the study area has been prepared based on visual interpretation of satellite data together with toposheets information and field works.
10. Digital Elevation Model (DEM) was re-projected into Universal Transverse Mercator (UTM), WGS 1984, 46 N zone projection system for further analyses.

Table 2.2. Methods of calculation of morphotectonic indices.

Sl. No.	**Morphotectonic indices**	**Formula**	**Reference**
1	Basin elongation ratio (Re)	$Re = [(1.128\sqrt{A})/ Lb]$	Bull and McFadden (1977)
2	Asymmetry factor (AF)	$AF = 100 (Ar/ At)$	Cox (1994)
3	Transverse topographic symmetry factor (T)	$T = Da/ Dd$	Cox (1994)
4	Channel sinuosity (S)	$S = Sl/ Vl$	Muller (1968)
5	Valley floor width to valley height ratio (Vf)	$Vf = 2Vfw/ [(Eld-Esc) + (Erd-Esc)]$	Bull and McFadden (1977)
6	Stream length gradient index (SL)	$SL = (\Delta H/ \Delta L) * L$	Bull and McFadden (1977)
7	Mountain front sinuosity (Smf)	$Smf = Lmf/ Ls$	Hack (1973)

Where,

A = Area of the basin, Lb = Length of the basin, At = Total area of the basin, Ar = Right hand side area of drainage basin facing downstream of the trunk stream, Da = Distance from midline of drainage basin to the midline of the active meander belt, Dd = Distance from the basin midline to the basin divide, Sl = Stream length, Vl = Valley length, Vfw = Width of the valley floor, Eld = Elevation of the left valley divide, Erd = Elevation of the right valley divide, Esc = Elevation of the valley floor, ΔH = Change in elevation of the reach,

ΔL = Change in length of the reach, L = Total channel length from the point of interest where the index is being calculated upstream to the highest point on the channel, Lmf = Length of the mountain front measured along the foot of the mountain, Ls = Straight line length of the mountain front

11. The slope map, aspect map and DEM were generated from ASTER GDEM 30 m resolution data using Surface Tools in ArcGIS-10.2 software.
12. The lineaments were identified from satellite imagery through visual interpretation. These lineaments normally show spatial variation in tone, colour, texture, soil tone, ridge lines and drainage course in satellite data.
13. Lineament extraction, digitization and analysis were carried out with the aid of ArcGIS v. 10.2 and ERDAS Imagine v. 9.2 image processing software. The orientations of the lineaments were analyzed with the help of rose diagram.
14. The river networks were digitized from SoI topographical maps as well as updated from satellite imagery using ArcGIS v. 10.2. Based on the ASTER digital elevation data, river profiles have been generated in GIS platform.
15. Contour interval of 40 m was accurately digitized within GIS environment from the scanned SoI topographic maps.
16. The hypsometric curves for the Tuirini watershed and its sub-watersheds were prepared based on Strahler (1952) method.
17. Hypsometric integrals of all the sub-watersheds have been calculated using empirical formula proposed by Pike and Wilson (1971).

CHAPTER III

REVIEW OF LITERATURE

There are numbers of studies have been carried out in the field of drainage morphometry and on the various aspects of tectonic activity of drainage basin using different morphotectonic indices in different parts of the globe. The available literatures related to various aspects of watershed studies have been reviewed in order to achieve the present study.

Angillieri (2008) has made a study on morphometric analysis of Colanguil river basin in the province of San Juan, Argentina in order to evaluate flash flood hazards. The computed morphometric parameters such as drainage density, circularity index and elongation ratio etc. show that lower order streams dominate the basin and nature of rocks is impervious with highly dissected areas. The study also reveals that the basin is structurally controlled, resistance to erosion, low infiltration capacity and high runoff.

Drainage morphometry and its influence on landforms in volcanic terrain of central Anatolia in Turkey was studied by Altin and Altin (2011). The study shows that the area is made up of hard volcanic rocks and exhibit steep slope with rugged nature of topography. The computed morphometric parameters include bifurcation ratio, stream frequency, texture ratio, compactness factor, shape factor, ruggedness number etc. also suggest that the area is characterized by high runoff zone and the low infiltration creates adequate runoff for formation of flood in upstream areas of the basin.

Subyani *et al.* (2012) have analyzed the morphometric parameters of western Saudi Arabia by utilizing DEM and GIS to understand the hydrological conditions of the area. The parameters such as circularity ratio, sinuosity factor, drainage density, relief ratio and elongation ratio reveal drainage patterns of the region are dendritic in nature with highly permeable landscape and low runoff potential.

Flash flood risk estimation based on morphometry and satellite imagery using GIS in southern Sinai, Egypt carried out by Youssef *et al.* (2011). The various morphometric parameters viz. bifurcation ratio, drainage density, length of overland flow, shape index, lemniscate ratio, hypsometric integral and sediment yield have been determined. The results of this study can initiate appropriate measures to mitigate the flash flood hazards in the area.

Evaluation of morphometric parameters of drainage networks by using topographic maps and DEM has studied by Ozdemir and Bird (2009) in the Havran river basin of the Balikesir district, Turkey to determine the influence of sub-basins to flooding on the main channel. The estimated morphometric parameters such as stream frequency, texture ratio, basin relief, time of concentrations etc. indicate that systematic analysis of morphometric parameters within drainage networks using a GIS can provide significant value in understanding sub-basins drainage characteristics with respect to flooding.

The morphometric characterization of the Roccella Torrent basin located in Italy was worked out by Rapisarda (2009) to describe the evaluative geomorphic state of the basin through the analysis of topographic maps and air photos. The analysis of parameters like stream order, bifurcation index, drainage density, hypsometric integral, asymmetry factor etc. stated a low hierarchization of drainage network caused mainly by tectonic structures and by intense landslides in the basin.

Eze and Efiong (2010) have studied morphometric parameters of the Calabar river basin in the Cross River State, Nigeria. The computed morphometric parameters such as bifurcation ratio, drainage density, form factor, basin relief, compaction coefficient and length of overland flow reveal that the basin is strongly elongated and the very low value of drainage intensity implies that drainage density and stream frequency have very little effect on the extent to which the surface has been lowered by agents of denudation. The study further shows that the Calabar river basin is susceptible to hydrologic processes like flooding, erosion and landslide.

Estimation of morphometric parameters using remote sensing data and GIS techniques performed by Dewidar (2013) in the Wadi El Gemal basin, Egypt. The estimated value of parameters viz. drainage density, form factor, texture ratio, relief ratio, compaction coefficient etc. indicate that the basin is elongated in shape with strong structural control in drainage patterns. The study also concluded that the area is high intensity of erosion and the basin tends to produce sharp peaks in surface water discharge.

Ghaffar *et al.* (2015) estimated morphometric parameters of Wadi El-Arish basin located in the Sinai Peninsula, Egypt using geographic information system and remote sensing techniques to evaluate the watershed characterization and ground water potentiality of the area. The calculated morphometric parameters such as bifurcation ratio, drainage density, infiltration number, elongation ratio, fitness ratio, length of overland flow etc. indicate that the basin is of eight order stream with dendritic type of drainage pattern and homogeneous lithology with late mature stage of geomorphic development. The study also reveals that the basin is having coarse to intermediate drainage texture and the groundwater potential is of the moderate class.

Yunus *et al.* (2014) have been carried out morphometric analysis of drainage basins in the western Arabian Peninsula considering various parameters like bifurcation ratio, drainage density, texture ratio, infiltration number, elongation ratio, fitness ratio, compactness constant, relative relief, hypsometric integral etc. The study reveals that the basin is elongated with immature basin and the drainage texture parameters have negative correlations with relief and slope parameters. The basin relief, slope and the length of each stream segment, which may also reflect the effect of mass wasting on stream development.

Koshak and Dawod (2011) carried out studies on morphometric analysis of hydrological catchments within Makkah metropolitan area in Kingdom of Saudi Arabia using GIS. The correlation results showed that the basin area is the most effective element that influences the sum of stream lengths of all orders. The analyzed parameters viz. stream frequency, texture ratio, circularity ratio, relative relief, ruggedness number etc. suggest that the catchment is characterized by medium drainage density with medium to low relief. The study also concluded that this catchment may be regarded as the most hazardous area in terms of flash flood impacts.

Paul and Bayode (2012) have been worked out the morphometric characteristics of the Sokoto basin in Nigeria to assessing the flood and water resources potential of the basin using GIS. The values of morphometric parameters such as bifurcation ratio, drainage intensity, elongation ratio, fitness ratio, relief gradient etc. reveal that the basin is sinuous in nature, circular in shape and compact where travel time and time of concentration are short. The low drainage density implies widely spaced steams due to the less resistance rocks, high rate of siltation and the basin has high flood potential.

Perez-Pena *et al.* (2009) have estimated the hypsometric integrals (HI) values for the Granada basin in Spain to understand tectonic uplift rates and lithology differences in the basin area. The Granada basin shows a strong correlation between the main distributions of active normal faults in the basin and the clusters of high or low HI values obtained in the analysis. The clusters of high HI values are clearly correlated with different structural domains related to the main active faults in the area. Low HI values occur in active and recent sedimentation areas in the footwall of the main faults, near the trace of the faults, which coincide with the main seismicity clusters in the region.

Quanbari *et al.* (2014) carried out studies on hypsometric properties of Marvdasht plain basins in SW Iran. In this study, spatial variations of tectonic activity at Marvdasht plain were investigated by hypsometric integral analysis. The results of the analysis indicate the high value of hypsometric integral is coincided to fault zones and folds and the northeast of Marvdasht plain with two stages of erosion cycle development, namely mature and old stages are distinguished.

Hypsometric integral (HI) and trend surface analysis (TSA) using DEM was performed by Siddiqui and Soldati (2014) to investigate active tectonics in the Emilia-Romagna Apennines of northern Italy. The results indicate that the high HI values and TSA anomalies are positively correlated with the areas of high tectonic activity and along the regional tectonic structures.

Sarp *et al.* (2011) have been carried out hypsometric study of hydraulic basins located on western part of the North Anatolian Fault Zone (NAFZ), Turkey in order to investigate erosional stage of the basins and the tectonic and lithological factors controlling it. They have reported the convex, S shaped and concave hypsometric curves, which indicate the erosional stage and level of tectonic activity of basins differs from each other.

Al-Taj *et al.* (2007) were measured morphotectonic indices such as mountain front sinuosity (Smf) and valley-floor width to height ratio

(Vf) along the eastern margin of the Dead sea and the Jordan valley in Jordan. The study concluded that the mountain fronts east of the Dead sea and the Jordan valley have low Smf and Vf values, which indicate active uplift of the eastern margin of the Dead sea and the Jordan valley.

Toudeshki and Arian (2011) carried out the study of morphotectonic analysis in the Ghezel Ozan river basin in NW Iran to discriminate the uplift and tilting rates of different segments of the basin. The morphotectonic indices viz. drainage basin shape, transverse topographic symmetry, valley floor width to valley height ratio, stream length gradient index and mountain front sinuosity show that different segments of the Ghezel Ozan river vary from each other regarding the amount of tectonic activity and movements increase from west to east. The uplift rate is high and the indices emphasize on the domination of the tectonic processes over the alluvial processes.

Hirnawan and Muslim (2006) have investigated drainage morphometry characterizing active tectonism in west Java, Indonesia. The study inferred neotectonic activity in the region between Barabis-Majenang faults system and Ciawi-Pangandaran faults in west Java.

Tilting of the Guadiamar drainage basin due to neotectonic activity in SW Spain was studied by Salvany (2004) using morphotectonic indices such as transverse topographic symmetry, asymmetry factor and drainage basin shape. The study reveals that the regional tectonic tilting toward the SSE, causing both the migration of the Guadiamar river towards the east and the migration of the Guadiamar tributaries towards the southwest. As a consequence of the Guadiamar river migration, an asymmetric valley developed, with a steep eastern margin caused by river dissection and the asymmetry of the basin as the results of tectonic tilting.

Analysis of tectonic-controlled fluvial morphology and sedimentary processes of the western Amazon basin in Brazil using satellite images and digital elevation model was carried out by Silva *et al.* (2007). The study indicates the role of neotectonics in controlling the fluvial morphology and sedimentation processes of the basin. The features such as fault scarps, anomalous drainage patterns, aligned ridges, spurs and valleys, are expressed in the enhanced images as conspicuous lineaments along NE-SW, NW-SE, E-W and N-S directions. These features are associated to the geometry of alternated horst and graben structures, which latter filled by the recent sediments.

Tsimi *et al.* (2007) have studied morphotectonics of the Psathopyrgos active fault in western Corinth Rift of central Greece using different morphotectonic indices such as hypsometric integral, drainage basin asymmetry and ratio of valley floor width to valley height. The analysed morphotectonic indices indicate tilt to the right (east) of the area and regions have a high value of mean topography, which results from high rates of tectonic activity. The study also suggests that these areas have experienced very recent uplift and intense down-cutting as a result of bi-directional fault growth.

Ramirez-Herrera (1998) carried out studies on geomorphic assessment of active tectonics in the Mexican volcanic belt in Mexico to assess the spatial variations of Quaternary deformation and tectonic activity of the faults along the Acambay graben using geomorphic and morphometric indices. The study concluded that the tectonic uplift in this area is relatively high and low dissection, convex river long-profiles as well as V-shaped valleys suggest high degree of tectonic activity.

Pirasteh *et al.* (2010) have studied the litho-morphotectonics analysis and geomorphological parameters in parts of Khuzestan and Lorestan provinces, Zagros Fold Belt (ZFB) in southwestern part of Iran to estimate the influence of lithology, structure and topography for the development of drainage networks in the region by using digital topography, remotely sensed data and GIS. The computed parameters like drainage density, drainage order, relief etc. reveal that the low drainage density in the study area is developed due to plunging fold in tectonically active region with high topography. This study also shows the advantages of the remotely sensed data and GIS techniques to correlate the lithological units with drainage network system.

Maroukian *et al.* (2008) carried out study of morphotectonic control on drainage network evolution in the Perachora Peninsula, Greece. The results of this study reveal the lower parts of the drainage systems are much younger than their upper mountainous parts. The drainage networks also display the different evolutionary and were primarily affected by tectonism.

Cuong and Zuchiewicz (2001) have been studied morphotectonic properties of the Lo river fault near Tam Dao in north Vietnam using the morphotectonic parameters like mountain front sinuosity index, valley floor width to height ratio and basin elongation ratio. It is inferred that the nature of Lo river fault as an uplift active fault showing 1-2 mm/year rate of dextral slip and about 0.1mm/year rate of uplift during the past 1-2 Ma and 1.7 Ma, respectively.

Sarp *et al.* (2013) have made a study on tectonic activity levels and development stages of the Bolu, Yenicaga, Dortdivan, Cerkes, Ilgaz, and Tosya structural basins along the western portions of the main trace of the North Anatolian Fault Zone (NAFZ) in Turkey. The analyses indicated that the basins have different characteristics of tectonic activity. The tectonic activity of the basins increases from west to east, whereas on the northern side, the tectonic activity increases westwards.

Altin (2012) has been investigated for geomorphic signatures of active tectonics in drainage basins in the southern Bolkar Mountain, Turkey using geomorphic indices such as valley floor width to height ratio, stream length-gradient index, topographic symmetry factor, concavity index, elongation ratio, basin compactness etc. The lower values of valley floor width to height and elongation ratios, higher values of convexity and stream length-gradient indices, hypsometric integral and convex nature of the hypsometric curves and topographic asymmetry show that relative tectonic activity is greater in the eastern sector which is affected by Ecemiş fault.

Ozkaymak and Sozbilir (2012) have made a study on tectonic geomorphology of the Spildagl High Ranges in western Anatolia to evaluate the impact of active tectonics on the landscape evolution of the region. The results of the calculated geomorphic indices of the mountain front sinuosity, facet slope to height ratio, percentage faceting, river incision and hypsometric curves suggest that the analyzed normal fault segments are linear and highly active.

Morphometric analysis of the upper catchment of Kosi river using GIS techniques for the identification of morphological features in between Nepal and India were carried out by Wakode *et al.* (2013). The computed parameters such as stream frequency, form factor, circularity ratio, channel gradient, runoff coefficient etc. indicate that the catchment area is elongated in nature and the drainage system is structurally controlled. The area is also characterized by high to moderate relief with sparse vegetation cover.

Magesh and Chandrasekar (2014) have carried out the morphometric characteristics of Tamiraparani sub-basin in Western Ghats, India to determine the drainage characteristics using GIS model technique. Bifurcation ratio in the study area indicates that the geological structures have little influence on the drainage networks and the drainage density suggests that the nature of subsurface strata is permeable with a very fine drainage texture. The elongation and circulatory ratio reveals that the sub-basin is less elongated with high relief and steep slope.

Morpho-tectonic analysis using Cartosat-1 (DEM) data and GIS techniques of Man river basin in Akola and Buldhana districts of Maharashtra, India studied by Khadri and Kanak (2013) to understand the hydrogeological conditions of the region. Based on the results of different parameters such as Rho coefficient, lemniscate ratio, elongation ratio, texture ratio, drainage intensity, relief ratio etc. suggest that the drainage networks of the watershed show dendritic with coarse texture, moderate drainage density, elongated shape, low degree of slope and low surface runoff. This study also concluded that Cartosat-1 (DEM) data, coupled with GIS techniques have been proven to be a competent tool in the proper interpretation of the morphometric analysis.

Rawat *et al.* (2013) have carried out the morphometric analyses of Sub-Himalayan region in relation to small hydro-electric power for developing a multipurpose small reservoir under GIS framework. The study reveals that the Bari-Ka- Khad watershed can be considered as a suitable site of interest for small-scale hydropower installation, which demonstrates better capacity to produce runoff. The computed value of morphometric parameters like bifurcation ratio, stream length ratio, Rho coefficient, compactness coefficient, lemniscate ratio, drainage density, elongation ratio, gradient ratio, dissection index etc. inferred that the area is composed of impermeable materials, coarse texture with elongated shape and higher values of Rho coefficient, suggesting higher water storage during rainfall and attenuation of effects of erosion during elevated discharge.

Jasmin and Mallikarjuna (2013) have applied remote sensing and GIS techniques at sub-basin level for the identification of groundwater potential zones of Araniar river basin in India using different morphometric parameters like stream frequency, form factor, texture ratio, infiltration number, relief ratio, ruggedness number etc. The analyses of the morphometric parameters indicate that the sub-basins are high groundwater potential zones. It is also inferred that the sub-basins of Araniar basin are comparatively permeable and possess favourable infiltration characteristics.

Prasannakumar *et al.* (2013) studies on terrain evaluation through the assessment of geomorphometric parameters using DEM and GIS in Attapady of south India. The analysis of geomorphometric parameters viz. stream length ratio, drainage density, texture ratio, elongation ratio, relief ratio etc. coupled with DEM and GIS suggest that the area is structurally complex with high relief and the denuded hills are undergoing severe soil erosion.

Gupta *et al.* (2013) performed morphometric and hydrological analysis of north east Punjab region, India by using GIS to study the quantitative analysis of drainage system. The estimated parameters such as bifurcation ratio, basin circularity, drainage frequency, drainage texture etc. show that the entire watershed area is dominated by 1^{st} and 2^{nd} order streams. The development of the stream segments in the area is more or less affected by rainfall and the general topographic gradient of the entire area is towards north east.

Hajam *et al.* (2013) have been carried out morphometric analysis using geo-spatial technology to identify the ground water potential zones through geo-morphometric parameters in Vishav drainage basin, India. The analyzed parameters like stream frequency, drainage texture, form factor, elongation ratio, infiltration number, basin relief, dissection index etc. indicate that the basin is elongated in shape with low runoff, moderate to high infiltration capacity and good groundwater resource. The study also reveals that morphometric analysis based on GIS technique is a competent tool for geo-hydrological studies.

Deshmukh (2012) carried out studies on morphometric and morphotectonic aspects of the Wani Rambhapur region, Akola district in Maharashtra, India with reference to remote sensing analysis to understand the drainage basin morphometry of the basaltic terrain. The calculated parameters such as bifurcation ratio, drainage density, form factor, texture ratio, infiltration number, circularity ratio etc. reflect that the watershed is less elongated and is in the late mature stage of erosional development.

Morphometric analysis of Terakanambi watershed was studied by Kumar *et al.* (2012) to determine the drainage characteristics. The analyzed parameters viz. stream frequency, drainage texture, Rho coefficient, length of overland flow, form factor, ruggedness number etc. indicate that the area is highly permeable subsoil with coarse drainage texture.

Chakraborty *et al.* (2002) have been carried out morphometric analysis of a watershed using remote sensing and GIS in western Rajasthan, India in order to characterize the hydrological response of the watershed for suitable soil and water conservation management. The analysis of morphometric parameters such as drainage density, form factor, infiltration number, elongation ratio, relief ratio etc. implies that the area is characterized by the impermeable subsurface material, high relief with high runoff and erosion potential of the area. The study also proved that morphometric analysis is a viable method of characterizing the hydrological response behaviour of the watershed.

Gayen *et al.* (2013) have been carried out morphometric analysis of Kangshabati-Darkeswar interfluves area in West Bengal, India using ASTER DEM and GIS techniques to understand the drainage characteristics of interfluves area. The study concluded that remote sensing data (ASTER-DEM) coupled with GIS techniques have been proven to be a competent tool in morphometric analysis and the area is characterized by moderate to poor groundwater prospect as the area has less permeable.

Golekar *et al.* (2013) carried out studies on morphometric and hydrogeological analysis of Anjani and Jhiri river basin in Maharashtra, India. The computed parameters like drainage frequency, bifurcation ratio, texture ratio, circulatory ratio etc. indicate that the area is elongated in nature and the drainage system is structurally controlled. The area is also characterized by dendritic to sub dendritic drainage pattern with massive and coarse drainage texture.

Pareta and Pareta (2011) have been carried out hydromorphogeological study of Karawan watershed using various morphometric parameters such as stream frequency, texture ratio, infiltration number, fitness ratio, compactness constant, relative relief, ruggedness number etc. Based on the morphometric evidences it is inferred that the erosional development of the area by the streams has progressed well beyond maturity and that lithology has an influence in the drainage development.

Morphometric analyses of upper part of Pambar watershed in Tamil Nadu, India was carried out by Narmatha *et al.* (2013) using GIS. The computed parameters viz. bifurcation ratio, stream frequency, drainage texture, elongation ratio, gradient ratio etc. reveal that the watershed is elongated in shape with low drainage density and the terrain is having low relief. The study also reveals that the drainage area is passing through an early mature stage to old stage of fluvial geomorphic cycle.

Shah and Patel (2009) have been quantitatively carried out morphometric analysis of Vishwamitri river basin in Gujarat, India using geographical information system. The analysed various morphometric parameters such as texture ratio, elongation ratio, relief ratio, constant of channel maintenance etc. suggest that the area is characterized by impermeable sub-surface materials, elongated shape with coarse drainage texture.

Bharadwaj *et al.* (2014) have been carried out morphometric analysis in Adyar watershed of Chennai, India based on GIS to understand the nature, landscape development and hydrologic responses of the region. It is inferred that the Adyar watershed is elongated with moderate to low relief. The study also demonstrated that GIS is a valuable tool for analysis of various morphometric parameters.

Aravinda and Balakrishna (2013) studied morphometric analysis of Vrishabhavathi watershed using remote sensing and GIS methods in Arkavathi river basin of Bangalore, India. The estimated morphometric parameters such as bifurcation ratio, stream frequency, form factor, texture ratio, infiltration number, compactness constant, relief ratio etc. reveal that the watershed has suffered less structural disturbance and coarser texture in nature with dendritic pattern of drainage.

Morphometric analysis of Rangat watershed in middle Andaman, India using geographic information system and remote sensing carried out by Shankar and Dharanirajan (2014). The computed values of drainage density, form factor, drainage texture, infiltration number, elongation ratio etc. reveal that the area is elongated having moderate relief and low infiltration capacity due to impervious sub-surface resulting rapid storm response giving rise to a higher runoff resulting in downstream flooding.

Malik *et al.* (2011) have been carried out morphometric analysis of Lidder catchment in Kashmir valley using geographical information system. The analysis revealed that the total number as well as total length of stream segments is maximum in first order streams and decreases as the stream order increases. The drainage density values of the watersheds exhibit high degree of positive correlation with the stream frequency suggesting that there is an increase in stream population with respect to increasing drainage density and vice versa.

The morphometric analysis of Domri river sub-basin was carried out by Snehal and Babar (2013) in order to hydrological implication. The analyzed morphometric parameters like drainage density, drainage texture etc. indicate that the watershed is characterized by massive and resistant rocks cause intermediate coarse texture with dendritic to sub dendritic drainage pattern is developed in the area.

Pal and Debnath (2013) have been studied the detail morphometric characteristics of Jaipanda watershed in Silabati river basin, West Bengal, India using ASTER (DEM) data and GIS. The estimated morphometric parameters like form factor, drainage texture, infiltration number, length of overland flow, relative relief etc. of the watershed show dendritic drainage patterns with moderate drainage texture and elongated shape in nature. The bifurcation ratio of the watershed indicates normal watershed category and the presence of moderate drainage density suggesting that it has moderate permeable sub-soil, and coarse drainage texture. The study also concluded that ASTER (DEM) data, coupled with GIS techniques have been proven to be a competent tool in morphometric analysis.

Ravikumar and Madesh (2012) have been studied drainage morphometry of Mariyala - Veeranapura watershed in Chamarajanagar district of Karnataka, India to understand its influence on hydrology of the area. The study reveals that the elongated shape of area is mainly due to guiding effect of thrusting and faulting. The analysis also indicates that the area is characterized by highly permeable sub-soil materials and drainage networks are not affected by tectonic disturbances.

Dikpal and Prasad (2013) carried out morphometric analysis of fourth order sub-basins in north Bangalore metropolitan region using remote sensing and geographic information system techniques to find out the relationship between the morphometric parameters at sub-basin level. The analysis of the drainage networks of the sub-basins show dendritic to sub-dendritic patterns. The computed values of drainage density, drainage texture, relief ratio etc. suggest that the area is characterized by moderate drainage texture and drainage system is less structurally controlled associated with moderate to high relief and steep slopes.

Iqbal *et al.* (2012) have been carried out watershed level morphometric analysis of Dudhganga catchment, Kashmir valley, India using GIS. The calculated morphometric parameters such as bifurcation ratio, drainage density, texture ratio, elongation ratio etc. show that the watersheds are almost elongated with high to moderate drainage density and also characterized by very coarse to coarse drainage texture.

Morphometric analysis of Lidder watershed, western Himalaya, India was carried out by Altaf *et al.* (2013) to infer hydrological behaviour of the area using geospatial technique. The outcome revealed that the entire study area has uniform lithology with structurally control drainage. The morphometric analysis also indicates that the area is more prone to weathering due to very coarse to coarse drainage texture with high surface runoff.

Brar (2014) has been carried out morphometric analysis of Siswan drainage basin, Punjab (India) using geographical information system for the identification and analysis of morphological features of the area. The analysed parameters like drainage density, elongation ratio, drainage texture etc. reveal that the basin is strongly elongated and highly permeable, homogenous geologic materials with moderate drainage texture.

Ramaiah *et al.* (2012) performed morphometric analysis of sub-basins in and around Malur Taluk, Kolar district in Karnataka, India using remote sensing and GIS techniques. The study shows that the terrain exhibits dendritic to sub-dendritic drainage pattern and has coarse to fine drainage texture associated with high relief and steep slopes. The study also reveals that remote sensing and GIS techniques proved to be the competent tool in analysing various morphometric parameters.

Murthy *et al.* (2014) have been carried out morphometric analysis of Cauvery sub-watershed of south Bangalore metropolitan region of Karnataka, India using geographic information system. The analysis of the drainage networks of the watershed show trellis to dendritic patterns. The computed values of shape parameters indicate elongated nature of the basin.

Analysis of morphometric parameters viz. bifurcation ratio, drainage texture, drainage density etc. using remote sensing and GIS techniques was carried out by Moharir and Pande (2014) in the Lonar Nala in Akola district of Maharashtra, India. The analysis shows dendritic and radial drainage patterns with moderate drainage texture of the area. The bifurcation ratio indicates normal watershed category and the presence of moderate drainage density suggesting that it has moderate permeable sub-soil.

Singh and Sinha (2009) studied morphotectonic analysis of watersheds in Saharanpur district of U. P., India using GIS tool. The analysed parameters such as drainage density, drainage texture, form factor, relief ratio etc. reflect that the watershed is characterized by dendritic drainage pattern and coarse texture with elongated shape of basins.

Umamathi and Aruchamy (2014) studied the morphometric analysis of Suruli Ar watershed in Theni district, Tamil Nadu, India using GIS. The study concluded that the area is characterized by high altitude, high drainage density and stream frequency with fine texture ratio, which imply impermeable subsistence sub-surface material, low infiltration capacity and low groundwater potential of these areas.

Dash *et al.* (2013) have been carried out morphometric analysis of Sirsa river basin in western Himalaya, India based on GIS to understand the drainage basin evolution. Overall analysis shows that the basin is well drained and elongated. The analysis of various morphometric parameter and their correlations indicate that sub-basins are in early mature stage, middle to late mature stage and early old stage of landscape development.

Herlekar and Sukhtankar (2011) have been investigated for morphometric and geomorphic evolution in relation to neotectonic activity in the part of Maharashtra coast, India. The study concluded that the drainage pattern is dendritic with moderate to high drainage density. Further the hypsometric parameter indicates that the NE part of the area has been uplifted in relation to SW part of the area with tectonic tilting and the basins are relatively younger stage of drainage evolution.

The morphotectonic analysis of Anandpur Sahib area, Punjab was worked out by Bhatt *et al.* (2007) through satellite data and GIS inferred the tectonic activity considering different geomorphic indices viz.

channel sinuosity, drainage basin asymmetry, basin elongation ratio, mountain front sinuosity and valley floor width to height ratio index in addition to the identification of fluvial anomalies like abrupt changes in flow direction, flow against gradient, beheaded streams and river terraces which have strong structural control on the fluvial features. The study concluded that asymmetric nature of drainage basin, elongated sub-watershed, straight to curvilinear mountain front and narrow incised valley floors are the evidences of active tectonic in this region.

Virdi *et al.* (2006) have been carried out morphotectonic analysis in the upper reaches of the Markanda and Bata rivers using morphotectonic parameters such as basin asymmetry factor (AF) and transverse topographic symmetry factor (TF) in Himachal Pradesh, India. The study concluded that the Markanda and Bata drainage basins are tilted due south, uplifted and strong asymmetry of the two basins. The tilting is either due to the reactivation of the Nahan Thrust (NT) or to the slip occurring in the terrain between the NT and the MBT. Uplift of the Quaternary fan material by the Bata Fault further corroborates the active tectonics in the current tectonic regime.

Geomorphic signatures of neotectonic activity in the Valapattanam river basin, Western Ghats, India has studied by Jayappa *et al.* (2012) using geomorphic indices such as stream-gradient index, drainage basin asymmetry, hypsometric integral, valley floor width–valley height ratio and drainage basin shape. In this study, relative tectonic activity classes obtained by the average (S/n) of different classes of geomorphic indices have been classified into three groups. Group I shows high tectonic activity with values of $S/n < 2$; group II shows moderate tectonic activity with $S/n > 2$ to < 2.5; and group III shows low tectonic activity with values of $S/n \geq 2.5$.

Ramu and Mahalingam (2012) have been carried out hypsometric properties of drainage basins using GIS in Karnataka, India. The results of the study show that all drainage basins come under maturely dissected landform.

Mondal (2013) has been studied the detail morphometric characteristics of Birbhum district in West Bengal, India to understand the geomorphological characteristics of the region. The various morphometric parameters such as mean stream length, drainage density, drainage texture, elongation ratio, compactness coefficient, absolute relief etc. reveal that the region is characterized by highly permeable, homogenous subsurface materials with moderate drainage texture and has gentle slopes.

Geomorphic indicators of active tectonics in the west Lidder watershed, Kashmir Himalayas carried out by Bhat *et al.* (2013) by applying different geomorphic indices like hypsometric integral, basin elongation ratio, drainage basin asymmetry etc. The study revealed that the area is tectonically active.

Sreedevi *et al.* (2013) studied drainage morphometry and its influence on hydrology of Peddavanka watershed, south India using SRTM data and GIS. The study reveals that SRTM DEM and GIS based approach in evaluation of drainage morphometric parameters and their influence on hydrological characteristics at watershed level is more appropriate than the conventional methods.

GIS based morphometric characterization of mini-watershed in Rachhar Nala of Anuppur district of Madhya Pradesh, India has been carried out by Soni *et al.* (2013). The estimated parameters viz. bifurcation ratio, drainage density, circularity ratio etc. indicate that the area is geologically controlled drainage pattern and impermeable sub-surface material with elongated basin shape.

Kumar *et al.* (2010) have been carried out hydrological-drainage analysis in the Gurpur basin of southern Karnataka, India using remote sensing and GIS techniques for evaluation of groundwater potential. Analysis of the morphometric parameters such as drainage density, circularity ratio, relief ratio etc. suggest that the Gurpur basin is in an elongated form with steep slopes and the nature of the surface strata of the river basin is moderately permeable.

The influence of active structure in the Dibru river basin of Assam (India) is investigated by Sarma *et al.* (2011) using morphotectonic indices viz. basin elongation ratio, transverse topographic symmetry, asymmetric factor, valley floor width to valley height ratio to identify the evidences of active structures in the area. The analysed indices indicate tilting, channel incision in the Dibru basin and tectonically active.

Srinivasa Rao and Ahmed (2011) have carried out morphometric study on upper Wahblei watershed in West Khasi Hills district of Meghalaya, India. The morphometric parameters like mean stream length, drainage density, elongation ratio, compactness coefficient, relative relief etc. have been studied. The study infers that the area is characterized by dendritic to trellis drainage pattern and the nature of sub-surface strata is permeable, sub-soil material and having dense vegetation.

Morphometric analysis of a highland micro-watershed (Wah Umbah) area in East Khasi Hills district of Meghalaya using remote sensing and geographic information system techniques was carried out by Sarmah *et al.* (2012). The study concluded that the Wah Umbah micro-watershed is characterized by sub-trellis drainage pattern with moderate drainage texture. Lithological, structural and geomorphological expression of the micro-watershed controls the flow direction of the entire drainage network.

Hypsometric analysis using GIS was performed by Kusre (2013) to understand the runoff generation potential of Diyung watershed in north eastern India. The result indicates that surface runoff is the dominant process with two stages of geomorphologic development, viz. equilibrium stage and monadnock stage. The study also highlights the use of hypsometric integral for prioritizing watershed for planning engineering measures to mitigate the impact.

Dutta and Sarma (2013) have been carried out morphotectonic analysis of Sonai river basin in the Barak valley of Assam, NE India to understand the geomorphic signatures of active tectonics using geographical information system. The morphotectonic indices viz. basin elongation ratio, asymmetric factor, transverse topographic symmetry, etc. reflect the evidences of tectonically active structures in the area.

Sarma *et al.* (2015) have studied morphotectonic characterises of the Brahmaputra basin in NE India using geoinformatics to examine the influence of active structures by applying different morphotectonic indices such as basin elongation ratio, asymmetric factor, mountain front sinuosity etc. The estimated indices indicate that the basin is tectonically active, asymmetric nature, tectonic tilt and active incision in the area.

Tiwari and Jha (1997) have estimated the run-off rate and sediment yield of twenty two watersheds in different parts of the Mizoram applying various morphometric parameters viz. rotundity factor, circularity ratio, compactness coefficient etc. The overall results suggest that the watersheds are highly elongated associated with high degree of soil erosion and high rate of run-off.

Chenkual *et al.* (2007) studied morphometric characteristics of Serlui drainage basin falls in Mizoram. The morphometric parameters have been calculated under linear, areal and relief aspects such as mean stream length, bifurcation ratio, drainage density, length of overland flow, relief ratio, relative relief etc. The analyzed parameters revel that the basin is elongated in shape with sixth order stream and the drainage patterns are structurally controlled having coarse texture.

Drainage morphometric parameters of lower Tlawng sub-watershed located in Aizawl district, Mizoram has computed by Udabhaskara Rao (2011). The analysis of the parameters like drainage density, elongation ratio etc. indicates that the watershed is elongated with highly permeable rocks and coarse drainage texture. The study also reveals that the area is having high infiltration capacity and high relief with steep slopes.

Ahmed *et al.* (2012) have studied drainage morphometry and tectonic implications of Tuikum watershed in Mizoram to understand the terrain conditions of the region along with the ongoing tectonic activity using different geomorphic indices viz. bifurcation ratio, drainage density, circularity index, elongation ratio, asymmetry factor, hypsometric integral etc. The results show that the area is tectonically active by titling due to upliftment.

Ahmed and Srinivasa Rao (2014) have been carried out morphometric and hypsometric analysis of Sairang sub-basin in Aizawl district of Mizoram using GIS techniques. The analyzed parameters like bifurcation ratio, drainage density, form factor, infiltration number, length of overland flow, ruggedness number, relative relief, hypsometric integral etc. indicate the greater degree of erosion and steep slopes associated with the structural complexity of the terrain. The study also shows that the landscape is under mature stage of geomorphologic development with impermeable nature of sub-surface strata.

Srinivasa Rao and Lalduhawma (2014) have studied morphometric analysis of Tut watershed in Mizoram under basic, derived and shape parameters. The study suggests that the watershed is elongated in shape, structurally controlled drainage with coarse to intermediate drainage texture. The watershed is also characterized by high relief with steep slopes and tectonically active in the form of folding and faulting.

Udabhaskara Rao (2015) has estimated sediment yield rate and total run-off in the lower Tlawng watershed in Mizoram based on morphometric parameters such as compactness co-efficient, circularity ratio and rotundity factor. The study reveals that the area is elongated and is prone to high soil erosion.

Ahmed and Srinivasa Rao (2015a) have made a study on geomorphometric analysis of Tuirini watershed in Mizoram to estimate the sediment production rate (SPR) and run-off rate of the area. The estimated value of SPR and run-off rate suggests that the watershed produces moderate amount of sediments annually with high discharge of runoff due to high relief with steeper slopes. The study also reveals that the watershed is having high time of concentration and is characterized by impermeable sedimentary rocks with very fine drainage texture.

Ahmed and Srinivasa Rao (2015b) have been worked out prioritization of sub-watersheds of the Tuirini watershed, Mizoram based on morphometric parameters like bifurcation ratio, drainage density, stream frequency, form factor, elongation ratio, length of overland flow, relief ratio etc. The morphometric parameters which influence the soil erodibility are considered to priorities the sub-watersheds. The twenty two sub-watersheds are categorized into three classes as high, medium and low in terms of priority.

The analysis reveals that high priority zone consists of 9 sub-watersheds, medium of 7 and low of 6 sub-watersheds. The sub-watersheds which are falling under high priority are much more susceptible to soil erosion and should be given high priority for land conservation measures.

Ahmed and Srinivasa Rao (2016a) have carried out hypsometric analysis of the Tuirini drainage basin to find out the geological stages of development and erosional status of the basin area. The results suggest that the entire basin is mature stages of geologic development with moderately eroded landscapes.

Ahmed and Srinivasa Rao (2016b) have studied morphotectonic of the Tuirini drainage basin in Mizoram by applying different morphotectonic indices such as basin elongation ratio, asymmetric factor, mountain front sinuosity etc. in order to understand the ongoing tectonic changes of the terrain. The estimated indices indicate that the basin is tectonically active, asymmetric nature, tectonic tilt and active incision in the area.

CHAPTER IV

DRAINAGE MORPHOMETRY

4.1 Morphometric Analysis

Measurement of the shape or geometry of any natural form, whether a plant, animal or relief features is termed as morphometry (Strahler, 1969). According to Clarke (1966), morphometry is the mathematical analyses the configuration of the basin surface thereby determines the shape and dimension of the landform. Drainage morphometry, on the other hand, denotes the measurement of geometrical properties of the land surface of a fluvially originated drainage basin. Morphometric analysis generally deals with the surface characteristics of drainage basin or watershed and it also provides a quantitative description of the drainage system which is an important aspect of the characterization of the watershed (Strahler, 1964). The American hydrologist Robert E. Horton was the first to establish quantitative methods for analysing drainage networks. Drainage basin is an ideal unit for understanding the geomorphological and hydrological processes and for evaluating the runoff pattern of the streams (Horton, 1932). The morphometric characteristics of the various basins in different parts of the globe have been studied by many scientists using conventional methods (Horton, 1945; Smith, 1950; Leopold and Maddock, 1953; Schumm, 1956; Strahler, 1957 & 1964; Krishnamurthy *et al.,* 1996; Biswas *et al.*, 1999). Morphometric analysis of a drainage basin is of great help in understanding the drainage development and its patterns, geological structures, hydrologic characteristics of rocks, groundwater potential zone, watershed prioritization for soil and water conservation, landform evaluation and its characteristics as well as natural resources management. Numerous advanced statistical and mathematical methods have been applied to analyses the drainage basin characteristics. In recent years, remote sensing and GIS have emerged as a powerful tool in morphometric analysis.

4.2 Analysis of Morphometric Parameters

The morphometric parameters of the Tuirini watershed have been classified into four categories, namely

1. linear parameters
2. textural parameters
3. geometric parameters and
4. relief parameters

This study has been carried out with respect to sub-watersheds, which have been delineated from the entire Tuirini watershed (Fig. 4.1). The various morphometric parameters of the watershed and its sub-watershed are discussed below.

4.2.1 Linear Parameters

The linear aspects include stream order, stream number, stream length, mean stream length, stream length ratio, bifurcation ratio and Rho coefficient, which were determined and there results have been presented in the following Tables (4.1 to 4.4).

Table 4.1. Linear aspects of the Tuirini watershed.

Stream order	Streams number	Streams length (km)	Mean stream length (km)	Stream length ratio	Bifurcation ratio	Mean bifurcation ratio	Rho coefficient
1st	2177	1246.75	0.57	1.24	4.99	4.66	0.47
2nd	436	311.73	0.71	2.12	4.79		
3rd	91	137.62	1.51	2.02	4.55		
4th	20	61.27	3.06	2.17	5.00		
5th	4	26.68	6.67	3.33	4.00		
6th	1	22.24	22.24	-	-		
Total	2729	1806.29	-	-	-		

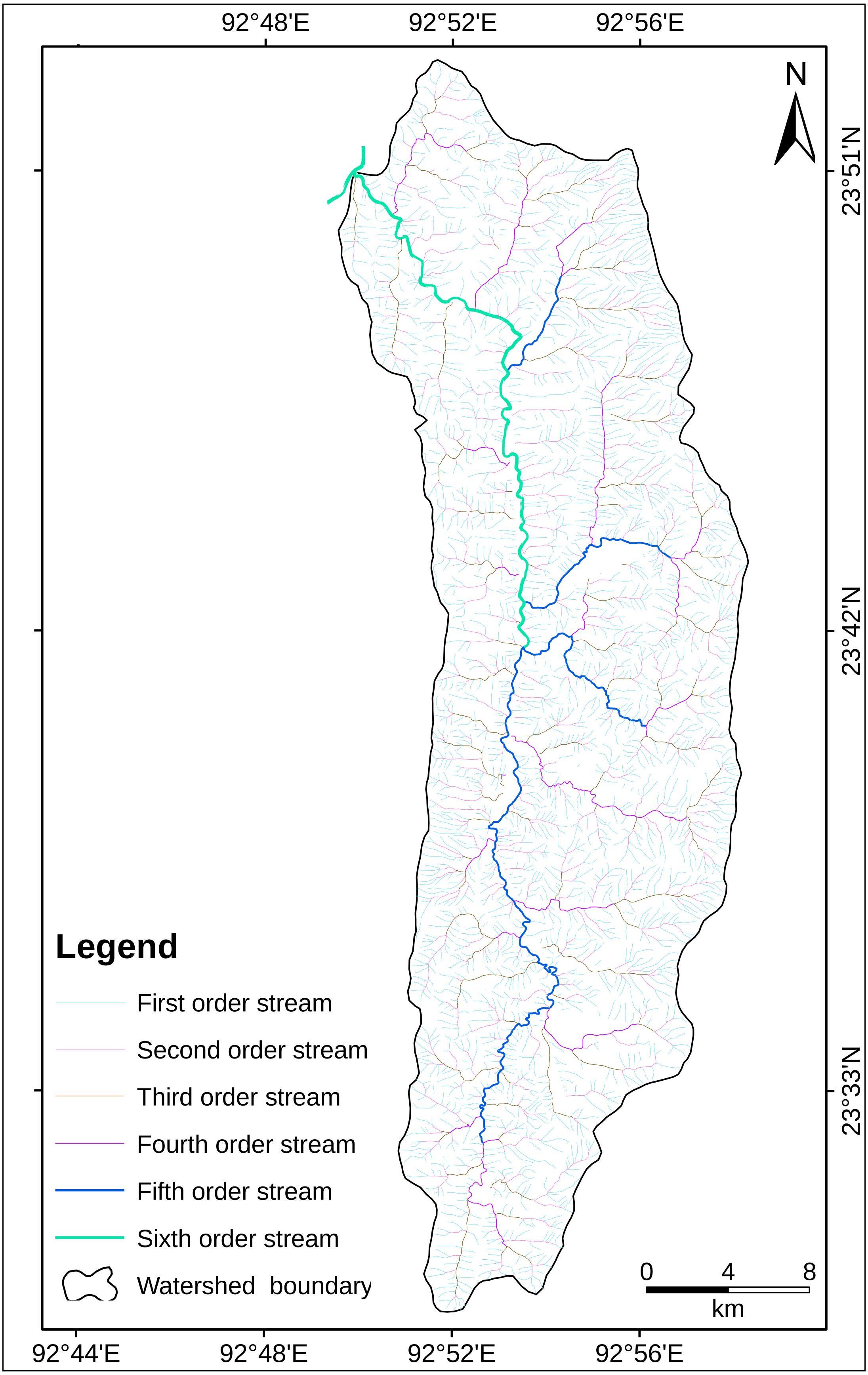


Figure 4.1. Drainage map of the Tuirini watershed.

Table 4.2. Order wise streams number and stream lengths of the sub-watersheds.

Name of sub-watersheds	Stream numbers						Stream lengths (km)					
	1st	2nd	3rd	4th	5th	Total	1st	2nd	3rd	4th	5th	Total
Maudarh	278	47	11	2	1	339	159.13	36.85	18.58	6.78	6.18	227.52
Khuai	104	17	5	1	-	127	60.13	13.48	7.56	4.53	-	85.70
Tuizal	65	10	2	-	-	77	36.68	8.35	5.18	-	-	50.21
Lungding	50	12	1	-	-	63	33.86	15.75	5.56	-	-	55.17
Chal	66	10	2	1	-	79	38.45	7.35	5.18	1.13	-	52.11
Saibual	151	26	4	1	-	182	94.53	22.65	5.16	4.26	-	126.6
Maltliak	61	15	4	1	-	81	42.53	13.68	3.18	1.50	-	60.89
Ramri	70	14	3	1	-	88	29.13	10.21	7.16	0.53	-	47.03
Kaihzawl	168	38	7	1	-	214	103.75	26.32	9.15	9.35	-	148.57
Sathang	34	8	1	-	-	43	16.23	5.57	2.25	-	-	24.05
Thangzai	17	5	2	-	-	24	10.12	3.50	2.10	-	-	15.72
Kang	199	39	10	3	1	252	101.25	24.98	11.90	4.48	8.50	151.11
Tuikhan	351	74	14	3	1	443	195.70	47.24	15.90	10.9	7.50	277.24
Sakei	99	20	5	1	-	125	57.50	12.03	5.50	5.62	-	80.65
Maumit	41	9	2	-	-	52	21.13	4.53	3.24	-	-	28.90
Dam	96	20	4	1	-	121	50.16	13.74	5.02	6.03	-	74.95
Inran	121	25	6	2	1	155	84.64	18.24	8.48	3.04	4.50	118.90
Inrum	51	12	2	1	-	66	28.50	9.14	2.08	1.06	-	40.78
Minpui	45	9	1	-	-	55	25.52	6.07	3.01	-	-	34.60
Damdiai	50	12	1	-	-	63	25.56	5.53	4.87	-	-	35.96
Chhimluang	44	12	3	1	-	60	23.13	5.50	4.08	2.06	-	34.77
Phekphe	16	2	1	-	-	19	9.07	1.02	2.48	-	-	12.57

4.2.1.1 Stream Order

The first step in drainage basin analysis is stream ordering, which expresses as the hierarchal relationship between the single stream segments within a drainage network. In the present study, ranking of streams have been carried out based on the method proposed by Strahler (1964). According to him the first order streams are those, which have no tributaries. The second order stream is formed below the junction of two first order streams. When two second order streams meet, the third order streams are formed and so on. The study area is a sixth order drainage basin. The total number of 2729 streams of different orders were identified and sprawled over an area of 420.07 sq.km. It is noticed from the Table 4.2, that the maximum stream frequency is in the case of first order streams and then for second order. It is also observed that there is a decrease in stream frequency as the stream order increases. Less number of streams in a basin indicates the mature topography, whereas presence of large number of streams indicates the topography is still undergoing erosion (Zaidi, 2011).

4.2.1.2 Stream Number

The number of stream segments (Nu) in each order is known as stream number. Horton (1945) states that the numbers of stream segments of each order form an inverse geometric sequence with order number. The number of streams usually decreases as the stream order increases (Table 4.2). Horton (1945) laws of stream numbers states that the number of stream segments of each order forms an inverse geometric relationship with plotted against order. Most drainage networks show a linear relationship with small deviation from a straight line. The plotting of logarithm of number of streams against stream order gives a straight line (Figs. 4.2a & 4.3). This means that the number of streams usually decreases as the stream order increases.

4.2.1.3 Stream Length

It is the total length of streams in a particular order is known as stream length (Lu). The stream length (Table 4.2) has been measured based on the law proposed by Horton (1945). Plot of the logarithm of streams length versus stream order showed the linear pattern (Figs. 4.2b & 4.4), it seems to be in geometric progression and agree with Horton's law of stream length and it is also observed that the total length of stream decreases with increasing order of stream. It can be noted from the Table

4.2 that in most of the sub-watersheds, the stream length decreases as the stream order increases. This change may be due to flowing of streams from higher altitude, lithological variations and moderately steep slopes (Singh and Singh, 1997).

Table 4.3. Mean stream length and stream length ratio of the sub-watersheds.

Sub-watersheds name	Mean stream length in km (Lsm)						Stream length ratio (Rl)				
	1st	2nd	3rd	4th	5th	Mean Lsm	2nd/1st	3rd/2nd	4th/3rd	5th/4th	Mean Rl
Maudarh	0.57	0.78	1.68	3.39	6.18	2.52	1.36	2.15	2.01	1.82	1.83
Khuai	0.57	0.79	1.51	4.53	-	1.85	1.38	1.91	3.00	-	2.09
Tuizal	0.56	0.83	2.59	-	-	1.32	1.48	3.12	-	-	2.30
Lungding	0.67	1.31	5.56	-	-	2.51	1.95	4.24	-	-	3.09
Chal	0.58	0.73	2.59	1.13	-	1.25	1.25	3.54	0.43	-	1.74
Saibual	0.62	0.87	1.29	4.26	-	1.76	1.40	1.48	3.30	-	2.06
Maltliak	0.69	0.91	0.79	1.50	-	0.97	1.31	0.86	1.89	-	1.35
Ramri	0.41	0.72	2.38	0.53	-	1.01	1.75	3.93	0.22	-	1.96
Kaihzawl	0.61	0.69	1.30	9.35	-	2.98	1.46	1.88	7.19	-	3.51
Sathang	0.47	0.69	2.25	-	-	1.13	1.46	3.26	-	-	2.36
Thangzai	0.59	0.70	1.05	-	-	0.78	1.18	1.50	-	-	1.34
Kang	0.50	0.64	1.19	1.49	8.50	2.46	1.28	1.85	1.25	5.70	2.52
Tuikhan	0.55	0.63	1.13	3.63	7.50	2.68	1.14	1.79	3.21	2.06	2.05
Sakei	0.58	0.60	1.10	5.62	-	1.97	1.03	1.83	5.10	-	2.65
Maumit	0.51	0.68	1.62	-	-	0.93	1.33	2.83	-	-	2.08
Dam	0.52	0.68	1.25	6.03	-	2.12	1.30	1.83	4.82	-	2.65
Inran	0.69	0.72	1.41	1.52	4.50	1.76	1.04	1.95	1.07	2.96	1.75
Inrum	0.55	0.76	1.04	1.06	-	0.85	1.38	1.36	1.01	-	1.25
Minpui	0.56	0.67	3.01	-	-	1.41	1.19	4.49	-	-	2.84
Damdiai	0.51	0.46	4.87	-	-	1.94	0.90	10.58	-	-	4.47
Chhimluang	0.52	0.45	1.36	2.06	-	1.09	0.86	3.02	1.51	-	1.79
Phekphe	0.56	0.51	2.48	-	-	1.18	0.91	4.86	-	-	2.88

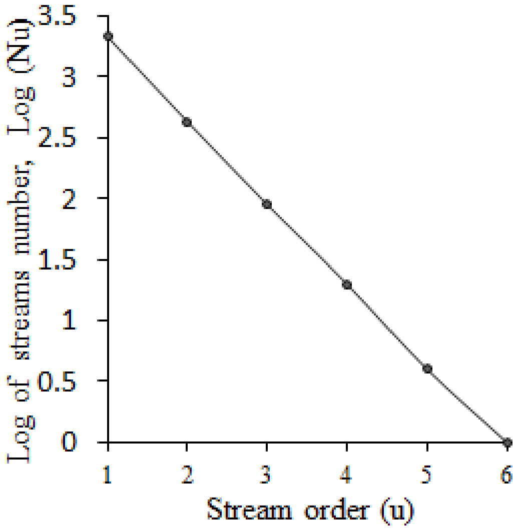


Figure 4.2a. Regression of logarithms of stream numbers Log (Nu) versus streams order (u) of the Tuirini watershed.

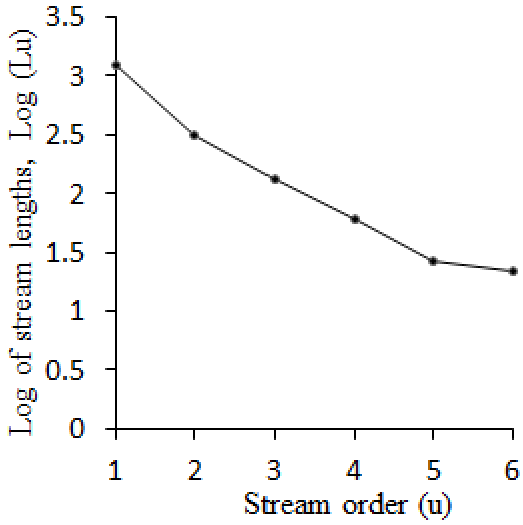
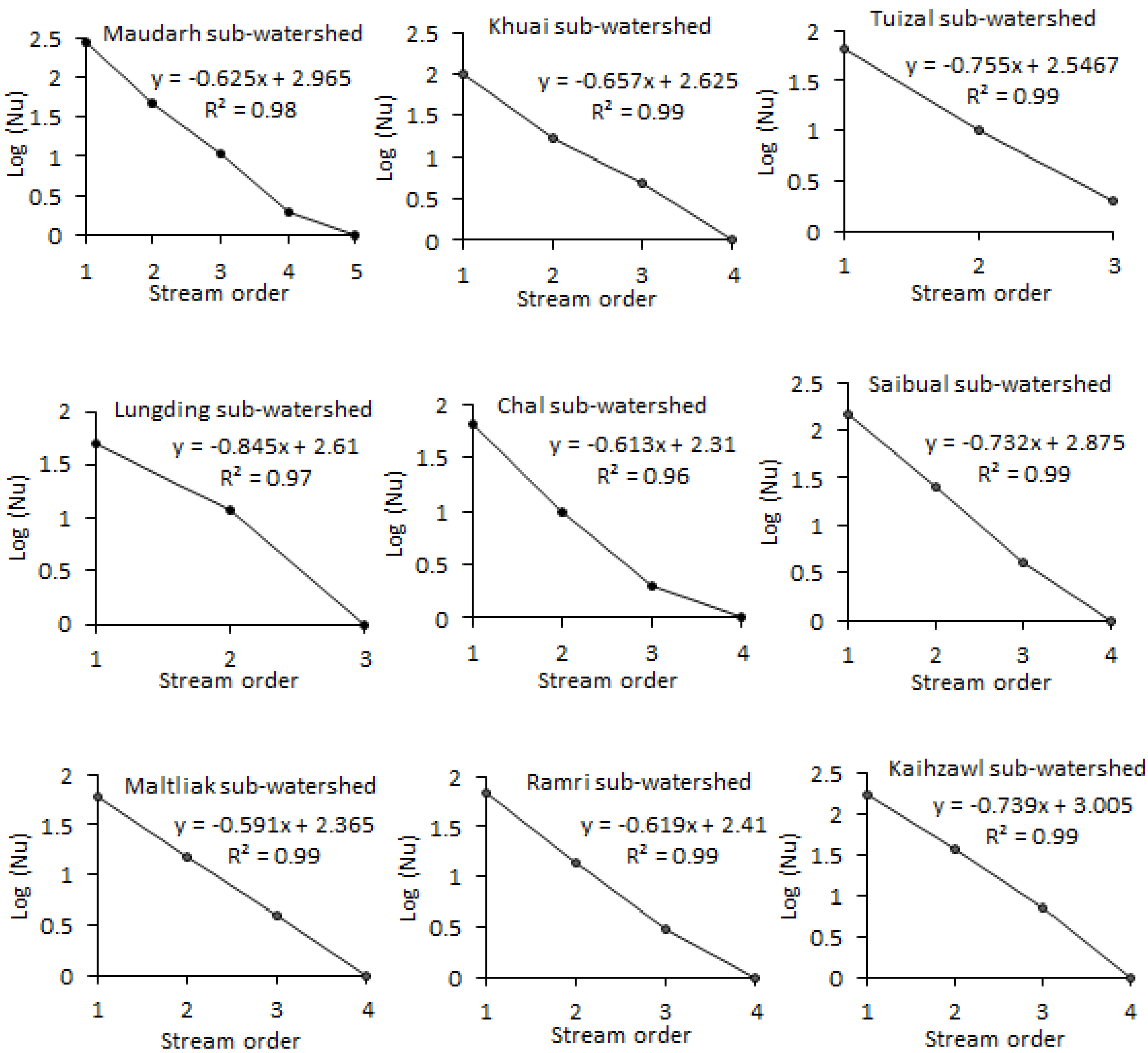


Figure 4.2b. Regression of logarithms of streams length Log (Lu) versus streams order (u) of the Tuirini watershed.



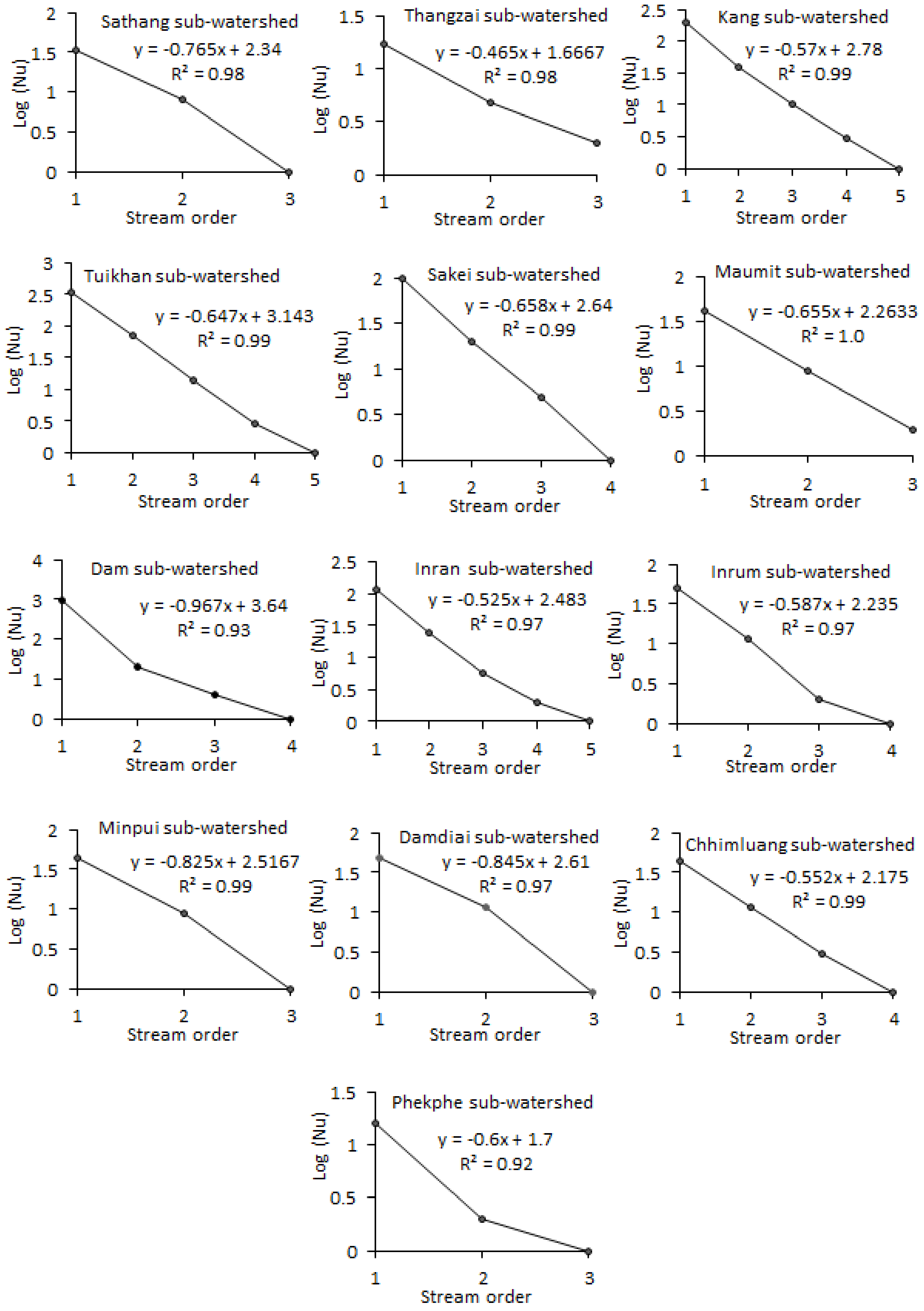
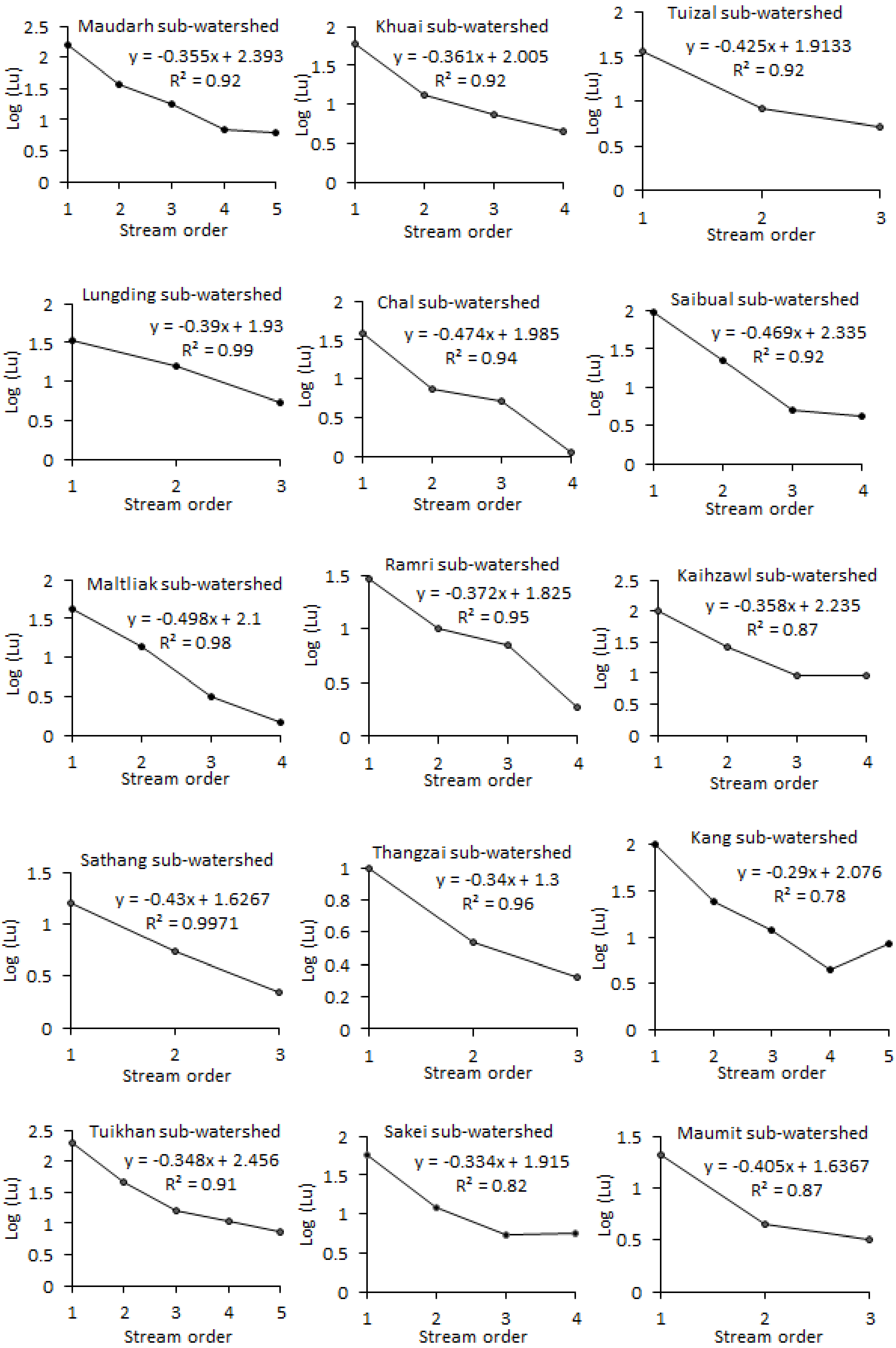


Figure 4.3. Regression of logarithms of stream numbers Log (Nu) versus streams order (u) of the sub-watersheds.



Maudarh sub-watershed
y = -0.355x + 2.393
R² = 0.92
Khuai sub-watershed
y = -0.361x + 2.005
R² = 0.92
Tuizal sub-watershed
y = -0.425x + 1.9133
R² = 0.92
Lungding sub-watershed
y = -0.39x + 1.93
R² = 0.99
Chal sub-watershed
y = -0.474x + 1.985
R² = 0.94
Saibual sub-watershed
y = -0.469x + 2.335
R² = 0.92
Maltliak sub-watershed
y = -0.498x + 2.1
R² = 0.98
Ramri sub-watershed
y = -0.372x + 1.825
R² = 0.95
Kaihzawl sub-watershed
y = -0.358x + 2.235
R² = 0.87
Sathang sub-watershed
y = -0.43x + 1.6267
R² = 0.9971
Thangzai sub-watershed
y = -0.34x + 1.3
R² = 0.96
Kang sub-watershed
y = -0.29x + 2.076
R² = 0.78
Tuikhan sub-watershed
y = -0.348x + 2.456
R² = 0.91
Sakei sub-watershed
y = -0.334x + 1.915
R² = 0.82
Maumit sub-watershed
y = -0.405x + 1.6367
R² = 0.87
Log (Lu)
Stream order

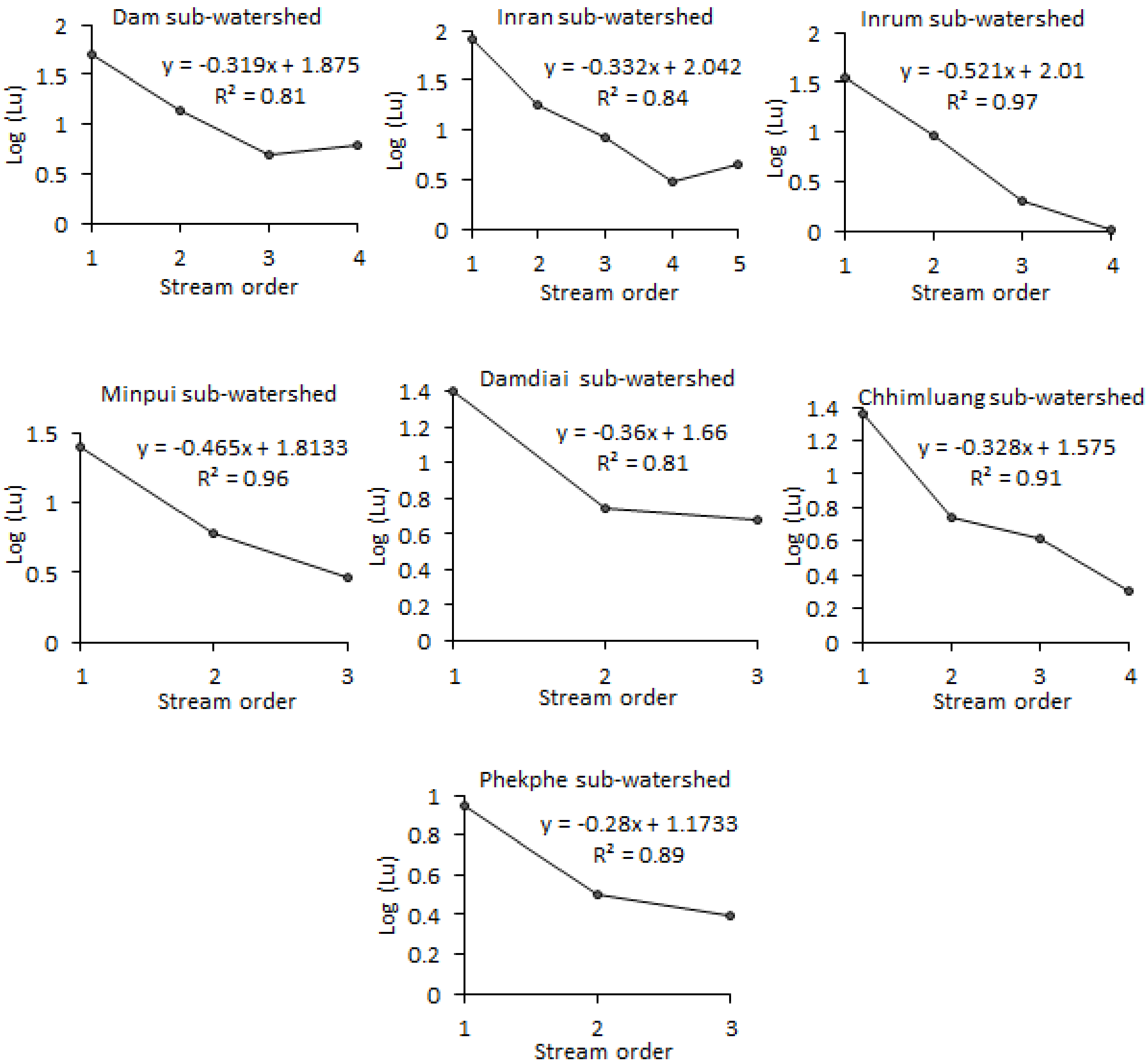


Figure 4.4. Regression of logarithms of streams length Log (Lu) versus stream order (u) of the sub-watersheds.

4.2.1.4 Mean Stream Length

The mean stream length of a channel is a dimensional property revealing the characteristic size of components of a drainage network and it has been calculated as the ratio of the total stream length of order ‘u’ to the number of streams of order ‘u’ (Strahler, 1964). It is observed from Table 4.3 that mean stream length values of Maudarh, Khuai, Lungding, Saibual, Kaihzawl, Sathang, Thangzai, Kang, Tuikhan, Sakei, Maumit, Dam, Inran, Minpui and Damdiai sub-watersheds indicate that mean stream length of the given order is greater than that of the next lower order and less than that of its next higher order, whereas in case of

Tuizal, Chal, Maltliak, Ramri, Inrum, Chhimluang and Phekphe there is a deviation from this general observation. This deviation might be due to variation in slope and topography. Normally mean stream length increases with increasing stream order.

4.2.1.5 Stream Length Ratio

The stream length ratio is the ratio of mean length of streams of one order (Lu) to that of the next lower order stream segments (Lu-1), which tends to be constant throughout the successive orders of a watershed. It has an important relationship with the discharge of surface flow and erosional stages of the basin (Horton, 1945). The stream length ratio of different sub-watersheds range from 1.25 to 4.47 (Table 4.3) and changes of stream length ratio from one order to another order indicating the late youth stage of geomorphic development of streams (Singh and Singh, 1997).

4.2.1.6 Bifurcation Ratio

Bifurcation ratio is calculated by dividing the total number of streams in the lower order by the number of streams of the next higher order (Schumm, 1956) and is a dimensionless property of the drainage basin supposed to be controlled by drainage density, lithological characteristics, stream entrance angles, basin shapes and basin areas (Singh, 1998). The higher values of bifurcation ratio indicate strong structural control in the drainage development whereas the lower values indicate that the watersheds are less affected by structural disturbance where the drainage patterns have not been distorted (Strahler, 1964; Nag, 1998). The bifurcation ratio of the study area varies from 2.0 to 12.0 (Table 4.4), lower values of sub-watersheds suggest less structural disturbance, whereas higher values of sub-watersheds indicate structurally controlled drainage pattern. The mean bifurcation ratio (Rbm) may be defined as the average of bifurcation ratios of all orders.

The mean bifurcation ratio in sub-watersheds fluctuate from 2.95 to 8.08 (Table 4.4) and all the sub-watersheds fall under normal basin category (Strahler, 1957).

Table 4.4. Calculated bifurcation ratio and Rho coefficient of the sub-watersheds.

Name of sub-watersheds	Bifurcation ratio (Rb)					Rho coefficient
	1st order/ 2nd order	2nd order/ 3rd order	3rd order/ 4th order	4th order/ 5th order	Mean (Rbm)	
Maudarh	5.91	4.27	5.50	2.00	4.42	0.42
Khuai	6.11	3.40	5.00	-	4.83	0.44
Tuizal	6.50	5.00	-	-	5.75	0.36
Lungding	4.16	12.00	-	-	8.08	0.39
Chal	6.60	5.00	2.00	-	4.86	0.35
Saibual	5.80	6.50	4.00	-	5.43	0.37
Maltliak	4.06	3.75	4.00	-	3.93	0.34
Ramri	5.00	4.66	3.00	-	4.22	0.46
Kaihzawl	4.42	5.42	7.00	-	5.61	0.62
Sathang	4.25	8.00	-	-	6.12	0.38
Thangzai	3.40	2.50	-	-	2.95	0.45
Kang	5.10	3.90	3.33	3.00	3.83	0.65
Tuikhan	4.74	5.28	4.66	3.00	4.35	0.47
Sakei	4.95	4.00	5.00	-	4.65	0.56
Maumit	4.55	4.50	-	-	4.52	0.46
Dam	4.80	5.00	4.00	-	4.60	0.57
Inran	4.84	4.16	3.00	2.00	3.50	0.50
Inrum	4.25	6.00	2.00	-	4.08	0.30
Minpui	5.00	9.00	-	-	7.00	0.41
Damdiai	4.16	12.00	-	-	8.08	0.71
Chhimluang	3.66	4.00	3.00	-	3.55	0.50
Phekphe	8.00	2.00	-	-	5.00	0.57

4.2.1.7 Rho Coefficient

It is defined as the ratio of stream length ratio to the bifurcation ratio and represents relationship between drainage density and physiographic development of a watershed which evaluates the amount of water storage capacity of the watershed (Horton, 1945). Higher values of Rho coefficient indicate high capacity for the storage of water and lower values indicate low storage capacity of water in a watershed.

The value of Rho coefficient for the Tuirini watershed is 0.47 and for its sub-watersheds range from 0.30 to 0.57 (Table 4.4), which reveal that the area is having low water storage capacity.

4.2.2 Textural Parameters

The textural parameters such as drainage density, stream frequency, drainage texture, length of overland flow and constant of channel maintenance have been calculated and there results are summarized below.

4.2.2.1 Drainage Density

Drainage density is defined as the ratio of the total stream length of all orders within a basin to the area of the basin, indicates the closeness of spacing between the channels (Horton, 1932). According to Nag (1998), the low drainage density of a region indicates permeable subsurface material under dense vegetative cover with low relief. High drainage density is related to the areas of impermeable subsurface strata and sparse vegetation with high relief. Based on the drainage density values (Table 4.5), the study area is divided into three classes (Fig. 4.5), viz. high drainage density (> 4 km/km^2), moderate drainage density (2-4 km/km^2) and low drainage density (< 2 km/km^2). Only Inrum and Chhimluang sub-watersheds show low drainage density, which may be due to the presence of permeable subsoil materials and dense vegetation whereas other sub-watersheds have medium to high drainage density indicate that the region is characterized by impermeable subsurface material, high relief and sparse vegetation cover.

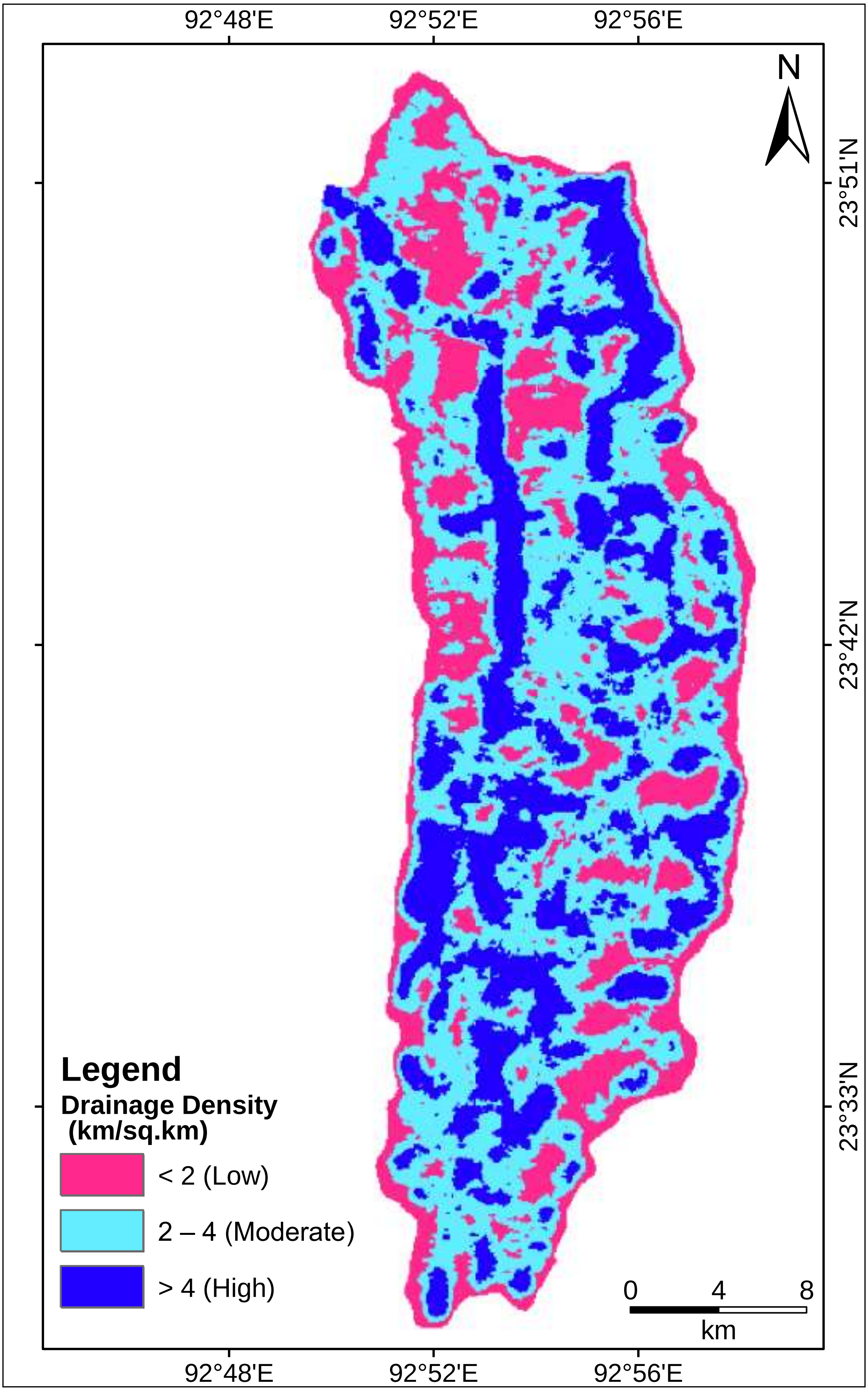


Figure 4.5. Drainage density map of the Tuirini watershed.

Table 4.5. Textural aspects of the Tuirini watershed and its sub-watersheds.

Name of sub-watersheds	Drainage density (km/ km^2)	Stream frequency (no/ km^2)	Drainage texture (km^{-1})	Length of overland flow (km)	Constant of channel maintenance (km)
Maudarh	4.40	6.54	28.77	0.11	0.23
Khuai	3.94	5.83	22.97	0.13	0.26
Tuizal	5.63	8.68	48.86	0.09	0.18
Lungding	4.35	4.96	21.57	0.11	0.23
Chal	5.32	8.06	42.32	0.10	0.19
Saibual	5.57	8.69	48.40	0.09	0.18
Maltliak	5.82	7.75	45.10	0.08	0.17
Ramri	4.27	7.54	32.19	0.12	0.23
Kaihzawl	4.26	6.14	26.15	0.11	0.24
Sathang	4.92	8.83	43.62	0.10	0.21
Thangzai	2.82	4.31	12.15	0.17	0.35
Kang	4.32	7.08	30.24	0.12	0.23
Tuikhan	4.21	6.81	26.01	0.12	0.23
Sakei	4.76	6.06	28.54	0.10	0.21
Maumit	4.93	8.67	42.75	0.10	0.20
Dam	5.38	8.68	46.69	0.09	0.19
Inran	4.79	6.24	29.47	0.11	0.21
Inrum	1.48	2.38	3.52	0.33	0.67
Minpui	4.56	7.25	33.06	0.11	0.21
Damdiai	3.65	6.40	23.36	0.13	0.27
Chhimluang	1.68	2.90	4.87	0.29	0.59
Phekphe	2.65	4.00	10.60	0.18	0.37
Tuirini watershed	4.35	6.57	28.57	0.12	0.23

4.2.2.2 Stream Frequency

It is expressed as the ratio between the total numbers of stream segment to the basin area (Horton, 1932). In general, the values of stream frequency for the sub-watersheds indicate positive correlation with the drainage density value indicating the increase in stream population with respect to increase in drainage density. The values of stream frequency for all the sub-watersheds vary from 2.38 to 8.83 streams/sq.km (Table 4.5), show higher stream frequency values, indicating resistant subsurface strata, sparse vegetation and high relief with low permeability of rock formations of the area.

4.2.2.3 Drainage Texture

It can be expressed as the multiplication of the drainage density and stream frequency and is depends upon a number of factors such as climate, rainfall, vegetation, soil type, infiltration capacity and relief (Smith, 1950). The drainage texture is classified according to Smith (1950) into five different classes i.e. very coarse (<2), coarse (2-4), moderate (4-6), fine (6-8) and very fine (>8). In the present study, the drainage texture values range from 3.52 to 48.86 per km (Table 4.5), indicating that all the sub-watersheds fall under coarse to very fine texture category.

4.2.2.4 Length of Overland Flow

According to Horton (1945), length of overland flow (Lg) is the length of the longest drainage path that water takes before it gets concentrated and is approximately equal to half of drainage density. This factor depends on the rock type, permeability, climatic regime, vegetation cover and relief as well as duration of erosion (Schumm, 1956). The higher values of Lg infer the longer flow paths, less surface runoff and low relief with gentle slopes whereas lower Lg values indicate the shorter flow paths, high surface runoff and high relief. The computed values of Lg for all sub-watersheds vary from 0.11 to 0.67 km (Table 4.5) show lower Lg values, indicating short flow paths having less infiltration and areas of high relief with steep slopes.

4.2.2.5 Constant of Channel Maintenance

Constant of channel maintenance is defined as the area of the watershed surface needed to maintain a unit length of stream channel and is expressed by the reciprocal of drainage density (Schumm, 1956). Higher value of this parameter suggests low relief, high permeability and low drainage density with coarse drainage texture. The constant of channel maintenance value for the Tuirini watershed is 0.23 sq.km/km, it means 0.23 sq.km of surface area is required to maintain each kilometer of channel length and for all sub-watersheds vary from 0.17 to 0.59 sq.km/km (Table 4.5) indicating that the area is characterized by high surface runoff, low permeability and high drainage density.

4.2.3 Geometric Parameters

The geometric parameters include form factor, circularity ratio and compactness coefficient have been calculated and there results are discussed below.

4.2.3.1 Form Factor

It is defined as a dimensionless ratio of the basin area to the square of the basin length (Horton, 1932). Higher the value of form factor, more circular shape of the watershed, whereas long narrow watershed has low form factor value, which is close to zero. The watersheds with higher form factor are normally circular in shape and have high peak flows for shorter duration, whereas elongated watersheds with lower values of form factor have low peak flows for longer duration (Das and Mukherjee, 2005). In the present study, form factor values vary between 0.10 to 0.91 (Table 4.7), suggesting that all sub-watersheds represent more or less elongated in nature with less side flow for longer duration.

Table 4.6. Geometric aspects of the sub-watersheds.

Name of sub-watersheds	Basin area (A) km^2	Basin perimeter (P) km	Basin length (Lb) km	Length of main channel (Ls) km
Maudarh	51.80	35.52	12.72	15.93
Khuai	21.76	19.07	5.62	6.92
Tuizal	8.87	15.12	5.52	3.7
Lungding	12.68	18.76	5.23	6.38
Chal	9.79	14.71	5.21	7.15
Saibual	22.58	22.90	7.75	7.36
Maltliak	10.46	16.46	5.54	5.67
Ramri	11.67	14.91	3.28	1.84
Kaihzawl	34.83	30.30	8.75	13.9
Sathang	4.87	9.18	2.91	2.95
Thangzai	5.58	9.28	8.17	1.67
Kang	35.57	27.62	8.13	11.44
Tuikhan	65.65	45.52	11.52	13.89
Sakei	8.77	12.57	3.52	2.90
Maumit	5.86	10.84	3.48	1.91
Dam	13.93	20.31	3.90	5.45
Inran	24.82	25.32	8.42	9.59
Inrum	27.73	23.89	7.15	9.15
Minpui	7.58	13.18	4.55	4.68
Damdiai	9.84	16.04	5.28	5.49
Chhimluang	20.68	20.13	6.65	7.24
Phekphe	4.75	9.92	4.56	5.13
Tuirini watershed	420.07	110.70	45.30	56.75

4.2.3.2 Circularity Ratio

Circularity ratio is a dimensionless quantity which is defined as the ratio of the basin area to the area of a circle having the same circumference as the perimeter of the basin and expresses the degree of circularity of the basin (Miller, 1953). It is influenced by the length and frequency of streams, geological structures, land use/cover, climate, relief and slope of the basin (Chopra *et al.*, 2005). In the present study, the circularity ratio values for all sub-watersheds range from 0.40 to 0.81 (Table 4.7), which show that the sub-watersheds are almost elongated in shape except Khuai, Sakei and Thangzai. The high value of circularity ratio for Khuai, Sakei and Thangzai sub-watersheds indicate that they are more or less circular in shape, and are characterized by high to moderate relief with structurally controlled drainage system.

Table 4.7. Estimated geometric parameters of the Tuirini watershed and its sub-watersheds.

Name of sub-watersheds	Form factor	Circularity ratio	Compactness coefficient
Maudarh	0.32	0.51	1.39
Khuai	0.68	0.75	1.15
Tuizal	0.29	0.48	1.42
Lungding	0.46	0.46	1.47
Chal	0.36	0.56	1.32
Saibual	0.37	0.54	1.35
Maltliak	0.34	0.48	1.42
Ramri	0.86	0.66	1.21
Kaihzawl	0.45	0.47	1.41
Sathang	0.57	0.72	1.13
Thangzai	0.10	0.81	1.10
Kang	0.53	0.58	1.29
Tuikhan	0.49	0.40	1.57
Sakei	0.70	0.70	1.18
Maumit	0.48	0.62	1.24
Dam	0.91	0.42	1.52
Inran	0.35	0.48	1.42
Inrum	0.54	0.62	1.26
Minpui	0.36	0.54	1.17
Damdiai	0.35	0.49	1.43
Chhimluang	0.46	0.64	1.24
Phekphe	0.23	0.60	1.27
Tuirini watershed	0.20	0.43	1.57

4.2.3.3 Compactness Coefficient

Compactness coefficient is defined as the ratio of basin perimeter to the circumference of a circular area having the same area of the basin (Gravelius, 1914). Lower values of this parameter indicate more elongation of the basin and less erosion, while higher values indicate less elongation and high erosion (Patel *et al.*, 2012). The values of compactness coefficient in the study area range from 1.10 to 1.57 (Table 4.7), showing wide variations across the sub-watersheds.

4.2.4 Relief Parameters

The relief parameters such as basin relief, relief ratio, relative relief, dissection index, ruggedness number and gradient ratio which are discussed below.

4.2.4.1 Basin Relief

It is an important factor in understanding the denudational characteristics (the denudational landforms are formed as a result of active processes of weathering, mass wasting and erosion caused by different exogenetic geomorphic processes such as fluvial, glacier, aeolian etc.) of the basin (Sreedevi *et al.*, 2009). 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 values of basin relief for sub-watersheds range from 0.54 to 1.68 km (Table 4.9) indicate low infiltration and high runoff conditions of the study area.

4.2.4.2 Relief Ratio

Relief ratio is the dimensionless height-length ratio equal to the tangent of the angle formed by two planes intersecting at the mouth of the basin, one representing the horizontal, the other passing through the highest point of the basin (Schumm, 1963). It measures the overall steepness of a drainage basin and is an indicator of intensity of erosion processes operating on the slopes of the basin (Chopra *et al.*, 2005).

Relief ratio normally increases with decreasing drainage area and size of a given drainage basin (Gottschalk, 1964). The values of relief ratio are given in Table 4.9 and range from 0.08 to 0.37 for sub-watersheds which indicate high relief and steep slopes.

Table 4.8. Relief and gradient aspects of the Tuirini watershed and its sub-watersheds.

Name of sub-watersheds	Elevation in m		Elevation at (m)		Fall in height (a-b) km
	Max (H)	Min (h)	Source (a)	Confluence (b)	
Maudarh	1445	340	780	340	0.44
Khuai	1837	340	1710	340	1.37
Tuizal	1156	320	840	320	0.52
Lungding	1460	310	1340	310	1.03
Chal	1260	300	1060	300	0.76
Saibual	1775	298	1020	298	0.73
Maltliak	1288	280	1210	280	0.94
Ramri	1040	260	420	260	0.16
Kaihzawl	1392	250	1180	250	0.93
Sathang	1052	245	740	245	0.50
Thangzai	982	240	480	240	0.24
Kang	1170	238	780	238	0.55
Tuikhan	1905	235	1280	235	1.05
Sakei	958	230	490	230	0.26
Maumit	960	225	420	225	0.19
Dam	921	220	840	220	0.62
Inran	1860	180	1460	180	1.28
Inrum	1866	160	1380	160	1.23
Minpui	925	135	580	135	0.44
Damdiai	745	120	425	120	0.30
Chhimluang	1064	100	870	100	0.77
Phekphe	625	80	610	80	0.53
Tuirini watershed	1905	78	780	78	0.70

4.2.4.3 Relative Relief

Relative relief is determined as the ratio between the basin relief (R) to the perimeter (P) of the watershed. Its lower value indicates gentle topography whereas higher value suggests steeper slopes of the terrain. The relative relief of the study area is 1.64 and for sub-watersheds are range from 3.09 to 8.71 (Table 4.9), which represent the land surface has moderate to steep slopes.

Table 4.9. Calculated relief parameters of the sub-watersheds.

Name of sub-watersheds	Basin relief (km)	Relief ratio	Relative relief (km)	Dissection index	Ruggedness number	Gradient ratio
Maudarh	1.10	0.08	3.09	0.76	4.84	0.026
Khuai	1.49	0.26	7.81	0.81	5.87	0.196
Tuizal	0.83	0.15	5.48	0.72	4.67	0.162
Lungding	1.15	0.21	6.13	0.78	5.00	0.161
Chal	0.96	0.18	6.52	0.76	5.10	0.106
Saibual	1.47	0.19	6.41	0.83	8.18	0.099
Maltliak	1.02	0.18	6.20	0.79	5.93	0.165
Ramri	0.78	0.23	5.23	0.75	3.33	0.086
Kaihzawl	1.14	0.13	3.76	0.82	4.85	0.066
Sathang	0.80	0.37	8.71	0.77	3.93	0.169
Thangzai	0.74	0.09	7.97	0.76	2.08	0.146
Kang	0.93	0.11	3.36	0.80	4.01	0.048
Tuikhan	1.67	0.14	3.68	0.88	7.03	0.075
Sakei	0.72	0.20	5.72	0.76	3.42	0.091
Maumit	0.73	0.21	6.73	0.77	3.59	0.103
Dam	0.70	0.18	3.44	0.76	3.76	0.113
Inran	1.68	0.19	6.63	0.90	8.04	0.133
Inrum	1.70	0.23	7.12	0.91	2.51	0.134
Minpui	0.79	0.17	5.99	0.85	3.60	0.095
Damdiai	0.62	0.12	3.87	0.86	2.26	0.057
Chhimluang	0.96	0.14	4.76	0.90	1.61	0.106
Phekphe	0.54	0.11	5.44	0.87	1.43	0.103
Tuirini watershed	1.82	0.04	1.64	0.95	6.58	0.011

4.2.4.4 Dissection Index

Dissection index is the ratio between basin relief to the absolute relief of an area and gives clue to the stages of landscape evolution and degree of dissection or vertical erosion of a region (Singh and Dubey, 1994). The values of dissection index range from 0 (complete absence of dissection) to 1 (vertical cliff). Dissection index value of the study area is 0.95 and for sub-watersheds range from 0.72 to 0.91 (Table 4.9) suggest that the landforms of the study area are highly dissected mountainous terrain.

4.2.4.5 Ruggedness Number

Ruggedness number is the product of basin relief (R) and drainage density (Dd), where both parameters are in the same unit (Strahler, 1957). Basin having low ruggedness value infers less prone to soil erosion and the high ruggedness value of the basin implies highly susceptible to erosion with structural complexity of the terrain. The calculated ruggedness number for the study area varies from 1.43 to 8.18 (Table 4.9), suggest that the sub-watersheds have high ruggedness number values, indicate the structural complexity of the terrain in association with high relief and drainage density.

4.2.4.6 Gradient Ratio

It is expressed as the ratio of the difference of source elevation (a) and mouth elevation (b) of major stream of the watershed to the length of major channel (Ls) of that watershed. The gradient ratio of the watershed is 0.012 and for sub-watersheds range from 0.026 to 0.196 (Table 4.9), which reveal the moderate to high gradient of the terrain.

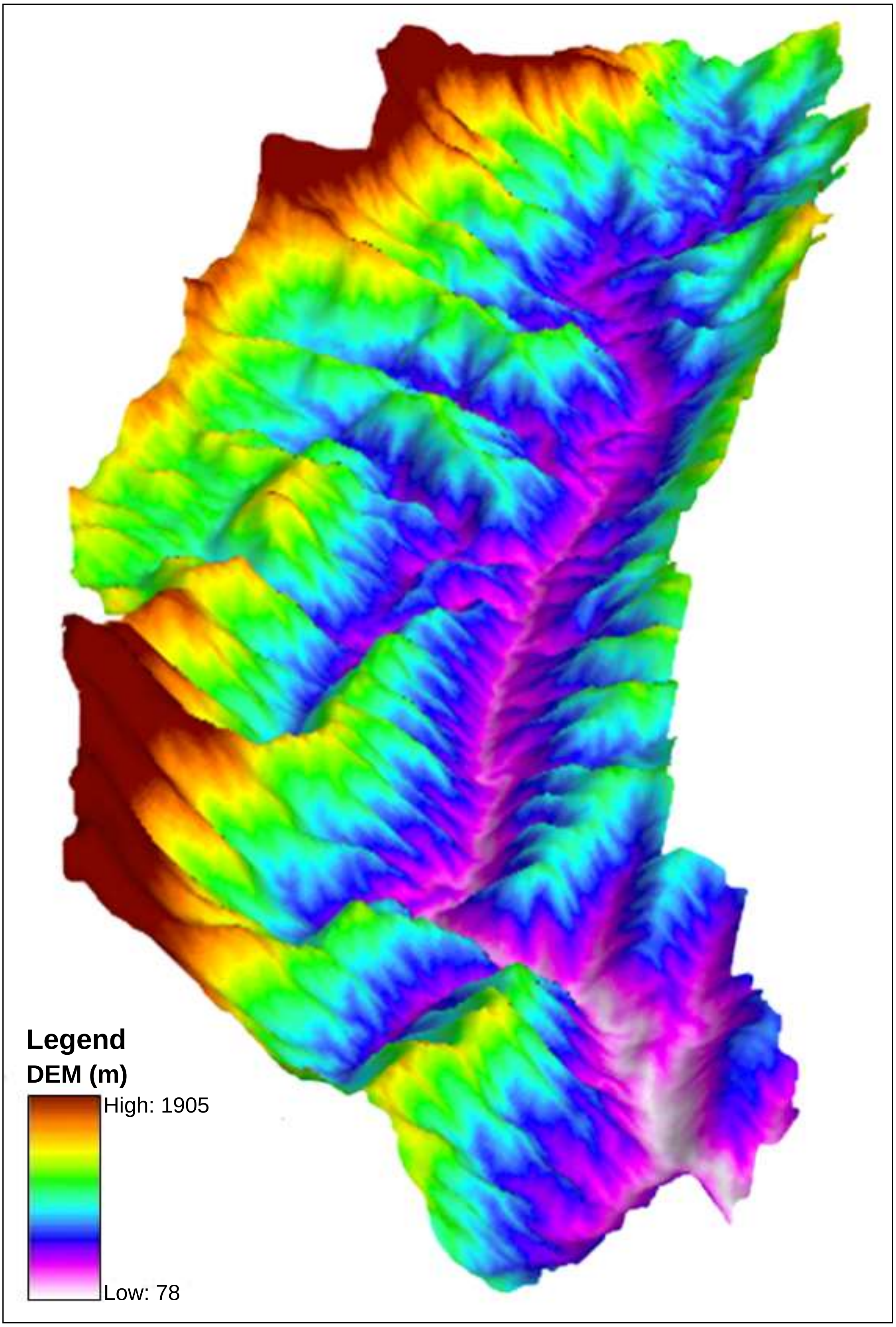


Figure 4.6. Digital Elevation Model (DEM) of the Tuirini watershed.

4.3 Hypsometric Analysis

4.3.1 Hypsometric Curve (Area Altitude Analysis)

The hypsometric curve is used to show the relationship between the altitude and area of a basin (Fig. 4.7). It describes the distribution of elevations across an area of land and has been used to differentiate between erosional landforms at different stages during their evolution (Keller and Pinter, 1996; Schumm, 1956). According to Strahler (1952), topography produced by stream channel erosion and associated processes of weathering, mass-movement, and sheet runoff is extremely complex, both in the geometry of the forms themselves and in the inter-relations of the process which produce the forms. Hypsometric curves and hypsometric integrals are important indicators of watershed conditions (Ritter *et al.*, 2002). Hypsometric curves and integrals can be interpreted in terms of degree of basin dissection and relative landform age: Convex-up curves with high integrals are typical for youthful stage, undisseceted (disequilibrium stage) landscapes; smooth, S-shaped curves crossing the center of the diagram characterize mature (equilibrium stage) landscapes and concave-up with low integrals typify old and deeply dissected landscapes (Strahler, 1952). Differences in the shape of the curve and the hypsometric integral value are related to the degree of disequilibria in the balance of erosive and tectonic forces (Weissel *et al.*, 1994).

4.3.2 Plotting of Percentage Hypsometric Curve

In the present study percentage hypsometric method has been used which is expressed as the ratio of relative height and relative area with respect to the total height and the total area of a drainage basin. These curves have been generated with the help of following ratios:

(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.

The value of relative area (a/A) varies from 1.0 at the lowest point in the basin (h/H = 0.0) to 0.0 at the highest point in the basin (h/H = 1.0).

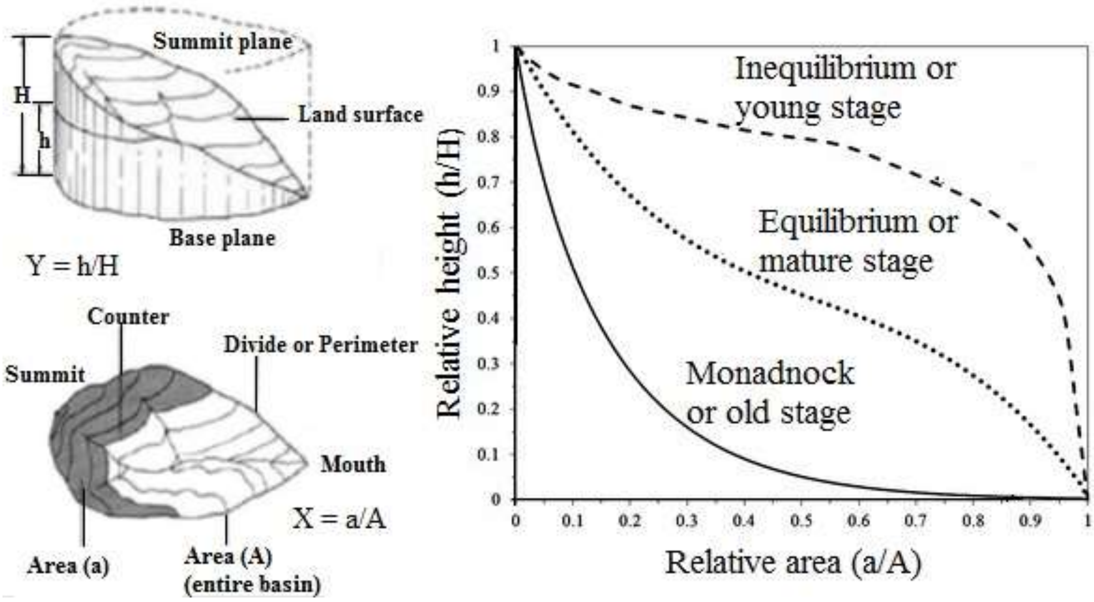


Figure 4.7. The concept of hypsometric analysis and the model hypsometric curves (Strahler, 1952; Ritter *et al.*, 2002).

The hypsometric curve of the entire Tuirini watershed represents S-shape curve indicating a mature stage of landscape development (Fig. 4.8). It is also observed from the figures (4.9) that there is a combination of convex, concave and S-shape curves, suggest that the sub-watersheds attain mature stage from the youth stage. The difference between the shapes of the hypsometric curve in the study area might be due to the lithological variations, incision of bed rocks, down slope movement of eroded materials and removal of the sediments from the basin.

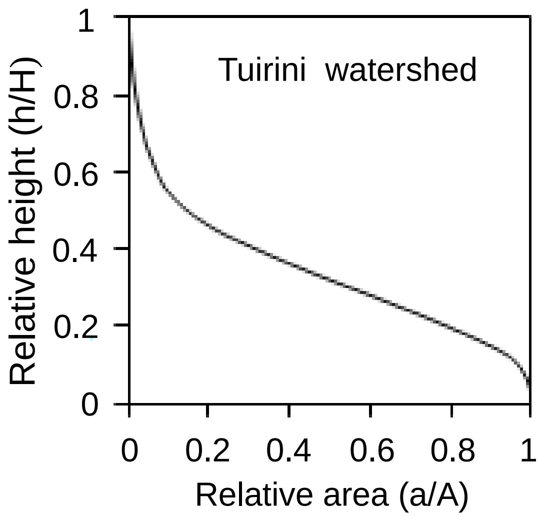
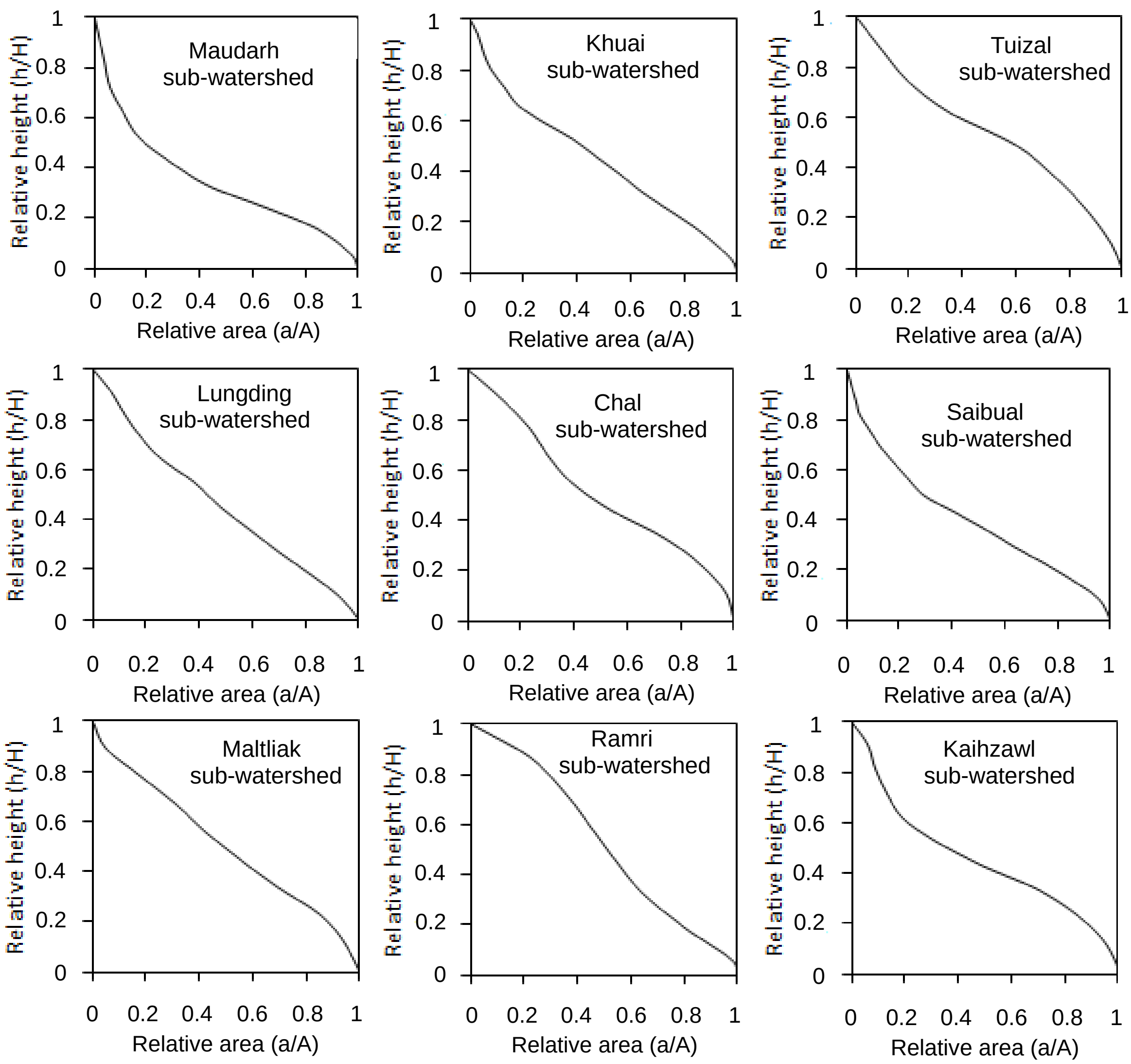


Figure 4.8. Hypsometric curve of the Tuirini watershed.



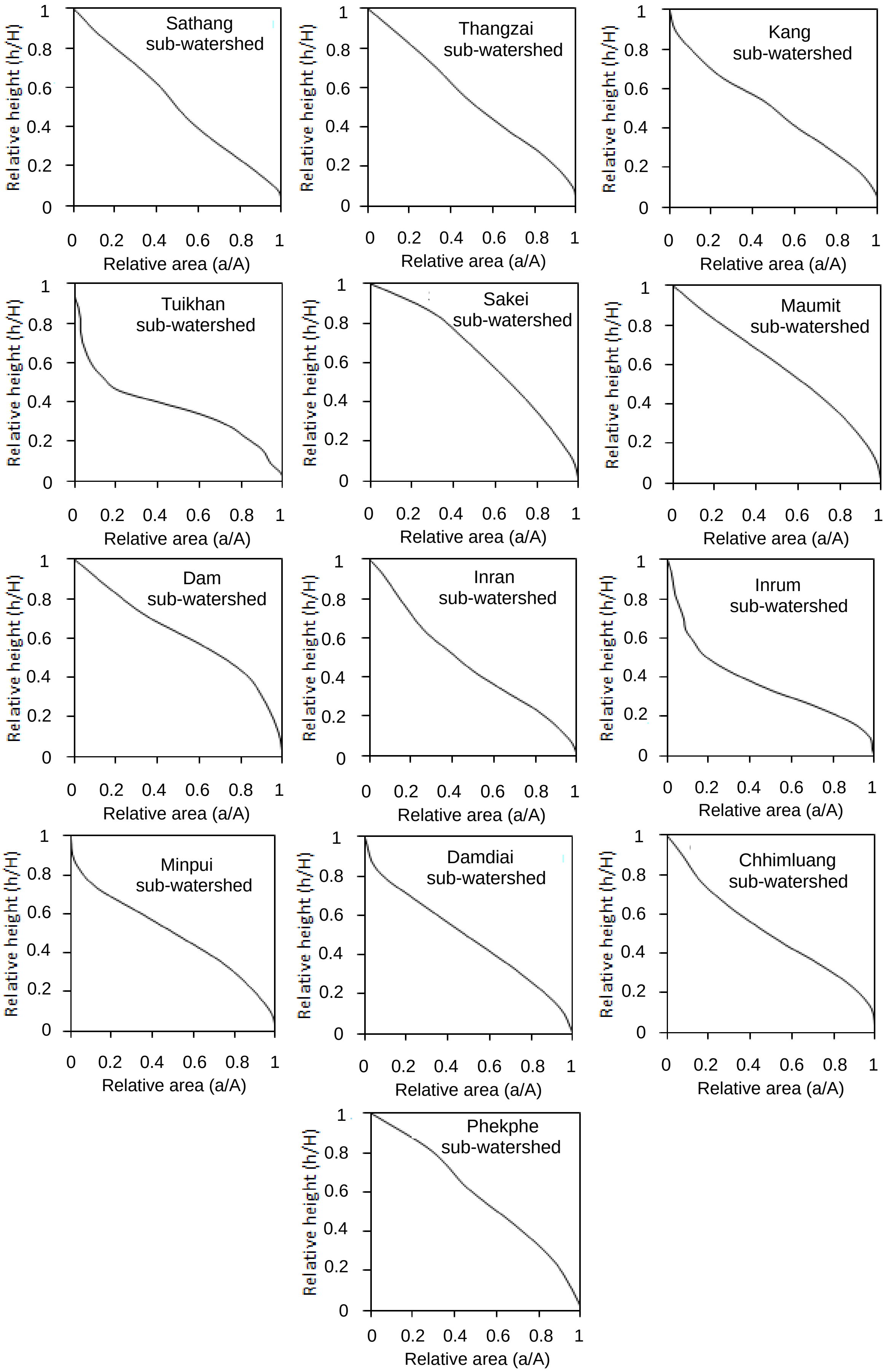


Figure 4.9. Hypsometric curves of the sub-watersheds.

4.3.3 Estimation of Hypsometric Integral

Integration of the hypsometric curve gives the hypsometric integral (HI), which is equivalent to the elevation-relief ratio (E) and is calculated according to Pike and Wilson (1971) formula. It is expressed as: E ~ HI = (Emean - Emin)/ (Emax - Emin) where, Emean is the mean elevation, Emin and Emax are the minimum and maximum elevations, respectively within the drainage basin. A.N. Strahler (1952) has classified the three threshold values for hypsometric integral, each representing the distinctive stages of the geomorphic cycle:

(i) the inequilibrium or young stage if the HI $\geq$ 0.60

(ii) the equilibrium or mature stage if 0.35 $\leq$ HI $\leq$ 0.60 and

(iii) the monadnock or old stage if HI $\leq$ 0.35.

In the young or inequilibrium stage, the drainage basin is highly susceptible to erosion and is considered under development. The equilibrium stage is the mature stage of drainage basin development i.e. the development has attained steady state condition. The monadnock or old stage, in which the drainage basin is fully stabilized.

The HI values of the study area have been grouped into six categories, each indicative of the stage of geomorphic development (i) early youth (above 80 %), (ii) middle youth (70 - 80 %), (iii) late youth (60 - 70 %), (iv) early mature (50 - 60 %), (v) middle mature (40 - 50 %) and (vi) late mature (below 40 %). The hypsometric integral (HI) values obtained for twenty two sub-watersheds are shown in the figure 4.10 and the data is presented in Table 4.10. The hypsometric integral value of the Tuirini watershed is computed to be 0.42, which reveals that 42 per cent of the rock masses still exist in basin. The calculated hypsometric integral values for all the sub-watersheds of the Tuirini watershed range from 0.37 to 0.89 (Table 4.10).

Table 4.10. Hypsometric integral values of the Tuirini watershed and its sub-watersheds.

Sl. No.	Name of sub-watersheds	Elevation (m)			Hypsometric integral (HI)	Geological stage
		Maximum	Minimum	Mean		
1	Maudarh	1145	350	875	0.58	Early maturity
2	Khuai	1837	348	1015	0.44	Middle maturity
3	Tuizal	1156	320	768	0.41	Middle maturity
4	Lungding	1460	310	982	0.49	Middle maturity
5	Chal	1150	300	850	0.64	Late youthful
6	Saibual	1775	290	1615	0.89	Early youthful
7	Maltliak	1288	270	860	0.42	Middle maturity
8	Ramri	1040	260	988	0.84	Early youthful
9	Kaihzawl	1392	250	795	0.45	Middle maturity
10	Sathang	1052	240	675	0.41	Middle maturity
11	Thangzai	982	235	595	0.48	Middle maturity
12	Kang	1170	230	865	0.50	Early maturity
13	Tuikhan	1905	225	885	0.38	Late maturity
14	Sakei	958	224	760	0.51	Early maturity
15	Maumit	960	222	692	0.51	Early maturity
16	Dam	921	220	695	0.53	Early maturity
17	Inran	1860	180	983	0.47	Middle maturity
18	Inrum	1866	150	887	0.37	Late maturity
19	Minpui	925	135	692	0.57	Early maturity
20	Damdiai	745	110	572	0.47	Middle maturity
21	Chhimluang	1064	100	677	0.49	Middle maturity
22	Phekphe	626	80	517	0.60	Late youthful
Tuirini watershed		1905	78	830	0.42	Middle maturity

Out of the twenty two sub-watersheds, only four sub-watersheds fall under younger stage, two sub-watersheds namely Saibual and Ramri belong to early youthful stage and two sub-watersheds namely Chal and Phekphe come under late youthful state of its development. The remaining eighteen sub-watersheds belong to mature stage of landscape evolution. The six sub-watersheds viz. Maudarh, Kang, Sakei, Maumit, Dam and Minpui have just entered into early mature stage of erosional development. There are ten sub-watersheds namely Khuai, Tuizal, Lungding, Maltliak, Kaihzawl, Sathang, Thangzai, Inran, Damdiai and Chhimluang are at middle maturity stage. Only Tuikhan and Inrum sub-watersheds represent late mature stage of landforms and reaching towards monadnock stage.

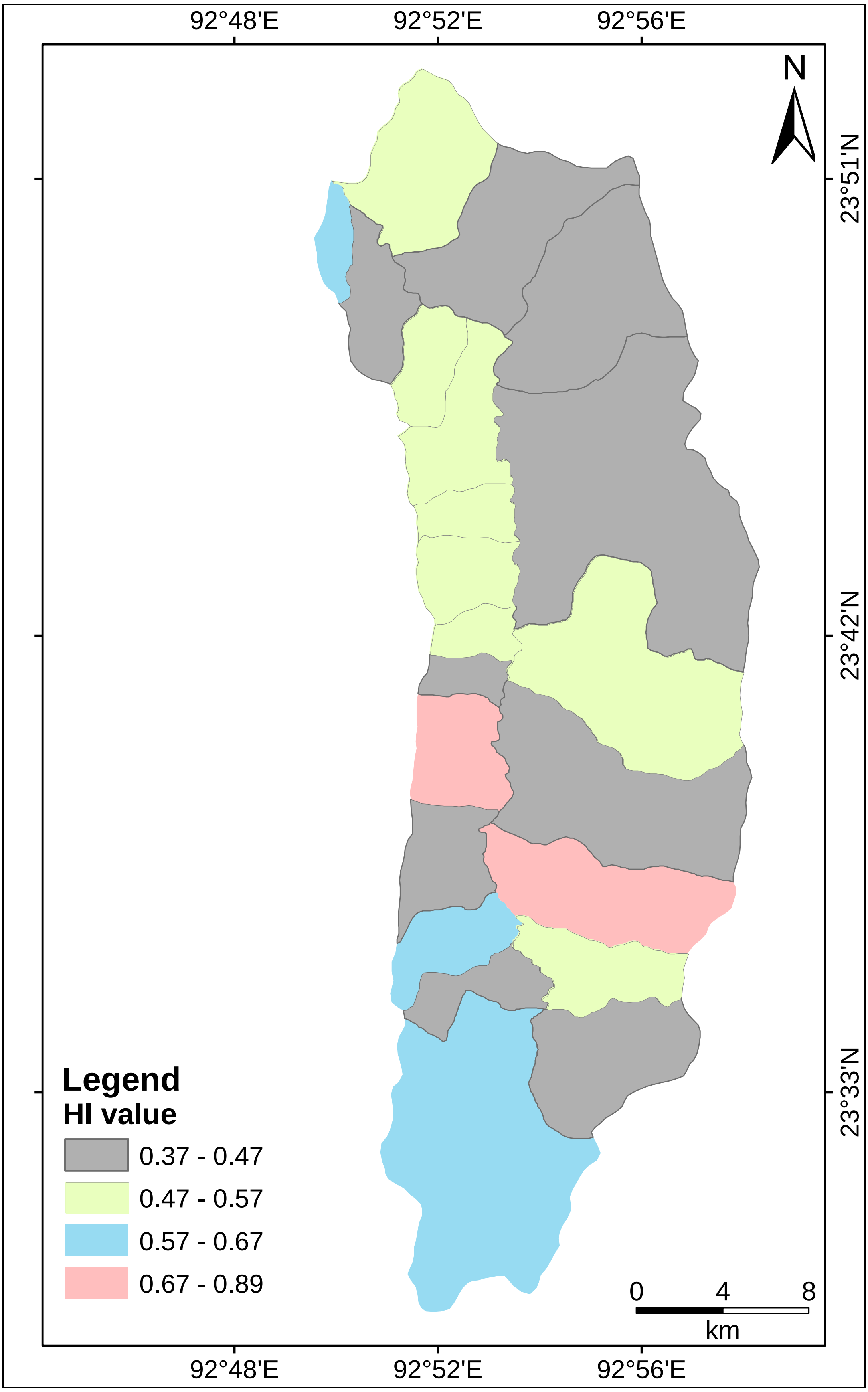


Figure 4.10. Hypsometric integral map of the sub-watersheds.

CHAPTER V

TECTONIC GEOMORPHOLOGY

5.1 Morphotectonic Analysis

Tectonics plays a vital role in landscape evolution. Landscapes in tectonically active areas result from a complex integration of the effects of vertical and horizontal motions of crustal blocks and erosion or deposition by surface processes (Burbank and Anderson, 2001). Morphotectonic is a relatively new direction in recognition of tectonic forces in landscape evolution and it has been considered as a tool to determine the intensity of tectonic activity in the tectonically active areas. Tectonic geomorphology or morphotectonic deals with the study of landforms formed by tectonic processes; focusing on the shapes and origins of landforms as a result of tectonic activities, or the application of geomorphic principles to explain tectonic problems; analysing landforms to evaluate the history, magnitude, and rate of tectonic processes (Keller and Pinter, 2002). Tectonic geomorphology has proven to be a useful tool for identifying and quantifying active and geologically recent tectonic deformation and also provides a whole kit of tools for deciphering the most recent activity on structures (Pinter, 1996; Burbank and Anderson, 2001; Keller and Pinter, 2002). The quantitative measurement of landscape is based on the calculation of geomorphic indices using topographic maps, aerial photographs/satellite data and field work. The results of several indices can be combined in order to highlight tectonic activity and to provide an assessment of a relative degree of tectonic activity in an area (Keller and Pinter, 2002). Tectonic activity produces characteristic landforms which can be studied by quantitative geomorphic analysis. Geomorphic indices are useful in the evaluation of active tectonics because they can provide rapid insights concerning specific areas within a region which is undergoing adjustments to relatively rapid and even slow rates of active tectonics (Keller, 1986).

5.2 Analysis of Morphotectonic Indices

Most commonly used geomorphic indices for morphotectonic analysis viz. (1) basin elongation ratio, (2) asymmetric factor, (3) transverse topographic symmetry factor, (4) channel sinuosity, (5) valley floor width to valley height ratio, (6) stream length gradient index and (7) mountain front sinuosity have been calculated, and are discussed below.

5.2.1 Basin Elongation Ratio

The basin elongation ratio (Re) proposed by Bull and McFadden (1977) which is defined as the ratio of the basin area (A) to the maximum basin length (Lb), and is expressed as:

$$Re = (1.128 \sqrt{A}) / Lb$$

According to Cuong and Zuchiewicz (2001) basin elongation ratio is one of the proxy indicators of recent tectonic activity. Bull and McFadden (1977) have shown that basins draining tectonically active areas are more elongated and become more circular with the cessation of uplift.

The elongation ratio values of less than 0.50, between 0.50 - 0.75 and more than 0.75 for tectonically active, slightly active and inactive settings, respectively (Bull and McFadden, 1977). The value of elongation ratio indicates that the Tuirini watershed is tectonically active as $Re < 0.50$. The elongation ratio values calculated for the sub-watersheds range between 0.35 to 0.73 (Table 5.1 and Fig. 5.1), suggest that the study area is slightly active to tectonically active.

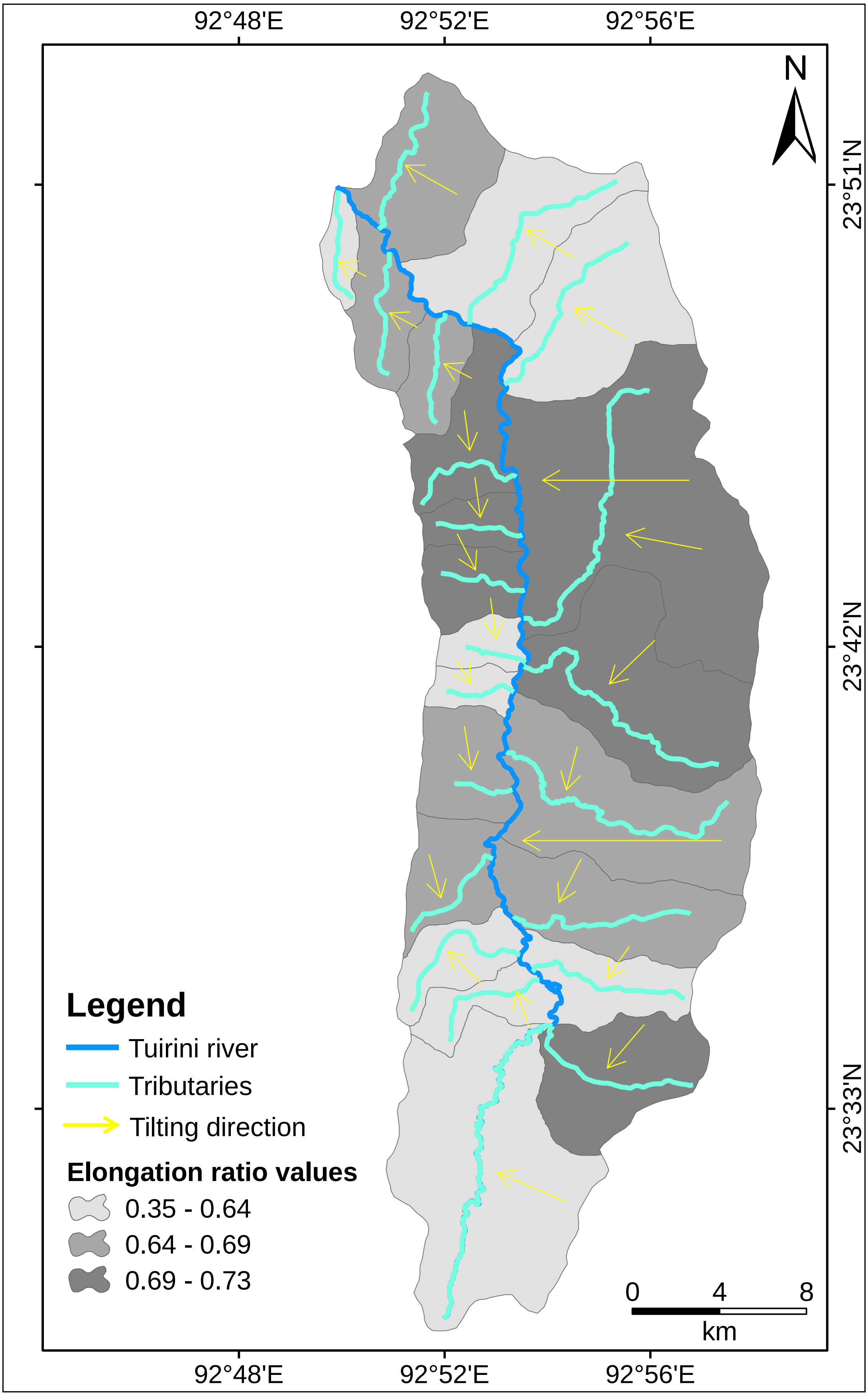


Figure 5.1. Elongation ratio map and tilting direction of the sub-watersheds.

Table 5.1. Computed elongation ratio and asymmetry factor of the sub-watersheds.

Name of sub-watersheds	Area (A) sq.km	Basin length (Lb) km	Basin elongation ratio (Re)	Asymmetry factor (AF)
Maudarh	51.80	12.72	0.63	57.67
Khuai	21.76	5.62	0.72	55.08
Tuizal	8.87	5.52	0.60	61.88
Lungding	12.68	5.23	0.63	63.09
Chal	9.79	5.21	0.64	42.97
Saibual	22.58	7.75	0.69	66.42
Maltliak	10.46	5.54	0.65	32.47
Ramri	11.67	3.28	0.68	54.96
Kaihzawl	34.83	8.75	0.67	45.19
Sathang	4.87	2.91	0.62	43.92
Thangzai	5.58	8.17	0.35	37.71
Kang	35.57	8.13	0.71	58.52
Tuikhan	65.65	11.52	0.73	37.02
Sakei	8.77	3.52	0.71	38.14
Maumit	5.86	3.48	0.72	44.09
Dam	13.93	3.90	0.70	38.65
Inran	24.82	8.42	0.63	42.76
Inrum	27.73	7.15	0.64	67.42
Minpui	7.58	4.55	0.68	40.10
Damdiai	9.84	5.28	0.67	39.95
Chhimluang	20.68	6.65	0.69	30.16
Phekphe	4.75	4.56	0.54	56.28
Tuirini watershed	420.07	45.30	0. 47	72.26

5.2.2 Asymmetry Factor

Asymmetry factor (AF) is a qualitative index which helps in evaluating basin asymmetry. AF is an areal morphometric variable that is used to detect the presence or absence of regional tilt of a basin in regional scale (Keller and Pinter, 2002). The asymmetry factor is defined as the ratio of right hand side area of drainage basin facing downstream of the trunk stream (Ar) to the total area of the drainage basin (At) i.e.

$$AF = (Ar/ At)\ 100$$

For a stream network that formed and continues to flow in a stable setting and uniform lithology, AF should be equal to about 50.

The AF is sensitive to tilting perpendicular to the trend of the trunk stream. Values of AF greater or less than 50 may suggest tilt (Keller and Pinter, 2002). In the present study, the calculated values of AF range from 30.16 to 67.42 (Table 5.1) for sub-watersheds indicate tectonic tilt whereas AF value for the Tuirini watershed is 72.26 suggests tectonic tilt towards the west (Fig. 5.1).

5.2.3 Transverse Topographic Symmetry Factor

A quantitative description of transverse topographic basin symmetry provides an important tool for several geologic processes of landscape evolution developed by recent ground tilting (Cox, 1994; Cox *et al.,* 2001). Transverse topographic symmetry factor (T) is defined as the ratio between distance from the midline of the drainage basin to the midline of the active meander belt (Da) and distance from the basin midline to the basin divide (Dd). The transverse topographic symmetry factor (T) is expressed by using the following formula:

$$T = Da/ Dd$$

Perfectly symmetric basin has value of transverse topographic symmetry (T) as zero, as the asymmetry increases T also increases and approaches the value of one. Transverse topographic symmetry factor is calculated for different segments of stream channels and indicates preferred migration of streams perpendicular to the drainage basin axis (Keller and Pinter, 2002).

In order to determine T values of the Tuirini basin, the basin area is divided into ten segments numbered from 1 to 10 by the straight line then the value of T calculated for each segment as shown in figure 5.2. The estimated T values in the study area vary from 0.20 to 0.52 (Table 5.2), indicating an asymmetric nature of the basin influenced by neotectonism.

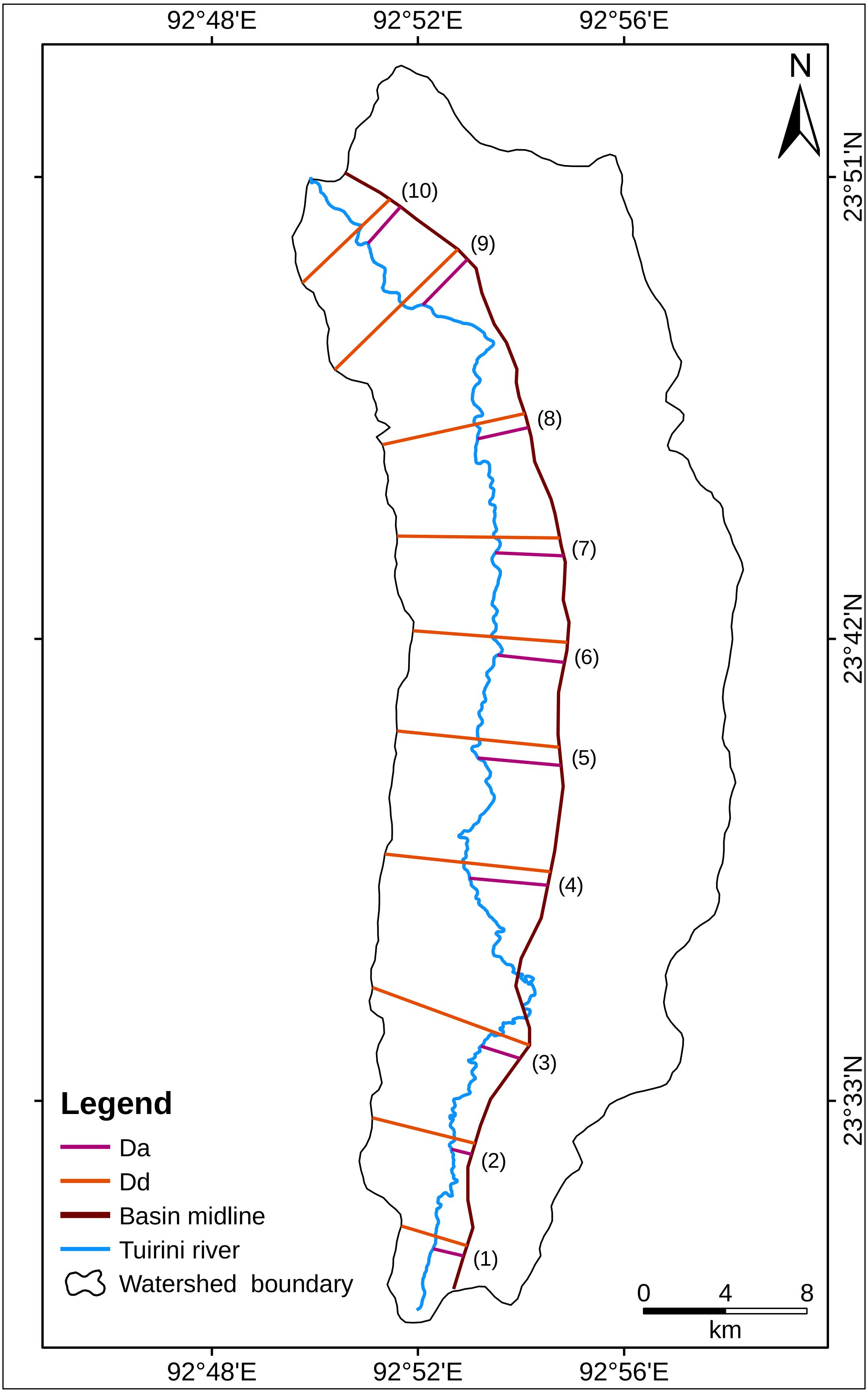


Figure 5.2. Transverse topographic symmetry factor map of the Tuirini watershed.

Table 5.2. Estimated T, S and Vf values of the Tuirini watershed.

Segments number	Transverse topographic symmetry factor (T)	Channel sinuosity (S)	Valley floor width to valley height ratio (Vf)
1	0.46	1.10	0.07
2	0.20	1.38	0.08
3	0.25	1.77	0.10
4	0.48	1.23	0.11
5	0.52	1.13	0.13
6	0.44	1.14	0.16
7	0.43	1.24	0.19
8	0.37	1.57	0.22
9	0.38	1.29	0.27
10	0.41	1.30	0.32

5.2.4 Channel Sinuosity

The channel sinuosity has been used to understand the role of tectonism. A river meanders when the straight line slope of the valley is too steep for equilibrium the sinuous path of the meander reduces the slope of the channel. Any tectonic deformation that changes the slope of a river valley results in a corresponding change in sinuosity to maintain the equilibrium channel slope (Keller and Pinter, 2002). In practice no river follows a straight course from source to mouth.

According to Muller (1968), the channel sinuosity (S) is the ratio between the stream length (Sl) to the valley length (Vl), which is expressed as $S = Sl/ Vl$.

The index value of 1.0 indicates straight river course. Values between 1.0 to 1.5 indicate sinuous river shape whereas S values more than 1.5 represents meandering course. For determination of channel sinuosity, the river channel is divided into ten segments numbered from 1 to 10. The channel sinuosity values for Tuirini river are measured at different sectors (Fig. 5.3) and there values range between 1.10 to 1.77 (Table 5.2), indicating sinuous character of river path (Plate 5B), as segments values are greater than one. The channel segments no. 3 and 8 are characterized by high sinuosity values as compared to other segments show meandering nature of river course.

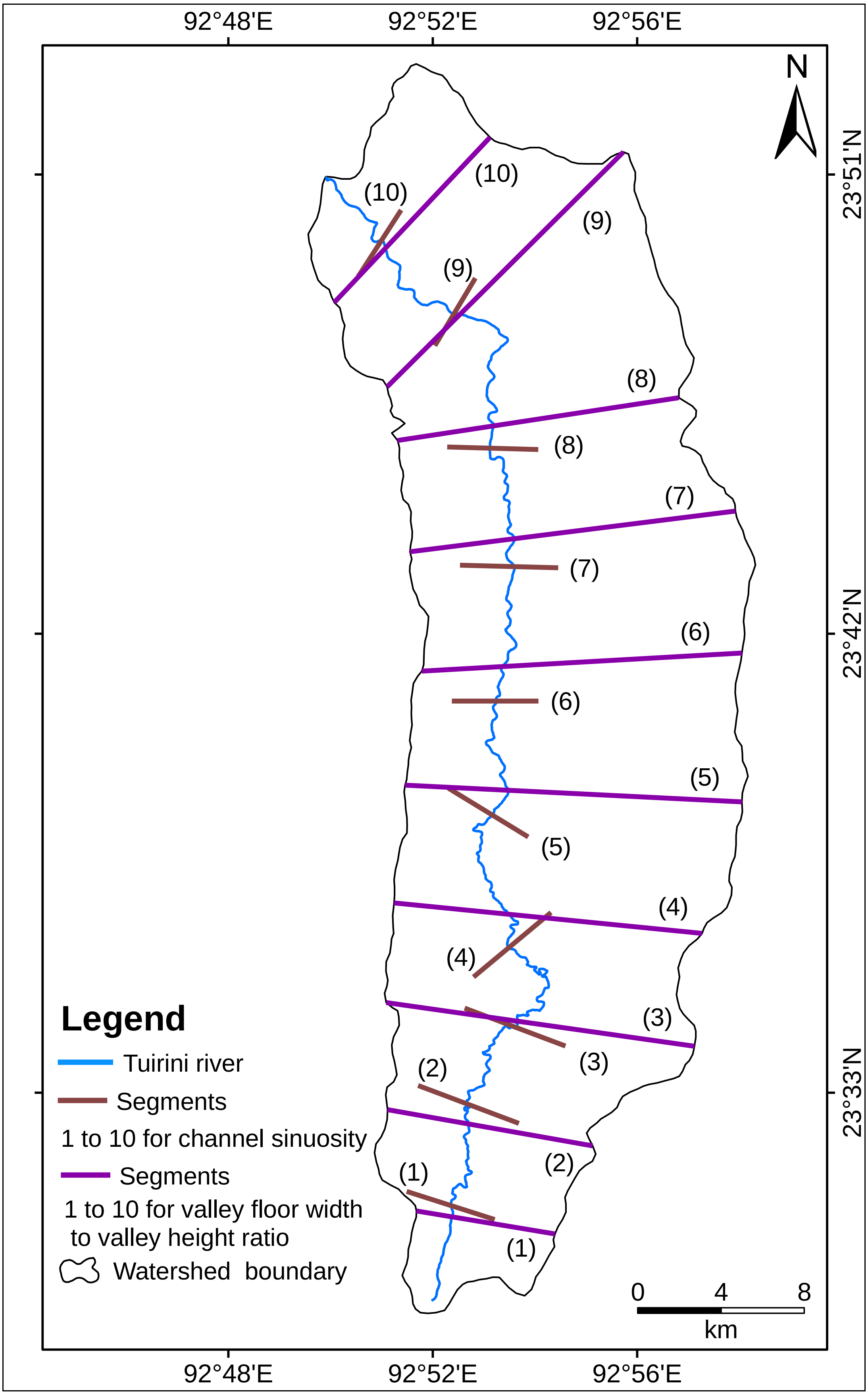


Figure 5.3. Channel sinuosity (S) and valley floor width to valley height ratio (Vf) map of the Tuirini watershed.

5.2.5 Valley Floor Width to Valley Height Ratio

Valley floor width to valley height ratio (Vf) is a good measure that indicates whether the river is actively downcutting and incision in uplifted areas (Bull and McFadden, 1977). The ratio of valley floor width to valley height ratio (Vf) may be expressed as:

$$Vf = 2\ Vfw / (E_{ld} - E_{sc}) + (E_{rd} - E_{sc})$$

Where, Vfw is the width of the valley floor, Esc is the elevation of the valley floor, Eld and Erd are the elevations of the left and right valley divides. This index differentiates between broad valleys floored with relatively high values of Vf and V-shaped with relatively low values. High values of Vf are associated with low uplift rates, so that streams cut broad valley floors whereas low values of Vf reflect deep valleys with streams that are actively incising, commonly associated with high uplift rates (Keller and Pinter, 2002). In the present study, the values of Vf are determined along the Tuirini river at ten locations viz. 1 to 10 as shown in figure 5.3 and there values range between 0.07 to 0.32 (Table 5.2), which represent deep, narrow, V-shaped valleys and also indicate on-going incision (Plate 6A) and gradual upliftment in the area.

5.2.6 Stream Length Gradient Index

The stream length gradient index (SL) is a useful parameter to identify recent tectonic activity by recognizing high index values within the variations on a particular rock type. It is sensitive to changes in slope, and this sensitivity allows the evaluation of relationships among possible tectonic activities, rock resistance and topography (Hack, 1973). The stream length gradient index is calculated for a particular reach of interest and defined as the product of the channel gradient of the reach ($\Delta H/\Delta L$) multiplied by the distance from the headwater divide (L) i.e. $SL = (\Delta H/\Delta L)/ L$. High SL index values are reflect where rivers cross hard rocks and indicate relatively high tectonic activity, while low SL index values indicate relatively low tectonic activity and suggest less resistant and softer rock types (Hack, 1973; Keller and Pinter, 2002). The SL index is calculated for the Tuirini river and its major tributaries along the courses of the streams. In the study area, values of SL index ranging from 15 m to 727 m and are grouped into seven classes (Fig. 5.4). The variations of SL index values across the drainage basin might be due to the lithological variations or influenced by tectonic activity.

5.2.7 Mountain Front Sinuosity

Bull and McFadden (1977) proposed that degree of tectonic activity and the erosional modifications of tectonic structures can be measured by mountain front sinuosity (Smf). It is an index that reflects the balance between erosion producing sinuous fronts and tectonic forces creating straight mountain fronts coincident with an active range boundary fault. Mountain front sinuosity is defined as the ratio between the length of the mountain front along its base at the distinct break in slope (Lmf) and the straight line length of the whole mountain front (Ls). The mountain front sinuosity (Smf) is expressed as: $Smf = Lmf / Ls$

The tectonically active mountain fronts typically show lower values of Smf, whereas higher values indicate relatively less active mountain fronts (Bull, 1977 & 1978; Bull and McFadden, 1977; Burbank and Anderson, 2001; Keller and Pinter, 2002). The values of Smf less than 1.4 indicate tectonically active areas, Smf values between 1.4 – 3.0 indicate slightly active areas and Smf values greater than 3.0 indicate inactive setting (Bull and McFadden, 1977). In the present study, Smf values are measured for fifty nine mountain fronts (Fig. 5.5) range between 1.07 to 2.88. Out of the 59 mountain fronts, 18 fronts show Smf value < 1.4, which suggest tectonically active, whereas for remaining forty one fronts show Smf value > 1.4 but < 3.0, fall in the slightly active category.

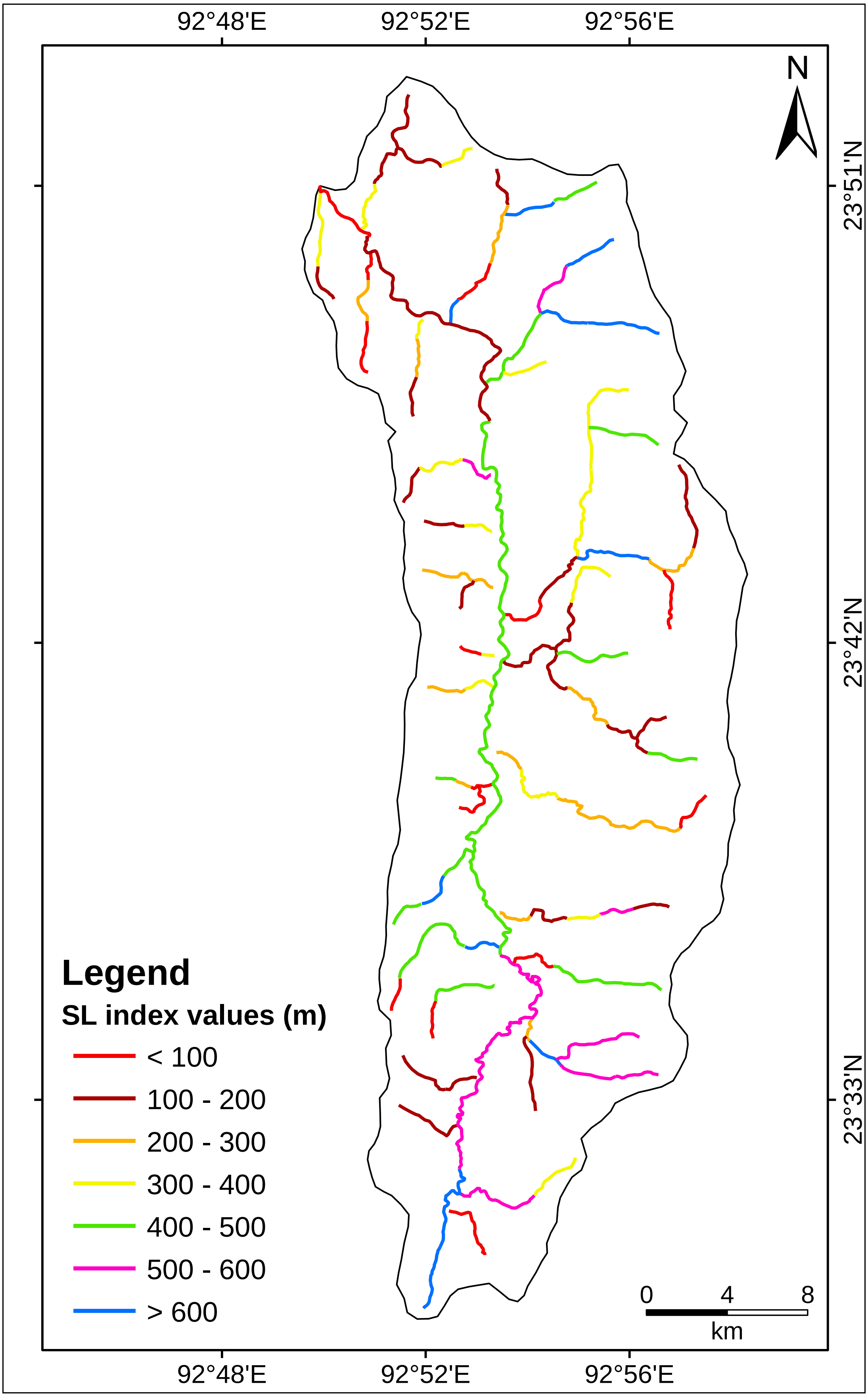


Figure 5.4. Stream length gradient index map of the Tuirini watershed.

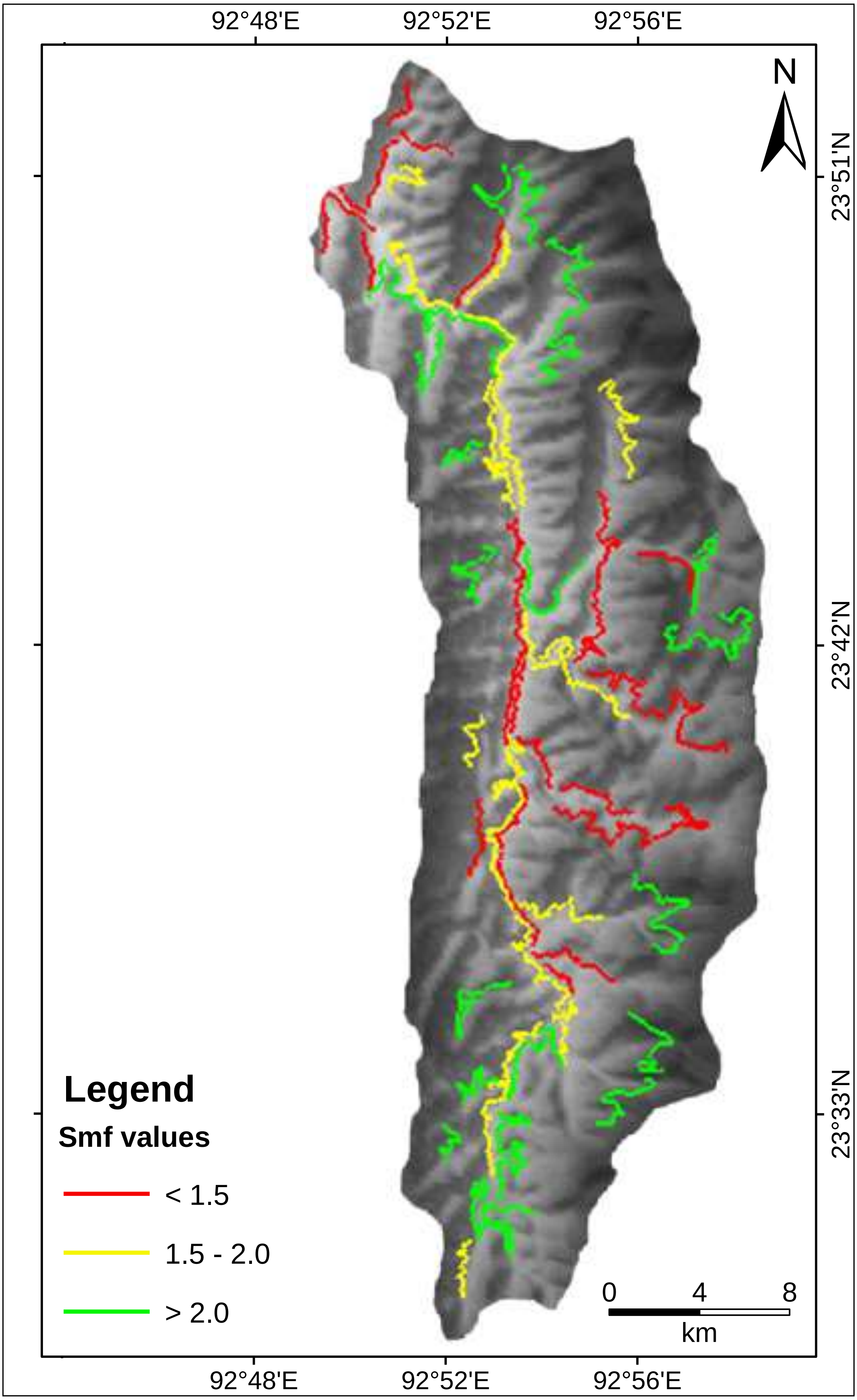


Figure 5.5. Mountain front sinuosity map of the Tuirini watershed.

5.3 River Profile Analysis

Rivers play an important role in the evolution of a landscape and are sensitive to changes in tectonic deformation, adjusting over different periods of time depending on the climate, physical properties of the host rocks and tectonic activity (Gloaguen *et al.*, 2008). The geometry of the river profile is a proxy for identifying spatial patterns of rock uplift (Seeber and Gornitz, 1983; Merritts and Vincent, 1989; Hurtrez *et al.*, 1999; Snyder *et al.*, 2000). The river profiles are divided into two types viz. (1) Longitudinal profile and (2) Transverse or cross-valley profile.

5.3.1 Longitudinal Profiles

River response to active tectonics is generally reflected in its longitudinal profile and 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 is a graphical representation of distance verses elevation, on the other hand, longitudinal profile is an erosional curve, which reflects the different stages of valley evolution from source to mouth. Longitudinal profile and its corresponding concavity and steepness are used to characterise the tectonics and base level change (Mackin, 1948; Gomez *et al.*, 1996; Holbrook and Schumm, 1999; Marple and Talwani, 2000; Lave and Avouac, 2000 & 2001).

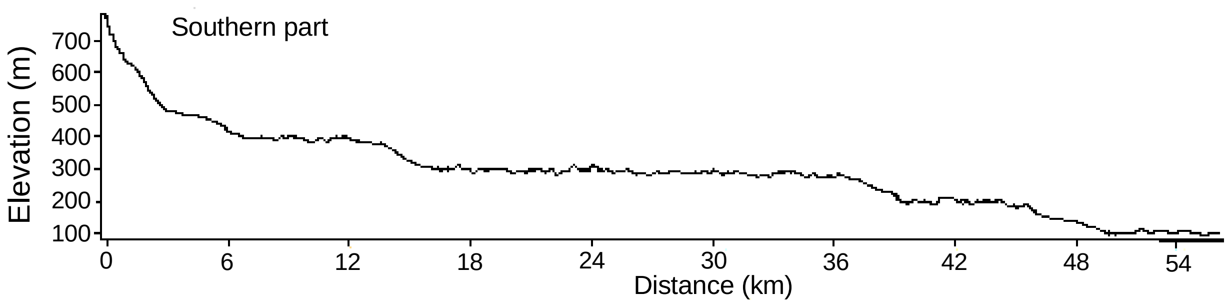


Figure 5.6. Longitudinal profile of the Tuirini river.

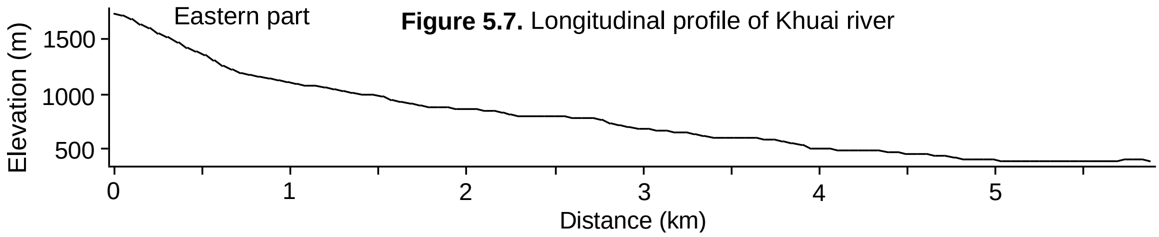


Figure 5.7. Longitudinal profile of Khuai river

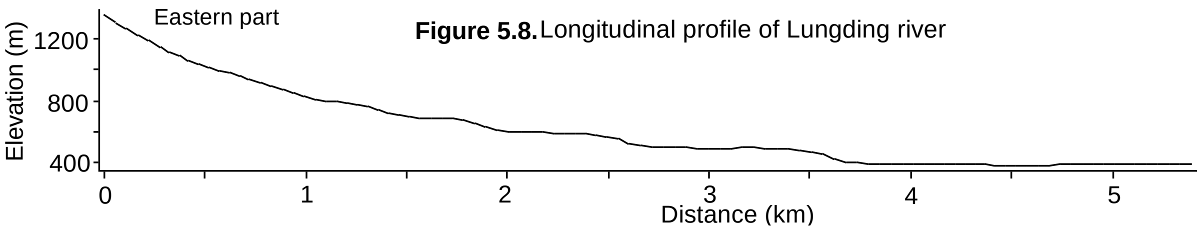


Figure 5.8. Longitudinal profile of Lungding river

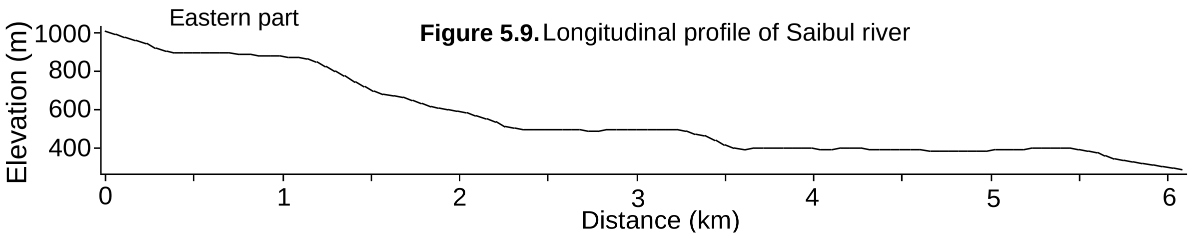


Figure 5.9. Longitudinal profile of Saibul river

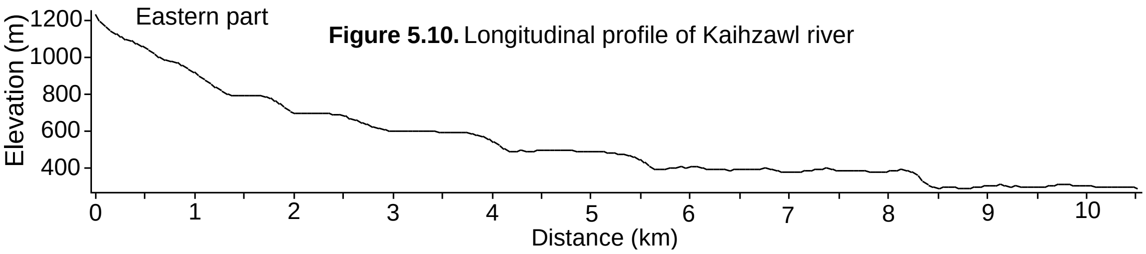


Figure 5.10. Longitudinal profile of Kaihzawl river

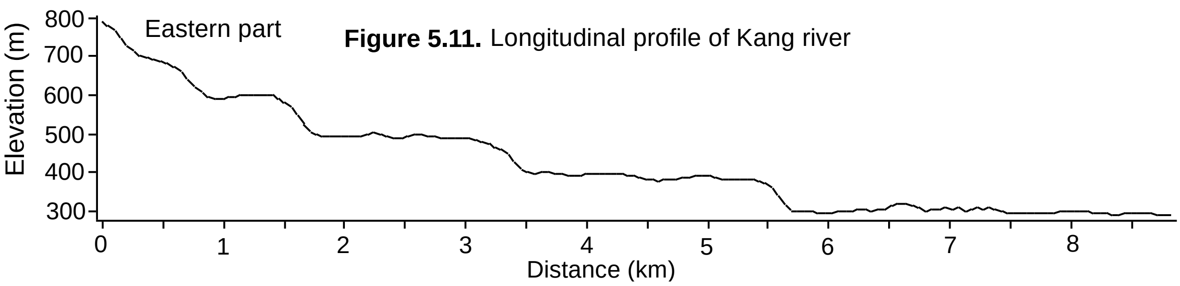


Figure 5.11. Longitudinal profile of Kang river

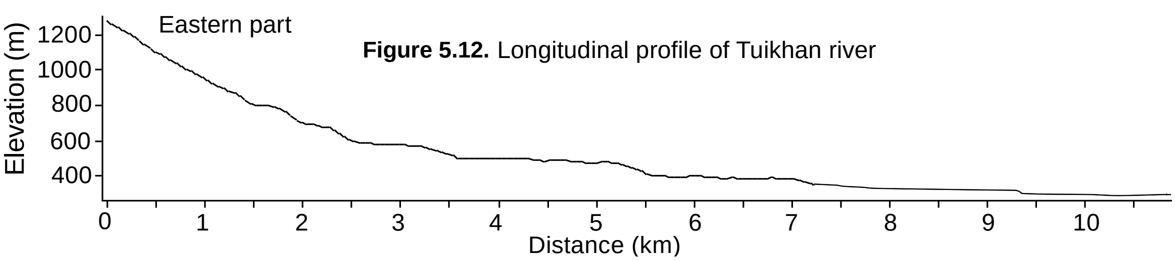


Figure 5.12. Longitudinal profile of Tuikhan river

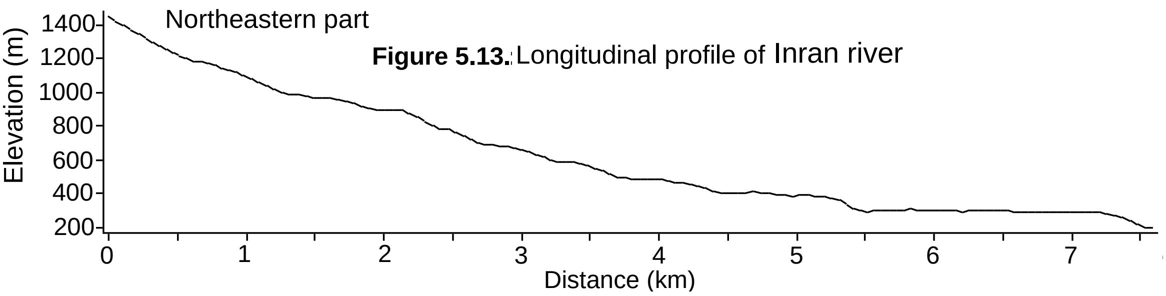


Figure 5.13. Longitudinal profile of Inran river

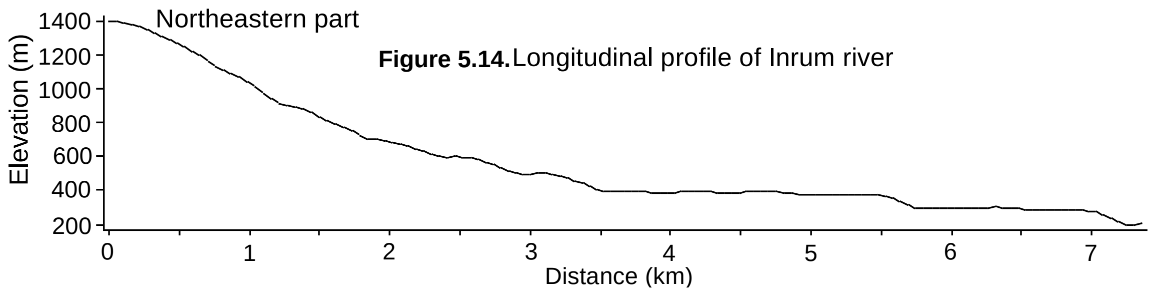


Figure 5.14. Longitudinal profile of Inrum river

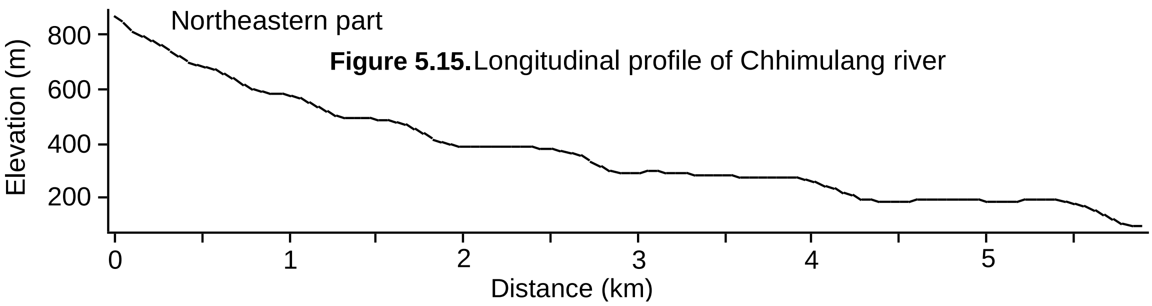


Figure 5.15. Longitudinal profile of Chhimulang river

The longitudinal profile of the Tuirini river (Fig. 5.6) shows sudden drop in elevation from its source of 780 m to 480 m within a short distance of 2.8 km. This profile also shows five prominent breaks in slope, two of which at the levels of 480 m and 400 m with steeply sloping up to 3.0 km in the upper reaches, and another three at 300 m, 190 m and 100 m in the middle and lower reaches, indicates base level changes along with three different stages of development. Several small knickpoints are found in the profile due to the presence of various resistance rocks or tectonic activities along the path of the river.

The Khuai (Fig. 5.7) is a short river and its longitudinal profile shows steep fall from the source height of 1710 m up to 1200 m within a short distance of 0.70 km and joins with the Tuirini river after traveling a distance of 5.8 km. On the other hand, Lungding river (Fig. 5.8) also shows steep fall in initial travel from its source height of 1340 m up to 800 m within a short distance of 1.0 km and joins with the main river after traveling a distance of 5.5 km.

Four breaks in slope are identified in the Saibul river (Fig. 5.9), one at 890 m, second and third at the levels of 510 m and 380 m respectively, and another at 298 m, showing four phases of cycle in its journey. In the upper reaches the profile also shows concave face indicates the scarp.

The longitudinal profile of Kaihzawl river (Fig. 5.10) is characterised by numerous knickpoints and these knickpoints have drops of about 790 m, 730 m, 600 m, 470 m, 400 m, 260 m and afterwards nearly level in the lower reaches.

The Kang river (Fig. 5.11) shows the well development of slope breaks in their course representing steep slopes of up to 0.8 km, moderately steep up to 4.7 km and thereafter gentle slope indicates three different base levels.

The Tuikhan river (Fig. 5.12) gradually grades down its height within 2.5 km and has small knickpoints with 580 m, 500 m, 420 m elevation drops and travels around 11 km before meeting the Tuirini river.

The longitudinal profile of Inran (Fig. 5.13) shows gradual decrease in gradient up to 5.3 km and again suddenly grades down its height at 290 m and 200 m within a distance of 2.1 km.

Similarly, river Inrum (Fig. 5.14) shows gradual decrease in gradient up to 3.5 km with steep slopes and afterwards flowing almost 3.5 km in the middle gradient and again suddenly drops its height at 200 m in the lower reaches.

River Chhimluang (Fig. 5.15) shows gradually drop from its source height of 870 m and maintain its flows in the lower reaches showing two phases in its journey.

From the figures 5.7 to 5.15, it is also observed that the most of the longitudinal profiles represent steeper gradients in the upper reaches with concave face near the scarp and changes in gradients represented by breaks in slope. The overall longitudinal profiles of rivers/ tributaries show graded curves, indicating the mature stage of geomorphic development. Prominent breaks in slope occur along the course of the rivers due to the variation in lithology and the structural disturbance. All the major fault and lineament are reflect as slope difference along the river profiles.

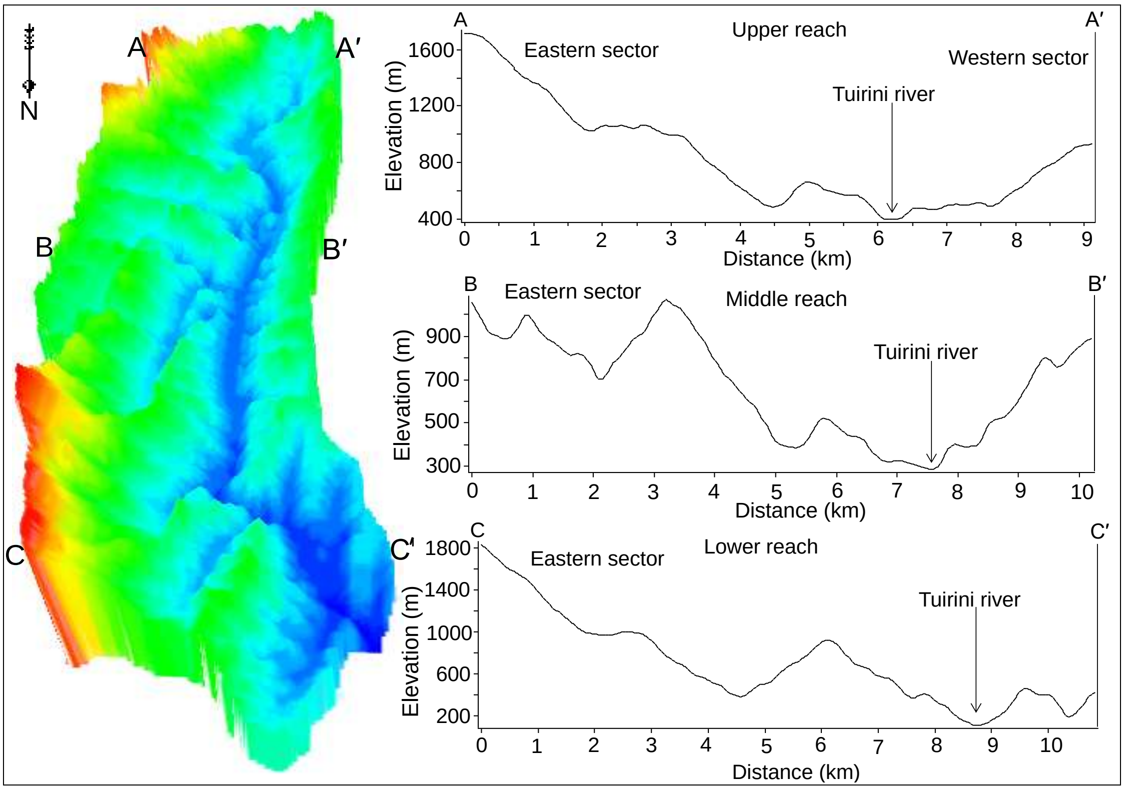


Figure 5.16. Transverse profiles of the Tuirini river.

5.3.2 Cross-valley Profiles

Cross-valley profile or transverse profile represents the surface configuration across the river beds. The cross-valley profiles of the river indicate the different stages in the cycle of erosion, slope differences, terrace formation and characteristics of the valley forms.

The Tuirini river has been divided into three reaches viz. upper, middle and lower reaches, and cross-valley profiles have been drawn from the right bank (east) to the left bank (west) at three different locations (AA′, BB′ and CC′) across the river and viewed from the north (Fig. 5.16).

It is observed from the profiles that the eastern sectors of the basin have higher elevation in comparison to the western sectors. The upper and the middle valley slopes are moderate to moderately steep whereas lower valleys are relatively gentle and the general trend of slope is towards south to north direction.

The cross-valley profiles of the Tuirini river shows a mature stage of river, where down cutting becomes almost imperceptibly slow and valley widening becomes dominant. These changes in characteristic river activity mark the transition from youth to maturity (Thornbury, 1954). The cross-valley profiles of the Turini river also indicate the tilting of the river floor is towards the western sector of the river.

5.4 Lineament Analysis

The study of lineaments has become an important part in analysing the structure and tectonics aspects of any region. Lineaments are large scale linear feature of tectonic origin, which may represent fault, fracture, joints sets, linear geological formations, straight course of streams, vegetation alignment or topographic linearity. In areas of gently folded or horizontal strata, lineaments are related to fractures and faults and their orientation and number gives an idea of the fracture pattern of rocks (Arlegui and Soriano, 1998; Cortes *et al.,* 1998).

In the study area, the lineaments have been identified from the satellite data on the basis of tonal differences, textural contrasts and structural alignments, which are of varying dimensions with different orientations. The lineaments developed in the study area may be the results of faulting and fracturing of rocks, and most of the tributaries are flowing along the lineaments or fractures reflect the structural controlled on the evolution of the drainage development. The lineaments extracted in the study area are shown in fig. 5.17.

The estimated number of lineaments of the study area is about 260 (Table 5.3). Out of 260, 109 numbers (41.92 %) of lineaments are in N60^0 – W direction, 63 numbers (24.23 %) of lineaments are in N60^0 – E direction, 37 numbers (14.23 %) of lineaments are in N30^0 – 60^{0}E direction, 31 numbers (11.93 %) of lineaments are in N – 30^{0}E direction, 12 numbers (4.61 %) of lineaments are in N30^0 – 60^{0}W direction and 8 numbers (3.08 %) of lineaments are in N – 30^{0}W direction. The length of the each lineament is also computed (Table 5.3) and the total lengths of lineaments are 243.80 km in the study area.

Table 5.3. Lineament data of the Tuirini watershed.

Azimuth range (In degrees)	Number of lineaments	Frequency (%)	Lineaments length (km)	Length (%)
0 - 10	11	4.23	10.58	4.33
10 - 20	9	3.46	7.90	3.24
20 - 30	11	4.23	10.81	4.43
30 - 40	10	3.84	8.67	3.55
40 - 50	13	5.00	11.92	4.88
50 - 60	14	5.37	12.45	5.10
60 - 70	12	4.61	10.91	4.47
70 - 80	29	11.15	27.32	11.20
80 - 90	22	8.46	20.84	8.54
90 - 100	59	22.69	58.18	23.86
100 - 110	35	13.46	34.03	13.95
110 - 120	15	5.67	13.67	5.60
120 - 130	9	3.45	7.62	3.12
130 - 140	1	0.38	0.82	0.34
140 - 150	2	0.76	1.58	0.65
150 - 160	1	0.38	0.78	0.31
160 - 170	3	1.5	2.05	0.84
170 - 180	4	1.54	3.67	1.50
Total	260.00	100.00	243.80	100.00

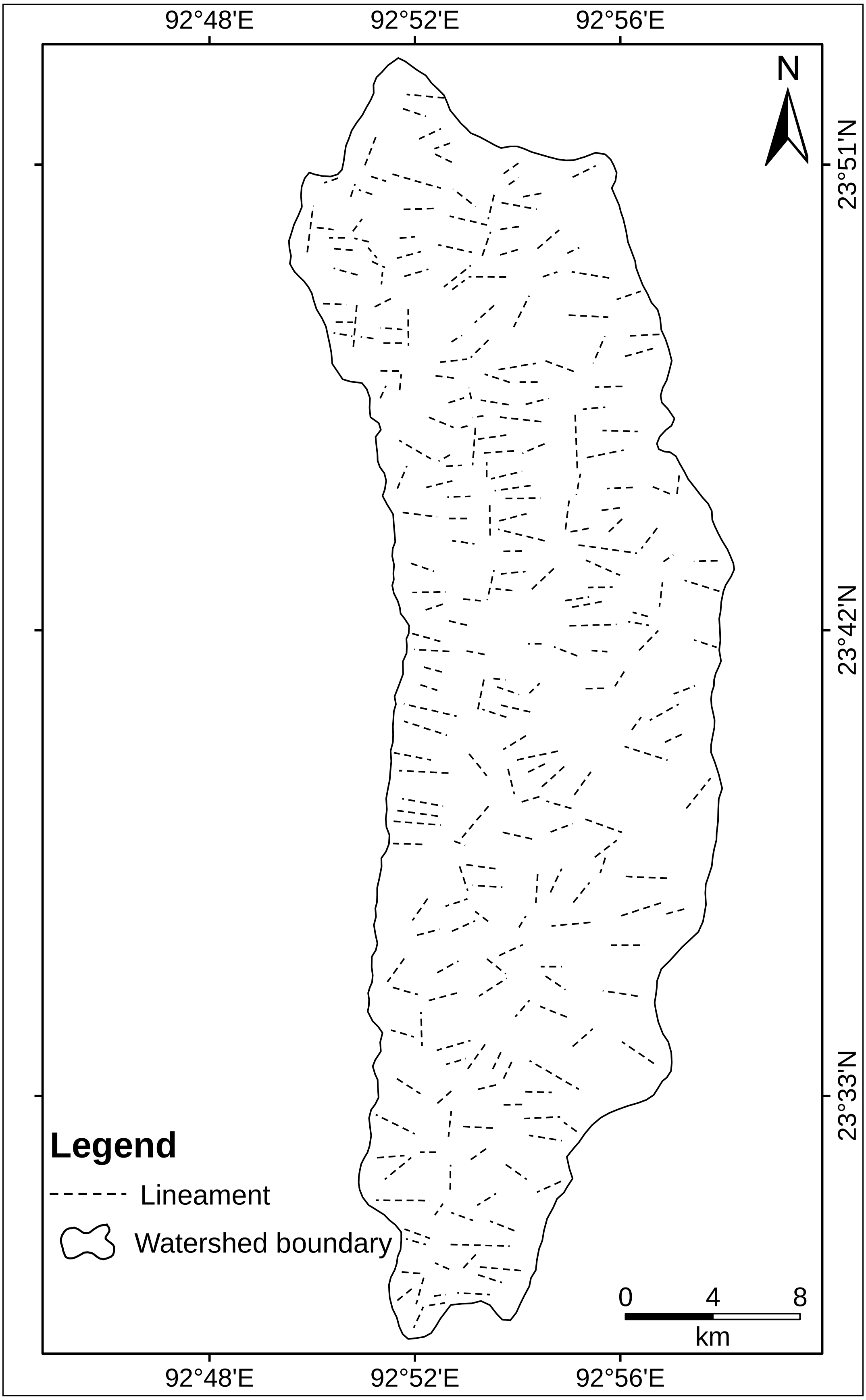


Figure 5.17. Lineament map of the Tuirini watershed.

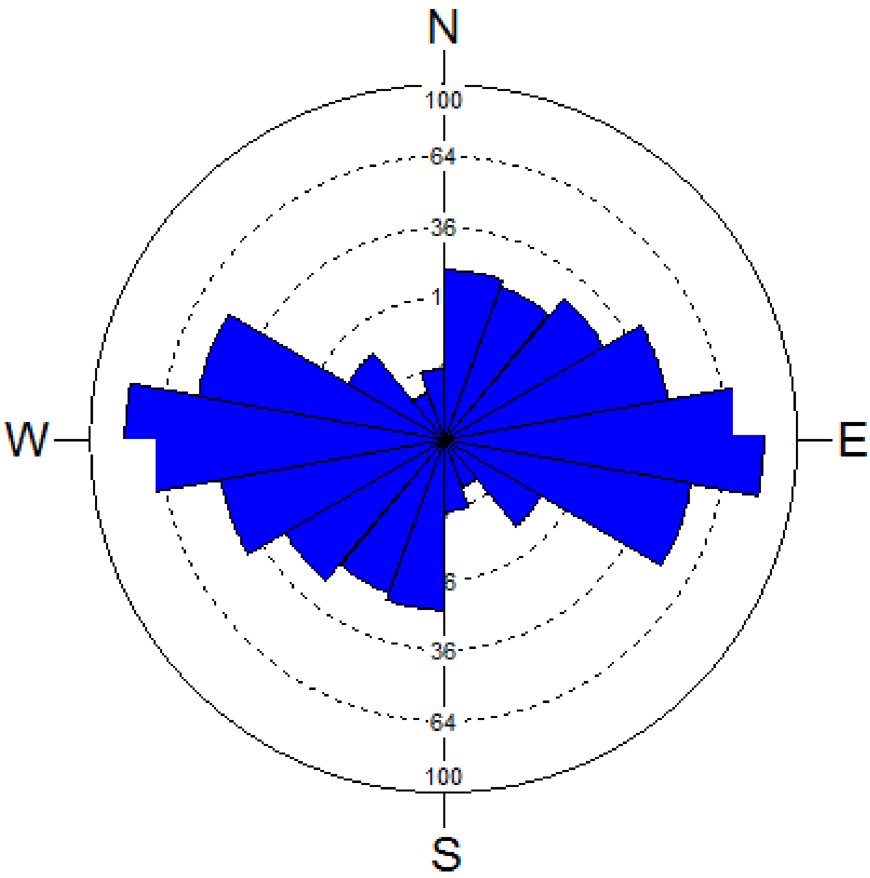


Figure 5.18. Rose diagram of the Tuirini watershed.

The distributions of the lineaments in the watershed are shown in the form of a rose diagram (Fig. 5.18) and the interpretation of the rose (azimuth-frequency) diagram shows the trends of the lineaments are NNE – SSW, NE – SW, EEN – WWS, WWN – EES, N – S and E – W directions. NW – SE and NNW – SSE trending lineaments are few in numbers (Table 5.3).

The azimuth data are tabulated at 10^0 class interval and for each frequency is calculated. The lineament azimuth density is high in 70^0 – 80^0, 80^0 – 90^0, 90^0 – 100^0 and 100^0 – 110^0 classes. In the study area, the prominent lineaments are WNW – ESE, ENE – WSW and NE – SW trends.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The quantitative analysis of morphometric parameters have been found to be of immense utility in watershed management and conservation of natural resources for their sustainable development. Morphotectonic indices have gained importance in evaluating the nature of tectonic activity in an area. A detailed morphometric and morphotectonics analysis of the Tuirini watershed has been therefore undertaken to understand the drainage characteristics and the ongoing tectonic changes of the terrain.

Different thematic maps such as base map, geomorphological map, sub-watershed map and drainage network map etc. have been derived based on visual interpretation of satellite data together with Survey of India toposheets. The slope map, aspect map and digital elevation model were generated from ASTER GDEM 30 m data using ArcGIS-10.2 software. For better accuracy of the thematic maps, ground truth verifications have been done in accessible areas.

The study area lies between longitudes 92°49′34″– 92°58′22″E and latitudes 23°28′37″– 23°53′20″N which covers an area of about 420.07 sq.km and the maximum length of 45.30 km from south to north and the maximum width of 11.5 km from east to west with watershed perimeter of 110.70 km. The Tuirini river is the major river of the study area, which originates from Buhkangkawn hill at an elevation 780 m above msl near the Buhkangkawn village in Serchhip district and flows northward for a distance of 56.75 km and then it joins to Tuirial river near Tuirinikai village at an elevation 78 m above msl in Aizawl district of Mizoram. The area is characterized by rugged nature of topography with steep slopes and narrow gorges. The entire study area was further sub-divided into 22 sub-watersheds based on the major tributaries of the Tuirini river. The study area is characterized by tropical semi evergreen forest.

The climate of the study area is humid tropical in nature and the average annual rainfall is about 2300 mm and 80% of the rainfall occurs during the monsoon season from June to September as it is under the direct influence of south-west monsoon. The average summer temperature is about 25°C and average winter temperature is about 18°C with average annual humidity of the watershed is about 70%.

Geologically, the study area belongs to Middle - Upper Bhuban Formations of Surma Group of Lower to Middle Miocene in age. The sedimentary rocks exposed in the study area are thickly bedded sandstones, shales and siltstones and their various intermixtures in varying proportions. These rocks have been folded into a series of longitudinal en-echelon anticlines and synclines. The anticlines are very tight, asymmetric while the synclines are narrow valleys. Most of the anticlines and synclines are doubly plunging. Major portion of the study area is occupied by shales and siltstones rocks which cover an area of 274.03 sq.km and minimum area is occupied by sandstones of 146.04 sq.km of the study area.

Geomorphologically, the study area is occupied by a series of ridges and deep valleys and is complexly deformed due to folding and faulting activities of the area. Most of the ridges are elongated and narrow crested, though a few of these are also broad crested. The terrain is occupied by high degree of slopes resulting from complex geological structures and the major portion of the basin area falls under steep slope category of 20^0 - 30^0. The elevation ranges from 1905 m to 78 m and the average elevation is about 830 m above msl. The study area is also characterised by trellis, parallel to sub-parallel and sub-dendritic drainage patterns. The geomorphic features observed in the study area are linear ridges, escarpments, structural valleys, terraces, point bars, waterfalls and valley fills. Structural hills are the product of diastrophic processes like folding and faulting. Valleys are controlled by the underlying structure and lithology.

The different morphometric parameters namely linear, textural, geometric and relief aspects of the Tuirini watershed and its sub-watersheds were computed based on Horton (1932 & 1945), Schumm (1956), Smith (1950), Miller (1953), Gravelius (1914), Melton (1957), Singh and Dubey (1994) and Sreedevi *et al.* (2005) standard methods. The stream ordering was carried out using the Strahler (1964) technique. The various morphotectonic indices were estimated using mathematical formulae proposed by Muller (1968), Hack (1973), Bull and McFadden (1977) and Cox (1994). All the measurements have been carried out in GIS platform using ArcGIS-10.2 version. The hypsometric analyses for the Tuirini watershed and its sub-watersheds have been carried out using Strahler (1952), and Pike and Wilson (1971) methods.

The lineaments were identified from satellite imagery through visual interpretation with the aid of ArcGIS v. 10.2 and ERDAS Imagine v. 9.2 image processing software. The orientations of the lineaments were analysed with the help of rose diagram, and based on the ASTER digital elevation data, river profiles have been generated in GIS environment.

The morphometric analysis of the study area has been carried out through the measurement of linear, textural, geometric and relief aspects of the watershed.

The linear aspects such as stream order, stream number, stream length, mean stream length, stream length ratio, bifurcation ratio and Rho coefficient have been estimated. In the study area, the stream order varies from 1^{st} to 6^{th} order, and altogether 2729 stream segments were recognized. 1^{st} and 2^{nd} order streams are the most dominant in the area and are located mostly in high elevated area with steep slopes. It is noticed that there is a decrease in stream frequency as the stream order increases. The stream length ratios between successive stream orders of the basin vary due to differences in slope and topographic conditions of the area. The bifurcation ratio of the study indicates that there is strong structural control over the drainage development and the value of Rho coefficient reveals that the watershed is having low water storage capacity.

The textural parameters such as drainage density, stream frequency, drainage texture, length of overland flow and constant of channel maintenance have been calculated. Drainage density and stream frequency indicate that the region is characterized by impervious rock formations and high relief with sparse vegetation cover. The drainage texture values indicate that all the sub-watersheds fall under coarse to very fine category of texture. The length of overland flow reveals short flow paths having low rate of infiltration due to the presence of impermeable subsurface material whereas the constant of channel maintenance suggests that the area is characterized by high surface runoff, low permeability and high drainage density.

The geometric parameters viz. form factor, circularity ratio and compactness coefficient are suggest the elongated shape of the basin with less side flow for longer duration.

The relief parameters include basin relief, relief ratio, relative relief, dissection index, ruggedness number and gradient ratio which have been computed. The analysis of basin relief, relief ratio and relative relief of the study area represents high relief with steep slopes and high runoff conditions of the study area. The dissection index of the study area suggests the mature stage of landscape development with highly dissected mountainous terrain. The ruggedness number suggests that the structural complexity of the terrain in association with high relief and drainage density and the area is also characterized by moderate to high gradient.

The hypsometric curve and hypsometric integral value of the entire Tuirini watershed reflects mature stage of landscape development. The hypsometric curves of the sub-watersheds represent the combination of convex, concave and S-shape curves, which might be due to the lithological variations or removal of the soils from the basin, suggests that the most of the sub-watersheds attain mature stage. The hypsometric integral values of the sub-watersheds show that the majority of the sub-watersheds are at mature stage of geomorphic development.

The morphotectonic indices viz. basin elongation ratio, asymmetric factor, transverse topographic symmetry factor, channel sinuosity, valley floor width to valley height ratio, stream length gradient index and mountain front sinuosity have been considered for the present study. The value of elongation ratio indicates that the area is tectonically active. The values of asymmetry factor reveal that majority of the sub-watersheds are tilted whereas asymmetry factor value of the entire basin suggests tectonic tilt towards the west due to tectonic activity. The estimated values of transverse topographic symmetry factor indicate an asymmetric nature of the basin influenced by neotectonism. The channel sinuosity values of the Tuirini river reveal sinuous character of river path. The values of valley floor width to valley height ratio represent deep, narrow, V-shaped valleys due to ongoing incision and gradual upliftment in the area. The variations of stream length gradient index values across the drainage basin might be due to the lithological variations or influenced by tectonic activity. The mountain front sinuosity values suggest that the mountain fronts are slightly active to tectonically active.

Most of the longitudinal profiles represent steeper gradients in the upper reaches with concave face near the scarp and changes in gradients represented by breaks in slope. The overall longitudinal profiles of tributaries/rivers show graded curves, indicating the mature stage of geomorphic development. Prominent breaks in slope occur along the course of the rivers due to the variations in lithology and the structural disturbance. All the major fault and lineament are reflects as slope difference along the river profiles.

The cross-valley profiles of the Tuirini river shows a mature stage of river development, where down cutting becomes almost imperceptibly slow and valley widening becomes dominant. The cross-valley profiles also indicate the tilting of the river floor is towards the western sector of the river.

The estimated numbers of lineaments are 260 with their total lengths of 243.80 km in the study area. Most prominent trends of lineaments are along WNW – ESE, ENE – WSW and NE – SW directions. Majority of the tributaries are flowing along the lineaments or fractures which reflect the structural controlled on the evolution of the drainage development.

The study has shown the drainage characteristics, basin geometry, slope morphometry, variations of lithology, hydrogeological nature of rocks, geomorphic evolution of landscape and tectonic activities of the area. The outcomes of this study would be helpful in various developmental activities and conservation of natural resources of the watershed area.

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P L A T E - 1

Plate 1A. Panoramic view of narrow crested hills with alternate narrow valleys in the study area.

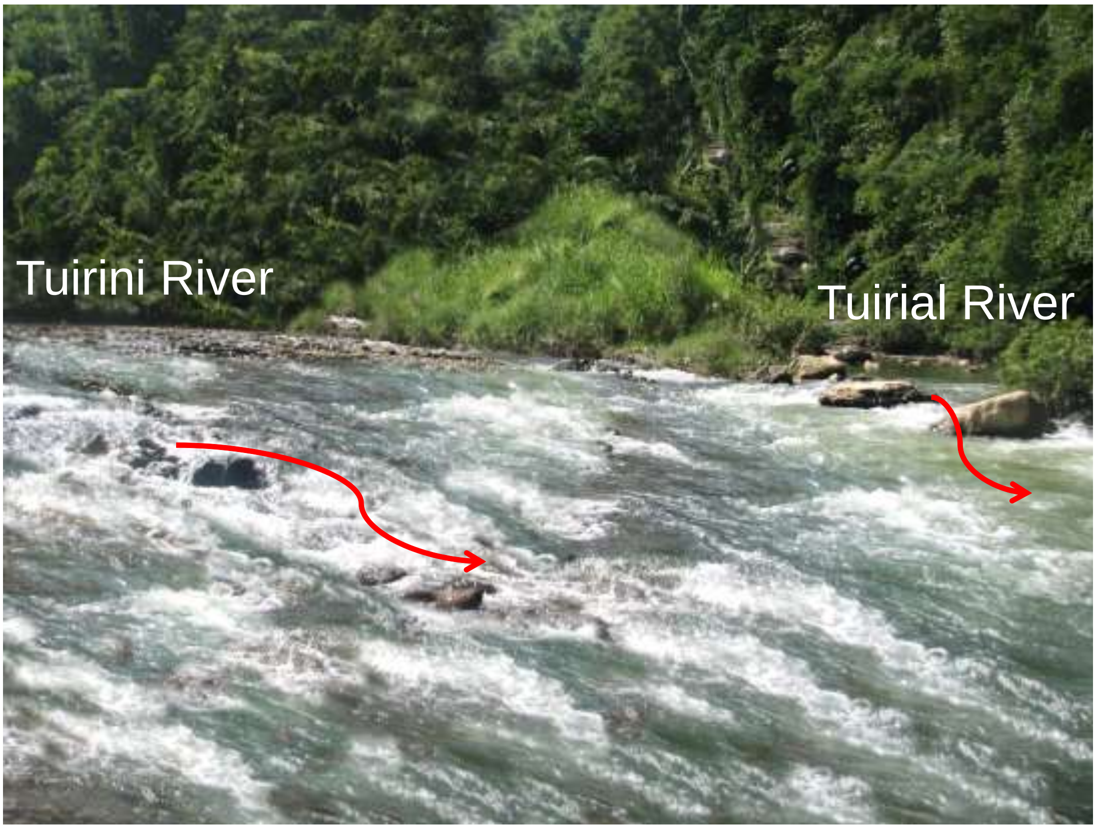

Plate 1B. Confluence of the Tuirini and Tuirial rivers.

PLATE-2

Plate 2A. The alternate sequences of sandstone and shale exposure along the Seling-Keifang road section.

Plate 2B. Deep and narrow gorge with steep valley side slopes in the upper reaches of the Tuirini river.

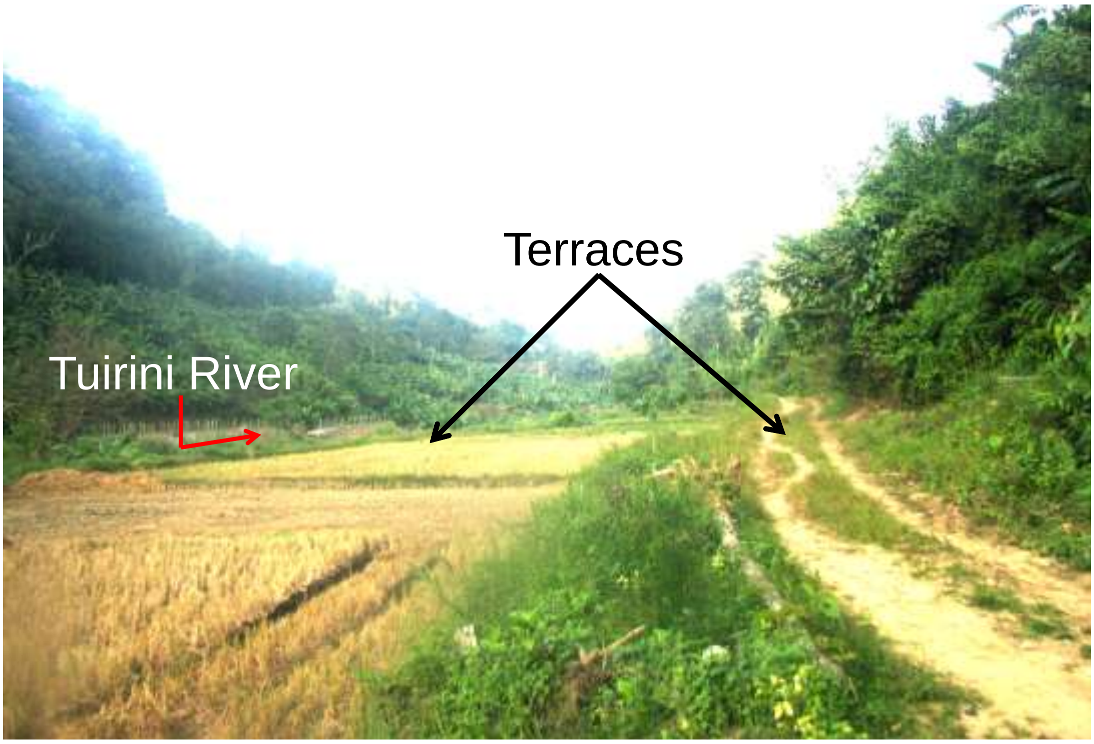

Plate 3A. Synclinal valley with river terraces in the middle reaches of the Tuirini river.

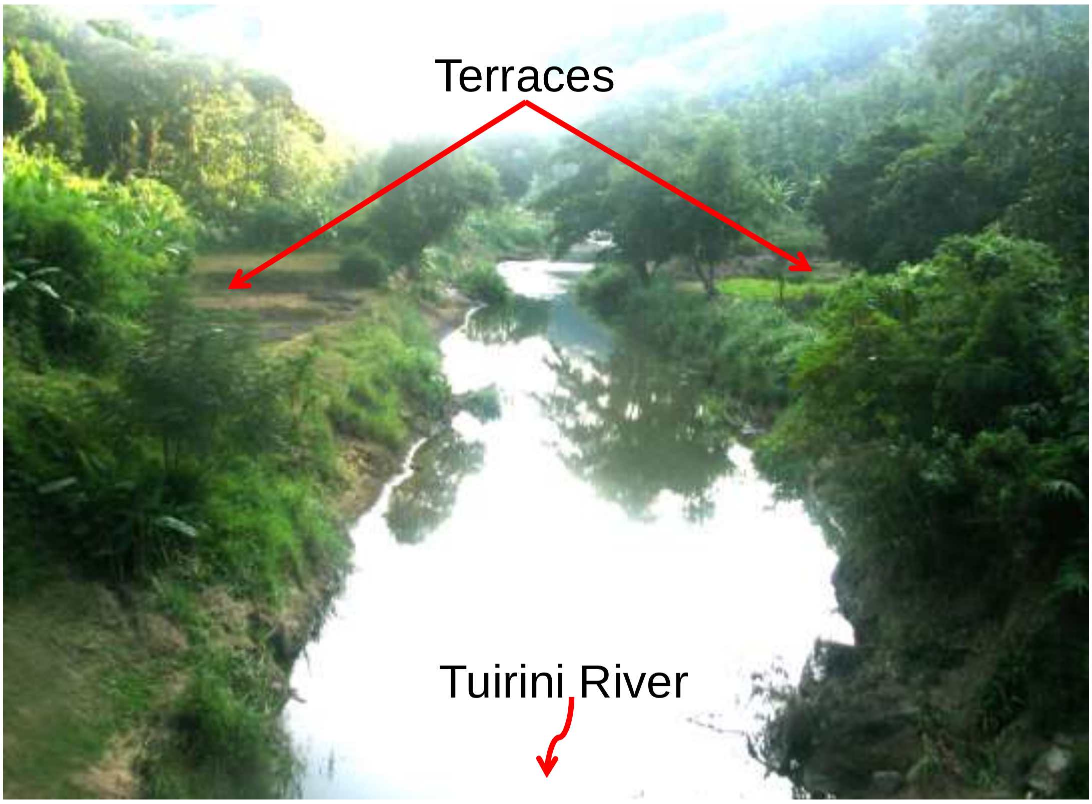

Plate 3B. The fault controlled straight course of the Tuirini river in the middle reaches.

P L A T E - 4

Plate 4A. Deposition of large amount of sediments (Gravels and Pebbles) along the Tuirini river near Tuirinikai village.

Plate 4B . Point bar in the lower reaches of the river. This point bar deposit is composed of medium to coarse grained sand on right bank section.

PLATE - 5

Plate 5A. Valley fills in the left course of the Tuirini river before reaching Tuirinikai village.

Plate 5B. Sinuous course with steep vegetated valley side scarp in the middle reaches of the Tuirini river.

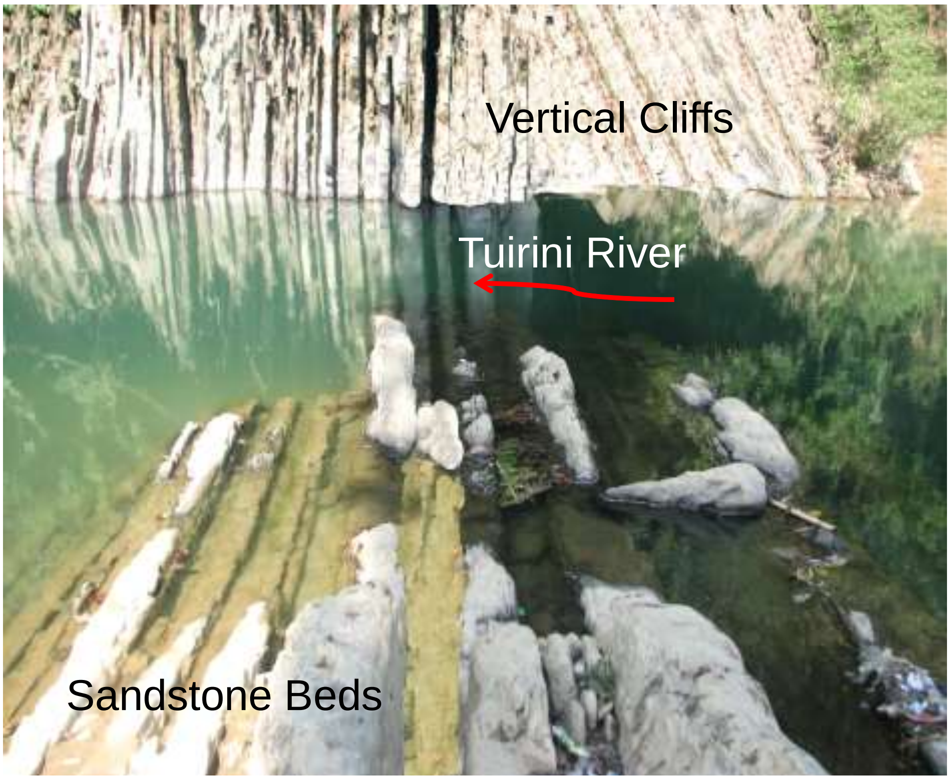

Plate 6A. Incision of river bed in the lower reaches of the river. Vertical cliff faces can be seen on right bank of the Tuirini river.

Plate 6B. View of ~ 30 m high waterfall (Bottom part) along the Seling-Keifang road.