DYNAMICS OF LAND DEGRADATION IN TUIRINI WATERSHED, MIZORAM

**A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF
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IN PARTIAL FULFILMENT OF THE REQUIREMENTS OF THE DEGREE OF DOCTOR OF PHILOSOPHY IN GEOGRAPHY OF MIZORAM UNIVERSITY, AIZAWL

CERTIFICATE

This is to certify that Vanlaltanpuia, registered under MZU/Ph.D./737 of 19.05.2015 is a research scholar working under my supervision on a thesis entitled 'Dynamics of Land Degradation in Tuirini Watershed, Mizoram'. He has fulfilled all the requirements laid down in the Ph.D. regulations of Mizoram University. I further certified that the thesis in this form is the result of the research scholar's original work. Neither the thesis as a whole nor any part of it was ever submitted to any other university for any research degree.

I recommend the thesis for due evaluation and recommendation.

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DECLARATION

I, Vanlaltanpuia, hereby declare that the subject matter of this thesis is the record of work done by me, that the content of this thesis did not form 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/Institute.

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Abbreviations

%	Percentage
^oC	Celsius degree
ANOVA	Analysis of Variance
ASTER GDEM	Advaned Spaceborne Thermal Emission and Reflection Global Digital Elevation Model
BD	Bulk density
cm	Centimeter
CSC	Current Shifting Cultivation
DI	Dissection Index
$dS.m^{-1}$	decisiemens per meter
EC	Electrical conductivity
et al.	et alia
etc.	et cetera
FAO	Food and Agriculture Organization
FCC	False Colour Composite
GIS	Geographic Information System
g/m^3	gram per cubic meter
ICFRE	Indian Council of Forestry Research and Education
IDW	Inverse Distance Weighted
K	Potassium
$Kg\ ha^{-1}$	Kilogram per hectare
kg	Kilogram
km^2	Square kilometer
KVK	Krishi Vigyan Kendra
LSD	Least significant difference
LULC	Landuse/Landcover
m	Meter
MDF	Moderately dense forest
mha	Million hectares
MIRSAC	Mizoram and Mizoram Remote Sensing Application Centre

mm	Millimeter
MSS	Multi Spectral Scanner
N	Nitrogen
NDVI	Normalized Difference Vegetation Index
NLUP	New land Use Project
NRSC	Natural Resources Conservation Service
OC	Organic carbon
OF	Open forest
OM	Organic matter
OLI	Operational Land Imager (OLI)
P	Phosphorous
SD	Standard Deviation
SFR	State of Forest Report
SPSS	Statistical Package for the Social Science
TGA	Total Geographical Area
TIRS	Thermal Infrared Sensor
TM	Thematic Mapper
UNCCD	United Nations Convention to Combat Desertification
USDA	United States Department of Agriculture
USLE	Universal Soil Loss Equation
VDF	Very dense forest
WMO	World Meteorological Organization

CHAPTER – 1

INTRODUCTION

1.1 Introduction

All human activities are based upon the availability of land resources and the ever-increasing population needs more land resources to manage their livelihood and economy. So, land is the wealth of human society and also the source of economy as many productive works like agriculture, horticulture, factory and industries depend on it. Population growth and rapid urbanization cause over exploitation of natural resources especially land and water resources thereby causing land degradation. Land degradation is one of the most serious problems that the contemporary world is facing, especially in the tropical countries. Morgan (2005) accused land degradation as hazard especially in the tropical and semi-arid regions because it is traditionally associated with agricultural practices and is reasonable for its long-term ill effects on soil productivity and sustainable agriculture.

With the development of economy of the world, exploitation of natural resources is a part of generating economic growth. Many industries in the world primarily depend on natural resources causing excessive exploitation which leads to the problem of land degradation. Rapid expansion of built-up land and agriculture area triggered the rate of deforestation and soil degradation, which have a direct impact on water scarcity. Healthy land has the natural capacity to store and filter water, which is lost when land is degraded.Land degradation takes number of forms, including, depletion of soil nutrients, salinization,soil erosion, degradation of vegetation as a result of urbanization and massive cutting of forest for agricultural activities. All these human activities of degradation cause decline in the productivity of land reducing expected high yields.

1.2 Meaning and Concept

Earlier, most of the researchers accepted that the concept of land degradation which originates from soil deterioration only and is generally used as an equivalent for soil degradation. In recent years, Land degradation is not only on soil but also extended to the surrounding water and vegetation also. It is composite and complex phenomena linked with how one or more of the land resources such as soil, water, vegetation, rock, topography have transformed the land into unproductive and assessments of primary production have recently become more common. World Meteorological Organization (2005) states that the causes of land degradation are not only bio-physical, but also socio-economic (e.g. land tenure, marketing, institutional support, income and human health) and political (e.g. incentives, political stability).

Land degradation can become any reduction or loss in the biological or economic productive capacity of the land resource base (Eswaran *et al.* 2001). It is explained as the loss of actual or potential productivity or utility as a result of natural or anthropogenic factors that is, the decline in land quality or reduction in its productivity.

Therefore, land degradation has a link with agricultural productivity, economic condition, political and human activities in any place. It may exist only for a short term with the degraded resource recovering rapidly or it may be precursor of a prolonged downward twist of degradation, causing a long-term, lasting change in the status of the resource (Stocking *et al.* 2001). Young (1998) explained land degradation as the temporary or permanent lowering of the productivity of the land due to anthropogenic activities which include various forms like erosion and soil fertility decline, deforestation and adverse impact on water resource. Land degradation has both on-site and off-site effects. On-site effects are lowering of productivity or reducing outputs like crop yields, livestock, or forest production or required for increasing inputs to give back for the losses. Off-site effects refer predominantly to changes in river flow, water quality and sedimentation, as brought about by deforestation and consequences of erosion.

One of the most prominent organizations regarding land degradation gives a clear-cut definition which reveals the meaning and concept. United Nations Convention to Combat Desertification (UNCCD) describes ‘Land’ as a “terrestrial bio-productive system that comprises soil, vegetation, other biota, and the ecological and hydrological processes that operate within the system”, and its ‘degradation’ as “reduction or loss, in arid, semi-arid, and dry sub-humid areas, of the biological or economic productivity and complexity of rain-fed cropland, irrigated cropland, or range, pasture, forest, and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns, such as: (i) soil erosion caused by wind and/or water (ii) deterioration of the physical, chemical, and biological or economic properties of soil; and (iii) long-term loss of natural vegetation.” (WMO,2005; Sivakumar& Ndiang’ui, 2007). Following the definition of UNCCD, Glossary of Environment Statistics (1997) defines land degradation as the reduction or loss of the biological or economic productivity and complexity of rainfed cropland, irrigated cropland, pasture, forest or woodlands resulting from natural processes, land uses or other human activities and habitation patterns such as land contamination, soil erosion and the destruction of the vegetation cover. It is clear from the definitions that land degradation is a composite and is caused by the multi-temporal deterioration of natural resources.

In the hilly regions like the study area, land degradation has generally resulted out of fragile ecosystems, weak and less productive functions of landscape not only because of the effects of geo-hydrological processes but also the advancement of traditional societies that confront the adverse conditions of ecosystem (Singh,*et al.* 2010). Bai, *et al.* (2008) defined land degradation as the long-term loss of ecosystem function and productivity caused by disturbances from which the land cannot recover unaided. It implies that long and continuous change in the function of land and its productivity noticed in highland regions leads to land degradation in many parts of the world.

1.3 Importance of the study

Due to the environmental deterioration, acquiring information on land degradation and socio-economic conditions are essential for various developmental planning purposes like implementation of reclamation programmes, rational land use planning for land resources management, etc,. To achieve economic growth, to improve agricultural productivity and attain sustainable development, it is needed to utilize the full potential of available land resources for meeting the basic needs of the society. Therefore, assessment of land degradation dynamics is the most important aspect to prevent further degradation of the precious land resources.

Mizoram is endowed with rich natural vegetation and abundant precipitation in the form of rainfall. But in recent years, there has been large scale deforestation and rapid expansion of settlement and agricultural area. That caused rapid land use/land cover change and accelerates the rate of forest degradation, water scarcity and deterioration of the physico-chemical properties of the soil leading to land degradation.

Based on the report of Desertification and Land Degradation Atlas of India (2016), about 96.40 million hectares (mha) area of the country is undergoing process of land degradation i.e., 29.32% of the total geographic area (TGA) of the country during 2011-13, while during 2003-05, the area under the process of land degradation is about 94.53 mha (28.76% of the TGA). There is a cumulative increase of 1.87 mha area under the process of land degradation in the country (constituting 0.57% of the TGA of the country) during the time frame. In Mizoram, it has been observed about 8.89% of the total geographical area under land degradation for the period of 2011-13. The area under land degradation in Mizoram has increased about 4.34% since 2003-05 (7.92% in 2011-13 and 3.88% in 2003-05 from TGA).

State of Forest Report 2005 - 2019 reveals that India's forest cover increased in the last 15 years with 35161 sq km. On the otherhand, Mizoram forest cover decreased with 1234.49 sq km since 2009 assessment upto 2019. The latest State of Forest Report 2019 shows that 180.49 km^2 of forest cover decreases from the previous assessment in the year 2017. (Table 1.1 and Table 1.2)

Table 1.1: Change in forest cover of India since 2005 (in km^2)

Year	VDF	Change	MDF	Change	OF	Change	Total	Change
2005	54569		332647		289872		677088	
2009	83510	28941	319012	-13635	288377	-1495	690899	13811
2011	83471	-39	320736	1724	287820	-557	692027	1128
2013	83502	31	318745	-1991	295651	7831	697898	5871
2015	85904	2402	315374	-3371	300395	4744	701673	3775
2017	98158	12254	308318	-7056	301797	1402	708273	6600
2019	99278	1120	308472	154	304499	2702	712249	3976

(Source : FSI, 2005;2009;2011;2013;2015;2017;2019)

Table 1.2: Change in forest cover of Mizoram since 2005 (in km^2)

Year	VDF	Change	MDF	Change	OF	Change	Total	Change
2005	133		6173		12378		18648	
2009	134	1	6251	78	12855	477	19240	592
2011	134	0	6086	-165	12897	42	19117	-123
2013	138	4	5900	-186	13016	119	19054	-63
2015	136	-2	5858	-42	12752	-264	18748	-306
2017	131	-5	5861	3	12194	-558	18186	-562
2019	157.05	26.05	5800.75	-60.25	12047.7	-146.29	18005.5	-180.49

(Source : FSI,2005;2009;2011;2013;2015;2017;2019)

The study region of Tuirini watershed is composed of rich flora and fauna but has been experiencing ecological degradation from time to time. It is difficult to restore its wealth of natural resources due to the accelerated degradation by different human interventions. The vast natural resources are under the menace of human pressure to fulfil their requirements, thereby transforming the land under degradation.

Forest had been their source of livelihood and conversion of forested land to agricultural land is a common practice in this region. Besides, expansion of settlement, construction of roads and other developmental activities adversely affect the existing ecological setting. It has been extended beyond the carrying capacity of the settlements and has led to scarcity of water, deforestation and degrading the soil fertility. That might cause the decline in economic condition, food insecurity and political instability. Therefore, it is needed to do something for attaining sustainable land resource management.

To achieve sustainable land resource management practices in the study area, it is needed to avoid land degradation. To assess land degradation accurately, the condition of changing land resources and socio-economic condition in a region must be known. The land degradation typically occurs due to the human influence on land resource deterioration and socio-economic development, which are not sustainable over a period of time.

1.4 Scope of the study

Inventory of potential natural resources and socio-economic condition are prerequisite for sensible management of the land and is much essential for suggesting development plan. The land is the most important natural resource, so that the scientific management is essential for optimal utilization of the land resources to the best of their capabilities without increasing the deterioration of natural resources.

The physical setting of the study area plays a crucial role in the natural resource phenomena. The topography, drainage systems, geology, soil conditions, etc., have positive impact on the available natural resources. As slope is the major factor controlling soil properties and water availability, it is imperative to analyse the degree of slope. The drainage network also controls erosion to a great extent, it is very important to analyse surface drainage along with ground water resource condition. As climate plays a most important role in available natural resources, it is essential to study climatic parameters like rainfall trend, and temperature of the study area.

Dynamics of land use / land cover change reveals the status and patterns of land degradation and is crucial for sustainable development plan. Assessment of deforestation is essential to understand the degradation status of other land based resources like soil and water resources. Forest provides a good protection against surface runoff and soil erosion which have direct impact on the physico-chemical properties of the soil. Usually in the deforestation state, the soil loses its capacity to check surface runoff. This trend, apart from causing erosion, reduces the fertility of the top soil and its ability to generate vital nutrients. Availability of surface water and groundwater resources are one of the most important natural resources which either directly or indirectly effects agriculture production. But it is influence by the physical setting and vegetation cover. So, it is needed to discover the condition and potential of surface and groundwater resources in the study area.

Human influence plays a significant role on land degradation. Due to increasing population, it is needed to expand of the land for settlement and agricultural area. It is also important to collect the perception of the local people for knowing the exact condition of the land degradation in the study area.

The studies have been paying more interest on the study of appraising land resources, assessing the land use/ land cover change, deforestation, soil degradation effecting with water scarcity in order to prevent land degradation.To find out the factors responsible for land degradation must be essential for suggesting land degradation mitigation measures in Tuirini watershed using the advanced techniques of remote sensing and geographic information systems.

1.5 Research Questions

By considering the importance of the study, it is possible raise the research questions as follows:

1) How far the land use/ land cover changes effects on soil properties in Tuirini watershed.

2) What is the rate of deforestation in Tuirini watershed?

3) What is the condition of soil fertility to develop agriculture in Tuirini watershed?

4) What is the role of farmer’s perception in the study of land degradation?

5) What are the factors responsible for land degradation in Tuirini watershed?

1.6 Objectives

The present study is aimed at achieving the following objectives in Tuirini watershed.

1) To evaluate the land resources.
2) To assess deforestation and soil degradation.
3) To suggest measures for combating land degradation problems.

1.7 Chapterization

The investigation has been reported in eight chapters, the first chapter deals with introduction, concept of land degradation, scope of the study, objectives, limitations and organization of the thesis.

The detailed analysis of various physical and environmental settings of study area like absolute relief, relative relief, dissection index, average slope, geology, geomorphology, lineament density, drainage system and climate, etc., are presented in the second chapter.

Literature review is presented in the third chapter and materials and methods of the study are presented in chapter four respectively. The fifth chapter deals with the appraisal of land resources like soil, water and forest.

Farmer's perception on land degradation is presented in chapter six.

Chapter seven highlights the trend of land use/ land cover change in the study area at different periods. The Physico-chemical properties of the soil, degradation problems and soil erosion prospects are also presented in this chapter.

Summary and Suggestions for land degradation in the study area are discussed in the last chapter.

1.8 Limitations

1. The availability of LANDSAT imageries of a particular period of high resolution are limited.

2. Limited-availability of rain gauge and weather stations in the study area affected the study of climate change and weather conditions.

3. The soil result might not have a very high degree of accuracy as the soil sample collection was not done at once due to inaccessible of some areas. Moreover, use of fertilizers in the agricultural land affected the variance of physico-chemical properties of the soil and soil texture. The analysis was done with the slight modification of prescribed format due to availability limited tools.

4. All the questions acquiring information in the questionnaire regarding the perception of the farmers doesn't include in final decision making due to limited responses from the respondents.

CHAPTER-2
PHYSICAL AND ENVIRONMENTAL SETTINGS

2.1 Study Area

The Tuirini watershed lies between 23º 28' 40" – 23º53'15" north latitudes and 92º49'15"-93º58'15" east longitudes has been selected for the present study. Geographically, it lies in the central part of Mizoram covering some parts of Serchhip and Aizawl districts. The watershed stretches in N-S direction in an area of about 411.38 km^2 of only 1.94% of the total geographical area of Mizoram. The area covers parts of survey of India topographical maps 84 A/13, 84 A/14 and 84 A/15.

Tuirini river is the major tributary of Tuirial river which flows from south towards north over a length of about 60 km including perennial and non-perennial streams. It originates near Chhingchhip village in Serchhip district, which is formed by adjoining two streams viz., Zawngsih and Maudarh. Geographically, the study area is composed of mountainous terrain with undulating topography and having an average altitude of about 709 metres above mean sea level. The highly undulated mountain ranges are inclined in north-south which runs parallel series. Geologically, the area is composed of various sedimentary rocks predominantly of arenaceous type and argillaceous type of the Surma Group. There are 30 sub-watersheds in the Tuirini watershed and the neighbouring watersheds are Tuirial on the west and north, Mat on the south and Tuivawl on the east to the study area.

The watershed area is surrounded by 29 villages with a total population of about 43,863 persons as per 2018, Directorate of Economics and Statistics, Govt. of Mizoram and the population density is 106 persons per km^2. The area experiences humid tropical moderate climate characterized by short winter seasons, long summer seasons and long rainy season with an average annual rainfall of about 280 cm. The entire study area is neither too hot nor too cold throughout the year. The summer temperatures range between 21^0 C and 31^0 C while the winter temperature varies from 11^0C to 23^0C like the other parts of Mizoram. Generally, it has a high relative humidity, with a minimum of 61.89 % and the maximum of 91.23 %.

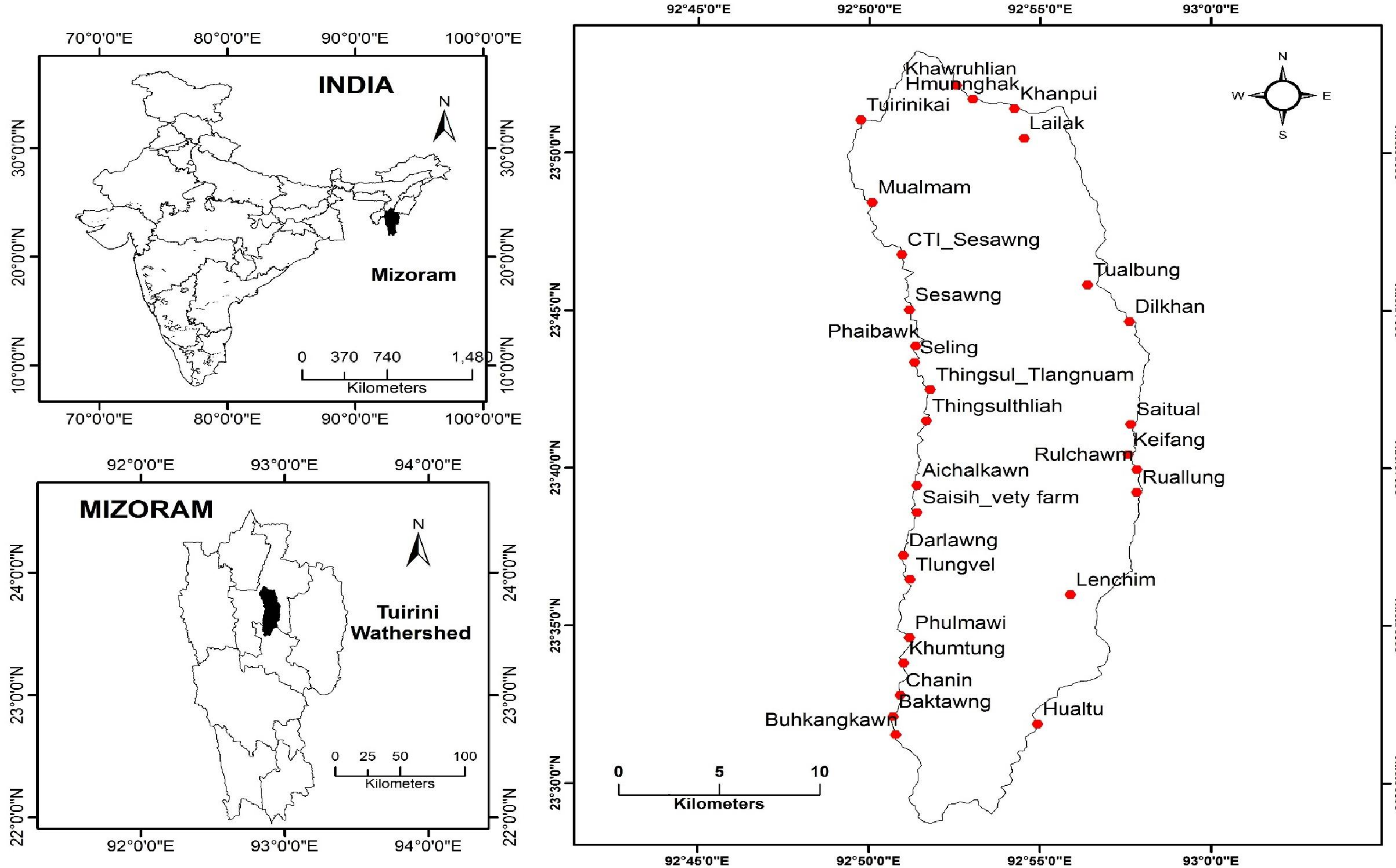


Fig 2.1: Location map of Tuirini watershed

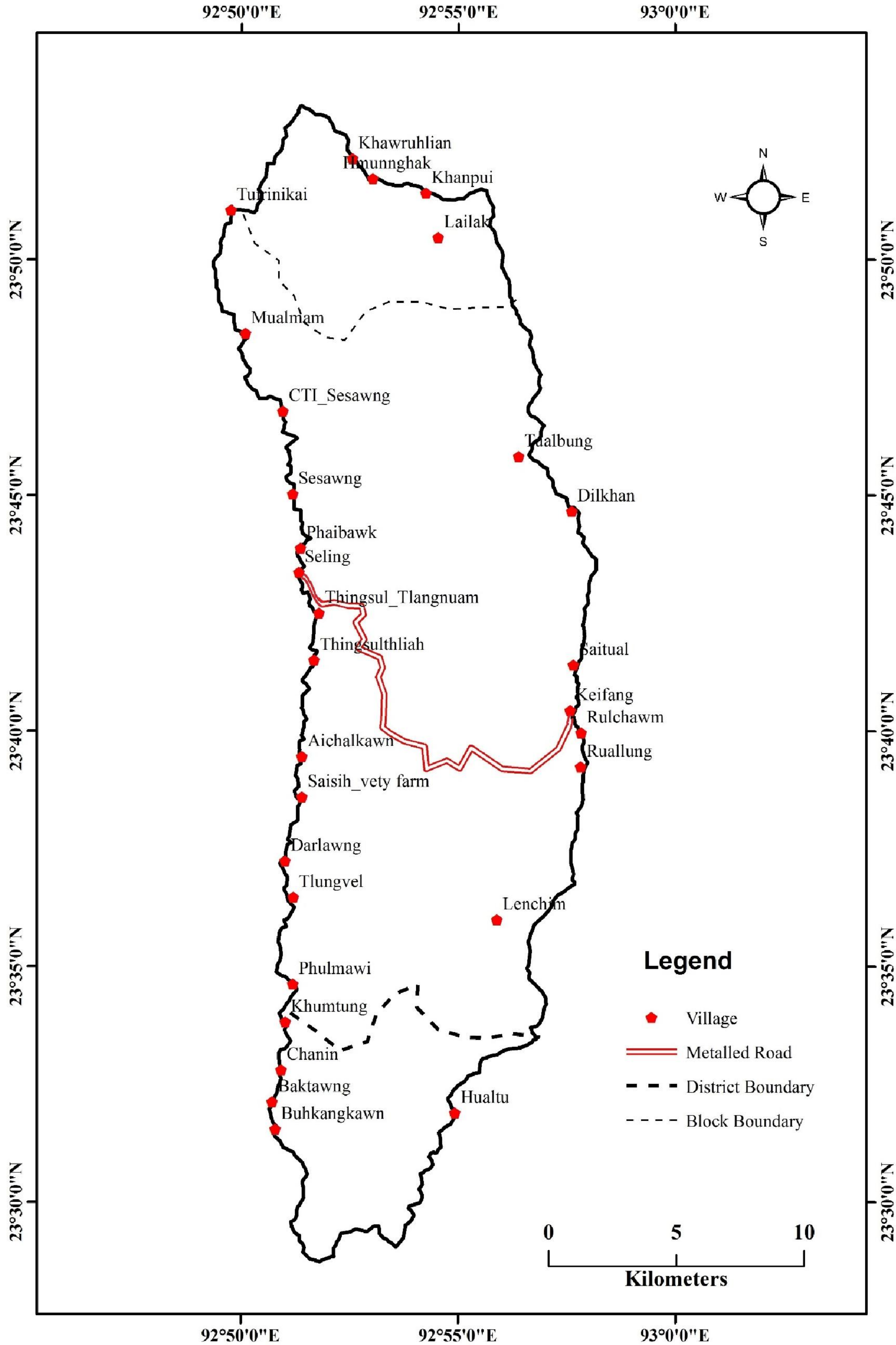


Fig 2.2: Settlements location in Tuirini Watershed

2.2 Absolute Relief

Absolute relief gives the elevation of any area above the sea level (Das, 2014). As seen in map 2.2 and from table 2.1, the maximum elevation of 1905 m is seen in the north eastern part and the minimum is 95 m found in the north western part. It has been observed that relief increases from valley bottom to top of the mountain in the eastern and western parts of the area while the highest class of relief i.e., above 1600 m is seen in the north eastern and south eastern parts. In fact, the eastern side is topographically higher than the western side. The absolute relief is classified into five classes like very low, low, moderate, high and very high. The very low class of below 400 m above mean sea level covers an area of 56.32 km^2 and mostly found along the main river channel. The low class which ranges in elevation between 400 and 800 m covers the largest area of 217.70 km^2 which is more than half (52.92%) of the total study area. The moderate class ranging from 800 to 1200 m occupies an area of 109.63 km^2 area and found mostly on the hill ridge of the western and the eastern parts of the area. The high class between 1200 and 1600 m is found only in the central, northern and southern parts covering an area of 21.72 km^2. Very high class of above 1600 m covers only 6.01 km^2 (1.46%) of the study area.

Table 2.1: Absolute relief of Tuirini watershed

Class	Height in metres	Area in km^2	%
Very Low	< 400	56.32	13.69
Low	400-800	217.70	52.92
Moderate	800-1200	109.63	26.65
High	1200-1600	21.72	5.28
Very High	> 1600	6.01	1.46
Total		411.38	100

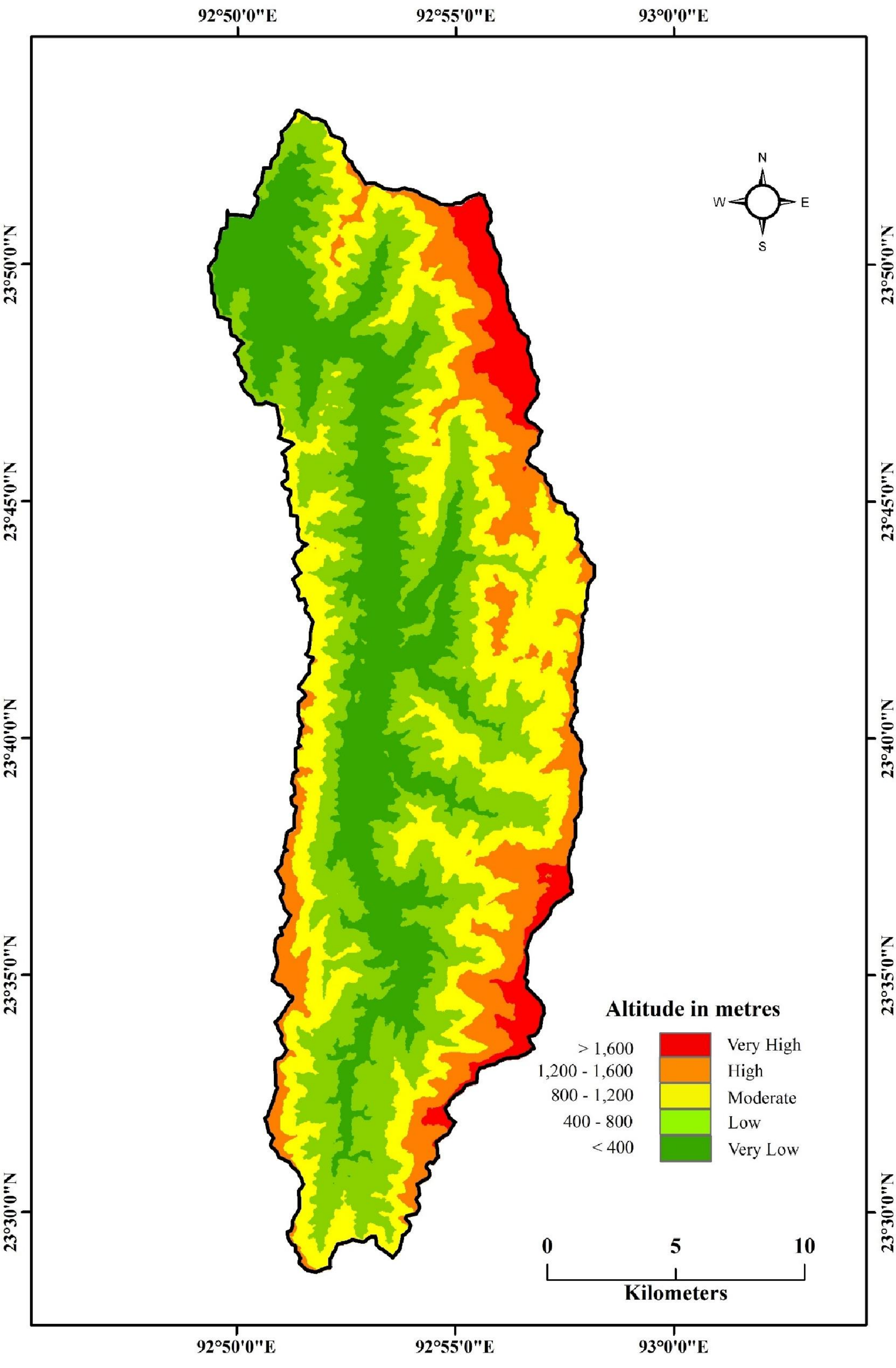


Fig 2.3: Absolute relief in Tuirini watershed

2.3 Relative Relief

Relative relief is also termed as local relief and is defined as the range between the highest and the lowest points in a unit area (Mustak, 2102). It is one of the most important parameters of the relief characteristics of an area computed without considering sea level (Singh,1992) and used for the overall assessment of morphological characteristics of terrain and degree of dissection. The study area is divided into five categories (Map 2.3 and table 2.2). Very low class containing below 150 m elevation above MSL is found in the central and eastern hill ridges in an area of only 0.53 km^2. Low class which ranges from 150 to 300 m covers 71.62 km^2. Moderate class between 300 and 450 m has the largest area coverage of 249.83 km^2 which is almost one-third (60.73%) of the study area. High class (450– 600 m) is found in the central, northern and south-central parts and also seen as an isolated patch in the western hill ranges. It covers 83.30 km^2 of area under study. The very high class (above 600 m) covers a very small extent of 6.09 km^2 area mostly found in the north eastern and the south eastern parts of the study area.

Table 2.2: Relative relief of Tuirini watershed

Class	Height in metres	Area in km^2	%
Very Low	< 150	0.53	0.13
Low	150-300	71.62	17.41
Moderate	300-450	249.83	60.73
High	450-600	83.30	20.25
Very High	> 600	6.09	1.48
Total		411.38	100

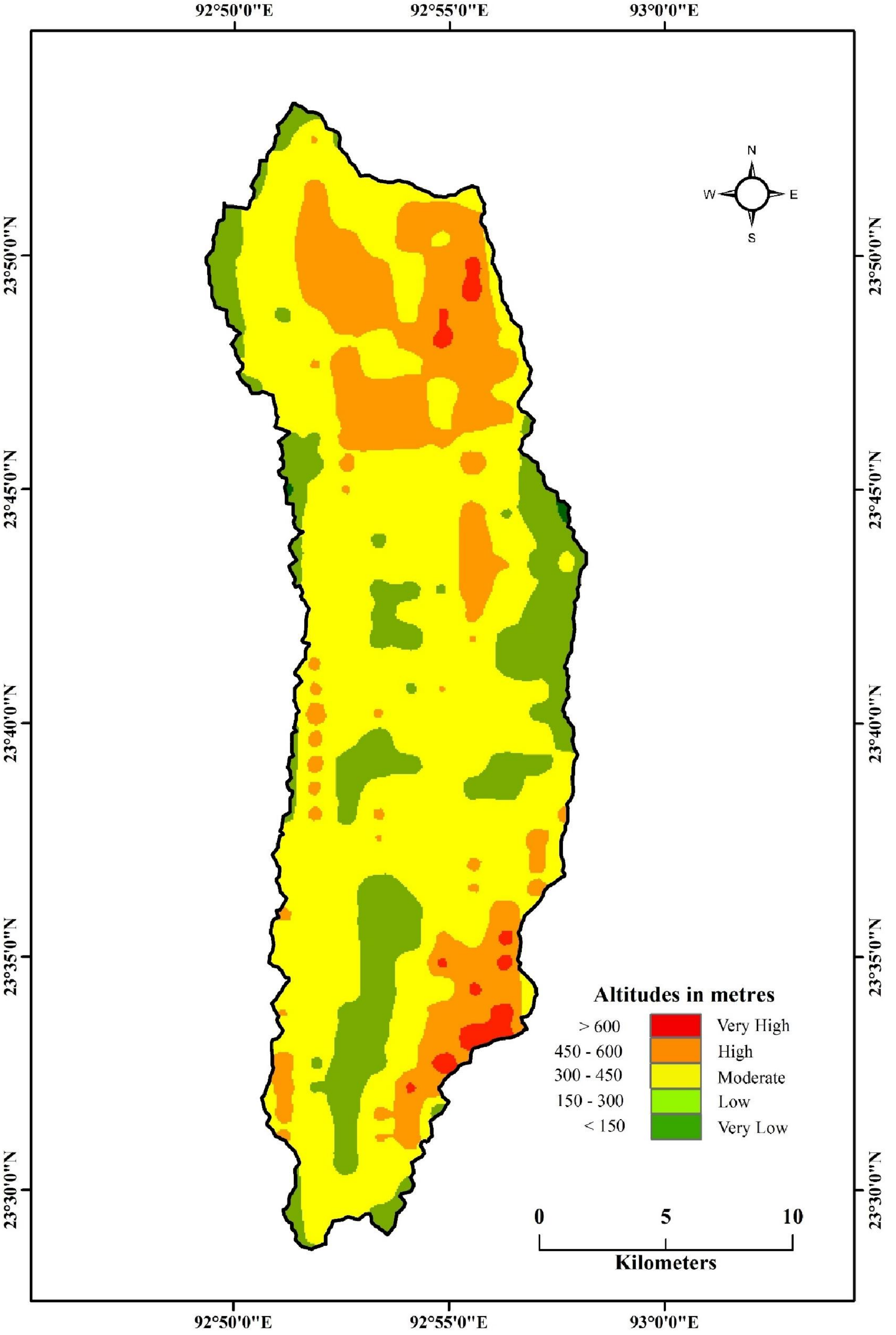


Fig 2.4: Relative relief in Tuirini Watershed

2.4 Dissection Index

Dissection Index (DI) is the ratio between the relative relief and absolute relief and gives better understanding of the physical features (Das, 2014). It is an important morphometric indicator of the nature and magnitude of dissection of terrain (Singh, 2000). The values of Dissection Index vary from 0 (complete absence of dissection) to 1 (vertical cliff at sea level). DI also expresses the relationship between the vertical distance of the relief from the erosion level and relative relief. Generally, low DI values correspond with the subdued relief or old stage and with low relative relief. Conversely, the areas with high DI indicate high relative relief where slope of the land is steep (Deen, 1982). DI can be obtained by the following formula.

Dissection Index (DI) = Relative Relief / Absolute Relief

The values obtained for the study area vary from 0.02 to 0.77. It has been classified into 5 categories like very low, low, medium, high and very high (Fig.4 and Table 3). Very low class is found in the central part of the eastern hill ridge covering only 0.44 km^2 area. Low class covers 40.38 km^2 area of watershed. This class is seen mostly in the eastern hill ranges. Medium class has the largest area coverage of 188.51 km^2 which is almost half (45.85%) of the total area. This class is found mostly in the southern, eastern and western parts along the valley. High class covers an area of 143.26 km^2 along the main river valley. Very high class covers around one-tenth (9.37%) of the study area, which occupies an area of 38.54 km^2. Very high DI value is mostly concentrated in the central, northern parts along the river valley.

The high values of DI mostly found from medium to very high class which is prone to high rate of erosion. This unit covers about 90.09% of the total area. Thus, both the absolute and relative relief are the important factors useful to identify the areas prone to high rate of erosion in the study area.

Table 2.3: Dissection Index value of Tuirini watershed

Class	Dissection Index Value	Area in km^2	%
Very Low	< 0.15	0.44	0.11
Low	0.15 - 0.30	40.38	9.82
Medium	0.30 - 0.45	188.51	45.85
High	0.45 - 0.60	143.26	34.85
Very High	> 0.60	38.54	9.37
Total		411.38	100

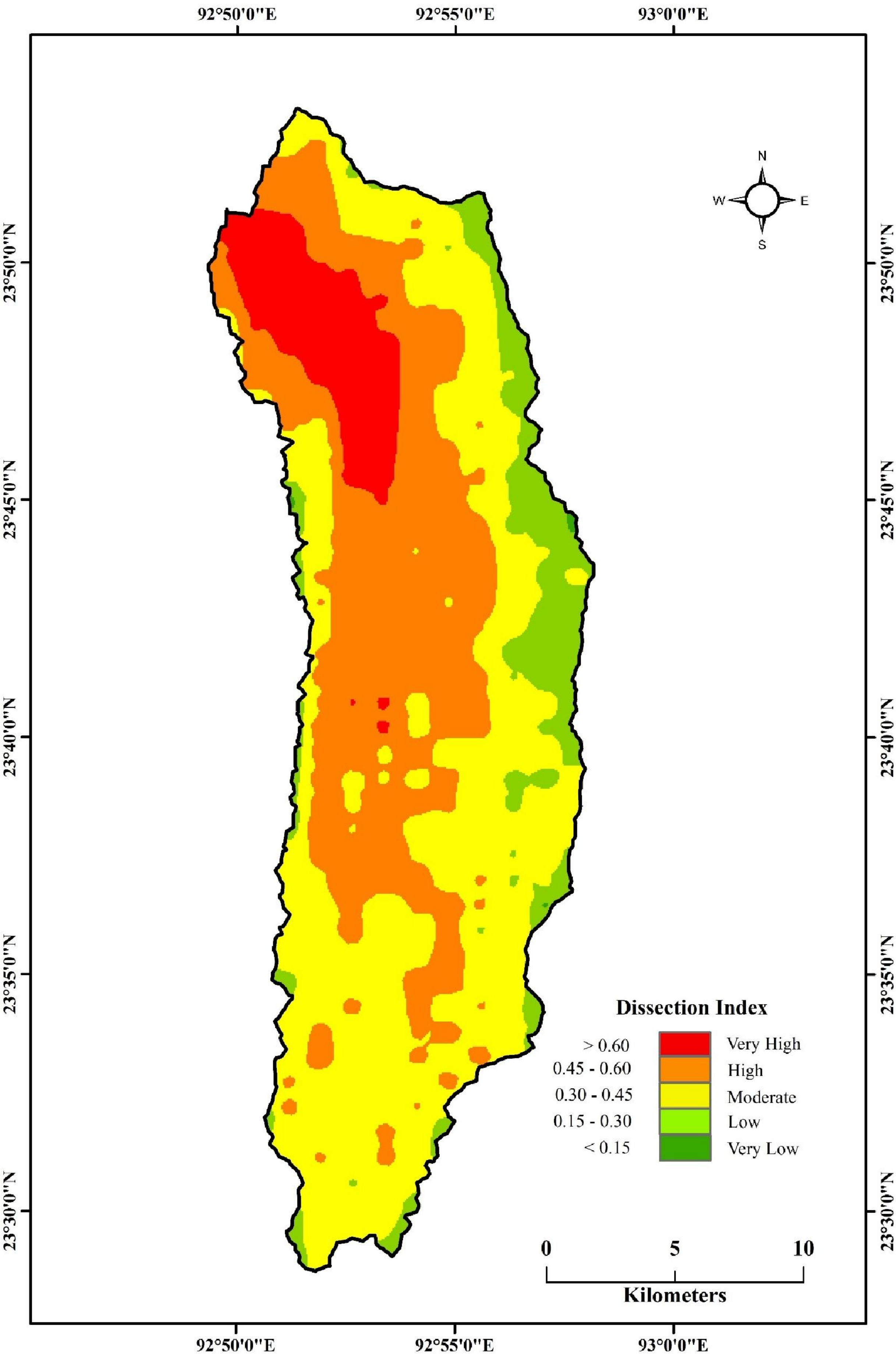


Fig 2.5: Dissection Index in Tuirini Watershed

2.5 Average Slope

The average slope may be defined as the vertical inclination between the hill top and valley bottom (Thakurdesai, 2016), explained by the horizontal line spacing of the contours and expressed generally in degrees. In general, closely spaced contours represent steeper slopes and sparse contours exhibit gentle slope. The degree of slope controls the amount of run-off, velocity of flow of river as well as the intensity of the processes of erosion, transportation and deposition. Thus, it plays a crucial role in landform development (Sinha, 1994).

Slope is one of the most important factors causing erosion and the intensity might increase by accompanying high rate of rainfall and deforestation. The average slope map shows the distribution of various slope classes in an area. The values of the slope angles derived from ASTER GDEM grid square are classified and tabulated (Table 2.4). As the terrain is highly undulating, the degree of slope is generally high and there is a possibility for high rate of erosion.

The area is classified into five slope classes like very low, low, medium, high and very high. Very low class (< 15^o) covers 70.51 km^2 of the area. This class is found along the deep river valleys and also in the areas nearby mouth of the river. It is also found concentrated in the western side of the eastern hill ranges. Low class (15^o – 25^o) occupies more than one-third (36.95%) of the total area (152.02 km^2). This class is evenly distributed in the entire study area. Medium class (25^o – 35^o) covers 142.81 km^2 of the study area. This class is found near the hill ridges and over the undulating terrain in the area. High and very high classes cover an area of 41.56 km^2 and 4.48 km^2 respectively. These two classes are sparsely distributed and mostly found on the top of the hill ranges and also in the northern part of the study area.

Table 2.4: Average Slope of Tuirini watershed

Class	Slope in Degrees	Area in km^2	%
Very Low	< 15	70.51	17.14
Low	15 to 25	152.02	36.95
Medium	25 to 35	142.81	34.72
High	35 to 45	41.56	10.10
Very High	> 45	4.48	1.09
Total		411.38	100

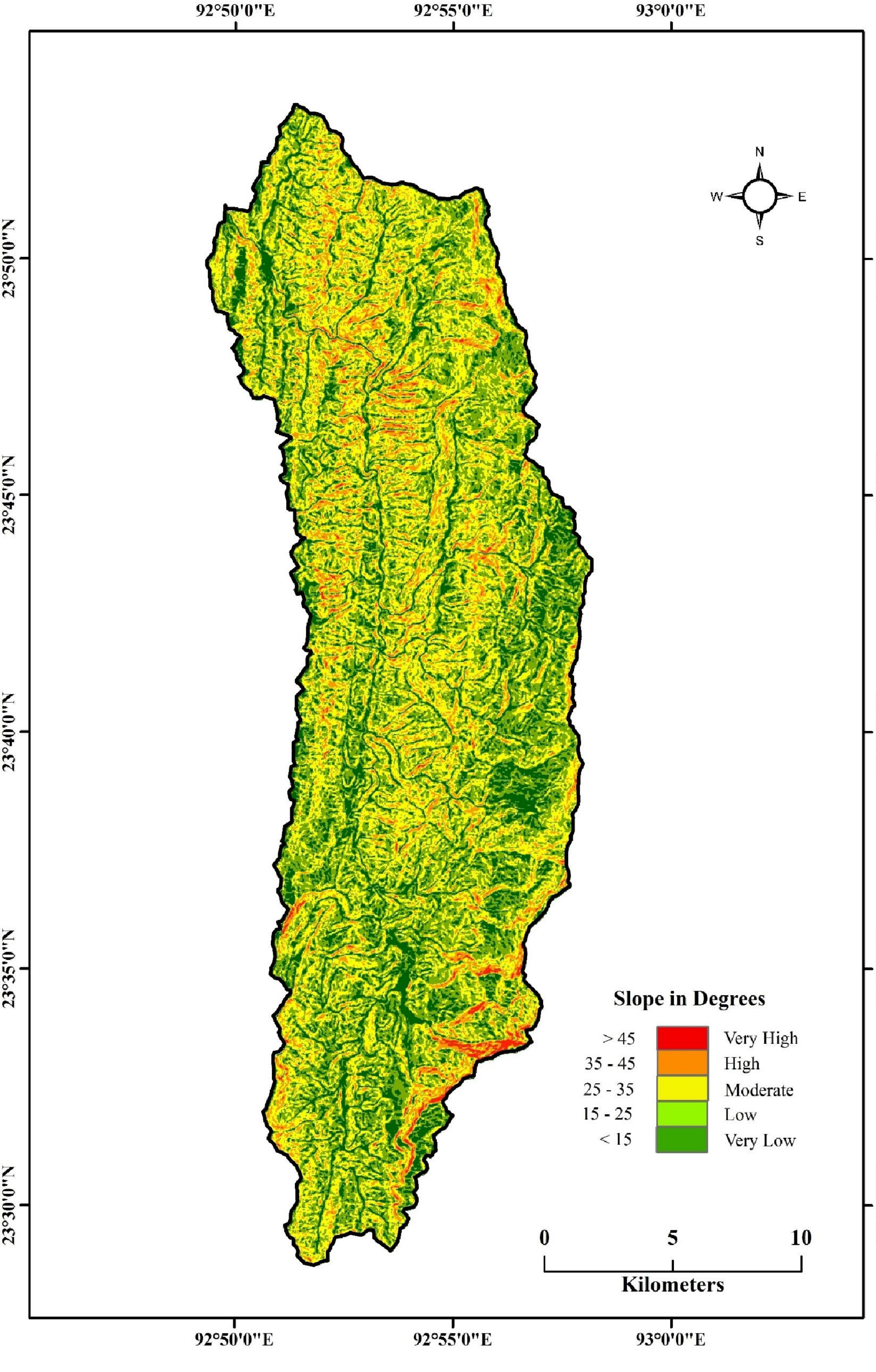


Fig 2.6: Average Slope in Tuirini Watershed

2.6 Geology

Geologically, the study area consist Surma group of rocks of Miocene period. It is composed of various sedimentary rocks of arenaceous and argillaceous types belong to upper to middle bhuban formations. The area is composed predominatly of shales, siltstone-shale and sandstones. (Table 2.5)

Age	Group	Formation	Unit	Lithology
Recent	Alluvium			Silt, clay and gravel
~ ~ ~ Unconformity ~ ~ ~				
Early Pliocene to Late Miocene	Tipam (+900 m)			Friable sandstone with occasional clay bands
~ ~ ~ Conformable and transitional contact ~ ~ ~				
Miocene to Upper Oligocene	Surma (+5950 m)	Bokabil (+950 m)		Shale, siltstone and sandstone
		~ ~ ~ Conformable and transitional contact ~ ~ ~		
		Bhuban	Upper Bhuban (+1100 m)	Arenaceous predominating with sandstone, shale and siltstone
			~~ Conformable and transitional contact ~~~~	
			Middle Bhuban (+3000 m)	Argillaceous predominating with shale, siltstone-shale alternations and sandstone
			~~ Conformable and transitional contact ~~~~~	
			Lower Bhuban (+900 m)	Arenaceous predominating with sandstone and silty-shale
~ ~ ~ Unconformity obliterated by faults ~ ~ ~				
Oligocene	Barail (+3000 m)			Shale, siltstone and sandstone

Table 2.5 : Generalised stratigraphic succession of Mizoram (Ganju, 1975; Karunakaran, 1974)

The sedimentary rocks exposed in the study area are thickly bedded sandstones, shales and siltstones and their various admixtures in varying proportions. (Ganju, 1975). Shale and Siltstone units have relatively low permeability resulting in significant surface flow. This lithology develops a high drainage density in the study area. Sandstone usually allows the percolation of water and porous enough to store large quantities of groundwater making valuable aquifers. The predominant rocks such as shales and siltstones rocks in the study area covers around 64.69 % of the total area, which is 266.13 km^2 and sandstone occupied an area of 145.25 km^2 which is 35.31 % of the total area.

Table 2.6: Geology of Tuirini watershed

Class	Area in km^2	%
Shale & Siltstone	266.13	64.69
Sandstone	145.25	35.31
Total	411.38	100

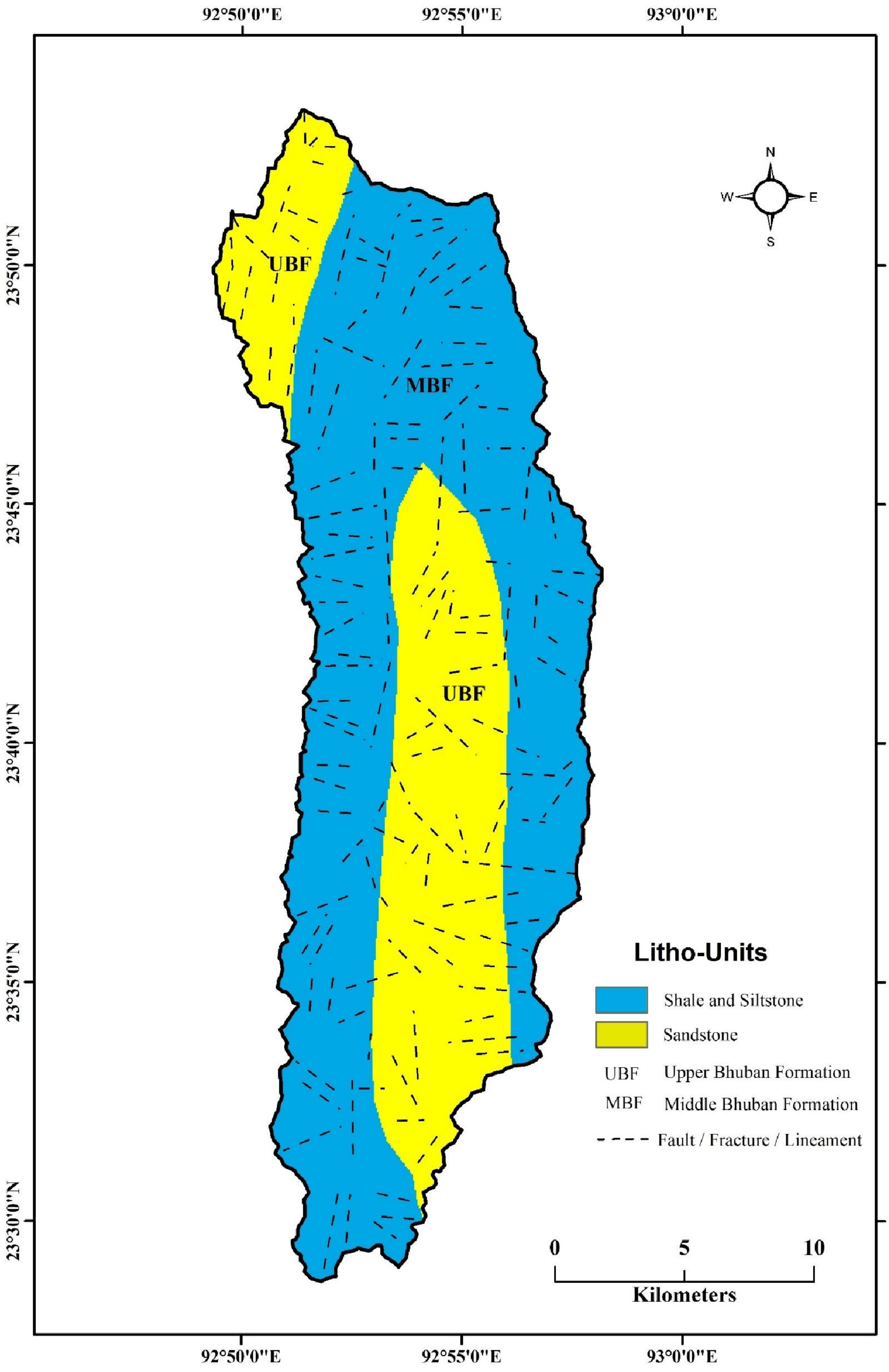


Fig 2.7: Geological map of Tuirini Watershed

2.7 Geomorphology

Geomorphology is the science of description and systematic interpretation of landforms (Bloom 1979). The topography of the study area is immature and north to south mountain ranges with steep slopes parallel to each other in the east and the west parts which are separated by the deep river valley. The study area is characterised by rugged nature of topography and features observed in the study area are structural hill, structural valley, valley fills, faults, fractures, escarpment and scarp. Faults are the predominant structural features found crossing across various litho units and mostly along the main river channel.

The structural hills are classified into three based on their altitudinal zone as low structural hills with an elevation of below 600 MSL covering an area of 155.21 km^2 (37.73%) and medium structural hills with an elevation of 600 to 1200 MSL with an area of 212.93 km^2 (51.76%) and high structural hills covers 32.92 km^2 with an altitude of above 1200 MSL. Structural valleys are found as linear to curvilinear pattern with narrow sides with an area of 5.98 km^2 (1.45%). Valley fills are found in intermontane valleys in the area composed by medium to coarse grained particle size of sand and boulders, pebbles, pebbly gravel covering 4.34 km^2 (1.05%)

Table 2.7: Geomorphology of Tuirini watershed

Class	Area in km^2	%
Structural Landforms		
High Structural Hill	32.92	8.0
Medium Structural Hill	212.93	51.76
Low Structural Hill	155.21	37.73
Structural valley	5.98	1.45
Fluvial Landform		
Valley Fill	4.34	1.05
Total	411.38	100

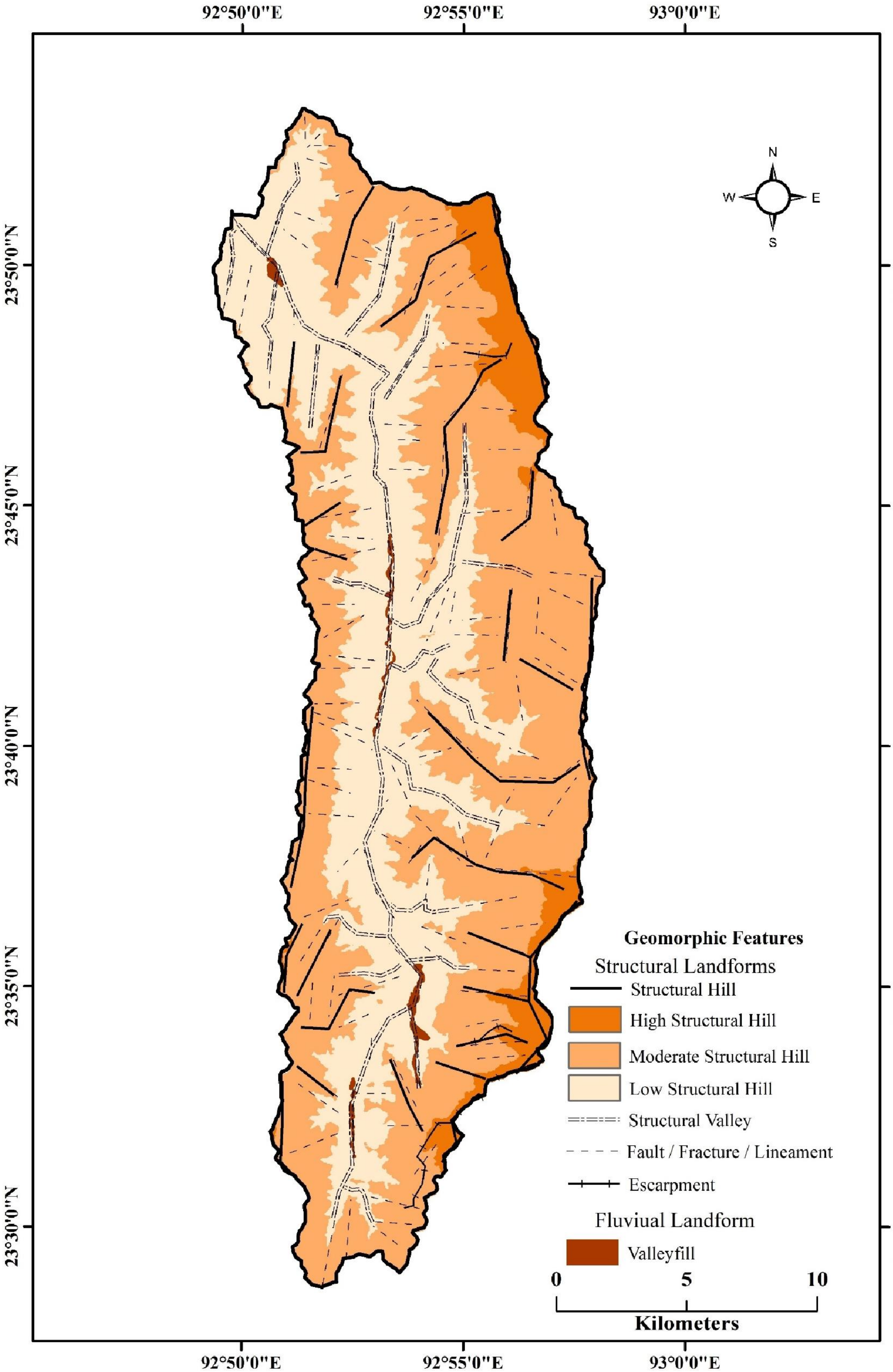


Fig 2.8: Geomorphological map of Tuirini Watershed

2.8 Lineament density

Lineament is the simple and complex linear properties of geological structures, such as faults, cleavages, fractures and various surfaces of discontinuity, that are arranged in a straight line or a slight curve as detected by remote sensing (Leary *et al*. 1976). Lineaments indirectly reveal the ground water potential zones. Areas with high lineament density facilitate infiltration and recharge of ground water indicating good potential for groundwater development. (Bhuvaneswaran *et al*. 2015). Lineaments are identified from the satellite imagery by their relative linear alignment of vegetation on both sides. The presence of lineaments in the study area reveals that the area is technically active.

Table 2.8: Lineament Density of Tuirini watershed

Class	Length per sq.km	Area in km^2	%
Very Low	< 0.4	173.85	42.26
Low	0.4 to 0.8	66.85	16.25
Moderate	0.8 to 1.2	91.16	22.16
High	1.2 to 1.6	63.89	15.53
Very High	> 1.6	15.63	3.8
Total		411.38	100

There are number of lineaments which cut across various litho units in different directions. Very high and high lineament density covers around $1/5^{th}$ of the total area. They represent only 3.8 % (15.63 km^2) and 15.53 % (63.89 km^2) respectively. Moderate density covers 22.16 %, which is 91.16 km^2. Low and Very low density covers more than half the region, 16.25 % (66.85 km^2) and 42.26 % (173.85 km^2) respectively. As a whole, the lineament density in the study area is considered to be good which indicates good groundwater potential.

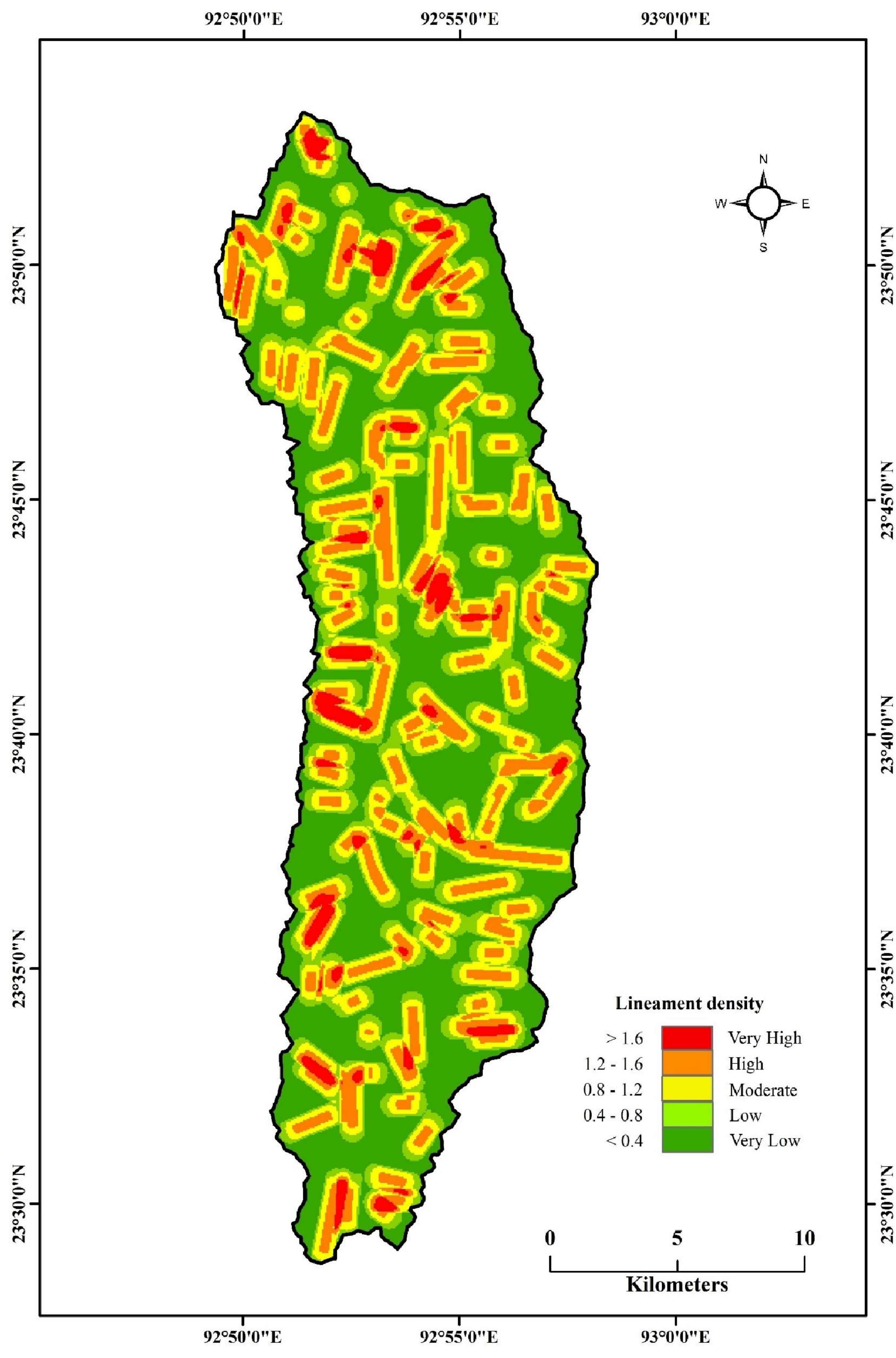


Fig 2.9: Lineament density in Tuirini Watershed

2.9 Drainage

Drainage network studies are significant as land transformation and land use activities change the river channel which lead to the change of drainage system. Drainage channel help to trace the definite morphological character of the area. Their distribution is dependent on complex variables of morphology like relief, slope, structure, climate and vegetal characteristics. The drainage provides clues to the general and specific indications of slope in an area and constitutes an important component of the surface hydrology.

The Tuirini river is the main river in the study area and is the major tributary of Tuirial river, it flows from south towards north over a length of about 47.58 km of perennial and joins the Tuirial river from the east. The Tuirini river originates near Chhingchhip village in Serchhip district, which is formed by the confluence of adjoining two streams namely, Zawngsih stream from the east and Maudarh stream from the west. It has many tributaries which join from the left and right banks of the river due to undulating topography. The study area is characterised by the drainage pattern of trellis, parallel and dendrictic. Trellis drainage pattern covers almost the entire region and parallel drainage pattern are found in the highly steep sloping areas. Dendrictic drainage pattern is found in a small particular area where there is homogeneous geological development with sandstones and shales.

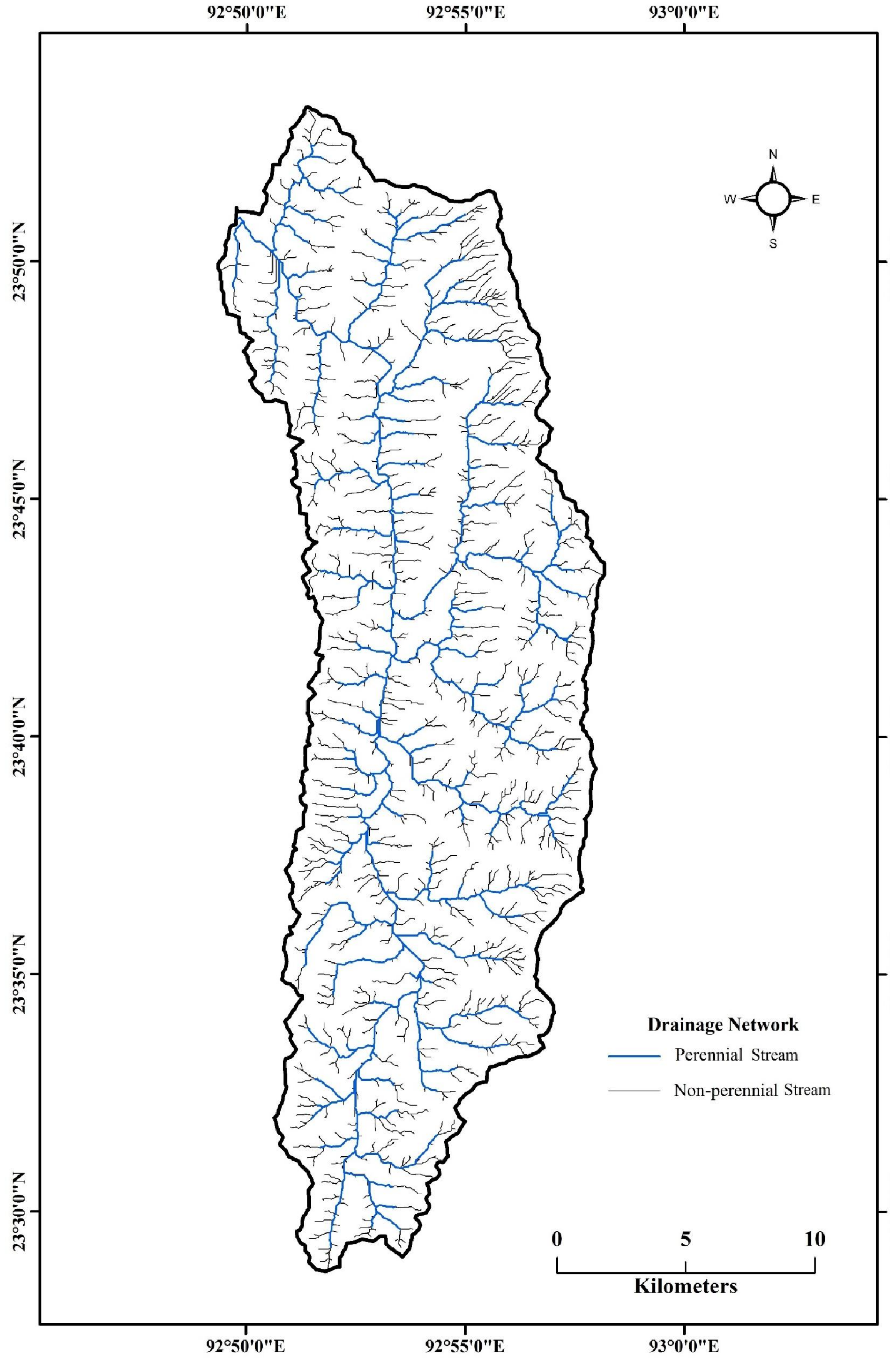


Fig 2.10: Drainage network in Tuirini Watershed

2.10 Drainage Density

Drainage density is defined as the length of stream segments per unit area. It is the function of the intensity of run-off, erosion proportionality factor, relief and absolute viscosity of the fluid and its acceleration due to gravity, rock types, soil strength and rainfall intensity (Singh, 2002). Drainage density is an inverse function of permeability which plays a vital role in the run-off distribution and level of infiltration. More the drainage density, higher would be the run-off and lesser the drainage density, higher is the probability of recharge to potential groundwater zone (Bathis & Ahmed, 2016; Tumare et al. 2014).

The values of drainage density obtained from the study area are grouped into five classes, viz., very low (less than 1 km per km^2), low (1 to 2 km per km^2), moderate class (2 to 3 km per km^2), high (3 to 4 km per km^2) and very high (over 4 km per km^2). The result reveals that the study area has low to moderate drainage density in general. Very high and high region covers an area of 2.23 % (9.18 km^2) and 14.11 % (58.05 km^2) respectively. Low to moderate class (1 to 2 & 2 to 3 km per km^2) covers around 3/5th of the study area, which is 133.52 km^2 and 117.23 km^2 (32.46% & 28.5 %) respectively. Very low class covers 22.7 %, 93.4 km^2 of the study area.

Table 2.9: Drainage Density of Tuirini watershed

Class	Length of stream per sq.km	Area in km^2	%
Very Low	< 1	93.4	22.7
Low	1 to 2	133.52	32.46
Moderate	2 to 3	117.23	28.5
High	3 to 4	58.05	14.11
Very High	> 4	9.18	2.23
Total		411.38	100

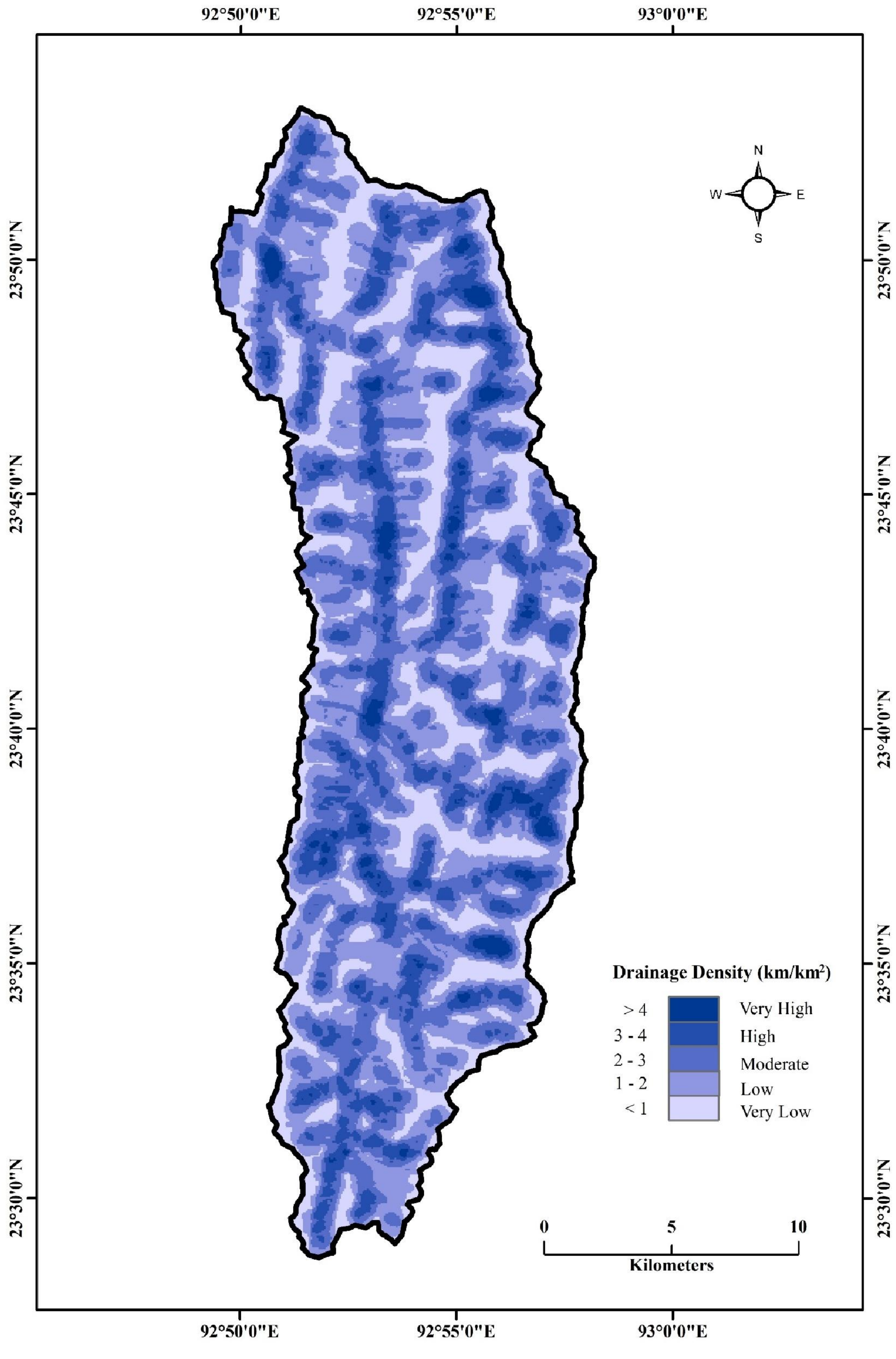


Fig 2.11: Drainage density in Tuirini Watershed

2.11 Climate

Climate is considered most important because it affects the human life on various ways and has direct impact on agricultural activities (Porwal, 2016). The study area experiences humid tropical climate, characterised by a short winter and long summer seasons with high amount of rainfall. As it lies in tropical region, the study area enjoys a moderate climate, which is neither too hot nor too cold throughout the year. The region falls under the direct influence of the south-west monsoon and receives abundant supply of rainfall (Pachuau, 2009).

Due to the lack of proper observatory stations of rainfall, temperature and relative humidity in the study area, it is not possible to give comprehensive information about the amount of rainfall, temperature and relative humidity condition in the region. They have been estimated from the neighbouring observatory stations by Inverse Distance Weighted (IDW) interpolation method to generalise the isohyets.

2.11.1 Rainfall

The average annual rainfall is 289.18 cm which is higher than the average rainfall of Mizoram of 257 cm per annum (Pachuau, 2009). Rainy season starts from the month of April and continues upto October. Heavy rains occur from May to September. The highest amount of average rainfall is recorded in the month of June, with 581.6 mm and driest month recorded is January with 7.95 mm of rainfall. The amount of rainfall decreases toward northeast direction in the study area due to the influence of the relief.

Table 2.10: Average monthly rainfall (in mm) in the viscinity of Tuirini watershed, 1999-2018.

Station	Aizawl	Sialsuk	Neihbawih	Serchhip	Khawruhlian	Average
Jan	6.38	7.51	16.39	5.12	4.37	**7.95**
Feb	12.42	14.92	25.37	8.14	11.25	**14.42**
March	66.65	76.39	146.64	46.34	47.72	**76.75**
April	183.11	198.08	332.84	116.63	152.37	**196.6**
May	377.13	393.36	638.22	297.68	291.13	**399.5**
June	398.33	720.76	1041.48	452.36	295.27	**581.64**
July	331.92	645.2	576.3	369.05	343.22	**453.14**
Aug	400.19	629.29	686.74	389.82	409.35	**503.08**
Sep	363.53	421.09	568.51	311.43	314.55	**395.82**
Oct	169.55	238.42	339.37	167.22	137.84	**210.48**
Nov	26.24	52.8	62.61	38.74	25.5	**41.18**
Dec	9.23	11.74	20.79	8.09	6.41	**11.25**
Total	**2344.66**	**3406.3**	**4149.36**	**2210.6**	**2038.64**	**2891.81**

Source: Statistical Abstract, Directorate of Agriculture (Crop Husbandry) and Meteorological data of Mizoram 2018, Directorate of Economics and Statistics, Govt, of Mizoram

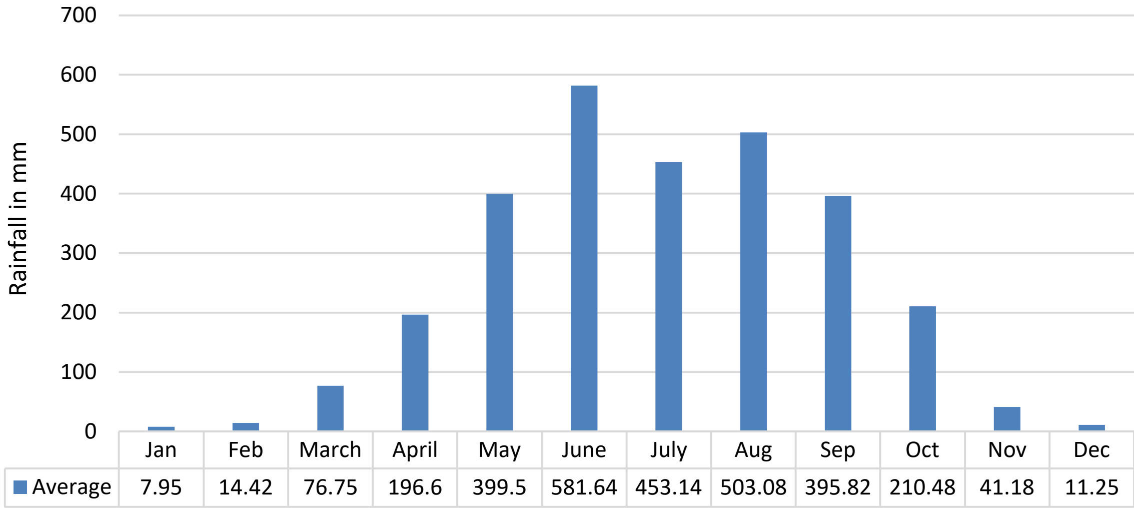


Fig 2.12: Bar graph showing average monthly rainfall in Tuirini watershed.

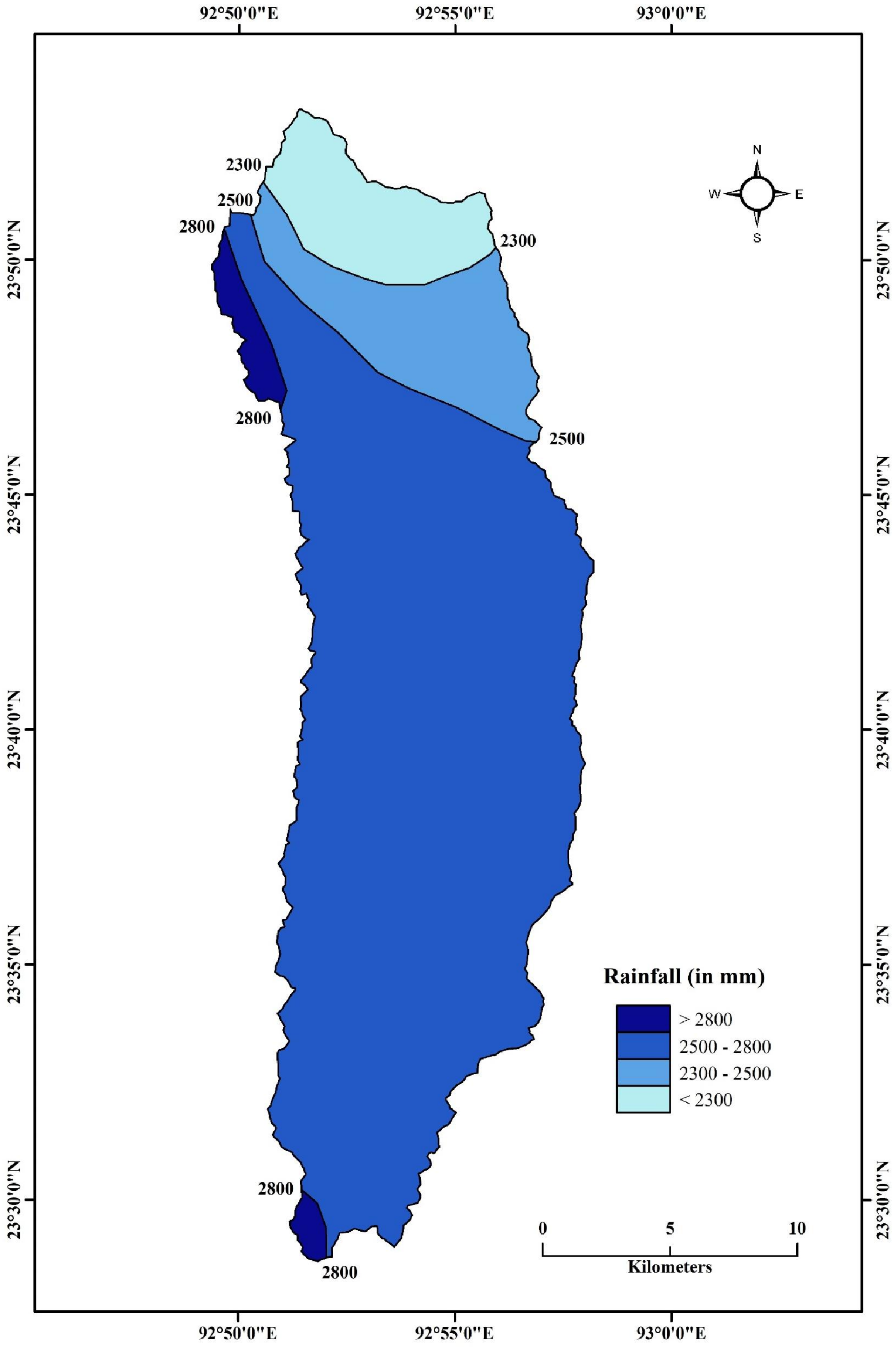


Fig 2.13: Rainfall distribution in Tuirini watershed

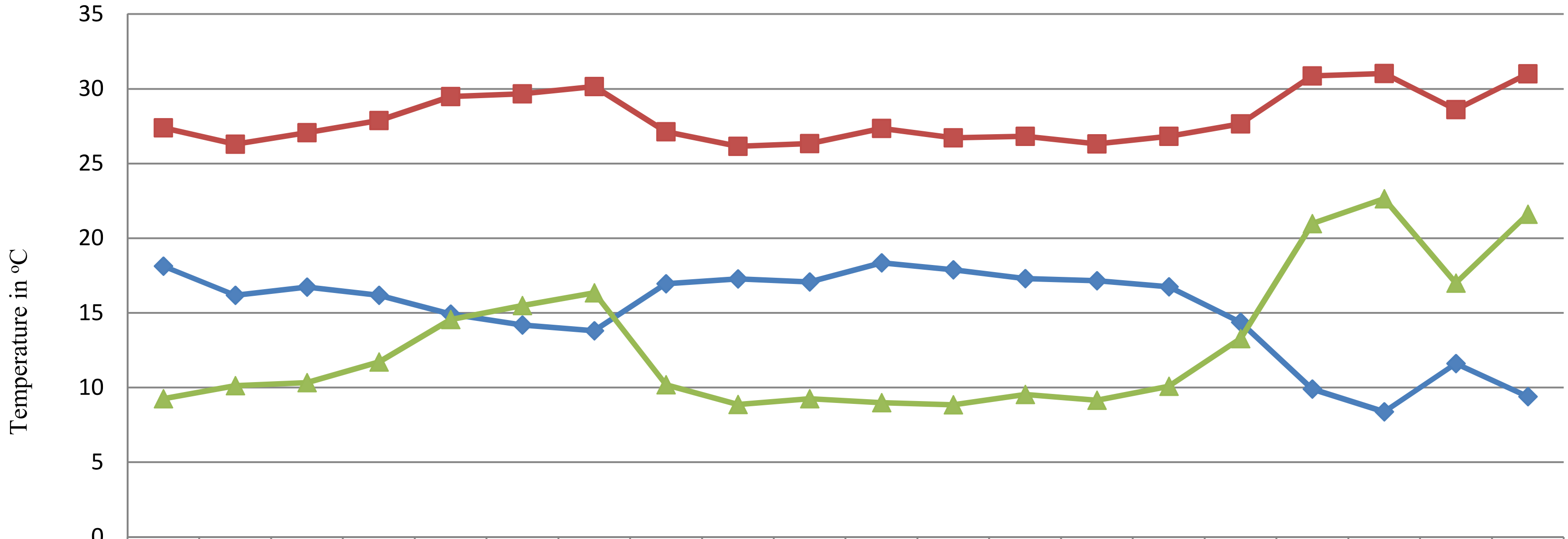
2.11.2 Temperature

Temperatures recorded in the nearest meteorological observatory station in Aizawl city, for the last 20 years by the Directorate of Science & Technology, Government of Mizoram (2018) have been analysed. The average temperature ranges between 15 ºC to 28 ºC. The temperature in the study area does not change much throughout the year, but highly fluctuated in the low-lying areas of valley region. The data reveals that the temperature is steadily increasing with high fluctuation in minimum and maximum temperature.

Table 2.11: Mean minimum and maximum temperatures in Tuirini watershed, 1999-2018

Year	Minimum (ºC)	Maximum(ºC)	Difference (ºC)
1999	18.13	27.39	9.26
2000	16.17	26.30	10.13
2001	16.73	27.07	10.34
2002	16.17	27.88	11.71
2003	14.93	29.48	14.55
2004	14.18	29.67	15.49
2005	13.80	30.15	16.35
2006	16.95	27.13	10.18
2007	17.28	26.15	8.87
2008	17.08	26.33	9.25
2009	18.36	27.35	8.99
2010	17.88	26.73	8.85
2011	17.29	26.82	9.53
2012	17.16	26.31	9.15
2013	16.74	26.82	10.08
2014	14.37	27.65	13.28
2015	9.90	30.87	20.97
2016	8.38	31.02	22.64
2017	11.60	28.60	17.00
2018	9.40	31.00	21.60
Average	15.13	28.04	12.91

Source: Directorate of Economics and Statistics, Govt. of Mizoram.



	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Min	18.13	16.17	16.73	16.17	14.93	14.18	13.8	16.95	17.28	17.08	18.36	17.88	17.29	17.16	16.74	14.37	9.9	8.38	11.6	9.4
Max	27.39	26.3	27.07	27.88	29.48	29.67	30.15	27.13	26.15	26.33	27.35	26.73	26.82	26.31	26.82	27.65	30.87	31.02	28.6	31
Difference	9.26	10.13	10.34	11.71	14.55	15.49	16.35	10.18	8.87	9.25	8.99	8.85	9.53	9.15	10.08	13.28	20.97	22.64	17	21.6

Fig 2.14: Line graph showing mean temperature in Tuirini watershed, 1999-2018.

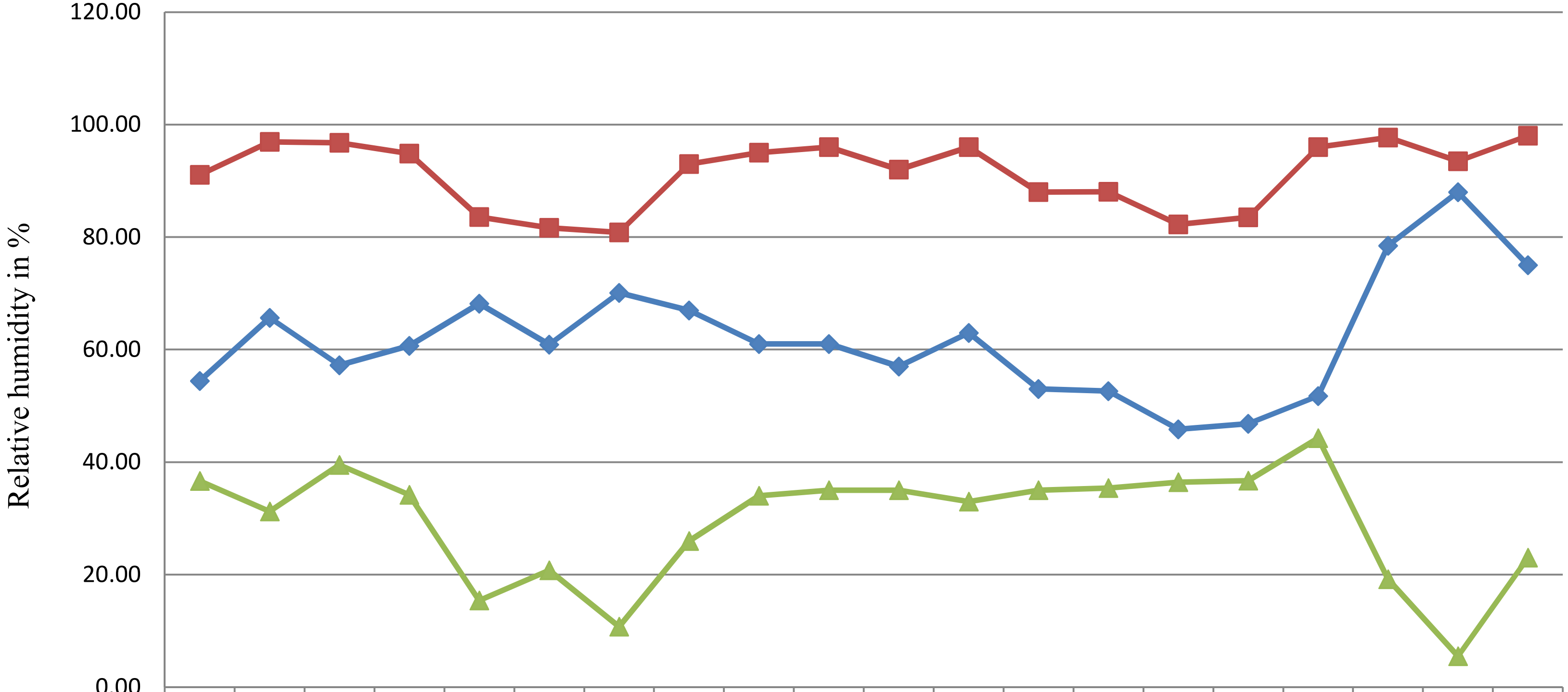
2.11.3 Relative Humidity

The relative humidity of the study area generally changes with the changing seasons. Due to having vast area of vegetative cover, the study region has high average relative humidity ranging from 61.89 % to 91.23 % for the past 20 years. The data shows that the maximum relative humidity is very stable between 80% - 100%, while the minimum is highly fluctuated with temperature variation. It has been observed negative correlation (-0.48) by comparing the differences of temperature and relative humidity using Pearson's correlation. It indicates that when the temperature difference is high, the relative humidity difference becomes low and when the temperature difference is low, the relative humidity difference becomes high.

Table 2.12: Average relative humidity (in %) in Tuirini watershed, 1999-2018

Year	Min	Max	Difference
1999	54.42	91.08	36.66
2000	65.67	96.92	31.25
2001	57.25	96.75	39.5
2002	60.67	94.83	34.16
2003	68.17	83.58	15.41
2004	60.92	81.67	20.75
2005	70.08	80.83	10.75
2006	67	93	26
2007	61	95	34
2008	61	96	35
2009	57	92	35
2010	63	96	33
2011	53	88	35
2012	52.65	88.05	35.4
2013	45.82	82.24	36.42
2014	46.82	83.53	36.71
2015	51.74	96.02	44.28
2016	78.5	97.67	19.17
2017	88	93.5	5.5
2018	75	98	23
Average	61.89	91.23	29.35

Source: *Meteorological data of Mizoram 2018*, Directorate of Economics and Statistics



	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
MIn	54.42	65.67	57.25	60.67	68.17	60.92	70.08	67.00	61.00	61.00	57.00	63.00	53.00	52.65	45.82	46.82	51.74	78.50	88.00	75.00
Max	91.08	96.92	96.75	94.83	83.58	81.67	80.83	93.00	95.00	96.00	92.00	96.00	88.00	88.05	82.24	83.53	96.02	97.67	93.50	98.00
Difference	36.66	31.25	39.50	34.16	15.41	20.75	10.75	26.00	34.00	35.00	35.00	33.00	35.00	35.40	36.42	36.71	44.28	19.17	5.50	23.00

Fig 2.15: Line graph showing mean relative humidity in Tuirini watershed, 1999-2018

CHAPTER-3

REVIEW OF LITERATURE

Quite a good number of studies have been carried out in different parts of the world on various aspects related to land degradation and associated problems. The results of a few significant studies are presented here.

3.1 Land degradation

Adugna (2005) has studied the determinants of land degradation and their implications for sustainable land management. The major objective of this study is to understand the bio-physical, socio-economic and institutional factors that are responsible for accelerated land degradation. He has also analyzed the characteristics of agricultural production, the rural population growth and its effect on land resource and the change in land use/land cover of the study area.

Eden and Parry (1996) have analysed the imperative problems of land degradation in the tropical countries. He discussed certain issues which coincide with the main objectives of global development and the environmental series. They further discussed the scenario of land degradation and the importance of remote sensing technology in land degradation monitoring. They further analysed the technical problems posed by the need to policy responses from a variety of different perspectives. It is only out of such an interdisciplinary matrix that the complex problems of scientific measurement, policy formulation and effective policy implementation which require sustainable development will be resolved.

Rao *et al.* (1994) have analyzed the problems of soil erosion and land degradation in Mizoram. They have analyzed the intensity of soil erosion and land degradation problems in different watersheds. They inferred that extension of deforestation and jhum practices accelerated the intensity of soil loss and run-off which led to land degradation in the study area.

Sarpong (1997) has evaluated the contribution of some aspects like climate, soil, population, bush burning, type of cultivation, livestock rearing and over–exploitation of fuel wood influencing land degradation in the upper east region of Ghana. He employed various tools and techniques of geographical information systems. He inferred that the evaluated factors have played the major role for causing and accelerating the land degradation in the study area. He suggested some possible measures like tree planting, afforestation, ploughing across the slope, intensifying family planning programme in rural areas, educating the community on environmental management for combating land degradation in the region.

Shrestha (2014) has devised land degradation modelling in the inaccessible mountainous areas in the tropics. He has estimated the dominant erosion process like sheet, rill and gully erosion. He used MMF model because of its simplicity, flexibility, strong physical base and because it has proven to be applicable in similar mountainous environments.

Sivakumar and Ndiang'ui (2007) in their book on 'Climate and Land Degradation' focusing on how climate induces and influences land degradation presented the measures needed to be taken to enhance the application of weather and climate information to combat land degradation. The trends of land degradation in different continents of developed and developing countries and the factors that are responsible for degradation of land resources. The conservation measurements adopted and the reliability of current conservation measurements for the sustainable land resources are also discussed.

Stocking and Niamh (2001) have carried a study for assessment of land degradation guidelines using the manual and advanced techniques of remote sensing and GIS. The study emphasized the importance of farmers who can both advise on what is important to them. They have assessed land degradation and its consequences. They have mentioned about the farmers' perspective on land degradation, land use, soil loss indicators that are common in different field conditions, production constraints and the benefits of soil loss conservation.

Wanyonyi (2012) has analysed the relationship between the increase in human population and land degradation over a span of years. The study was designed to determine the extent of land degradation emanating from human activities, to assess the relationship between human activities on land use and land cover changes, and to assess and describe the types of land conservation and management measures that are practiced in the study area. The study revealed that the high potential areas of the country which support large population seeking to fully exploit the land resources for their livelihoods and welfare.

Yang (1999) has made an attempt to examine land degradation and its control strategies in China using the sophisticated techniques of GIS. He inferred that land degradation in China is mainly caused by the anthropogenic activities like overgrazing, excessive cutting of fuel wood, deforestation, industrial and mining activities, steep slope land-reclamation, improper forest management, etc,. It also happened due to increasing population, salinization, soil acidification, pollution and mostly erosion by wind and water. He made some fundamental control strategies such as to achieve sustainable development strategy and to adjust industrial structure, straitening legislation and intensified supervision and management, protecting cultivated land resources, develop eco-farming, conducting scientific research and monitoring, mobilizing and promoting public awareness, etc. for combating land degradation in China.

Venkataraman and Ravisankar (2004) have analysed the importance of Remote Sensing and GIS techniques dealing with systematic development in the application of remote sensing techniques for mapping and monitoring soil resources and land degradation. They have mentioned that the different applications of Remote Sensing and GIS for different studying purposes like soil mapping, land evaluation, land capability classification, crop suitability, watershed planning, soil erosion and shifting cultivation.

Zonunsanga and Rao (2013) have analyzed the link between shifting cultivation and land degradation in Teirei Watershed of Mizoram. They inferred that the clearing of forest for agriculture practices led to severe soil erosion due to the fragile nature of the terrain which is composed of unconsolidated sedimentary rock formation with steep slopes aided by heavy monsoonal rainfall in the study area. They have estimated the rate of soil loss through the integration of thematic data layers like rainfall erosivity, soil erodibility, slope length, steepness, land use/ land cover and vegetation/canopy cover and the anthropogenic management practices. They found that shifting cultivation is attributed as the major contributor of land degradation towards the negative scenario like accelerating soil erosion, deforestation and loss of biodiversity.

Kathuria (2012) studied about the identification and utilisation of wasteland for sustainable development in her book ‘Land Degradation, Problems and Prospects’. She said that the vast stretches and varieties of wastelands that exist throughout the country need to be identified in their typical characteristics mapped and developed properly and put to gainful utilization.

Jha (2003), in his edited book on ‘Land Degradation and Desertification’. He opined that land degradation and desertification have become common problems due to climatic conditions and changes in land use, particularly in the tropical lands. Land degradation relates to the loss of potential utility and accelerates the process of land desertification.

3.2 Water resource analysis

Mutekwa and Kusanngaya (2006) have analyzed the contribution of rainwater harvesting (RWH) technology to rural livelihood and consequently to the sustainability of agriculture and rural livelihoods thereof. The technique of RWH technology includes the collection of rainfall, store and maintenance of rainfall and surface run off. They opined that the adoption of technology increases agricultural production improves the people’s standard of living and reduces environmental degradation.

Yadav and Shriram (2014) studied the techniques and methods of rainwater harvesting in the hilly region. Storing, treatment and filtration system have been analysed. They proposed to stock the rainwater during the rainy season in different methods and stored with safe for the dry season.

Thiemann and Forch (2004) assess the water resources of precipitation variability. Precipitation amounts generally depend on altitude and higher altitude receives more rainfall during the rainy season but not in the dry season.

Fu *et al*. (2017) examine the flood problems and the contradiction between supply and demand of water resources in urban area. Comprehensive utilization of urban rainwater resources leads to enhancing the urban water security capability, water conservation capacity and disaster mitigation of urban flood.

Islam *et al.* (2017) examine the potential of rainwater harvesting for farming system development in hilly areas. A study was conducted in Bangladesh to investigate the potential of monsoon rainwater harvesting and its impact on local cropping system development.

3.3 Ground water potential zonation

Magesh *et al.* (2012), Lalbiakmawia and Lalruatkima (2014), Elbeih (2015), Dinesan *et al.* (2015), Yeh *et al*. (2016), Ibrahim-Bathis and Ahmed (2016), Mondal (2012), Radhakrishnan and Ramamoorthy (2014), Ramu *et al*. (2014) , Avtar *et al*. (2010), Tumare *et al*. (2014), Hammouri *et al*. (2012), Periyasamy *et al*. (2014), Hussein *et al*. (2017) studied the identification and delineation of groundwater potential zones using the geospatial techniques of Remote Sensing and GIS.

They generally used similar factors and parameters as much as available. Due to the unavailability of data in the particular region, they used only four to five factors for identification.

Delineated groundwater potential zone map is useful for locating the drilled well and dug well for the irrigation and domestic water consumption purpose. The majority of the crops in the region depend on rainfall, and the development of the irrigation facility will enhance the agricultural productivity in the region.

3.4 Soil Physico-Chemical properties and degradation

Shimrah, *et al*. (2015) examined the variation of soil properties under different land use/cover in north-east India. They found that the land cover change greatly influence soils in terms of its water holding capacity, structure stability and compactness, nutrient supply and storage, etc. The decreasing fallow period results the degradation of soil and for the minimum, seven fallow years is ideal period for recuperation of sufficient soil nutrients in humid sub tropical mountain landscape.

Bhuyan, *et al*. (2013) has analysed the physico-chemical properties of soil under agro-ecosystem in Arunachal Pradesh, Eastern Himalaya. They compared four different types of agricultural areas. Due to the various management techniques as well as erosional processes, different types of physical and chemical properties are found.

Deshpande and Salunkhe (2015) have carried out a study of correlation between the macro and micro nutrients and their effects on soil fertility. They proposed that to estimate nutrient quantity and availability of nutrients to plans. Pearson's correlation coefficient was adopted for computing relations among the major and micro nutrients content with different physico-chemical properties of the soil. They adopted the soil fertility index analysis for evaluating soil fertility status for making judicious use of fertilizer.

Worku *et al.* (2014), Getachew *et al*. (2012) evaluated the effect of land use/land cover change on physico-chemical properties of soil. Different types of landuse/landcover have been analysed and Analysis of Variance (ANOVA) was performed to test whether or not significant difference observed on the values of soil properties.

Adam *et al*. (2015) have studied the analysis of soil NPK, pH and Electrical conductivity (EC) to investigate soil type, potentiality and their association with the types to determine a suitable cropping pattern.

Abbasi *et al*. (2007) studied the influence of different land-cover types on the changes of selected soil properties in the mountain region. Soil data were analysed by ANOVA and Least significant Differences (LSD) was applied to indicate significant variations between the values of either landuse type, depth and timings.

Bier and Singh (2018) studied the soil fertility status of different landuse system in Nagaland. They revealed that the organic carbon is higher in the forest land which contribute to the availability of medium to high nitrogen content in the soil.

Emmanuel *et al.* (2018) assessed the relationship between the organic carbon and available nitrogen in the soil. They revealed that the soils of slightly acidic have average structural stability due to medium organic matter content which also affects the availability of low to medium nitrogen content in the soil.

Matano *et al*. (2015) studied to determine the effects of land use change on land degradation reflected by soil physico-chemical properties. The result reveals that the physical properties of soil and available nitrogen differed significantly in different sites of land use. The result indicated that the changing landuse types affected land degradation. One way ANOVA was performed to test for significant differences among different soil and water quality parameters in relation to the different land use types.

Kizilkaya and Dengiz (2010) analyzed the variation of land use and land cover effects on soil physico–chemical characteristics and soil enzyme activity. They tried to determine some physical, chemical properties and extracellular enzymatic activities of soil modified after forest land into cropland and pasture. Land use change and subsequent tillage practices resulted in significant decrease in organic matter, total porosity, total nitrogen and soil aggregate stability. There was also a significant change in bulk density among cultivate land, pasture and natural forest soil. The result shows that after long term continuous cultivation of the natural forest soils resulted in change in soil both in physical and chemical characteristics. It was found out that changes of land use and land cover associated with organic matter content can alter the soil enzyme activities within the soil profile.

Jat *et al.* (2018) studied the assessment of soil physico-chemical properties and nutrient availability under conservation agriculture practices. Person's correlation matrix was constructed among the studied soil properties. For knowing the significant change on soil properties, ANOVA was adopted.

Rahal and Shamkhi (2015) studied the characterization of spatial variability of soil physico-chemical properties. Analysis of variance (ANOVA) and LSD test were used to measure the variability among soil properties.

Muche *et al.* (2015) studies the assessment of soil physico-chemical properties on different landuse types. Analysis of variance (ANOVA) and LSD test were used to measure the variability among soil properties.

Sharma (2015) analysed the physico-chemical properties of soils with special reference to organic carbon stock under different land use systems. He compared different landuse systems based on the major vegetation.

Tewari *et al.* (2016) studied the assessment of physicochemical properties of soils from different land use system. They revealed that the forest soil had significantly higher water holding capacity, organic carbon, cation exchange capacity, available nitrogen and phosphorous and lower values of pH, EC and available phosphorous as compared to the cultivated soil.

Kenye, *et al.* (2019) and Sahoo *et al.* (2019) studied about the soil organic carbon of Mizoram and is affected by different land use. Manpoong and Tripathi (2019) also studied the soil properties under different land use system of Mizoram. Lungmuana *et al.* (2016) the analyzed the soil health importance, option and challenges in Mizoram. They found out that the available organic carbon stock is high in the natural forest and changes with conversion to other land use. In general, the soil pH is low and soil is acidic in nature.

3.5 Soil Nutrient Index

Chase and Singh (2016) studied the Status of soil nutrients and fertility in three traditional land use systems viz. Natural Forest (NF); Alder based Jhum Fallow (JF) and Wet Terrace Paddy cultivation (PF) in Khonoma, Nagaland. They analysed the soil fertility with nutrient index method and statistical comparison have been performed by ANOVA. The analysis revealed that less availability of soil nutrients among the three different land uses, with the absence of proper management, the conversion of Natural Forest to cultivation leads to decrease in soil nutrients and thus, its fertility.

Amara *et al.* (2017) assessed the soil fertility status using nutrient index approach in Bogur micro watershed in Karnataka. Different chemical properties of the soils were analysed and found that the situation demands the adoption of appropriate management practices in order to boost the fertility status.

Singh *et al.* (2014) and Deshpande and Salunkhe (2013) studied about the correlation of macro and micro nutrients of the soil and their fertility status in Madhya Pradesh and Maharashtra. They applied the same assessment techniques and processes. Soil fertility status was studied for making agriculture development and managing the use of fertilizers.

Singh *et al.* (2016) and Singh *et al.* (2018) assessed the soil fertility status of Kapurthala district of Punjab and Varanasi district of Uttar Pradesh. They analysed the physico-chemical properties of the soil with the help of Parker's nutrient index approach. The studies were conducted for the better management of the soil for agriculture practices.

3.6 Soil Erosion and Erosion prone zonation

Basu (1979) has carried out a study in the Darjeeling Himalaya for soil erosion and landslide related problems. Soil erosion plays very important role in this area due to mountainous terrain receiving intense rainfall with certain anthropogenic causes. Basu and De (1998) have also carried out a study in this area tracing the course of events of the nature and amount of soil loss.

Bhaware (2006) has made an assessment of soil erosion and risk modelling with the help of remote sensing and GIS techniques in Sitla-rao watershed, Dehradun district of Uttaranchal state. She suggested the methods applicable in the hilly areas. She has made an attempt for soil erosion risk management using erosion indicators and erosion assessment based on field survey and Spatial Soil Erosion Risk Modelling using Morgan–Morgan–Finney (MMF) model Hierarchical approach.

Nasre *et al*. (2013) have made an attempt to understand the importance of soil erosion mapping for land resource management in Karanji watershed of Maharastra using remote sensing and GIS techniques. The area is predominantly under rainfed farming and associated with soil erosion problems and low crop productivity. Spatial information related to elevation, physiography, slope, land use/land cover and soils has been derived through remote sensing and field survey and other secondary data are used as inputs in Universal Soil Loss Equation (USLE) to compute soil loss in GIS environment.

Hazarika and Honda (2001) used simple and efficient method of soil erosion rate assessment for studying the estimation of soil erosion using remote sensing and GIS, its valuation and economic implication on agricultural production in Mae Ao watershed, Thailand. They found the rate of erosion simply with two factors like Normalized Difference Vegetation Index (NDVI) and Digital Elevation Model (DEM) derived from remote sensing data. Sureshbabu (2017) followed the similar method but applied in Tamilnadu. Vijith *et al.* (2012) assessed soil erosion probability and erosion rate in a tropical mountainous watershed by an efficient, fast and simple methodology using the remote sensing and GIS data integration and analysis. Weighted index overlay method has been used for erosion probability zonation and Hazarika and Honda (2001) model was used for evaluating the rate of erosion.

Londhe *et al.* (2010); Oliveira, *et al*. (2011); Bouguerra *et al.* (2017); Arabameri *et al.* (2018); Ali *et al.* (2018) analyzed and tried to identify erosion prone areas in different landforms using the more or less similar methods and tried to utilize the modern techniques of remote sensing and GIS for decision making.

3.7 Deforestation

Puyravaud (2003) adopted the new standardized calculation of the annual rate of deforestation. Reddy *et al.* (2009) and Reddy *et al.* (2016) have done the assessment and monitoring of deforestation and land-use changes in Nawarangpur district, Orissa, India and Andaman and Nicobar Islands, India respectively. Satellite remote sensing and geographical information system (GIS) techniques have been used to analyse forest cover changes, rate of deforestation and mapping the pattern of forest cover distribution. To calculate annual rate of deforestation in percentage per year, compounds interest formula adopted by Puyravaud (2003) have been applied.

Reddy *et al.* (2013) analysed the gross and net deforestation rates in India. In order to analyse deforestation, the annual rate of change is calculated by comparing the area under forest cover in the same region at two different times. Annual rate of forest change is derived from the compound interest formula adopted by Food & Agriculture organisation (FAO) due to its explicit biological meaning.

Mayaux *et al.* (2005) and Shearman *et al.* (2009) analyzed the tropical forest cover change and degradation for different period of time.

Mukul and Herbohn (2015) analysed the impacts of shifting cultivation on secondary forest dynamics in tropics. They found out that the shifting cultivation has been attributed to cause large-scale deforestation and forest degradation in tropical forest –agriculture frontier.

Bera and Namasudra (2016) carried out an assessment of shifting cultivation impact on the environmental changes like deforestation, losing biodiversity, climate change and soil degradation, etc,. The cycle of the fallow length period decreases in recent decade causes the intensity of environmental impact becomes more vulnerable.

Baruah and Barua (2019) analysed the effect of deforestation on environment. Due to the high growth of population and their activities causing intolerable imbalance in nature and is a major factor leading to climate change, extinction of rare animals, desertation and displacement of the people. It also causes global warming, soil erosion and disturbing the water cycle.

Jeus *et al.* (2016) analysed the impact of shifting cultivation in the forest ecosystem. They tried to characterize and reveal the socio-economic importance of shifting agriculture to rural community and to identify its impacts in the environmental sustainability of the ecosystems, as well as to suggest some solutions to mitigate their negative impacts.

GOI (2016) in the book of Desertification and Land Degradation Atlas of India assessed the desertification and land degradation problems of India as a whole and each of the states and Union Territories. They mapped the status of the entire India to bring out the changes in landuse/landcover. The analysis reveals that 96.40 million hectares area of India is undergoing the process of land degradation i.e., 29.32 % of the total geographical area of the country during 2011-2013, which is higher than the previous decade of 2003-2005 i.e., 28.76% of the total geographical area.

Kumari *et al.* (2019) analysed the main causes attributed to reduction in forest cover and impact of deforestation. They mentioned the different points for preventive measures to attain for practicing sustainable forest management. They also highlighted the role of Indian government in forest conservation.

Dutta and Das (2014) tried to highlight the trend of degradation of green cover and the dynamics of deforestation in north-east India.

Pachuau (2014) tried to assess the declining trend of the village safety in terms of protection and security and supply of forest resources as well as the changing pattern of landuse. The study reveals that the safety/supply forest is decreasing at -40.9% and the tradition of keeping safety/supply forest for the sake of village community is declining in the minds of the people.

ICFRE (2017) in *Drivers of deforestation and forest degradation in Mizoram* published by Indian Council of Forestry Research and Education highlighted that the condition of forest and their resources. They reveal that the major drivers in deforestation and forest degradation are induced by the livelihood activities of the forest dependent communities. On the basis of the people's perception, shifting cultivation and collection of fuel wood from forest are the major drivers of forest degradation.

Das (2015) examined the trends of forest dynamics and degradation and also to make an assessment of the causes responsible for forest depletion and management prospects. He opined that forest is a multipurpose resource and the exploitation of forest resources affects the quality of life for both present and future generation.

3.8 Change Detection using the Normalized Difference Vegetation Index (NDVI)

Mohapatra and Pani (2011) have analyzed the importance of advanced techniques and tools like remote sensing and GIS, especially Normalized Difference Vegetation Index (NDVI) techniques for mapping and assessment of land degradation. On the basis this technique with the help of satellite image, the land has been classified into different erosion prone zones showing the intensity of land degradation.

Yacouba *et al.* (2010), Gandhi *et al.* (2015) have done the assessment of land use cover change detection. The change detection method used for the assessment of natural resources was based on NDVI differences in multi-date satellite imagery. Remote sensing data from Landsat TM image and DEM data layers have been used to performed multi-sources classification.

Al-doski *et al.* (2013) analysed the vegetation change detecting in Halabja City, Iraq by using Landsat 5 TM images. The NDVI image differencing and post classification techniques were applied. NDVI was derived and then classified to produce vegetation map for quantifying the changes.

Singh *et al.* (2016) have carried the study of NDVI based classification to assess the change in Land use/Land Cover (LULC) in lower Assam, India. Remote Sensing and GIS technology has been used to analyse the change in land use and land cover of the area at spatial and temporal scale. The NDVI based classification has indicated about significant change in land use land cover between the multi-date satellite imagery.

Menses-Tovar (2012) has analysed the importance of NDVI as the indicator of vegetation degradation. He opined that NDVI is an indicator of vegetation health, because degradation of ecosystem vegetation, or a decrease in green, would be reflected in a decrease in NDVI value.

3.9 Land use planning

Amler, *et al.* (1999) have proposed integrated land use planning. They suggested various important strategies, tools and methods for designing land use strategies. They have mentioned that the scenario of land use planning, importance of integrated land use planning for planning system, elements of planning processes and the role of participants in planning process, implementation, project organization and general conditions of land use planning.

Morgan (2005) has carried out a study on the conservation strategies with emphasize on crop and vegetation management, soil management and mechanical methods of erosion control in his book. He inferred that the volume of water also deals with the processes of soil erosion, the assessment of erosion risk at different scales and the monitoring and modelling of erosion.

He analysed the importance of tillage in moving soil over the landscape, the use of terrain analysis in erosion risk assessment, the use of tracers in erosion measurement, the validation of erosion models and problems of uncertainty in their output, defining soil loss tolerance by performance-related criteria, traditional soil conservation measures, incentives for soil conservation and community approaches to land care. The sections on gully erosion, the mechanics of wind erosion, the dynamic nature of soil erodibility, and the effects of vegetation on wind erosion and mass movement, economic evaluation of erosion control, the use of legislative instruments in promoting soil conservation have been substantially analysed and presented in his study.

Chakrabortty (2010) has applied Remote Sensing and GIS techniques successfully for land use planning and management in the Siddheshwari-Nunbil riparian tract of western Birbhum district, West Bengal. Under the catchment of these two rivers, he evaluated the existing land resources through satellite images and topographical maps together with field survey to analyse the land use problem, and suggested for measuring land use planning and management. He has suggested that two approaches for land use planning and management, such as short term approach to provide immediate benefits to the society or inhabitants of the particular region where planning and management work is to be implemented and long term approach for preservation of natural resources of the region.

FAO (1996) has framed guidelines for land use planning. They explained land use planning as a systematic assessment of physical, socio-economic factors in order to assist and encourage land users to select land use options that increase the land productivity to meet the needs of society. They further, defined that land use planning process and some important steps to be included in land use planning.

Hironi (1991) has studied about the importance of geomorphological studies for land use planning. He studied in detail of various aspects of morphology of landforms in the study of land use planning especially agricultural land use. He had identified and delineated the land system which form land units with the basis of land use planning. He also examined the relationship and interaction between fluvial morphology and flood, soil and genesis of ravines with other allied factors such as climate, vegetation, geology, topography and time.

Kumar (1986) has analysed the land use of Nalanda district, Bihar. He revealed the importance of economic development, resource planning and management and cultural advancement of the people in this area. He further highlighted the significance of the study of land uses, agricultural operation, facilities and cropping patterns. Based on the evaluation of the existing problems, suggested alternate land use plan for the area.

Mandal (1990) has made an attempt to analyze land utilization, theory and practices. He developed some techniques of land use survey and the formulated model for land use. Land use classification and utilization in terms of agricultural type, method of land capability classification and agricultural efficiency, importance of land use planning were discussed extensively. He emphasized the theory of model which should be more applicable for practising in the real prospect.

Prasad (1995) has analysed the hill resources management in India. Number of factors causing the problems in management of hill resources like land degradation by shifting cultivation, soil erosion, deforestation and others such as mismanagement of water resources, over grazing and depletion of soil fertility. He made a recommendation for the upliftment of resource management like organizing 'Village Resource Management Society' for making land use plan of the village and every farmer or individual should have a land use plan depending on his interest and available resources.

Singh (1995) has elucidated the problems of environmental degradation and suggested measures for controlling further degradation in the north-eastern hill region of India. He said that proper awareness plays a very important role for checking further land degradation in this hill region. Different scientific methods have been suggested for conservation base on farming/land use system like contour bunds, bench terraces, half moon terraces, grasses water ways, etc,.

Singh *et al.* (2010) have carried out a study for eco-restoration and management of natural resources in the extremely monsoon area of Cherrapunji. The study is based on rainfall, run-off and soil erosion for geo-ecological perspective and socio-economic condition of the degraded landscape of the study area. The study highlights link between human activities with land degradation. They have suggested some remedial measures to promote less use of biological productivity of the ecosystem.

Young (1998) has made an attempt on the evaluation of land resources, their management, conservation and their role in human welfare in the world. His study emphasizes the critical role of land resources in sustainable development and the need to improve land management. It provides an authoritative review of the resources of soils, water, climate, forest and pastures on which agriculture and rural land use is based. He also assessed the prospects for feeding future population in the area. The study also addressed certain environmental issues of erosion, loss of soil fertility, deforestation and desertification using the advanced methods of remote sensing and GIS techniques. The study emphasises the link between land resources and wider aspect of development, including population and poverty. This study reveals that if the land available for food production is degrading and unchecked, the world will face a serious problem of food security and conflict in future.

Zonunsanga (2014) has carried out a study for the evaluation of potentials of agriculture development in Teirei watershed using the advanced techniques of remote sensing and GIS. He thoroughly discussed about the topography, climatic condition and population status in the study area. He estimated soil loss with the help of USLE model. Based on the results obtained in his study, he proposed alternate farming systems for different potential areas for agriculture, horticulture and aquaculture, reserved forest and commercial plantation. He also identified the areas which are not suitable for agriculture in the watershed.

Porwal (1997) analysed the environmental resources for planning and development with the help of remote sensing in his book. In this study, an attempt was made to assess the environmental resources distribution, environmental resource utilization pattern and problem identification. He also suggested measures for conservation of resources and planning for the future prospects.

3.10 Farmers' perception on land degradation

Lindskog and Tengberg (1994) proposed a conceptual model that integrates physical and ecological aspects of land degradation through a multidisciplinary approach like satellite imagery analysis, interviews with local people and field surveys. The result reveals that the local knowledge of the physical symptoms of land degradation and of the physical variables like the spatial variations in rainfall is very close to scientific logic.

Joshi *et al.* (1996) have assessed farmers' perception of land degradation and examined their actions to alleviate its perceived effects. Farmers feel that the high degree of sloping area is a less productive due to erosion and where the land is flatter, it will also cause less production due to waterlogging and salt accumulation in the study area.

Yeshaneh (2015) has carried out an assessment of farmers' perceptions about soil fertility with different management practices. The result shows that there was good agreement between assessment of soil fertility by farmers and scientific indicators of soil fertility.

Shit *et al.* (2015) have analysed the farmers' perceptions of soil erosion and management strategies. The result indicates that soil erosion is an imperative environmental deterioration leading serious impact on physical, economical and ecological in developing countries. The analysis reveals that farmer age, experience, training, education were responsible for soil erosion and soil water conservation.

Saguye (2017), Akinnagbe and Umukora (2011) and Kassa *et al.* (2013) carried out an analysis of farmers' perception on the impact of land degradation hazard on agricultural activities.

CHAPTER-4

METHODOLOGY

4.1 Introduction

In the olden times, most of the geographers have followed the observational techniques in their research studies. But in the present computer age, the researchers have been utilizing the scientific tools, methods and techniques for making decisions. The present study is based on the utilization of the most advanced scientific techniques of Geoinformatics along with field surveys for assessing and identifying the dynamics of land degradation status in the study area.

4.2 Sources of Data

Primary and Secondary data is mandatory for further analysis and they were collected from various sources and field work.

4.2.1 Primary Data: The following data were used extensively in various analyses.

4.2.1.1 Thematic Map and Satellite Imagery

- Survey of India Topographical Maps No. 84 A/13, 84 A/14 and 84 A/15 with a scale of 1:50,000 for preparing base map.
- Advaned Spaceborne Thermal Emission and Reflection GLOBAL DIGITAL ELEVATION MODEL (ASTER GDEM) 30x30 meter spatial resolution.
- Landsat 1 Multi Spectral Scanner (MSS) Image, Path 135-Row 44 and the date of acquisition dated 27th January, 1974.
- Landsat 5 Thematic Mapper (TM) Image, Path 135-Row 44 and the date of acquisition dated 26th January, 1996.
- Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) Image, Path 135-Row 44 and the date of acquisition dated 22nd January, 2018.

4.2.1.2 Soil Samples collection

Soil samples were collected from the study area following the pattern of grid based staggered start sampling also known as triangular or diamond sampling method (Fig 4.1 and 4.2). A total of 73 soil samples were collected from the evenly distributed study area. Chemical properties of the soil like Nitrogen (N), Phosphorous (P), Potassium (K), Electric Conductivity (EC), pH, Organic Carbon (OC), Organic Matter (OM) and the physical properties like Bulk Density (BD), Porosity and Soil texture have been analyzed on the basis of laboratory work.

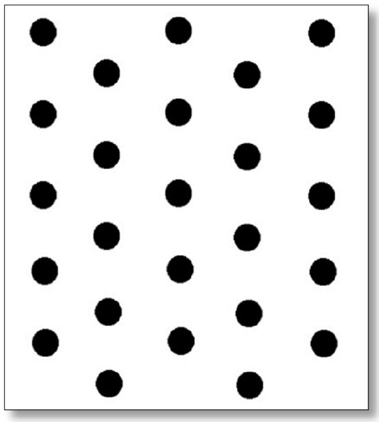


Fig 4.1: Staggered start sampling method

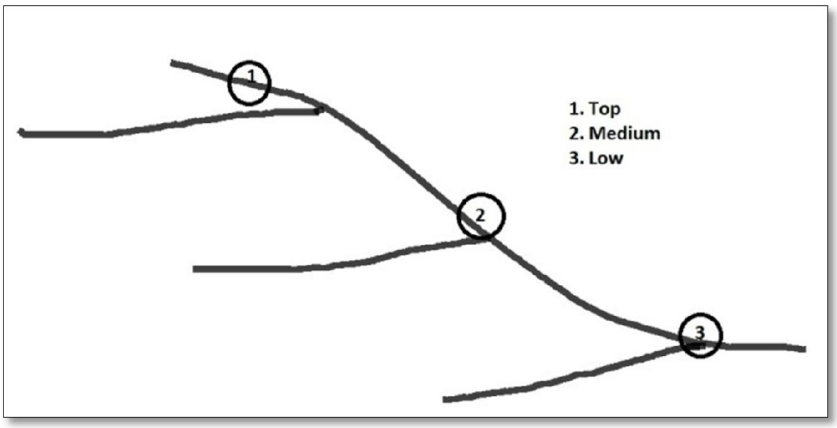


Fig 4.2: Location of soil sample sites along the slope boundary.

Soil samples from surface layer of 0 to 15 cm or 6 inches depth were collected for chemical properties and soil texture, and 0 to 9 cm or 3 inches depth with a diameter of 9 cm were collected for bulk density and porosity. In each sample site, areas are demarcated based on natural slope boundary i.e. top, medium and low. Three replicate samples were taken along the direction of each of the natural slope boundary and mixed them all to make one composite sample for testing.

4.2.1.3 Ground Truth Survey

Ground truth verification has been adopted for identifying and analyzing the land use/land cover, topography, geomorphology, groundwater potential zones. The survey has been extensively used for delineation and identifying the Built-up land, Agricultural land, Forest, Water bodies and others.

4.1.2.4 Interview and Questionnaire Method

Interview and Questionnaire methods have been adopted for collecting the perception of farmers regarding the land use / land cover change and land degradation in their respective land. Purposive Random Sampling has been applied for data collection and interviewed elders and other prominent persons in every villages of the study area.

4.2.2 Secondary Data:

A variety of secondary data were obtained from various sources in the form of published and unpublished books, Abstracts, Journals, Handbooks, etc., from different departments of state and central government. The following data have been used.

- Rainfall data from Directorate of Agriculture (Crop Husbandry), Directorate of Economics and Statistics, Mizoram and Mizoram Remote Sensing Application Centre (MIRSAC).
- Rainfall, Temperature and Relative Humidity from Meteorological data of Mizoram (2018), Directorate of Economics and Statistics, Govt. of Mizoram.
- Forest data (1987 - 2019, Forest Survey of India and Ddepartment of Environment, Forest and Climate change, Govt. of Mizoram)

- Census data of Population growth (1971 - 2011, Census of India)
- Survey of India Topographical map with a scale of 1:50,000 (Surveyed 1970-71)
- Rural Land Use Plan for New land Use Project Mizoram (2013, NLUP Implementing Board)
- Village Profile and Development Indicators 2017-2018, Mizoram State (2019, Directorate of Economics & Statistics, Government of Mizoram).
- Other relevant information.

4.3 Techniques of synthesizing data

When the collection of primary and secondary data has been done, the data are arranged in a proper format. The quantitative technique is one of the most important methods in geographical research study. Along with quantitative techniques, graphical as well as thematic mapping techniques are extensively used in the present study. Regarding the quantitative techniques, simple statistical methods and the existing methods adopted by different researchers are used. Graphical methods like pie-diagram, bar diagram, Line diagram, etc., are used. Tables and figures are also used for proper presentation of the data.

4.3.1 Assessment of soil resources and its degradation

Soil samples for determining the chemical properties were air dried under room temperature. The air dried soil samples were then ground gently with pestle and mortar and passed through a 2 millimeter (mm) sieve. The soil samples were sent to Agriculture Department, Government of Mizoram and Krishi Vigyan Kendra (KVK), Lengpui, Mizoram for testing the chemical properties.

Soil physical properties were tested by the researcher himself. Following the method of McKenzie *et al.* (2004) the Bulk Density was measured by collecting a known volume of soil sample using a cylinder pressed into the soil (intact core), and determined the weight after drying. The bulk density was then calculated based on mass/volume ratio of bulk density sampling ring and dry weight recorded.

The soil particle size (Soil texture) was also determined with the slight modification of Bouyoucocus soil hydrometer method as described by Jaiswal (2003) and classified them to different textural class based on the United States Department of Agriculture (USDA) classification.

Soil Nutrient Index introduced by Parker *et al.* (1951), modified by Brajendra *et al.* (2014) and Chase and Singh (2014) have been adopted to evaluate the fertility status of soils in the study area.

Soil degradation in the study area has been analysed from the physical and chemical properties of the soil. The results of the soil properties of the six different land use / land cover classes were analysed with the help of statistical techniques like Microsoft Excel and Statistical Package for Social Science (SPSS) 21 to get the relation and distinction of properties. Microsoft Excel has been applied for analyzing the Mean, Standard Deviation (SD) and Pearsons' correlation to measure the relations among the physico-chemical properties of the soil. Analysis of Variance (ANOVA) under Statistical Package for Social Science (SPSS) 21 has been applied for assessing the significant change of soil physico-chemical properties among different land use / land cover class units.

4.3.2 Assessment of forest resources and deforestation pattern

Forest condition in the study area was assessed using the data collected from the State of Forest Report (1987 to 2019) of the Forest Survey of India and the thematic data interpreted from False Colour Composite (FCC) of Landsat Satellite imageries. Multi-date satellite imagery were used to find out temporal changes in land use / land cover pattern by supervised classification under the environment of Geographical Information System (GIS). Forest density was evaluated with the help of Normalized Difference Vegetation Index (NDVI) technique under the GIS environment.

$$NDVI = NIR-RED/NIR+RED$$

Where,

NIR = Near Infra-Red band

RED = Red band

In order to analyse deforestation rate, the annual rate of change is calculated by comparing the area under forest cover in the same region at different times. Following the formula adopted by Puyravoud (2003), the annual rate of forest change is derived from the compound interest formula due to its explicit biological meaning.

Change rate = $[Ln (At_1)-Ln (At_0)] / t_1 - t_0 \times 100$

Where,

Change rate in percentage per year, At_1 is area of class in current year, At_0 is area of class in base year, t_1 is current year, t_0 is base year and Ln is natural logarithm.

4.4 Thematic map preparation

The International Cartographic Association defines the thematic map as "*A map designed to demonstrate particular features or concepts. In conventional use this term excludes topographic maps*" (Shekhar, 2015). Thematic map displays the particular distribution of geographical data in simply reasonable and represent the real picture of the earth's phenomena for a particular time. In the present study, two types of satellite imageries have been used for depicting various physical settings and environmental resources. Besides the satellite imagery, Survey of India topographical mapswere utilized with a scale of RF 1:50,000. Ground truth verification was conducted to verify the data in the field. Soil samples, vegetation type, crops grown, altitude, slope degree and other important information for assistance of preparing thematic map have been collected. Before thematic map preparation from satellite imageries, pre-processing method like Radiometric and Geometric correction have been done to images to improve the fidelity of the brightness value and correcting for geometric distortions.

Inverse Distance Weighted (IDW) interpolation method has been significantly used to generate different thematic maps in GIS environment. It is useful for drawing imaginary line on unknown point based on the known point. It explicitly implements the assumption that things that are close to one another are more alike than those that are farther apart. In other words, the estimated value of a point is influenced more by nearby known points than by those farther away (Chang, 2019).

Landsat satellite Imagery of false colour composite (FCC) was used to generate Land use / land cover thematic map of the study area. ASTER Global Digital Elevation Model (ASTER GDEM) with a spatial resolution of 30 m has been used to generate the thematic layers pertaining to relief, slope, drainage and other geomorphic features. Beside these, rainfall data and soil texture class have been generated.

Land use / land cover condition in the study area was assessed using multi-temporal satellite imagery with the help of supervised classification method under the environment of Geographical Information System (GIS) in the study area.

For determining the relief characteristics of the study area, survey of India topographical maps with a scale of RF 1:50,000 with contour interval of 20 m and Aster GDEM at 30 m spatial resolution were used. Absolute relief has been generated with a contour interval of 400 m and relative relief also generated with the help of Fishnet tools in ArcGIS 10.1. After computing the difference value of each grid point in fishnet, Inverse Distance weighted (IDW) interpolation method has been adopted to demarcate the different heights of relative relief. Dissection index has been calculated from the thematic layer of absolute relief and relative relief with the help of raster calculator and also applied IDW interpolation method for demarcating the different values of dissection index.

Slope map was generated using a grid based digital elevation model in a raster environment through surface tools in GIS software. Fault, fracture and lineaments were identified from the different thematic layers and make lineament density map using the line density tool in ArcGIS software. Geomorphic map has been arranged from the different thematic layers of physical features in GIS environment.

Existing Geological map (Ganju, 1975) has been rectified with ArcGIS software and digitized to make a new layer of Geology map.

Drainage map generated from India topographical maps by digitization and GDEM by ArcHydro, extension tools of ArcGIS software. These are used to acquire information of the surface water resources. Drainage density map was prepared by using the line density tools in ArcGIS.

With the help of IDW interpolation method in GIS environment, Rainfall map (Isohyets) and Soil texture map has been generated with the help of the collected data from other source.

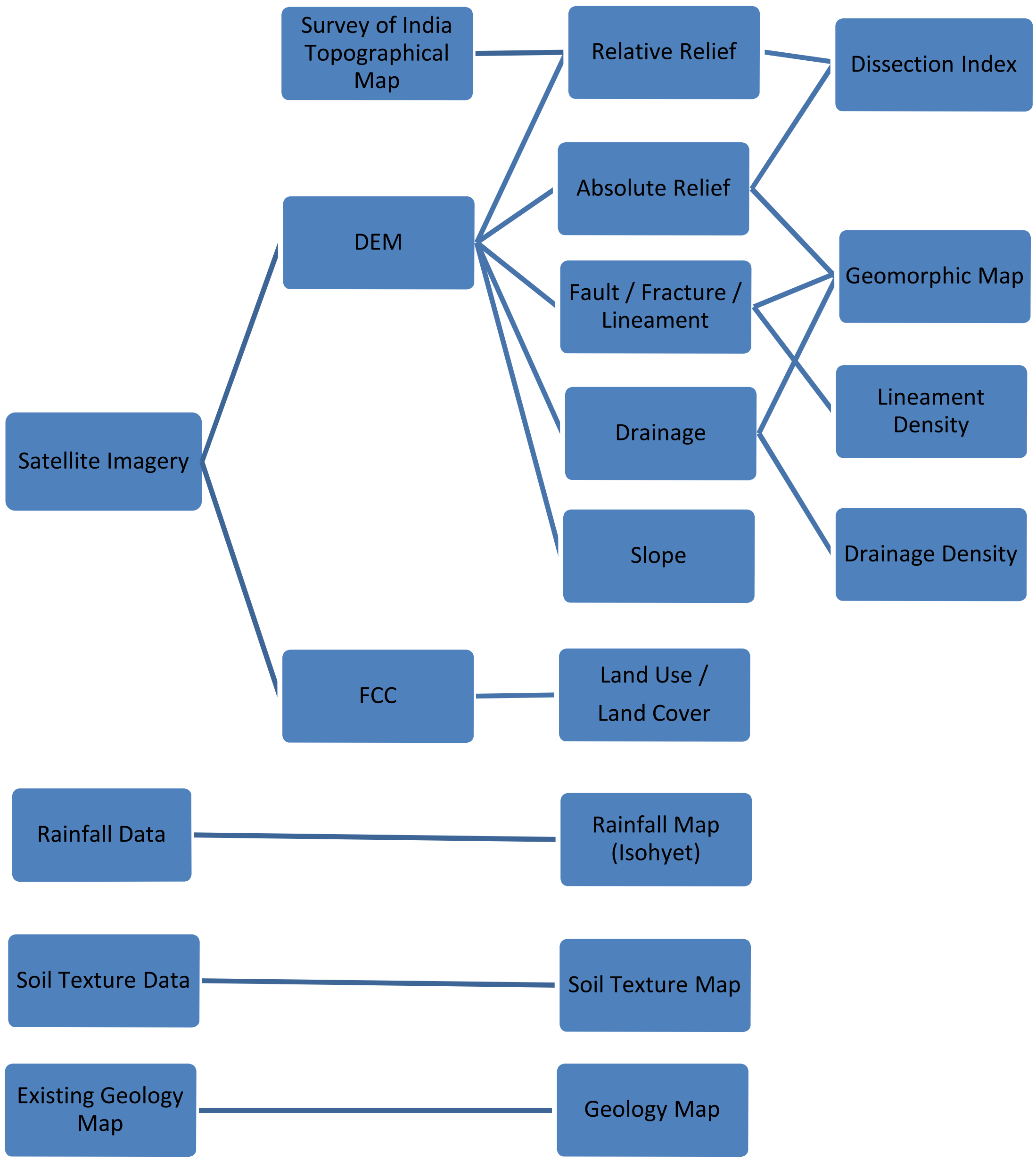


Fig 4.3: Flowchart showing the thematic map preparation

Groundwater potential zones and Erosion prone zones have been delineated with the help of weighted overlay under the environment of ArcGIS 10.1. Different physico-environmental characteristics have been analysed and made decision with the weighted overlay method. In weighted overlay method, different variables of thematic layers are coverted to raster and reclassified them to proper format. It is also needed to resample the grid size to equalize all the variables as similar resolution. Integration of the thematic layers have been done by weighted overlay and give weight values in percentage and rank different classes based on their relative significance for the final output.

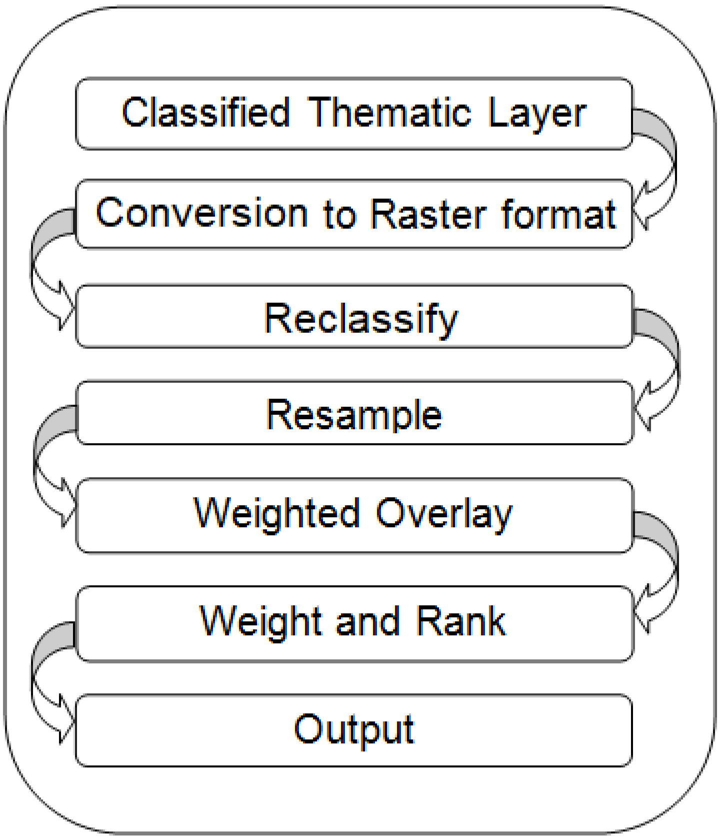


Fig 4.4: Flowchart showing Weighted Overlay method

CHAPTER 5

RESOURCE APPRAISAL

5.1 Introduction

The potential resource mobilization contributes a lot to the development of the nation. Resources can be anything in our environment which can satisfy human needs and resources of a country are the stores with useful materials and components. Natural resources are materials or substances that occur naturally which are useful to mankind in any manner. The present study analyzes the assessment of natural resources like water, soil and forest which are essential for the existence of life.

5.2 Water resources

Water is one of the most important natural resources for the existence of life. It is required in substantial quantity for domestic purposes like drinking water, cleaning, etc., industrial purposes and agricultural development. The evaluation of water resources in the study area can be classified into three different aspects like rainfall, surface water resource and groundwater potential resource.

5.2.1 Rainfall

Rainwater is a free source of safe drinking water without much treatment. It is a primary source of water and plays a vital role in the development of water resources in the study area due to rain fed region. The area receives an average annual rainfall of about 2891.81 mm as recorded for period of 20 years (1999-2018) (Table 5.1). The rain gauge station data in the surrounding regions are taken to generalise the average rainfall pattern in the study area. The high amount of rainfall in this area seems to be the effect of high relief features as a rain barrier which occurs in the eastern part of the study area.

In the study area, the rainy season starts from the month of April and continues upto the month of October. During the rainy season in the months of May, June, July, August and September, the study area receive a good amount of rainfall, an average of more than 390 mm in each month with 80.68 % from the total receiving annually, whereas the remaining rainy season of April and October also receives more than 190 mm in a month with 14.07%. The total rainy seasons from April to October receives 94.75 % of the average annual rainfall as recorded during 20 years.

The dry season starts from the month of November and continues upto March and receives 5.25 % of the total rainfall received during 20 years. During this period, the area received small amount of rainfall (Less than 80 mm) and due to this reason, most of the streams are dried up. But compared to other places, the area received higher amount of winter rainfall.

Though the area receives excess rain water in the monsoon season there is insufficiency in the dry season which creates a situation of water security and insecurity in the study area thereby affecting water supply for domestic and irrigation purpose. The rainy season is longer than the dry season and has a good potential for rainwater harvesting to fill the gap of water scarcity in the dry season. In the dry season, the water sources of rivers are neither dependable nor capable of supplying enough water for both domestic utilisation and irrigation for crop production.

Table 5.1: Mean monthly rainfall (in mm) in the surrounding Tuirini watershed, 1999 – 2018.

Month	Stations						
	Aizawl	Sialsuk	Neihbawih	Serchhip	Khawruhlian	Average	%
Jan	6.38	7.51	16.39	5.12	4.37	7.95	0.27
Feb	12.42	14.92	25.37	8.14	11.25	14.42	0.50
March	66.65	76.39	146.64	46.34	47.72	76.75	2.65
April	183.11	198.08	332.84	116.63	152.37	196.6	6.80
May	377.13	393.36	638.22	297.68	291.13	399.5	13.81
June	398.33	720.76	1041.48	452.36	295.27	581.64	20.11
July	331.92	645.2	576.3	369.05	343.22	453.14	15.67
Aug	400.19	629.29	686.74	389.82	409.35	503.08	17.40
Sep	363.53	421.09	568.51	311.43	314.55	395.82	13.69
Oct	169.55	238.42	339.37	167.22	137.84	210.48	7.28
Nov	26.24	52.8	62.61	38.74	25.5	41.18	1.42
Dec	9.23	11.74	20.79	8.09	6.41	11.25	0.39
Total	2344.66	3406.3	4149.36	2210.6	2038.64	2891.81	100

Source: Meteorological data of Mizoram 2018, Directorate of Economics and Statistics and Statistical Abstract, Directorate of Agriculture (Crop Husbandry) Mizoram.

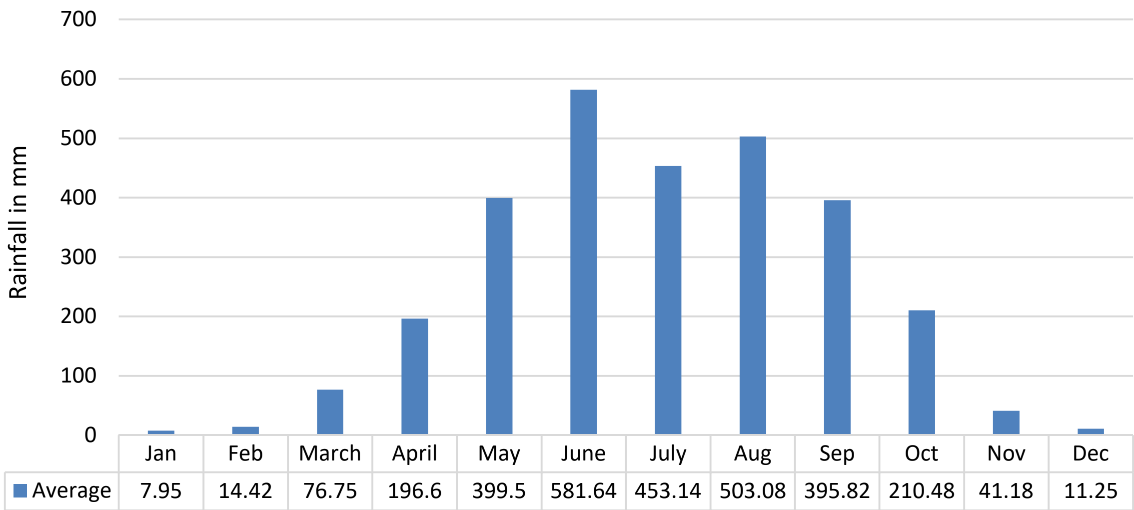


Fig 5.1: Bar graph showing mean monthly rainfall of Tuirini watershed, 1999-2018.

5.2.2 Surface water resources

Surface water in a general term describes any water body flowing or stagnant on the surface like streams, rivers, ponds, lakes, etc., and is available from various multi-sources. Rainfall is the basic source of surface water in the study area. A number of rivers, streams flow within the watershed. Owing to the dominance of parallel hill ranges on the east and the west with rugged terrain and steep slopes, the study area has a lot of tributaries in the left and right banks from the east and western sides. There are 30 perennial tributaries in the study area adjoining the main river, 13 streams from the eastern side and 17 streams from the western side respectively. Since most of the settlement area and cropland are located on top of the hill ranges with steep slopes, the streams do not have significance for domestic water and irrigation for agriculture development. Only a very few streams play an important role in domestic water supply in the study area.

The drainage systems mostly exhibit trellis, parallel and dendrictic patterns with numerous tributaries. For knowing the surface water resources, drainage density of perennial rivers have been analysed due to available as resources for the whole year.

Table 5.2: Tuirini river and its tributaries

River / Stream	Watershed and Sub-watershed Code	Stream Length (in km)	Area in km^2	Drainage Density
Tuirini lui	D2CBAR25	47.58		
Chhimluang lui	D2CBAR25h	11.76	19.65	0.6
Inrum lui	D2CBAR25i	14.48	26.03	0.56
Inran lui	D2CBAR25i	17.55	26.5	0.66
Tuikhau lui	D2CBAR25f	42.95	62.45	0.69
Kang lui	D2CBAR25d	22.89	32.77	0.7
Kaihzawl lui	D2CBAR25d	19.12	34.24	0.56
Saibual lui	D2CBAR25c	12.78	21.98	0.58
Lungding lui	D2CBAR25c	5.35	10.88	0.49
Saikar lui	D2CBAR25b	14.63	19.89	0.74
Sazuksih lui	D2CBAR25a	2.12	4.24	0.5
Rulchuk lui	D2CBAR25a	1.89	4.25	0.44
Mauawk lui	D2CBAR25a	4.35	5.94	0.73
Zawngsih lui	D2CBAR25a	4.84	6.93	0.7
Maudarh lui	D2CBAR25a	3.15	7.81	0.4
Lungdin lui	D2CBAR25a	1.66	4.01	0.41
Hmar lui	D2CBAR25a	4.36	7.35	0.59
Minpui lui	D2CBAR25b	5.5	11.66	0.47
Tuizal lui	D2CBAR25b	4.39	5.98	0.73
Chal lui	D2CBAR25b	6.78	10.39	0.65
Maltliak lui	D2CBAR25c	4.9	12.54	0.39
Ramri lui	D2CBAR25c	5.01	7.81	0.64
Sihpui lui	D2CBAR25c	3.1	5.16	0.6
Sathang lui	D2CBAR25e	2.17	4.24	0.51
Thangzai lui	D2CBAR25e	2.31	4.7	0.49
Sakei lui	D2CBAR25e	4.59	9.82	0.47
Maumit lui	D2CBAR25g	2.83	5.91	0.48
Dam lui	D2CBAR25g	6.05	14.21	0.43
Minpui lui	D2CBAR25h	3.81	9.42	0.4
Damdiai lui	D2CBAR25h	5.27	9.38	0.56
Phekphe lui	D2CBAR25h	2.92	5.23	0.56
TOTAL		291.08	411.38	0.71

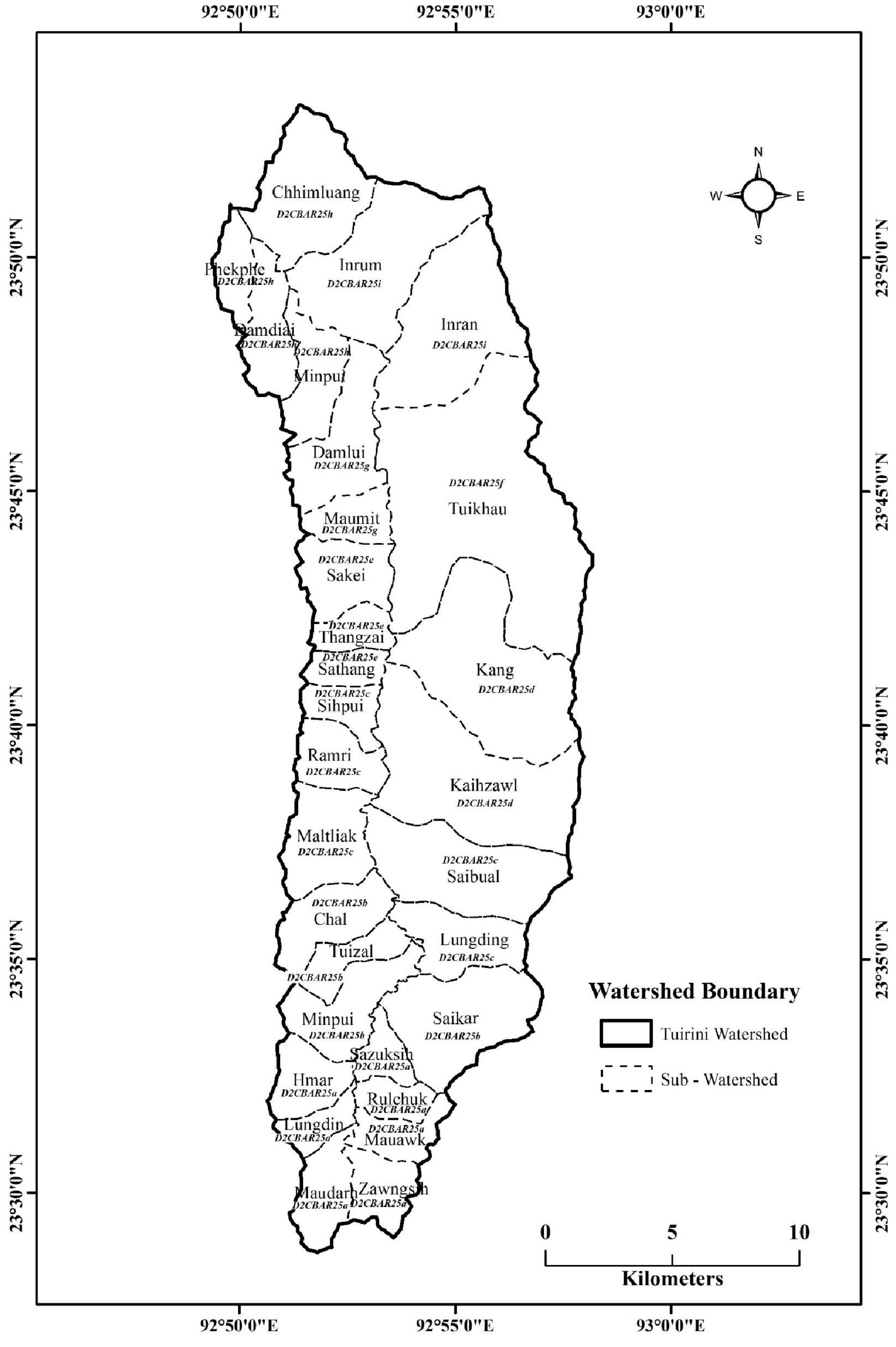


Fig 5.2 : Sub-watershed map of Tuirini Watershed

Tuirini River

Tuirini river is formed after confluence of the Zawngsih river from the east and Maudarh river from the west. It flows towards the north direction for a distance of 47.58 km approximately and join the river of Tuirial. The river serves as a good potential of agricultural practices and aquaculture along the banks of both sides in the upper and lower course of the river channel. It has many tributaries joining from the left and right banks due to rugged topography. The basin has a density of 0.71 km / km^2 of perennial drainage.

Left bank tributaries

Chhimluang Lui: The stream lies in the northern most part of the left bank. It is under the land of Khawruhlian and Hmunnghak village. It flows towards south direction and joins the main river in the lower course. The basin has an area of about 19.69 km^2 and a length of 11.76 km perennial streams with 0.60 km / km^2 perennial drainage density.

Inrum Lui: Stream of Inrum has its mouth between Hmunnghak village and Khanpui village. It flows in southward direction with a length of 14.48 kms and has a catchment of 26.03 km^2 with a perennial drainage density of 0.56 km / km^2.

Inran Lui: The stream has its mouth in the western hill slope of Chalfilh mountain ranges. It passes through the high degree of slope in the upper course and gentle slope in the lower course. The basin has the size of 26.5 km^2 with a perennial river flowing over a distance of 17.55 km. The area has a perennial drainage density of 0.66 km / km^2.

The river is the main source of drinking water for Khawruhlian, Hmunnghak, Khanpui and Lailak villages in the eastern side and the villages are located in the western hill ranges like Mualmam, Sesawng and CTI Sesawng also drawing drinking water through pipeline.

Tuikhau Lui: Tuikhau stream originates from the Chalfilh mountain ranges and flows towards south and join Tamdil stream. After its confluence with the stream of Tamdil, it turns towards west and joins Turini river. It is one of the biggest stream having high catchment sized sub-watershed of 62.45 km^2 area found in the Turini watershed. It has a perennial stream flows a length of 42.95 km with a drainage density is 0.69 km / km^2.

The stream is one of the major sources of drinking water, which is supplied in the nearby villages and towns like Tualbung, Dilkan, Sihfa, Saitual, Keifang in the east hill ranges and Seling, Phaibawk, Thingsulthliah in the western hill ranges after crossing the main river of Tuirini with pipeline. Besides the domestic water supply, the stream provides water for irrigation for agricultural practices in the hill slopes of Chalfilh mountain.

Kang Lui: It originates from the hill ranges of Saitual Town and Keifang villages. The river joins the Upazau stream from the northern side in the lower course of the river before joining the Tuirini river. It flows a distance of 22.89 km as perennial and has a basin area of 32.77 km^2. The perennial drainage density is high (0.7 km / km^2) in this region.

Kaihzawl Lui: The stream has its mouth below Rualluang village and is joined with the upper course of river by Zawntui stream from the northern side. It has a basin area of 32.24 km^2 and a perennial river with length of 19.12 km before joining the main river. The perennial drainage density is only 0.56 km / km^2.

The river is utilised for the agricultural practices along the river banks. Due to lower degree of slope in the upper course of the river, agriculture has been practiced for wet rice cultivation (WRC) and found a number of Fish pond/lake.

Saibual Lui: The stream originates from Tawi mountain peak and flows for a distance of 12.78 km as a perennial river and It has the basin area of around 21.98 km^2 with a perennial drainage density of 0.58 km / km^2. The river does not have any significance for irrigation purpose as it flows in the thick forest.

Lungding Lui: The stream originates from the Tawi mountain ranges near the village of Lenchim. It flows for a distance of 5.35 km as perennial and has a basin size of 10.88 km^2. The river has 0.49 km / km^2 densities of perennial stream.

Lenchim is the only village which uses water resources for domestic and agricultural purposes.

Saikar Lui: The stream originates from the Tawi mountain ranges and flows toward northwest. The stream is joined by the other two perennial stream like Vawmhrawh Lui and Khuai Lui from the northern side. The stream has a basin area of 19.89 km^2 and flows as a perennial stream with a distance of 14.63 km. Perennial drainage density is highest (0.74 km / km^2) among the left bank tributary streams .

Thingsulthliah, Darlawng and Tlungvel villages receives water for domestic usages from Vawmhrawh Lui through pipeline.

Sazuksih Lui & Rulchuk Lui: These are small sub-watersheds but have perennial rivers. They have a small basin area of 4.24 km^2 and 4.25 km^2 respectively. They are under the land of Hualtu village and have a perennial drainage density of 0.5 km / km^2 and 0.4 km / km^2 respectively. They are located in the remote areas under the high degree of slope of Tawi mountain ranges.

Mauawk Lui: It originates from near by the village of Hualtu. The stream has 0.73 km / km^2 perennial drainage density and basin area of 5.94 km^2. It flows as perennial for a distance of 4.35 km before joining the main river of Tuirini.

Zawngsih Lui: It is the southern most stream found in the left bank tributaries of the study area. It joins the main river from the eastern side and flows for a distance of 4.84 km as perennial with a basin area of about 6.93 km^2 and perennial drainage density of 0.7 km / km^2. This is the one source forming the Tuirini river after confluence with the Maudarh stream from the west.

Right bank tributaries

Maudarh Lui: Maudarh stream is one of the main source of Tuirini river situated on the land of Chhingchhip village. It flows towards north with a length of 3.15 km as perennial and has a small basin area of 7.81 km^2 with low perennial drainage density of 0.4 km / km^2. After its confluence with the stream Zawngsih from the east formed Tuirini river.

Lungdin Lui: It is one of the smallest perennial streams inside the study area. It originates in the western hill ranges and pass through a very steep slope. Perennial river flows for a length of only 1.66 km and has basin area of 4.01 km^2 with a drainage density of 0.41 km / km^2. It is under the land of Buhkangkawn village.

Hmar Lui: Hmar lui originates in the villages of Baktawng and Chanin. Three streams with a short length join together and form this stream before joining the main river of Tuirini. It flows for a length of 4.36 km of perennial with the basin area of 7.35 km^2. Perennial drainage density is in the medium class of 0.56 km / km^2.

Minpui Lui: Minpui stream originates between the villages of Khumtung and Phulmawi. It flows towards south east in the upper course and turns to the east side in the lower course before joining the main river Tuirini. It flows for a length of 5.5 km perennial river with the basin area of 11.6 km^2. Due to rugged terrain with steep slopes, the area has a low perennial drainage density (0.47 km / km^2).

Tuizal Lui: Tuizal stream originates under the village of Phulmawi village and flows towards the northern side in the upper course and turns to eastern side in the lower course before joining the main river. It flows for a length of 4.39 km. It has a basin area of 5.98 km^2, and perennial drainage density of 0.73 km / km^2.

Chal Lui: It originates near Phulmawi village and flows towards the northern side and turns to the eastern side and finally joins the main river. It flows for a length of 6.78 km as perennial and has a density of 0.65 km / km^2. It also has a basin area of 10.39 km^2.

Maltliak Lui: Maltliak stream originates between Tlungvel and Darlawng villages and flows to the direction of northeast and runs a length of 4.9 km of perennial river. It and has an area 12.54 km^2. Drainage density of perennial river is very less of 0.39 km / km^2. Most of the areas are highly steep slopes in the upper course of the stream and not favourable for agriculture practices.

Ramri Lui: Ramri stream originates in and around the village of Aichalkawn and has a perennial river of 5.01 km long with an area of 7.81 km^2. The area has a drainage density of 0.64 km / km^2. Due to high degree of slope, the stream does not have potential for irrigation and most of the basin area covered by vegetation.

Sihpui Lui: It originates between the villages of Aichalkawn and Thingsulthliah and flows straight downward and joins the main river, Tuirini. It flows for a length of 3.1 km with an area of 5.16 km^2. It has a perennial drainage density of 0.6 km / km^2. Similar to the neighbouring sub-watershed, undulating topography does not favour agriculture development and it is mostly covered by thick vegetation.

Sathang Lui: Sathang stream is originated near the village of Thingsulthliah and has a length of 2.17 km of perennial with an area of 4.24 km^2. It has perennial drainage density of 0.51 km / km^2.

Thangzai Lui: It is originated between the villages of Thingsulthliah and Thingsul Tlangnuam. It flows straight downward over a length of 2.31 km of perennial river. The basin area is around 4.7 km^2 with a perennial drainage density of 0.49 km / km^2. Due to the steep slope topography in the upper and middle course of the stream in Thangzai and Sathang, it is not favourable for irrigation.

Sakei Lui: Sakei stream originates under the land of Seling village and joined by the other perennial river from the southern side before joining the Tuirini river. It flows for a length of 4.59 km and has basin area 9.82 km^2 with a perennial drainage density of 0.47 km / km^2.

Maumit Lui: Maumit stream originates between Seling and Sesawng villages. It flows straight downward and joins the main river over a length of 2.83 km perennial river and has a basin area 5.91 km^2. The drainage density is only 0.48 km / km^2. The area is mostly covered by the thick vegetation.

Dam Lui: Dam stream originates between Sesawng and C.T.I Sesawng villages. It has a length of 6.05 km with a basin area of14.21 km^2 and has a perennial drainage density of only 0.43 km / km^2. It flows toward north in the upper course of the river and after its confluence with the smaller river from the north, it turns to east and turns again toward South before joining the main river.

Minpui Lui: Minpui stream flows towards the north with parallel to the main river Tuirini under the land of Sesawng village and joins the meandering course of the main river in the lower course. It flows as perennial for a length of 3.81 km with a basin area 9.42 km^2. It has perennial drainage density of only 0.4 km / km^2.

Damdiai Lui: Damdiai stream also flows towards south and originates between the villages of Sesawng and Mualmam. It flows parallel to Minpui stream and joins the main river in the lower course with gentle gradient. It has a length of 5.27 km of perennial stream with basin area of 9.38 km^2. It has perennial drainage density of 0.56 km / km^2.

Phekphe Lui: This stream is the northern most tributary from the west of 2.92 km long perennial stream. It has a basin area of 5.23 km^2 with a perennial drainage density of 0.56 km / km^2. The river flows parallel to Damdiai stream and joins the main river near the confluence of Tuirini and Tuirial rivers.

5.2.3 Groundwater resources

Groundwater resource is considered as one of the most important valuable natural resources which determine the pattern of human settlement and agricultural development. As it occurs in the sub-surface, its delineation is possible only through the study of physical and environmental characteristics. The occurrence and distribution depend on the physical setting including surface and sub-surface characteristics such as lithology, land use land cover, occurence of fractures in the underlying rocks, geomorphic features, structural features and their interrelationship with the hydrological characteristics. (Edet et al. 1998; Kumar et al. 2007; Senthil Kumar and Shankar, 2014) Groundwater demand is drastically increasing due to the immense pressure on population and urbanization, global impact due to climate and weather change, repetitive drought condition and lack of rainfall. (Jaturon *et al.* 2014).

For delineation of the potential zone of groundwater resource in the study area, geo-spatial techniques of remote sensing and GIS have been applied for generating thematic data and assessment through different physico-environmental factors like drainage density, average slope,g, landuse/landcover, Geology, lineament density, average rainfall and soil texture. All the thematic layers were integrated into the GIS domain by weighted overlay analysis for the delineation of groundwater potential zones in the study area. All the factors were assigned weights and ranked based on their relative significance in the groundwater development (Table 5.3). The thematic layer were integrated using raster calculator in spatial analyst tools of ArcGIS software.

The composite layer of the ground water potential zone (Fig. 5.3 & Table 5.4) shows that the very high groundwater potential zone constitutes only 0.25% of the study area, which is 1.03 km^2 and is located along the lower course of the main river valley. High zone covers only 6.46% (26.59 km^2). It is found in the wide river valley side of low altitude and in areas of medium slope. Moderate groundwater potential zone is distributed predominantly in the study area spreading in about 215 km^2 (52.26%) area. Low potential zone covers a vast area of rugged and higher degree of sloping areas with high drainage density zone. It constitutes 38.89 % (159.97 km^2) and very low zone covers 2.14%, which is 8.79 km^2 mostly found along the structural hills with steep slopes.

Table 5.3: Details of the factors responsible for groundwater potential

Sl No.	Factors	Class Name	Class Value	Area	%	Weight	Rank
1	Drainage Density	Very Low	< 1	93.40	22.70	15	9
		Low	1 to 2	133.52	32.46		7
		Moderate	2 to 3	117.23	28.50		5
		High	3 to 4	58.05	14.11		3
		Very High	> 4	9.18	2.23		1
2	Average Slope	Very Low	< 15	70.51	17.14	15	9
		Low	15 to 25	152.02	36.95		7
		Moderate	25 to 35	142.82	34.72		5
		High	35 to 45	41.56	10.10		3
		Very High	> 45	4.48	1.09		1
3	Geomorphology					15	
		Structural valley		5.98	1.45		7
		Valley Fill		4.34	1.05		9
		Low Structural Hill		155.21	37.73		5
		Medium Structural Hill		212.93	51.76		3
		High Structural Hill		32.92	8.0		1
4	Landuse/Landcover	Very dense forest		2.26	0.55	15	9
		Moderately dense forest		152.78	37.14		7
		Open Forest		228.89	55.64		5
		Cropland		10.55	2.57		3
		Waterbodies		1.91	0.46		7
		Built-up		14.98	3.64		1
5	Geology	Shale & Siltstone		266.13	64.69	10	3
		Sandstone		145.25	35.31		8
6	Lineament Density	Very Low	< 0.4	173.87	42.26	10	1
		Low	0.4 to 0.8	66.85	16.25		3
		Moderate	0.8 to 1.2	91.17	22.16		5
		High	1.2 to 1.6	63.88	15.53		7
		Very High	> 1.6	15.62	3.80		9
7	Rainfall	Low	< 2300	32.11	7.80	10	6
		Moderate	2300 to 2500	43.21	10.50		7
		High	2500 to 2700	328.26	79.80		8
		Very High	> 2700	7.80	1.90		9
8	Soil Texture	Loam		2.16	0.53	10	2
		Very Fine Sandy Loam		6.84	1.66		3
		Fine Sandy Loam		51.84	12.60		5
		Sandy Loam		209.45	50.91		6
		Coarse Sandy Loam		129.63	31.51		7
		Loamy Sand		11.45	2.78		9

In the present study, selection of adequate number of relevant thematic layers and proper assignment of weights are key to the success of geospatial techniques in identifying groundwater potential. The final groundwater potential layer prepared would provide first hand information for exploration. The decision makers can formulate an efficient groundwater utilization plan for sustainable development.

Table 5.4: Groundwater potential zones

Sl No.	Class	Area in km^2	%
1	Very Low	8.79	2.14
2	Low	159.97	38.89
3	Moderate	215.00	52.26
4	High	26.59	6.46
5	Very High	1.03	0.25
	TOTAL	411.38	100

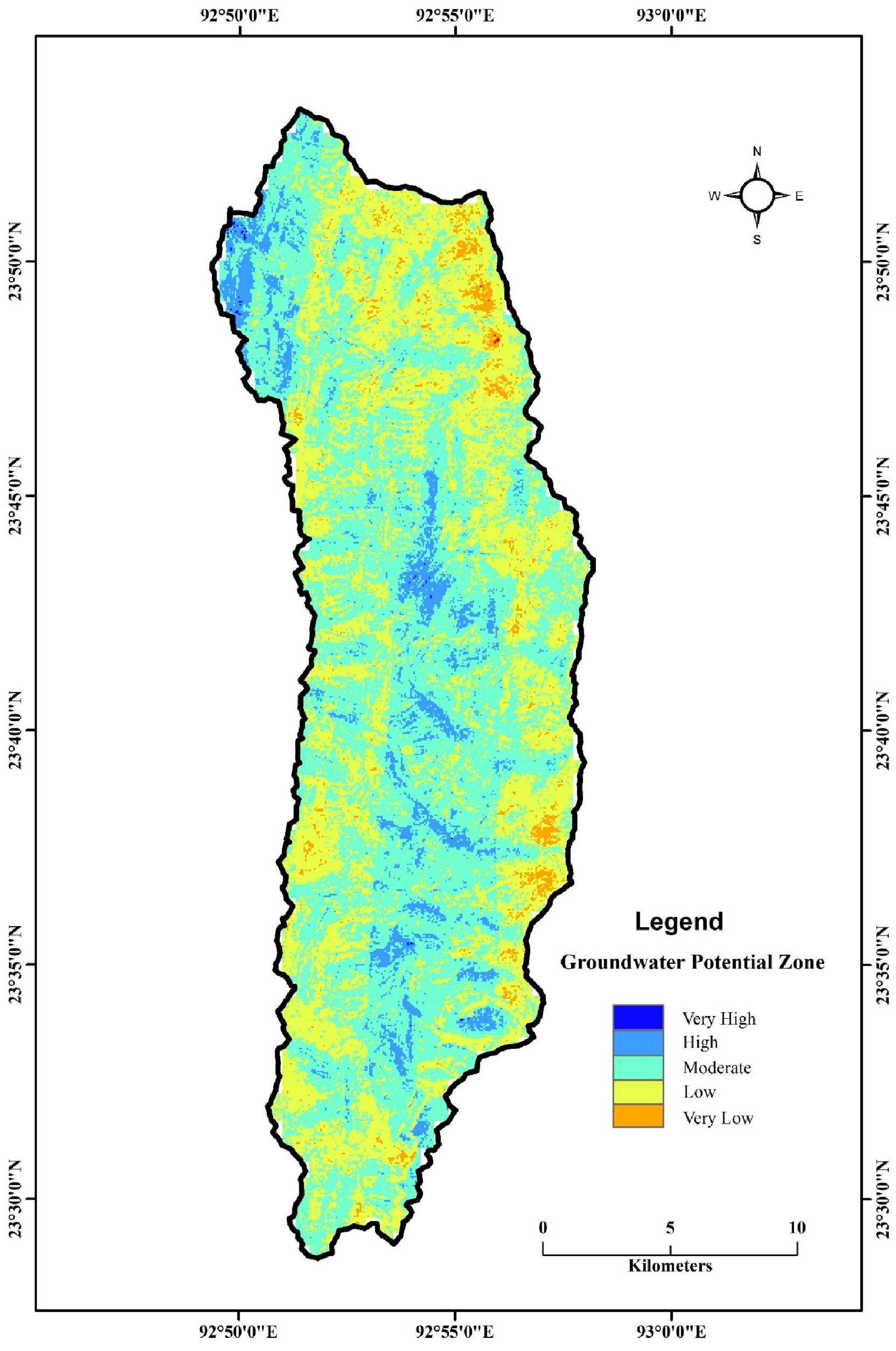


Fig 5.3: Groundwater potential zone map

5.3 Soil resources

Soil is one of the most important natural resources and has a great impact on agriculture and economic development. The physical and chemical characteristics of the soils determine the basis of agriculture development, production and well-being of the human population. (Porwal, 2016).

The physical and chemical characteristics of soils play a very important part in the plant's ability to extract water and nutrients. High quality soils not only produce better food and fibre with high production but also help to establish natural ecosystems and enhance air and water quality.

The knowledge of the physical and chemical properties of soils help in managing resources. Soils need to be studied to improve the fertility of the soil mass thereby increasing the productivity. The studies of relevant status of soil properties are very important to enhance agriculture production on a sustainable basis. Classification of the soil resources in the present study based on Laboratory Testing Procedure for Soil and Water Sample Analysis, Government of Maharashtra (2009). The soil sample points are shown in fig. 5.4 and the details are shown in table 5.5.

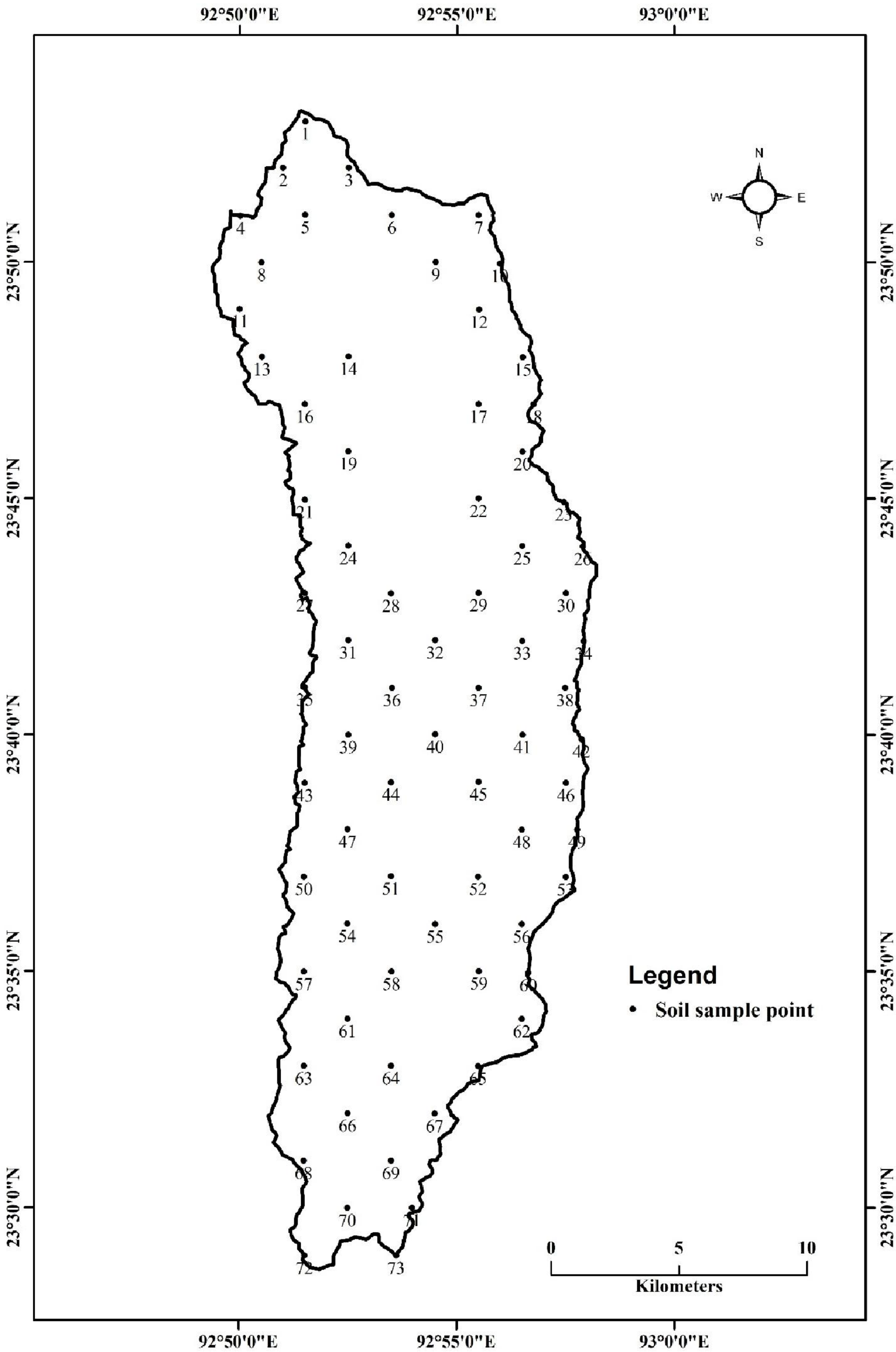


Fig 5.4: Location of soil sample points

Table 5.5: Geographical location of soil sample points

Sample No	Village Area	Latitude	Longitude	Sample No	Village Area	Latitude	Longitude
1	Khawruhlian	23°53'0" N	92°51'30" E	37	Saitual	23°41'0" N	92°55'30" E
2	Khawruhlian	23°52'0" N	92°51'00" E	38	Saitual	23°41'0" N	92°57'30" E
3	Khawruhlian	23°52'0" N	92°52'30" E	39	Thingsulthliah	23°40'0" N	92°52'30" E
4	Khawruhlian	23°51'0" N	92°50'00" E	40	Saitual	23°40'0" N	92°54'30" E
5	Hmunnghak	23°51'0" N	92°51'30" E	41	Keifang	23°40'0" N	92°56'30" E
6	Hmunnghak	23°51'0" N	92°53'30" E	42	Keifang	23°40'0" N	92°58'00" E
7	Khanpui	23°51'0" N	92°55'30" E	43	Darlawng	23°39'0" N	92°51'30" E
8	Sesawng	23°50'0" N	92°50'30" E	44	Saitual	23°39'0" N	92°53'30" E
9	Lailak	23°50'0" N	92°54'30" E	45	Keifang	23°39'0" N	92°55'30" E
10	Vanzau	23°50'0" N	92°56'15" E	46	Saitual	23°39'0" N	92°57'30" E
11	Sesawng	23°49'0" N	92°50'00" E	47	Darlawng	23°38'0" N	92°52'30" E
12	Lailak	23°49'0" N	92°55'30" E	48	Saitual	23°38'0" N	92°56'30" E
13	Sesawng	23°48'0" N	92°50'30" E	49	Ruallung	23°38'0" N	92°58'00" E
14	Sesawng	23°48'0" N	92°52'30" E	50	Darlawng	23°37'0" N	92°51'30" E
15	Tualbung	23°48'0" N	92°56'30" E	51	Lenchim	23°37'0" N	92°53'30" E
16	CTI Sesawng	23°47'0" N	92°51'30" E	52	Lenchim	23°37'0" N	92°55'30" E
17	Tualbung	23°47'0" N	92°55'30" E	53	Mualpheng	23°37'0" N	92°57'30" E
18	Tualbung	23°47'0" N	92°57'00" E	54	Phulmawi	23°36'0" N	92°52'30" E
19	Sesawng	23°46'0" N	92°52'30" E	55	Lenchim	23°36'0" N	92°54'30" E
20	Tualbung	23°46'0" N	92°56'30" E	56	Lenchim	23°36'0" N	92°56'30" E
21	Sesawng	23°45'0" N	92°51'30" E	57	Phulmawi	23°35'0" N	92°51'30" E
22	Tualbung	23°45'0" N	92°55'30" E	58	Phulmawi	23°35'0" N	92°53'30" E
23	Tualbung	23°45'0" N	92°57'30" E	59	Lenchim	23°35'0" N	92°55'30" E
24	Seling	23°44'0" N	92°52'30" E	60	Mualpheng	23°35'0" N	92°51'30" E
25	Tualbung	23°44'0" N	92°56'30" E	61	Phulmawi	23°34'0" N	92°52'30" E
26	Sihfa	23°44'0" N	92°58'00" E	62	Tawizo	23°34'0" N	92°56'30" E
27	Seling	23°43'0" N	92°51'30" E	63	Baktawng(Chanin)	23°33'0" N	92°51'30" E
28	Seling	23°43'0" N	92°53'30" E	64	Hualtu	23°33'0" N	92°53'30" E
29	Saitual	23°43'0" N	92°55'30" E	65	Hualtu	23°32'0" N	92°55'30" E
30	Saitual	23°43'0" N	92°57'30" E	66	Baktawng(Chanin)	23°32'0" N	92°52'30" E
31	Seling	23°42'0" N	92°52'30" E	67	Hualtu	23°32'0" N	92°54'30" E
32	Saitual	23°42'0" N	92°54'30" E	68	Baktawng	23°31'0" N	92°51'30" E
33	Saitual	23°42'0" N	92°56'30" E	69	Hualtu	23°31'0" N	92°53'30" E
34	Saitual	23°42'0" N	92°58'00" E	70	Chhingchhip	23°30'0" N	92°52'30" E
35	Thingsulthliah	23°41'0" N	92°51'30" E	71	Hualtu	23°30'0" N	92°54'30" E
36	Keifang	23°41'0" N	92°53'30" E	72	Chhingchhip	23°29'0" N	92°51'30" E
				73	Hualtu	23°29'0" N	92°53'30" E

5.3.1 Physical properties

Mechanical analyses of the soils have been done to understand one of the most important physical properties of soil like Bulk Density, Porosity and soil Texture.

5.3.1.1 Bulk Density and Soil Porosity

Both bulk density of the soil and porosity reflects the size, shape and arrangement of particles in a pedon. Soil structure gives a good indication of the suitability for plant root growth and soil permeability which are vitally important for the soil plant atmosphere system (Cresswell and Hamilton, 2002; McKenzie et al. 2004).

Bulk density is an indicator of soil compaction and soil health. It affects infiltration, rooting depth/restrictions, water carrying capacity, soil porosity, plant nutrients availability and soil microorganism activity. It is the weight of dry soil per unit of volume typically expressed in grams/cm^3 (USDA-NRCS, 142p2_053260). It is generally desirable to have soil with a low BD (<1.5 g/cm3) (Hunt and Gilkes, 1992) for optimum movement of air and water through the soil.

The study area has bulk density ranges between 1.04 g/m^3 and 1.64 g/m^3 with an average of 1.44 g/m^3 which is fairly comfortable for moving air and water freely. There is no restriction for the growth of roots and the plants can accommodate without any difficulties. The data have a standard deviation of 0.12 reveals that there is a significantly high difference between the minimum and maximum value.

Table 5.6: Details of soil bulk density and porosity

	BD (g/m3)	Porosity (%)
Average	1.44	0.45
Min	1.04	0.38
Max	1.64	0.61
SD (±)	0.12	0.04

Soil porosity is the ratio of the volume of soil pores to the total soil volume. It is a measure of the amount of spaces or pores in the soil that can be filled with either air or water. (CPFE ,1991). Porosity is inversely related to the bulk density and can be calculated through the following formula (Morgan, 2005)

$$n = 1 - (\rho b / \rho s)$$

Where, n = porosity ; ρb = bulk density and ρs= particle density (6.25)

Opposite to Bulk density, higher the bulk density has lower the percentage of porosity. The porosity percent ranges from 0.38 to 0.61 with an average of 45 %. The data have only 0.04% standard deviation indicating a close difference among the data.

5.3.1.2 Soil Texture

Soil in different regions shows different texture, the texture of the soil mostly depends upon the size of particles. The determination of the soil texture analysis consists of the percentage of the particles of different sizes as they exist in the soil. The soil texture has a profound influence on tree and plant growth because of moisture retention, nutrient supplies, aeration and root development. (Porwal, 2016)

The determination of size comparison of sand, silt, and clay particles based on the revised texture class by United States Department of Agriculture (USDA, 1999) System and is one of the most commonly used particle size classification systems. Clays have a particle size diameter of < 0.002 mm, silts between 0.002 and 0.05 mm, and sands 0.05 to 2.0 mm. Percentages of sand, silt, and clay categorize soil particles into different textural classes.

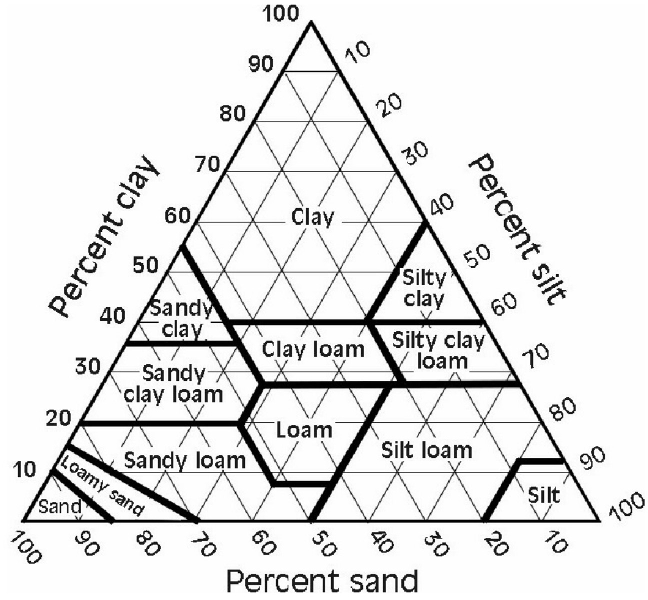


Fig 5.5: USDA-NRCS soil textural triangle

The soil texture analysis revealed that the soil particle size ranging from loam as a finest particle and loamy sand as the largest particle size. Loam soil covers only 2.16 km^2, which is 0.53% of the total area. Loam has the highest percentage of the clay and lowest in sand among the soil texture class. Very fine sandy loam covers 6.84 km^2 with a percentage of 1.66 of the total area. Fine sandy loam is the third largest area covering 51.84 km^2 (12.6%). Sandy loam covers the largest area with half of the total area (50.91%) which is 209.45 km^2. Coarse sandy loam holds the second largest area covering 31.51% (129.63 km^2). Loamy sand covers 11.45 km^2, which is only 2.78 % of the total area. It has highest concentration of sand percent and lowest clay percent. (Table 5.7) The details of the averages (Means) and standard deviation (SD) of the different soil texture class are highlighted under. (Table 5.8)

Table 5.7: Details of Soil texture class

Texture Class	Area in km^2	%
Loam	2.16	0.53
Very Fine Sandy Loam	6.84	1.66
Fine Sandy Loam	51.84	12.6
Sandy Loam	209.45	50.91
Coarse Sandy Loam	129.63	31.51
Loamy Sand	11.45	2.78
Total	411.38	100

Table 5.8: Detail components of Soil texture class

Texture Class	Clay %	Silt %	Sand %
Loamy Sand	4.00 ± 0.71	17.40 ± 2.79	78.60 ± 2.79
Coarse Sandy Loam	6.82 ± 3.05	24.55 ± 3.47	68.64 ± 2.48
Sandy Loam	8.15 ± 1.80	29.69 ± 1.72	62.15 ± 1.74
Fine Sandy Loam	9.31 ± 2.15	33.38 ± 2.58	57.31 ± 1.35
Very Fine Sandy Loam	10.50 ± 6.36	38.00 ± 8.49	51.50 ± 2.12
Loam	12.50 ± 3.54	37.50 ± 0.71	50.00 ± 2.83

Values represent means ± SD

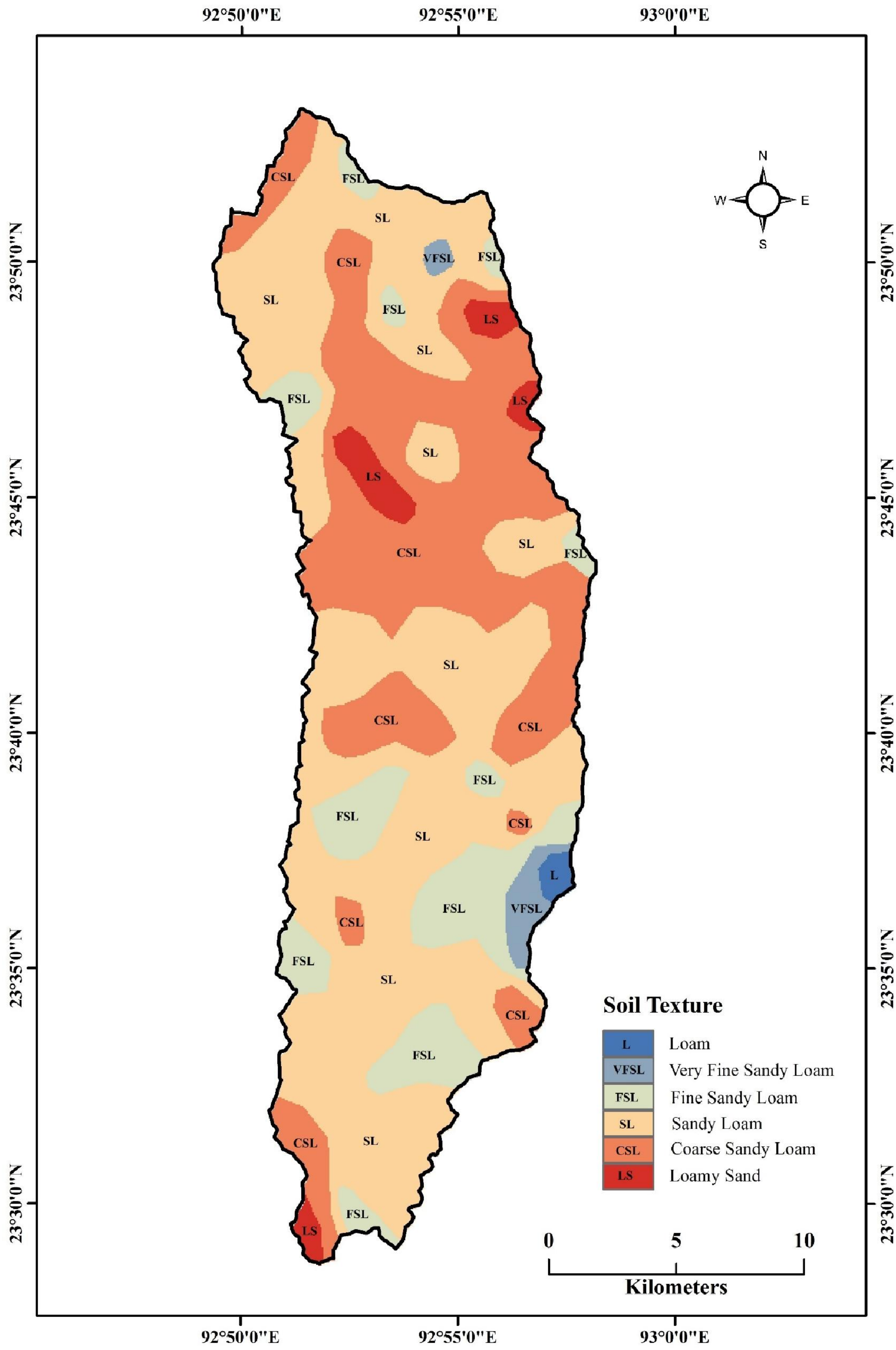


Fig 5.6: Soil Texture in Tuirini watershed

5.3.2 Chemical properties

Chemical property analysis of the soils in this study involves the study of characteristics of soil primary macronutrients (N P K) and available Organic Carbon (%), Organic Matter (%), Electrical Conductivity (EC) and pH of the soil.

5.3.2.1 Available macronutrients:

The soil supplies the essential nutrients for proper plant growth and production. Those nutrients originate from weathered minerals or from decomposing organic matter. Nitrogen, Phosphorous and Potassium are referred to as the primary macronutrients of soil and most important to provide the vitality and performance of the plant growth (Tewari, *et al.* 2016). The analyzed chemical properties of the soils in the study area are presented in Table 5.5.

Available Nitrogen (N):

Nitrogen is a key element in plant growth and is part of the chlorophyll molecule. Plants require nitrogen in order to produce amino acids for building proteins. When deficient in nitrogen, plants become stunted and turn to yellow colour.

Available Nitrogen varies between 150.48 (kg/ha) and 627 (kg/ha), and the average value is 255.10 (kg/ha) which is in a Low class. Due to varied land use / land cover and slope gradient, available nitrogen is unevenly distributed in the study area.

Available Phosphorous (P):

Phosphorus is the second macronutrient next to nitrogen needed for optimal plant growth. The majority of soil P is derived from mineral weathering and organic matter decomposition, but concentrations of plant-available P are generally very low in soils (Schoonoverand and Crim, 2015). Phosphorus is important in developing healthy root systems, normal seed development, uniform crop maturation, photosynthesis, respiration, cell division, and many other processes. Phosphorus deficiency results in stunted plant growth and purple or reddish pigmentation in the older leaves.

Available Phosphorous ranges from 11.5 (kg/ha) to 16.2 (kg/ha), they are in the class of low to moderate. The average available Phosphorous in the study area is 13.78 (kg/ha), which is an intermediate class.

Available Potassium (K):

Potassium is available in greater quantities than any other soil macronutrient and is essential in providing protection against crop disease. However, most of the K within the soil exists as a mineral and is not readily available for plant uptake (Schoonoverand and Crim, 2015). Only 2 % of soil K is readily available for plant uptake and is either in soluble form or exchangeable form (Brady and Weil 2007).

Potassium is responsible for the regulation of water usage in plants, disease resistance, stem strength, photosynthesis and protein synthesis. Deficiency in potassium results in scorching or necrosis of older leaf margins and poor root systems. Potassium deficient plants also develop slowly.

The study area as a whole has a high potassium available in the soil. The available Potassium in the study area varied from 209 (kg/ha) to 277 (kg/ha) falls in the class of moderate to moderately high. The average available potassium is 246.36 (kg/ha) in the class of moderately high in the study area.

5.3.2.2 Organic Carbon (OC) and Organic Matter Content (OM):

Soil Organic Carbon (SOC) is the carbon stored in soil organic matter. The main sources of organic carbon are the decomposition of plants and animal residues, root exudates, living and dead organisms, and soil biota. It is one of the most important constituents of the soil due to its capacity to affect plant growth as both a source of energy and a trigger for nutrient availability through mineralization (USDA).

Organic carbon varied from 0.33 % to 2.67% with an average of 1.36%, which is low to very high with an average of very high class in the study area. Due to cover of vast area by the vegetation, the study area has a good amount of organic carbon in an average. But some areas of thin vegetation cover with higher degree of slope have less chance to accumulate organic carbon content.

Soil organic matters (SOM) have been determined from the available organic carbon, multiplying the percentage of OC by 1.72 (Jaiswal, 2003). Organic matter refers to all organic material including fresh crop residues. Soil organic matter plays an important role in soil physical, chemical and biological properties which helps in creating a favourable medium for biological reactions and life support in the environment (Horwath, 2005). The soil organic matter ranges from 0.57% to 4.57% with an average of 2.34% in the study area.

Table 5.9: Average chemical properties of the soil and its ranks.

	OC (%)	OM (%)	EC ($dS.m^{-1}$)	pH	N (kg/ha)	P (kg/ha)	K (kg/ha)
Average	1.36	2.34	1.23	5.78	255.10	13.78	246.36
Min	0.33	0.57	0.44	4.46	150.48	11.50	209.00
Max	2.67	4.59	3.84	7.84	627.00	16.20	277.00
SD (±)	0.39	0.68	0.68	0.61	93.82	1.15	17.39

Average	Very high		Poor seed emergence	Slightly Acidic	Low	Moderate	Moderately High
Min	Low		Good Soil	Strongly Acidic	Low	Low	Moderate
Max	Very High		Harmful to some crops	Moderately alkaline	High	Moderate	Moderately High

Source: Laboratory Testing Procedure for Soil and Water Sample Analysis, Government of Maharashtra (2009)

5.3.2.3 Soil pH and Electrical Conductivity (EC):

Measuring of pH and electrical conductivity (EC) parameters will provide valuable information for assessing soil condition for plant growth, nutrient cycling and biological activity.

Soil acidity is expressed as soil pH, using the scale from 0 to 14. Soil pH values below 7 indicate acidic nature and above 7 indicate alkaline (basic) nature. Soil pH is a measure of the hydronium ion in the soil solution, which determines the acidity or alkalinity of the soil. It is determined largely by soil composition, cation exchange processes, and hydrolysis reactions associated with the various organic and inorganic soil components, as well as by the CO_2 concentration in the soil gases.

Soil pH affects nutrient solubility and decomposition rates in soil and thereby has a profound effect on the availability of nutrients to plants. A slightly acidic soil pH ranges between 6 and 7 appears to provide optimal nutrient availability to plants, though there are exceptions (Kimmins, 1997).

The soil is slightly acidic in nature (5.78) in the study area as the pH value ranges between 4.46 and 7.84 which are strongly acidic to moderately alkaline. The pH of the soils in the study area varies with location.

Soil electrical conductivity (EC) is a measure of the amount of dissolved salts in soil (salinity of soil). It is an important indicator of soil health. It affects crop yields, crop suitability, plant nutrient availability, and activity of soil micro-organisms. Soil micro-organism activity declines as EC increases. Soil EC is affected by cropping, irrigation, land use type and application of fertilizer, manure, and compost. (USDA-NRCS, 2011)

The electrical conductivity of soils varies depending on the amount of moisture held by soil particles. Generally, Sands have a low conductivity, silts have a medium conductivity, and clays have a high conductivity.

Electrical conductivity has an average of 1.23 ($dS.m^{-1}$), which indicates poor seed emergence. The EC values in the study area range between 0.44 ($dS.m^{-1}$)

indicates the good soil for agriculture practices to 3.86 ($dS.m^{-1}$) which is harmful for growing some crops.

5.3.3 Soil Nutrient Index

Soil Nutrient Index was studied for evaluating soil fertility status for making agriculture practice management and judicious use of fertilizers. The nutrient index approach was introduced by Parker, *et al.* (1951) and has been modified the rating chart by several researchers in different countries. Here the specific rating chart modified by Brajendra, *et al.* (2014) and Chase and Singh (2014) has been adopted to evaluate the fertility status of soils in the study area. Different soil physico-chemical properties that affect nutrient availability including Organic carbon (OC), Organic matter (OM), pH, Electrical conductivity (EC) and available N, P, K were calculated.

In order to compare the levels of soil fertility of one area with those of another it was necessary to obtain a single value for each nutrient. The nutrient index is a three tier system used to evaluate the fertility status of soils based on the number of samples in each of the three classes. Nutrient Index was calculated using the following formula:

Nutrient Index (N.I.) = $(N_L \times 1 + N_M \times 2 + N_H \times 3) / N_T$

where,

N_L : Indicates number of samples falling in low class of nutrient status

N_M : Indicates number of samples falling in medium class of nutrient status

N_H : Indicates number of samples falling in high class of nutrient status

N_T : Indicates total number of samples analysed for a given area.

Table 5.10: Details of the Soil Nutrient Index status

Soil Nutrients	No. of Samples			N.I. Value	Fertility Status
	L	M	H		
OC (%)	1	1	71	2.96	High
OM (%)	2	3	68	2.90	High
EC (dS m^{-1})	31	33	9	1.70	Medium
pH	15	58	0	1.79	Medium
Available N (kg ha^{-1})	55	16	2	1.27	Low
Available P (kg ha^{-1})	52	20	1	1.30	Low
Available K (kg ha^{-1})	0	73	0	2.00	Medium

Nutrient Index value is the measure of nutrient supplying capacity of soil to plants (Singh *et al.* 2016). The soil nutrient index of the study area was calculated from low, medium and high ratings of soil nutrients. If the index value is less than 1.67, the fertility status was low and the value between 1.67-2.33 then the status was medium. If the value is greater than 2.33, the fertility status is high. The EnviStats India (2019) regarding the soil nutrient indices in states of India reported that Mizoram has low nutrient index value of OC and available P, medium nutrient index value of available N and available K in both the first cycle (2015-17) and second cycle (2017-19) respectively. Nutrient index analysis for the study area revealed that soil nutrient values from low to high. In contrast to EnviStats India (2019) report, OC and OM in the study area have the high fertility status of 2.96 and 2.90 nutrient index value respectively. Electrical conductivity (EC) (1.70), pH (1.79) and available K (2.0) show medium fertility status of nutrient index value and low fertility status is found in available N (1.27) and available P (1.30). Here also, available N has the low fertility status contrasting with the report of EnviStats India (2019).

5.4 Forest resources

Forest resources are considered as the essential for maintaining the environmental stability and are related to geo-ecological aspects. Forests are closely interrelated with climatic conditions and have a direct impact on physical and cultural environment, which in turn affect the socio-economic condition of the study area. Forest covers 383.94 km^2 (93.33 %) of the study area in 2018 assessment through the LANDSAT satellite imagery. Forests are mostly found in the river valley but very thick forests are found at the high altitudes in the north eastern and the south eastern corner of the study area.

On the basis of the classification made by Singh et al. (2002), the study area can be classified into three types of forest based on altitude, rainfall and dominant species composition. The classifications is presented here.

1. Tropical Semi-Evergreen Forest
2. Bamboo Forests
3. Jhumland

5.4.1 Tropical semi-evergreen forest

Tropical semi-evergreen forest usually covers the entire region with rich species diversity. Patches of this forest can be seen usually on the steep slopes, rocky and steady river banks. It exhibits clear zonation or canopies consisting of an admixture of numerous species with dense and impenetrable herbaceous undergrowth. Most of the species of the top canopy are evergreen trees with tall trunk. The middle and lower canopies are dense, evergreen and diverse. *Changel* (Musa paradisiaca L. var. Sylvestris) is common and evenly distributed in every parts of the region.

The area is classified into three types of forest on the basis of Forest survey of India classification, viz., very dense forest, moderately dense forest and open forest.

Very dense forests are concentrated only in the high altitude zone of above 1200 metres in Chalfilh peak in the north eastern corner and Tawi mountain ranges in the south eastern corner of the study area covering only 2.26 km^2 (0.55%) (Table 5.10). Moderately dense forest and open forest are found in the hill slopes and river valley. They cover 152.78 km^2 (37.14 %) and 228.89 km^2 (55.64%) respectively in 2018 assessment through satellite imagery.

Table 5.11: Forest resources in Tuirini Watershed

Sl No.	Forest Types	2018	
		Area in km^2	%
1	Very Dense Forest	2.26	0.55
2	Moderately Dense Forest	152.78	37.14
3	Open Forest	228.89	55.64
	Total	383.93	93.33
4	Cropland	10.55	2.57

Source: Landsat Satellite Imagery, 2018

5.4.2 Bamboo forest

Bamboos usually grow as an under-storey to the tree species in the study area, whereas *Mautak* (Melocanna baccifera*)* forms dense or pure forests in certain areas. Large tracts of bamboos are seen throughout the study area but their distribution is somewhat restricted to about 1,200m and above. They occur mostly at altitude below 1,200m and few species occur in the higher altitudes like *Phar* (Sinarundinaria griffithiana / Chimonobambusa griffithiana), *Chal* (Schizostachyum polymorphum) and *Rawngal (*Schizostachyum fuchsianum*)* in areas of Chalfilh and Tawi mountains. It appears that bamboos have resulted from jhumming system of cultivation (Deb and Dutta, 1987). For practicing jhum cultivation the forests are burnt and tree species are destroyed but the bamboo rhizomes throw out new culms as soon as favourable temperature and seasonal monsoon arrive. Therefore, in abandoned jhumland they are the first colonizer and grow rapidly. They are generally common along the river banks.

5.4.3 Jhumland

Jhumland (Cropland) is included in the forest resources due to involvement in the regeneration of forest. It was cleared for only one time and followed by the regeneration to establish new forest. It is a common type of agriculture production in the study area. They are classified variously as current shifting cultivation and abandoned shifting cultivation. Jhumlands are more prevalent in slope areas of both sides of the river banks where extensive and intensive jhumming have been practicing. It is also found in the upper slope mountain region. It occupies an area of 10.55 km^2, which is 2.57 % of the total geographical area.

CHAPTER 6

FARMERS' PERCEPTION ON LAND DEGRADATION

6.1 Introduction

Land degradation may cause a serious threat to current and upcoming agriculture development and sustainability. Deforestation and top soil erosion seems to be the top most serious problems in the rainfed agriculture practicing in the study area. Rainfed agriculture is constrained by water and nutrient stress and top soil fertility loss further aggravates the situation which adversely affects agricultural development and production.

Different forms of land degradation were observed in the study area like soil degradation, deforestation and water scarcity. A wide spatial variability in different forms of land degradation was noticed within the study area through the farmers' responses and their perceptions regarding land degradation on the basis of their experiences.

Understanding farmers' perception on causes and impacts of land degradation and the conservation measures facilitate to give specific proposal for designing appropriate conservation strategies to combat land degradation in the study area. To draw the strategies for sustainable land management, it is important to determine the causes and symptoms of land degradation through both the scientific methods and from the perspective of the inhabitants of the area (Lambin 1993; Martin & Lockie 1993).

Many researchers highlighted that the importance of better understanding of farmer perceptions regarding the causes and effect of land degradation and implementation of sustainable land management measures and their determinants, that will be important to influence policy for future successful adaptation of the agricultural sector (Tegene, 1992; Tesfaye et al., 2014; Gebremedhin, 1998). Therefore, to enhance policy towards tackling the challenges that land degradation poses to farmers, it is important to have full understanding of farmers' perception on land degradation and its severe effects on their agricultural productivity (Tegene, 1992; Tesfaye et al. 2014).

The farmers response to the questionnaire and interview on whether the study area experiences land degradation and its impact on their agricultural lands have shown that 100 % of the surveyed respondents perceived land degradation being a serious problem in their local area. 290 persons were approached and got perceptions from 276 respondents. The local communities have been observing that shifting cultivation especially growing ginger, fuel wood collection and commercial lumbering causes high rate of deforestation and erosion of top soil.

6.2 Soil degradation:

Regarding the soil degradation, the survey result reveals that the high proportions (100%) of the farmers were aware about the problem of soil erosion. Both sheet and rill erosion are the prevailing forms of erosion with 98.9 % and 79.35% respectively in the study area. Gully erosion is also found (14.13%) in the foothill zone where the high velocity runoff with huge volume of water. While doing a ground truth the researcher found signs of flashfloods in many places. Majority of the farmers (73.91%) perceived erosion as severe in their farmland. Therefore, the farmers felt that the crop yields are highly controlled (70.65%) by the intensity of soil erosion and accused the main two causes of crop yield declining are shortening of Jhum cycle (98.91%) and fertility decline (93.48%). These are also followed by soil erosion (85.87%) and continuous cultivation (16.3%) in the agricultural land.

Table 6.1: Soil degradation characteristics as revealed by the respondents (n=276).

Sl No.	Questions	Characteristics	Frequency	Percent
1	Erosion faced in own farm	Yes	276	100.00
		No	0	0.00
2	Prevailing form of Erosion	Sheet	273	98.91
		Rill	219	79.35
		Gully	39	14.13
3	Severity of Soil erosion	Severe	204	73.91
		Moderate	72	26.09
		Minor	0	0.00
4	Impact of erosion on crop yield	Severe	195	70.65
		Moderate	78	28.26
		Minor	3	1.09
5	The rate of erosion over time	Increasing	261	94.57
		Same	15	5.43
		Decreasing	0	0.00
6	Causes of soil erosion	Erosive rain	18	6.52
		Slope Steepness	261	94.57
		Weak conservation measure	150	54.35
		Tillage	231	83.70
		Deforestation	267	96.74
7	Causes of Crop productivity decline	Heavy rainfall	0	0.00
		Rainfall Shortage/Drought	0	0.00
		Fertility decline	258	93.48
		Continuous cultivation	45	16.30
		Soil Erosion	237	85.87
		Shortening of jhum cycle	273	98.91
8	Soil fertility status in own plots	High fertility	21	7.61
		Medium fertility	252	91.30
		Poor fertility	3	1.09
9	Causes of Soil fertility declining	Soil erosion	276	100.00
		Repeated cultivation	21	7.61
		Improper Management	189	68.48
10	Changes in fertility over time	Improving	0	0.00
		Declining	270	97.83
		No change	6	2.17
11	Conservation measure applied/adopted	Yes	39	14.13
		No	237	85.87
12	If Yes, type of conservation measure applied/adopted (n=39)	Contour Trenching	9	23.08
		Changkham	18	46.15
		Terrace	12	30.77
		Others	0	0.00

Multiple response frames were used and some total count is more than number of respondents.

The perceptions about the rate of soil erosion in their area found that highly increasing over time (94.57 %) and no responses as decreasing. And concerning about the causes of soil erosion, deforestation got the highest score (96.74 %), slope steepness (94.57%), tillage (83.7%) and followed by weak conservation measures (54.35%) respectively.

Farmers were also asked about the fertility status of their agricultural land and report that only 7.61 % of farmers perceived their lands as high fertility, 91.3 % judged as the medium fertility and the remaining only 1.09 % respondents feels their land as poor in fertility. Concerning the perception of farmers to the causes of soil fertility decline in their agricultural land, the respondents ranked soil erosion (100%) as the main cause of soil fertility decline and followed by the improper management (68.48%) and repeated cultivation (7.61%). Of the total respondents, 97.83 % felt that declining the soil fertility change over time, only 2.17 % responded as stable over time and none responded as improving the soil fertility over time.

Response regarding the conservation measures adopted and practices in their land reveals that about only 1/7th, which is 14.13 % of the farmers practicing conservation measures in their agricultural land. Among those practices, traditional way of conservation measures 'Changkham' adopted by the major farmers (46.15 %) followed by Terracing (30.77%) and contour trenching (23.08%) respectively.

The farmers perceive that growing of ginger enhance the intensity of soil erosion and leads serious soil degradation. Firstly, they cut down virgin forest for high rate of production and sown ginger and wait for around two to three years before yielding. During that period, they clear the field regularly and plough the land for good yielding. These caused a high rate of soil erosion in the study area and degrade the nutrients leading to soil degradation.

6.3 Deforestation:

The farmers' perception on deforestation in the study area reveals that hundred percent of the respondents accepted the deforestation faced in their own land. The main cause of deforestation is by the local activities of shifting cultivation (100%), fuel wood collection (94.57%) and commercial lumbering (36.96%) respectively. Government activities also caused deforestation in the way of commercial forest plantation (75%) and government flagship programmes like New Land Use Policy (NLUP) (66.3%) and Mizoram Intodelhna Project (MIP) (60.87%), which were followed by road construction (7.61%). Besides these local and government activities, forest fire (6.52%) caused deforestation during the dry season. They felt that after introduction of the NLUP Phase-I, the farmers started to practice shifting cultivation or plantation in their own land. These caused a serious forest fire in every part of the land which cannot be controlled. Before that, all of the farmers had common land for practicing shifting cultivation and can diminish the forest fire. Most of the farmers in different villages highlighted that they would like to abolish commercial forest plantation in their land by the government due to clearing the virgin forest of natural growth for growing the different species of tree and bamboo. They felt that those planting of unnatural species of trees and bamboos disturb the ecosystem and can't replace the natural growth. They suggested that establishment of community-based forest management for conserving the natural growth of forest for checking the forest degradation.

Shifting cultivation is the main dominant type of agriculture practice (80.43%) followed by the horticultural plantation type (53.26%) and terrace farming (13.04%). Wet Rice Cultivation (WRC) type of agriculture practice by only 2.17% due to undulating terrain and less width of river banks.

Table 6.2: Deforestation characteristics as revealed by the respondents (n=276).

Sl No.	Questions	Characteristics	Frequency	Percent
1	Deforestation faced in own land (Village area)	Yes	276	100.00
		No	0	0.00
2	Causes of Deforestation	By Local activities	276	100.00
		By Govt. activities	51	18.48
		By company or organization or society	0	0.00
		Forest Fire	18	6.52
3	If local activities	Fuel wood collection	261	94.57
		Shifting cultivation	276	100.00
		Raw material for House construction	0	0.00
		Commercial Lumbering	102	36.96
4	If Govt. activities	NLUP	183	66.30
		Road Construction	21	7.61
		MIP	168	60.87
		Commercial forest plantation	207	75.00
5	Type of agriculture practices	Shifting cultivation	222	80.43
		Terrace farming	36	13.04
		WRC	6	2.17
		Plantation (Horticultural crops)	147	53.26
6	Land use change occur	Severe	270	97.83
		Moderate	6	2.17
		Minor	0	0.00
		No change	0	0.00
7	Increasing distance of collecting raw materials from forest?	Increasing	276	100.00
		Decreasing	0	0.00
		No change	0	0.00
8	Period of jhum cycle in the past years	Recently	5 to 8	
		15 years back	11 to 15	
		30 years back	22 to 28	
9	Main type of crops	Rice	237	85.87
		Ginger	198	71.74
		Chili	9	3.26
		Vegetables	42	15.22
10	Type of fruit plantation	Banana	216	78.26
		Orange	15	5.43
		Papaya	129	46.74
		Others	12	4.35
11	Type of tree plantation	Teak	18	6.52
		Tung	9	3.26
		Others	0	0.00

Multiple response frames were used and some total count is more than number of respondents.

Farmers felt that land use is highly changing with severe (97.83%) and only 2.17% moderate change. Unfortunately, farmers felt that the forest areas are speedily transformed from dense forest to sparse forest and other land uses. The study areas of Mizo community have tradition of allotting a portion of forest in the vicinity of the village, called Safety Reserve Forest to supply multi-resources for the villagers. But, due to the increasing pressure land use change by socio-economic development and population growth, it is difficult to maintain the traditional way of forest conservation. That affects the distance of collecting raw materials from forest is highly increasing (100%).

Regarding farmers' perceptions on the period of Jhum cycle in the study area for highlighting the duration of fallow period, the farmers reveal that due to the small population leading to less demand for jhum practices, the fallow period was around 22 to 28 years in the past 30 years. It is highly decreasing in the past 15 years back that only 11 to 15 years of fallow period. Recently around 5 years back, the duration of fallow period is reduced to only 5 to 8 years. This is due to the high pressure of demand by the rapidly increasing population and high degree of land use change.

Under the deforestation characteristics in the study area, the researcher included the questions of crop types and types of fruit plantation, because deforestation and types of agricultural practice are directly linked to each other in the study area. Around 85.87 % of the cultivator grown rice and 71.74 % grow ginger as main crop. Vegetables like Cabbage, Mustard, Corn, Brinjal, Pumpkin, Bean, Chilli, Tomato, etc., are also grown for a season. Fruit plantation like Banana, Orange, Papaya, Nimbu, Hatkora, etc., are found in the study area. Regarding the method of agricultural practices in the crop types, the farmer's felt that growing of ginger cause a serious degradation more than the other crops. For growing a ginger, they need to cut down the virgin dense forest for high rate of yielding at the end of the year (November to December). Other type of crops doesn't need to cut the similar type of land and within the same period. In addition to cutting forest type and period, the yielding season is much longer than the other crops. It might need to wait for one and half to three years, based on the market which might be longer than that. Due to these reasons, the ginger growing areas have highly vulnerable to deforestation and soil degradation. The growing method of rice is only within one year and vegetables are only in a season. Generally, fruit plantation areas will not be regenerated as forest cover.

Besides the government activities, local people are also undertaking tree plantation. They are planting Teak especially in the river valley side and Tung in both the river valley and hill side of some particular area. But these are practices only for commercial purpose and don't have impact on reforestation project. The farmers felt that these are the factors of forest degradation mostly due to the replacement of the natural growth of forest.

6.4 Water scarcity

Water is a vital resource to human life and has directly influences the public health and living standard. The demand of water resource is ever-increasing due to rapid urbanization, increasing population pressures, agricultural intensification and the impact of climate change and variability, etc. Water scarcity becomes a crucial limiting factor driving farmer vulnerability. The response of people to water scarcity is now a challenge in all areas of the world and even in the study area especially in the context of the impact on climate and land use / land cover changes.

Most of the villages in the watershed maintained the community-based water management. The village council selected the persons on salary bases to monitor the water supply, condition of the pipelines and source of water condition in the nearby source stream/river. The government provides water supply through pipeline and provide grants to set up a large capacity of water tank. But, all the costs of the maintenance are contributed by the villagers.

Table 6.3: Condition of water scarcity as revealed by the respondents (n=276).

Sl No.	Questions	Characteristics	Frequency	Percent
1	Face water scarcity in dry season	Yes	198	71.74
		No	78	28.26
2	Source of domestic water	Bore well/Hand pump	12	4.35
		Public Tap	213	77.17
		Spring	57	20.65
		Private Connection	87	31.52
3	Main source of water	Bore well/Hand pump	0	0.00
		Public Tap	168	60.87
		Spring	21	7.61
		Private Connection	87	31.52
4	Available throughout the year	Yes	180	65.22
		No	96	34.78
6	Month of water scarcity		Dec-April	
7	Cost of water for a month (in rupees)	Public Tap	30 - 50	
		Private Connection	150 - 300	
8	Satisfied with water supply	Yes	177	64.13
		No	99	35.87
9	If No, reason for dissatisfaction (n=99)	Less Supply	96	96.97
		Improper maintenance	3	9.09
		Others	0	0.00
10	Changing rainfall pattern	Severe	222	80.43
		Moderate	54	19.57
		No change	0	0.00
11	River water volume in dry season	Increasing	0	0.00
		Decreasing	198	71.74
		Rapid Decreasing	78	28.26
	Rainwater harvesting			
12	Harvest rainwater	Yes	69	25.00
		No	207	75.00
13	Have big tank for storing water	Yes	54	19.57
		No	222	80.43
14	Consuming rain water (n=69)	Domestic needs	69	100.00
		Gardening	0	0.00
		Others	0	0.00

Multiple response frames were used and some total count is more than number of respondents.

Table 6.4: Condition of water supply as revealed by the respondents (n=276).

Sl No.	Questions	Characteristics	Frequency	Percent
	Public Tap			
15	How far is public tap from home	In meters	20 to 100	
16	Time taken for fetching	In minutes	5 to 10	
17	Frequency of supply	More than once a day	36	13.04
		Once in a day	12	4.35
		Once in two days	45	16.30
		Once in a week	96	34.78
		Twice in a week	63	22.83
		Twice in a month	24	8.70
19	Frequency of supply pipe broke down	Once in a week	0	0.00
		Once in a month	39	14.13
		Once in a quarter	57	20.65
		Once in a half year	114	41.30
		Once in a year	66	23.91
20	Fixed promptly when breakdown	Yes	231	83.70
		No	45	16.30
	Natural Spring or Artificial spring			
21	How far is Spring from home	In meters	20 to 100	
22	Time taken for fetching	In minutes	10 to 30	
	Private connection			
23	Frequency of water supply	24 x 7	6	2.17
		Once in a day	12	4.35
		Once in two days	15	5.43
		Once in three days	27	9.78
		Once in a week	216	78.26
25	If assistance is needed (n=33)	Bore well/ Hand pump	3	9.09
		Spring	6	18.18
		Public Tap	24	72.73

Multiple response frames were used and some total count is more than number of respondents.

From all of the total respondents, 71 % of the people face the shortage of water supply during the dry season. They use different sources of the domestic water like public tap, private connection, spring and bore well or hand pump. Around 60%

of the respondents used public tap as the main source of water, followed by private connection (31.52 %) and the rest (7.61%) used spring as the main source of water. No one used bore well/ hand pump as the main source of water, they may use as assistance only. Among the respondents, 65.22% felt that the water supply is available throughout the year but less supply during the dry season. On the other hand, 34.78 % felt that the water supply was not available throughout the year and have been facing water scarcity problem.

The people around 35.87 % are not satisfied with their main source of water due to less supply and improper maintenance. They fulfil their needs from spring and bore well/hand pump. They pay 30 to 50 rupees for public tab and 150 to 300 for the private connection per month. The farmers perceive that the dry season holds for five months, starting from December to April in the next year. The more irregular distribution of rainfall in space and time today as compared to the previous years was a matter of concern of the respondents. About 80.43 % of the people observed that the rainfall patterns are severely changed and 19.57 % of the total respondents observed it as moderate change. During the dry season, as compared to the previous years, farmers of 71.74 % felt that the volume of the river water is decreasing and 28.26 % perceived it as rapidly decreasing.

Due to high amount of annual rainfall in the study area during the long rainy season, it seems that the local people did not face water scarcity problem. Unfortunately, more than one-third of the local people faced that problem because only 25 % of the people harvested rainwater through rooftop and used them for domestic needs. Only 19.57 % have a big sized water tanks for collecting and keeping rainwater and 80.43 % do not have such type of tanks and utilized rainwater for their immediate usage.

Among the users of the public tap as the main source of water, they need to walk for around 20 to 100 meters and spend 5 to 10 minutes to collect water. The frequency of water supply is greatly varies in the study area and it also changes with the seasons. Water supply occurs generally once or twice in a week (34.78 % and 22.83%) but some villages received more than that. Some villages received public tap water for once in a six month as observed during field survey. Most of the villages do not have a good source of water in their land and they need to take domestic water for miles by pipeline. The pipeline frequently broke down due to different causes and tried to fix promptly by the community itself. Generally, the local people felt that the supply of water through public tap is irregular during the peak rainy season due to problem of sedimentation and breakage of pipelines during landslide occurance. In the dry season also, there is not enough water to feed the village abundantly.

As mentioned earlier, only 7.61 % people used spring as main source of water but increases users rapidly in the dry season up to more than 60 % due to lack of water supply through public tap and also private connection. Generally, the natural springs are located in an isolated place and need to spend time for collecting water. But in some villages, they construct artificial spring along the major road and take water through pipelines from the nearby stream. But these are also dried up in the dry peak seasons as observed.

Regarding the private connection in the study area, the general frequency of water supply is once in a month as revealed by 78.26% of respondents. But in some villages, where they have good source of water and favourable location, they receive in higher frequency. If they are not satisfied with the water supply, and seek assistance from other sources, mostly by the tankers or sometimes they filled their needs from public tap and nearby springs.

With the intention of understanding the farmers' perception, the respondents were asked to mention the major consequences of land degradation that they have been experiencing. The result reveals how farmers are associated with soil fertility decline, soil erosion, deforestation and its impact on water scarcity, which probably show the land degradation problem and have great opportunity with high chances to promote conservation strategies in the study area. This is essential for achieving a sustainable development and management of natural resources and may be crucial to attain the necessary motivation to make the choice to invest in the land by the farmers.

CHAPTER 7

LAND DEGRADATION DYNAMICS

7.1 Introduction

Land degradation is a global as well as a regional concern because land resources have been facing serious threats of deterioration due to rapid population growth and their excessive utilization of land contrary to its capacity in every corner of the earth. It is required to check further degradation and restoration of the degraded land as much as possible to achieve sustainable land use management. Evaluation of land degradation is difficult to understand as a whole. It cannot be assessed simply by any single measure and need to use different factors of variables as indicators which may show that land degradation has taken place but sometimes they appear as not the actual factors of degradation.

For effective monitoring and accurate assessment of land degradation to achieve sustainable land use management, it is necessary to adopt multiple processes of direct field observation along with the application of modern technological method and also including the perspective of the local people. Above the field observation and collection of local people perception methods, the modern technological tools of remote sensing and GIS techniques is more cost-effective and time-efficient in which a huge land area can be monitored and assessed at regular interval using satellite imagery. In this study, a large number of data have been analysed using different methods of remote sensing and GIS and field observation to determine land degradation.

7.2 Land Use and Land Cover (LU/LC) changes in Tuirini Watershed

Land use and land cover are changing over time due to various physico-environmental and human interferences, but the rate and distribution of changes differ from one place to another based on the several factors. Land use and land cover are closely related and often used interchangeably but have a distinct meaning. Land use refers to various man's activities carried out on the land and land cover denotes natural vegetation, water bodies, rock/soil, artificial cover and others noticeable on the land (NRSA, 1989). Lillesand and Kiefer (2000) also defines Land use as to the human activity or economy related function associated with a specific piece of land and land cover refers to the type of features present on the surface of the earth.

Land use/land cover identification and classification have been analysed by the supervised classification with maximum likelihood algorithm under the environment of Geographical Information System (GIS) and ground truth. Three satellite imageries with different dates of acquisition were analysed to find out the type and size of land covers. The data reveals that forest area covers a very vast area of 93.85 % in 1974 and decreased to 92.55% in 1996 but increased to 93.33% in 2018. Very dense forest and moderately dense forest continuously decreased during the study period but open forest is in opposite to the other forest class. Due to agriculture as the mainstay of economy, cropland covers second vast area after forest. It covers 17.76 km^2 in 1974 and increased to 20.54 km^2 in 1996. Owing to the economic development and changing the mode of activities, cropland cover decreased to10.55 km^2 in 2018. The covers of waterbody almost stable within the period, it covers 0.45 % (1.86 km^2) in 1974 and a little increased to 0.47% (1.94 km^2) in 1996 but declined to 0.46 % (1.91 km^2) in 2018. Built-up land covers have increased rapidly from 1.38% (5.68 km^2) to 1.99% (8.20 km^2) in 1974 and 1996 respectively. It also jumps to 3.64% (14.98 km^2) in 2018.

Table 7.1: Distribution of land use / land cover areas in Tuirini watershed from 1974 to 2018

Sl No.	Landuse/Landcover	Years					
		1974		1996		2018	
		Area in km^2	%	Area in km^2	%	Area in km^2	%
1	Very Dense Forest	9.76	2.37	5.83	1.42	2.26	0.55
2	Moderately Dense Forest	169.31	41.16	162.35	39.47	152.78	37.14
3	Open Forest	207.01	50.32	212.51	51.66	228.89	55.64
4	Cropland	17.76	4.32	20.54	4.99	10.55	2.57
5	Waterbodies	1.86	0.45	1.94	0.47	1.91	0.46
6	Builtup	5.68	1.38	8.2	1.99	14.98	3.64
	Total	411.38	100	411.38	100	411.38	100

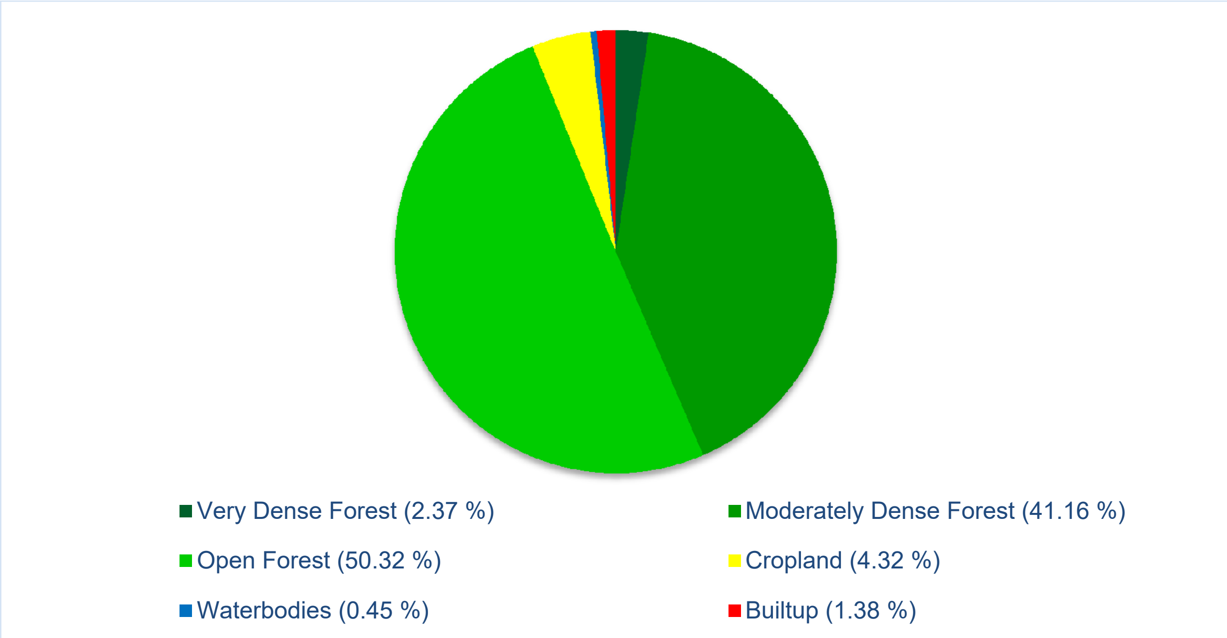


Fig 7.1: Pie-diagram showing the distribution of land use / land cover class in the year 1974.

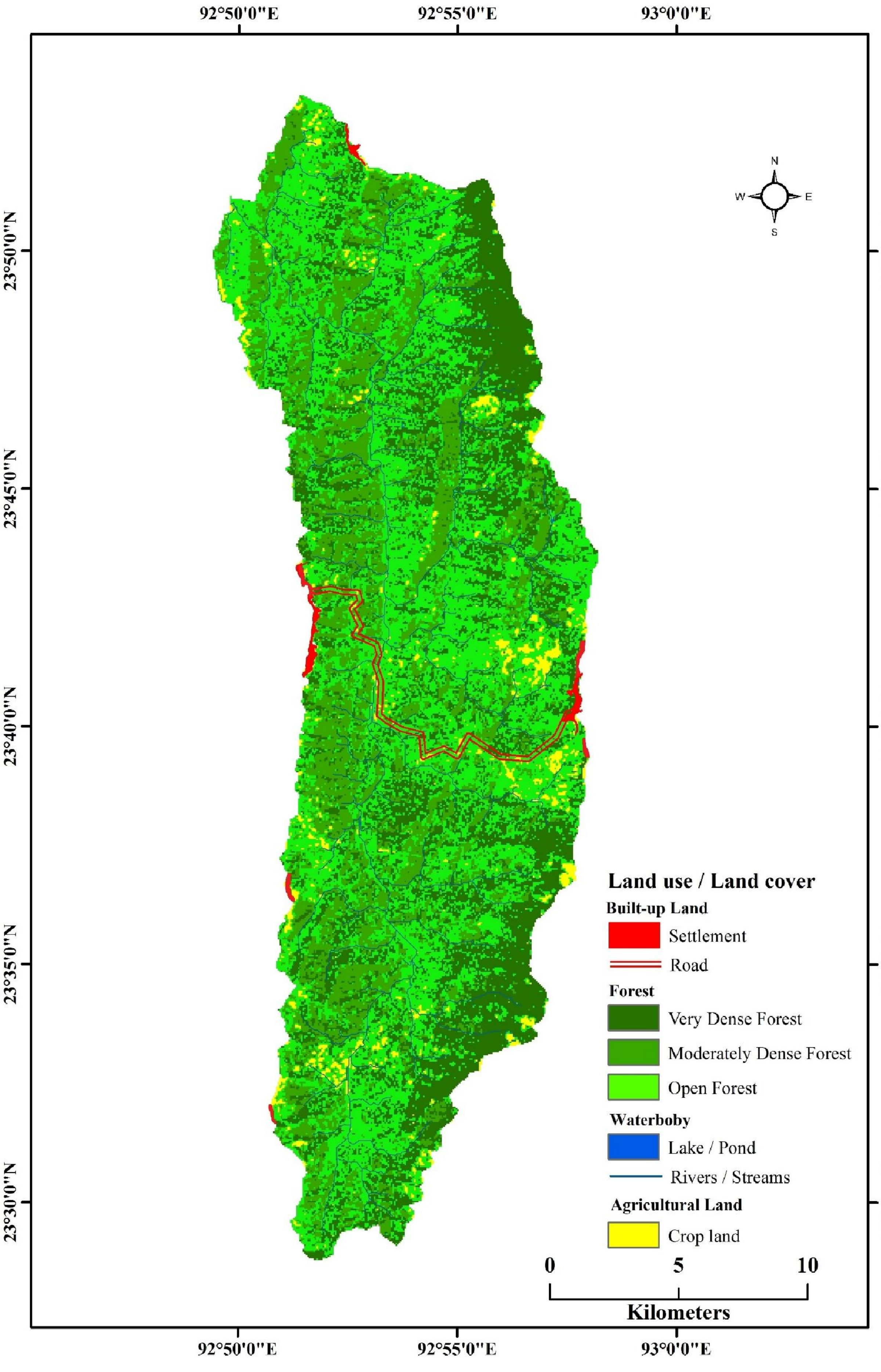


Fig 7.2 : Land use/ land cover pattern in the year 1974.

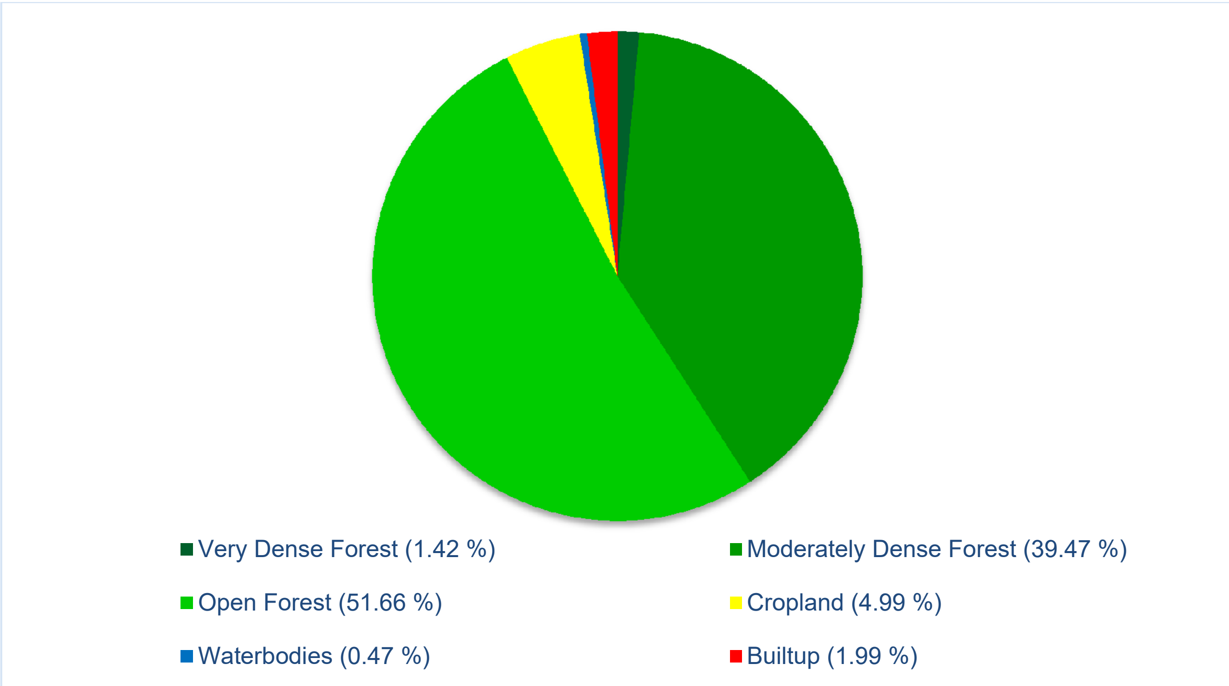


Fig 7.3 : Pie-diagram showing the distribution of land use / land cover class in the year 1996.

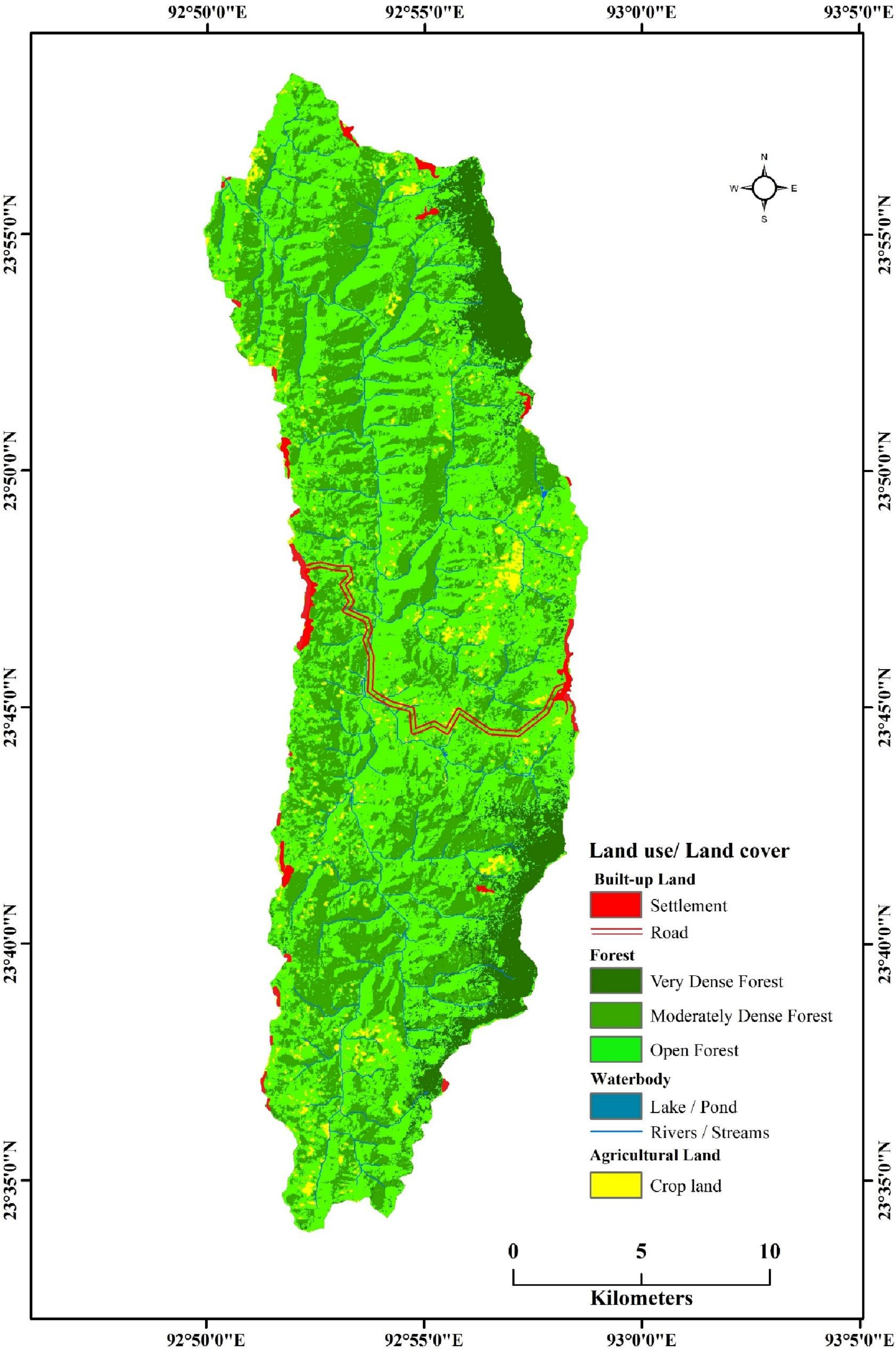


Fig 7.4 : Land use/ land cover pattern in the year 1996.

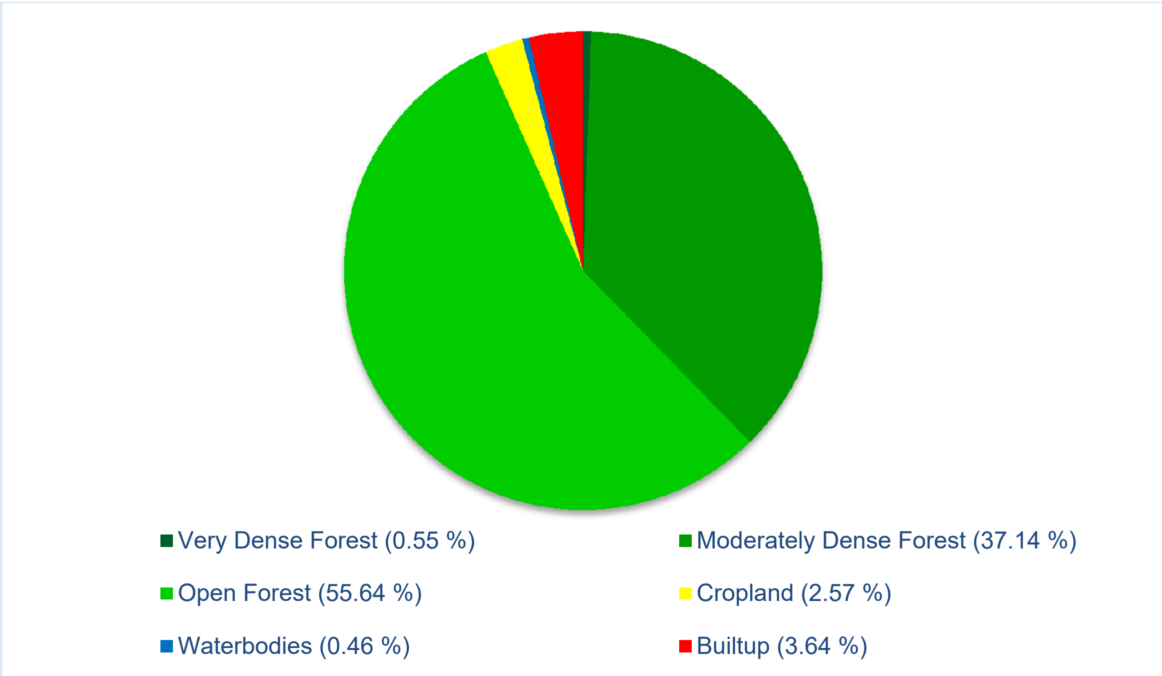


Fig 7.5: Pie-diagram showing the distribution of land use / land cover class in the year 2018.

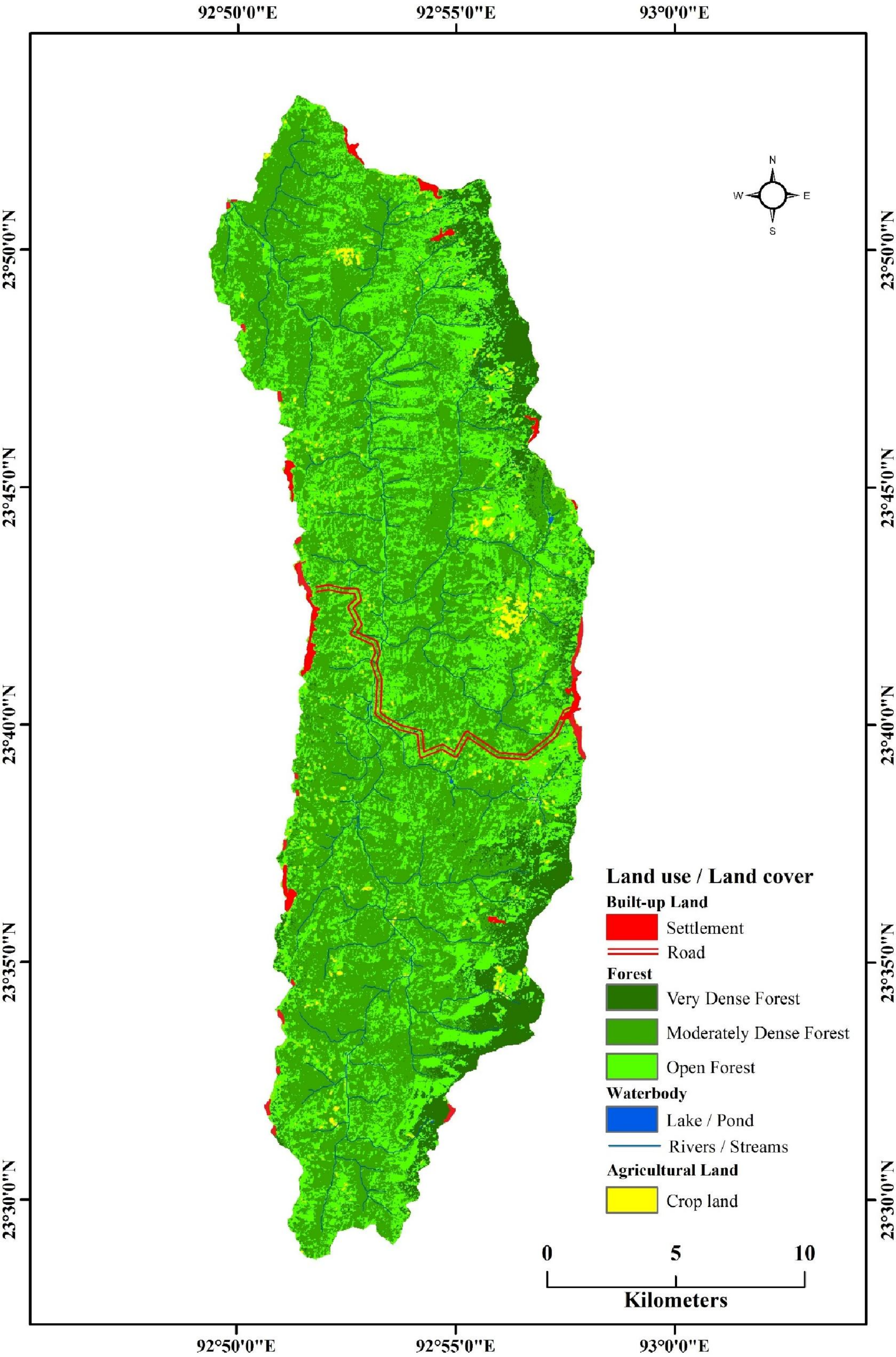


Fig 7.6 : Land use/ land cover pattern in the year 2018.

Multi-temporal satellite imageries were compared to find out the amount of change occurred during the study period. From 1974 to 1996, very dense forest has changed with 40.27% (3.93 km^2) lost and also lost in moderately dense forest with 4.11% (6.96 km^2). In contrast to other forest classes, open forest has positive change with 2.66%, which is 5.5 km^2. Crop land also changed in positive direction with 15.67 % (2.78 km^2). The covers of Waterbody changes in gain with 4.61 %, which is 0.09 km^2 and the built-up area highly increased to 44.37 % (2.52 km^2). In between 1996 and 2018, very dense forest and moderately dense forest covers continuously decreased with a high rate of 61.23 % (3.57 km^2) and 5.89 % (9.57 km^2) respectively. With similar to the trends of previous assessment, the change rate of open forest has increased to 7.7 % (16.38 km^2). Regarding the cropland, negative changes have been found in opposed to the previous assessment with high rate of 48.61 % (9.99 km^2). Waterbodies also have negative change with 1.74 % (0.03 km^2) and Built-up land was highly increased to 82.68 %, which is 6.78 km^2.

In the overall study period of 1974 to 2018, the changes of very dense forest is unexpected with 76.84 % (7.5 km^2) lost. Moderately dense forest is also changed with negative growth of 9.76 % which is 16.53 km^2. Among the forest classes, open forest is the only one having positive change with 10.57% (21.88 km^2). Cropland has lost vast area with 40.56 % which is 7.20 km^2, most of them are transformed to the built-up land. Waterbody increases with slight change of 2.80 % which is only 0.05 km^2. Built-up land has changed surprisingly with 163.73 % which is 9.3 km^2. The rapid expansion of built-up land due to the re-establishment of villages, previously left due to village grouping and setup a new settlements. According to the Census of India 1971, there are only 6 villages found in the study area due to the village grouping in big villages (grouping centre). But in the census data 1991, there are 25 settlements and increased to 29 in 2011 census, it is still constant up to the survey period of 2016-18. The population in this area is also highly increased from 18,712 in 1971 to 27,231 in 1991 and again raised to 37,378 in 2011. From the report of Village Profile & Development Indicators 2017-2018, Mizoram State (2018) and population data collected by the village councils, the number of population is 43,863 in 2018.

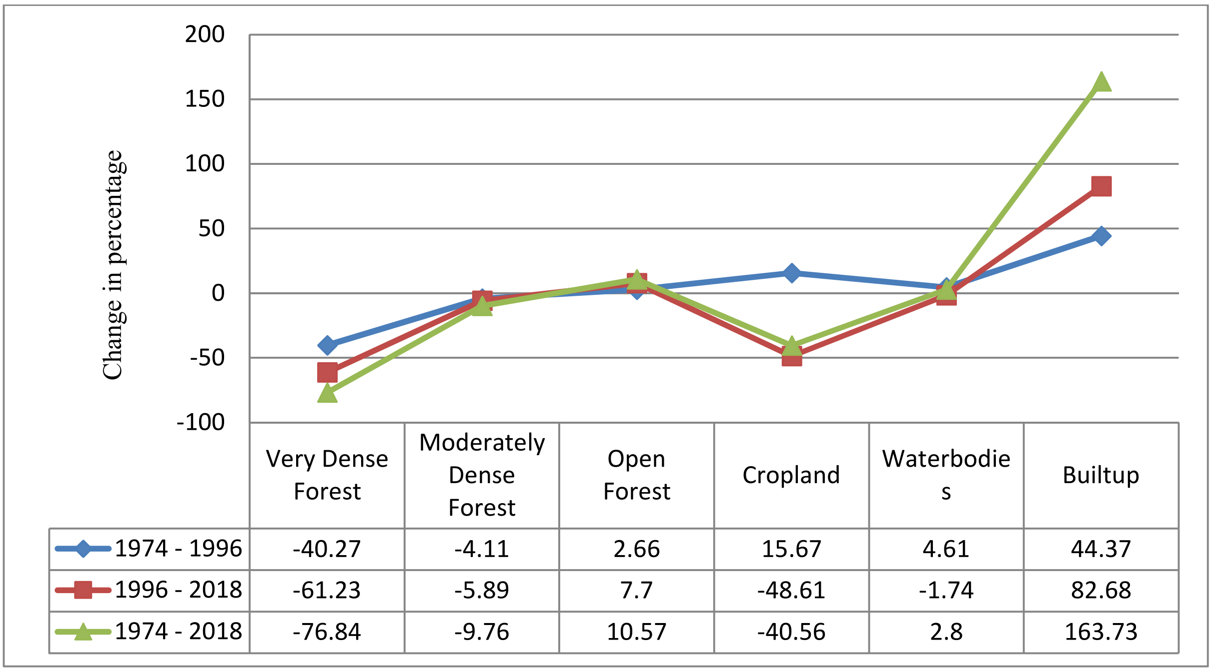
Table 7.2 : Population statistics in Tuirini watershed.

Year	Population (no. of persons)	Change	Population density (no.of persons per km^2)
1971	18712		45
1981	19704	992	48
1991	27231	7527	66
2001	34978	7747	85
2011	37378	2400	91
2018	43863	6485	106

Source : Census of India & Village Profile & Development Indicators 2017-2018, Mizoram State.

Table 7.3 : Landuse/Landcover changes in Tuirini Watershed.

Sl no.	Landuse/Landcover	1974 - 1996		1996 - 2018		1974 - 2018	
		Area in km^2	%	Area in km^2	%	Area in km^2	%
1	Very Dense Forest	-3.93	-40.27	-3.57	-61.23	-7.5	-76.84
2	Moderately Dense Forest	-6.96	-4.11	-9.57	-5.89	-16.53	-9.76
3	Open Forest	5.5	2.66	16.38	7.7	21.88	10.57
4	Cropland	2.78	15.67	-9.99	-48.61	-7.20	-40.56
5	Waterbodies	0.09	4.61	-0.03	-1.74	0.05	2.80
6	Builtup	2.52	44.37	6.78	82.68	9.3	163.73



	Very Dense Forest	Moderately Dense Forest	Open Forest	Cropland	Waterbodies	Builtup
1974 - 1996	-40.27	-4.11	2.66	15.67	4.61	44.37
1996 - 2018	-61.23	-5.89	7.7	-48.61	-1.74	82.68
1974 - 2018	-76.84	-9.76	10.57	-40.56	2.8	163.73

Fig 7.7 : Line graph showing land use / land cover changes in Tuirini watershed (in %).

7.3 Deforestation

Deforestation is one of the most important burning environmental issues that the world is facing today. It is the conversion of forested land to non-forested land and occurs when a land dominated by naturally occurring trees is converted to provide certain services in response to the human demand (Kumari *et al.* 2019). In 2015, The Food and Agricultural Organization (FAO) coordinated with the Global Forest Resources Assessment (FRA) reported that 3.16% is lost in the global forest cover during 1990 to 2015. Rapid industrialization, urbanization and excessive exploitation of forest resources have resulted not only in decline but also in permanent loss of forest cover to an alarming rate (Nagdeve, 2007).

Deforestation plays one of the most significant roles in land degradation because it has direct impact on both the soil degradation and water scarcity. Clearing the vegetative cover exposes the bare soil to the extreme weather of high solar insolation and heavy rainfall (Lawson, 1986) which enhance the soil erosion and deteriorate the soil physico-chemical properties leading to land degradation.

Deforestation can also result into lands that are no longer able to sustain and regulate water flows from rivers and streams (Chakravarty *et al.* 2012).

The forest cover of India was found to be increased since 2013 up to 2019 (Table 1.1, chapter 1), this positive change in the forest cover is mainly attributed to the conservation and management practices that include afforestation activities, participation of local people for better protection measures in plantation areas, etc.

7.3.1 Deforestation in Mizoram

In Mizoram, forest has been playing a very important role in the socio-economic development due to 60% of the economy depends on agriculture and allied activities (Economic Survey 2016-17), which are either directly or indirectly linked to vegetative cover area. Mizoram has vast natural forest resources, according to the State of Forest Report (SFR) 2019, the forest cover in the State is 18,005.51 km^2 which is 85.41% of the State's total geographical area. It has higher score than the national policy, National Forest Policy of India 1988 envisages a goal of achieving 33 % of the geographical area of the country under forest and tree cover. In terms of forest canopy density classes, the State has 157.05 km^2 under Very Dense Forest (VDF), 5,800.75 km^2 under Moderately Dense Forest (MDF) and 12,047.71 km^2 under Open Forest (OF). Forest Cover in the State is decreased by 180.49 km^2 as compared to the previous assessment reported in SFR 2017. Nikhil and Joshi (2009) analyze the forest cover change and deforestation rates in North East India during 1972 to 1999, they reported that Mizoram has 13,860 km^2 (65.72%) of forest cover from the total geographical area in 1972. It decreased to 11,971 km^2 (56.76%) in 1982 and the rate of deforestation was 0.636 % per year of forest cover losses.

Remote sensing technique based forest cover assessment in a periodic manner has been practising since 1987 by Forest Survey of India (FSI). They published the assessment result in a book form as State of Forest Report (SFR) in consecutive year. Forest cover reported in ISFR includes all lands having trees more than one hectare in area with tree canopy density of more than 10%, irrespective of ownership, legal status of the land and species composition of trees (SFR ,2019). Forest cover classified in terms of canopy density classes as in table 7.4.

Table 7.4: Forest classification by Forest Survey of India

Class	Description
Very Dense Forest	All lands with canopy density of 70% and above.
Moderately Dense Forest	All lands with canopy density of 40% and more but less than 70%.
Open Forest	All lands with canopy density of 10% and more but less than 40%
Scrub	Forest land with canopy density less than 10%
Non-forest	Land not included in any of the above classes. (including water)

Source : Indian State of Forest Report, 2019

Due to continuous practice of traditional method of shifting cultivation and rapid urbanization in Mizoram, vast area comprising valuable timber, trees, bamboos and other forest resources have been degraded and fertile land loses its fertility. Most of the thick forest is now concentrated in remote areas in small pockets where the inaccessible rugged terrain exist. Shifting cultivation and fuel wood collection are the two major drivers of forest degradation in this region. Shifting cultivation has played a major significant role towards the economic status of local community and the per capita per day consumption of fuel wood in the region is estimated to be 31.42 kg (ICFRE, 2017). Next to the shifting cultivation and fuel wood collection, there are certain other indirect drivers of forest degradation like excessive exploitation of non-timber forest products, expansion of agricultural area except shifting cultivation, population growth and rapid urbanization and lack of knowledge and awareness about the importance of natural forest resources.

In order to analyse deforestation, the annual rate of change is calculated by comparing the area under forest cover in the same region at different times. To assess the magnitude of the changes of various classes,the compound interest formula was used due to its explicit biological meaning (Puyravaud,2003). It provided changes in the native land use/land cover category.

$$\text{Changerate} = \frac{[\text{Ln}(A_{t_1}) - \text{Ln}(A_{t_0})]}{t_1 - t_0} \times 100$$

Where,

Change rate in percentage per year, At_1 is area of class in current year, At_0 is area of class in base year, t_1 is current year, t_0 is base year and Ln is natural logarithm.

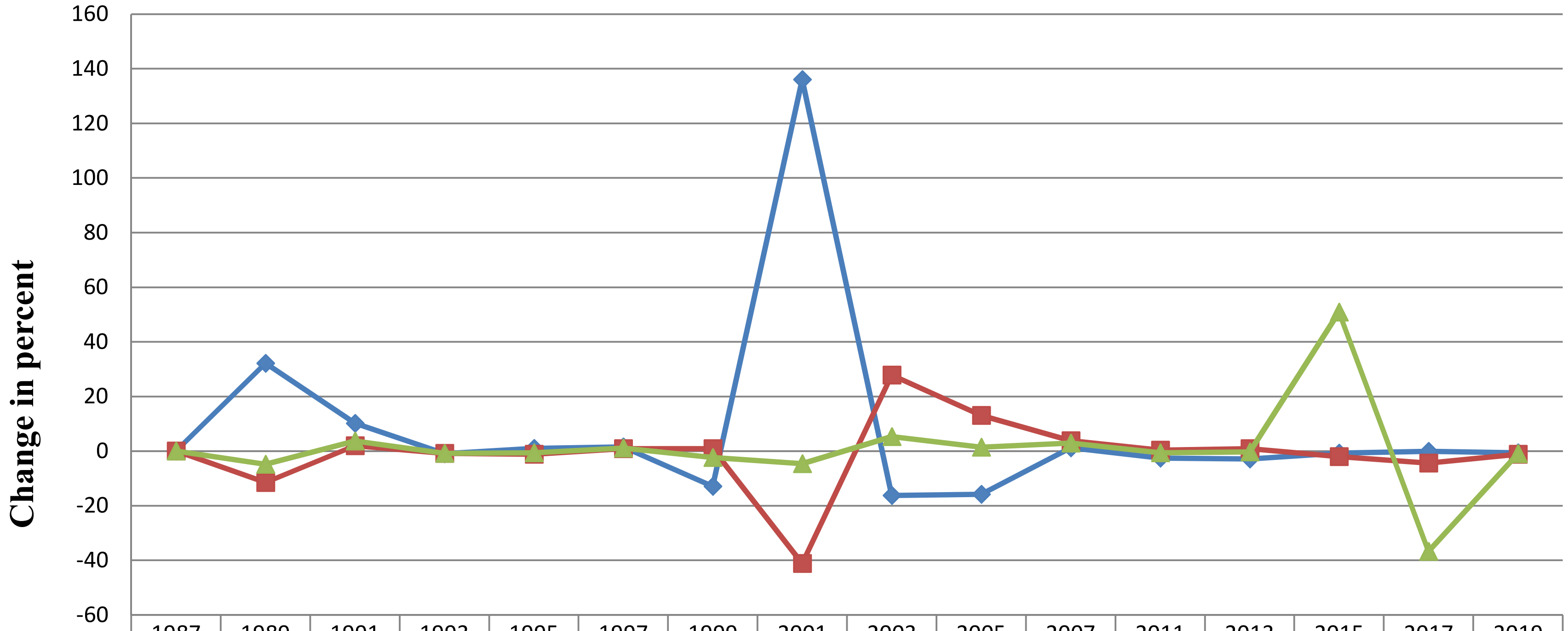
For assessing the rate of deforestation in Mizoram, the rate of forest cover change has been computed since 1987 to 2019 (Table 7.5). The forest has been reclassified into two classes based on the FSI guidelines (Table 7.4), viz., Dense Forest (> 40% Canopy density) and Open Forest (< 40% Canopy density but more than 10 %). The data reveals that the total forest cover area decreases from 19,092 km^2 in 1987 to 18,006 km^2 in 2019, which means about 1,086 km^2 of forest cover area lost within the study period of 44 years. The average change during the study period is 72.4 km^2 lost in every assessment and 0.19 percent per year. The forest cover area has changed with time and shows high fluctuating in some years. The highest forest cover lost found between 2015 and 2017 (10,562 km^2), which means 36.74 % from the total previous forest cover or 22.9 % per year deforestation happened. Followed by 914 km^2 (4.79 % from the total previous forest cover or 2.45% per year) loss in the years 1987-89 and 844 km^2 (4.6% from the total previous forest cover or 2.36 % per year) loss in the years 1999-2001. In contrast to highest loss of forest cover, it increases very high in the previous year of highest loss from the year of 2013 to 2015, here 9,694 km^2 (50.88% from the total previous forest cover or 20.56 % per year) gains within two years only. High increase of forest cover is also found as 936 km^2 (5.35% from the total previous forest cover or 2.61 % per year) in the years 2001-03 and 675 km^2 (3.71% from the total previous forest cover or 1.82 % per year) in the years 1989-91 respectively.

Dense forest cover area increased to 3,020 km^2 between the years 1987 and 2019. It is highly increased in the years 1999-2001, there is 5,150 km^2 (136.03% from the total previous forest cover or 42.94% per year) increase. Another high increase is found in the year of 1987-89, which is 945 km^2 (32.16% from the total previous forest cover or 13.94% per year). But, in recent years, the percentage of dense forest cover area decreases in every periodic assessment except in the year 2007. The highest decrease is found in the years 2001-03, which is 16.2 % from the total previous forest cover (1,448 km^2 or 8.84% per year) followed by the next assessment of 2003-05, 15.79% from the total previous forest cover (1,182 km^2 or 8.59 % per year) respectively.

Open forest cover area decreases from 16,154 km^2 in the year 1987 to 12,048 km^2 in the year 2019, which is 4,106 km^2. Some area was regenerated to dense forest, but most of the open forest area transformed to built-up land and permanent agricultural area. Abrupt highly negative change is found in the years 1999-2001, which is 5,994 km^2 (41.19% from the total previous forest cover or 26.54% per year) lost but followed by the two consecutive high positive change 2,384 km^2 (27.86% from the total previous forest cover or 12.29% per year) in the years 2001-03 and 1,436 km^2 (13.12% from the total previous forest cover or 6.17% per year) in the years 2003-05 respectively. The positive growth continues gradually with a smaller amount of percentage but in the last three assessments, the open forest area changes in negative growth since 2013-15.

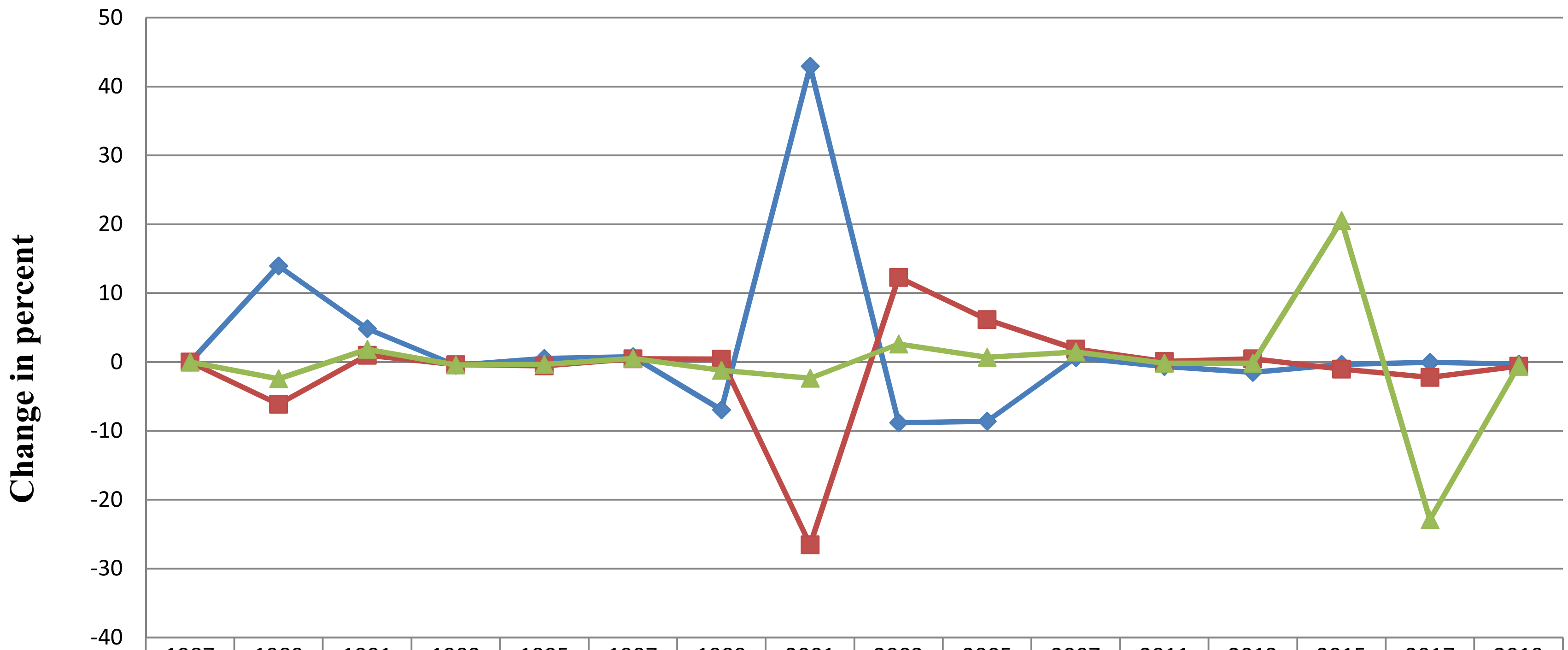
The forest cover area in Mizoram decreases and experiencing deforestation gradually due to the lost of both the quantity and quality of forest resources. The forest changes in percentage from the total previous forest cover and percent per year have rapid unexpected changes from the year 1999 to 2003, these three periodic assessments of five years can be assumed as the transitional period in the forest resources of Mizoram.

Regarding the changes of forest cover in percentage from the total previous forest cover and percent per year, dense forest rapidly changed from 12.93 % (6.92% per year) negative change in the year 1999 to 136.03% (42.94% per year) positive change in the year 2001 and followed by 16.2 % (8.84% per year) negative change in the year 2003. Open forest also changes from 0.87% (0.43% per year) positive change in the year 1999 to 41.19% (26.54% per year) abruptly negative change in the years 2001, followed by rapid positive change of 27.86 % (12.29% per year) in the year 2003. Total forest areas have two consecutive negative changes, 2.33 % (1.18% per year) in 1999 and 4.6% (2.36% per year) in 2001 but continued by positive change of 5.35% (2.61 % per year) in 2003 respectively. Recently, abrupt change happened in the total forest covers area, 0.33 % (0.17% per year) negative change in 2013 rapidly jumps to 50.88 % (20.56% per year) positive change in 2015 and falls to 36.74% negative changes in 2017.



	1987	1989	1991	1993	1995	1997	1999	2001	2003	2005	2007	2011	2013	2015	2017	2019
Dense Forest	0	32.16	10.2	-0.96	1.01	1.57	-12.93	136.03	-16.2	-15.79	1.25	-2.58	-2.93	-0.7	-0.07	-0.57
Open Forest	0	-11.51	1.95	-0.79	-1.13	0.92	0.87	-41.19	27.86	13.12	3.85	0.33	0.92	-2.03	-4.38	-1.21
Total Forest	0	-4.79	3.71	-0.83	-0.65	1.07	-2.33	-4.6	5.35	1.38	2.98	-0.64	-0.33	50.88	-36.74	-0.99

Fig 7.8: Line graph showing forest cover change of Mizoram between 1987 – 2019 (in %).



	1987	1989	1991	1993	1995	1997	1999	2001	2003	2005	2007	2011	2013	2015	2017	2019
Dense Forest	0	13.94	4.86	-0.48	0.50	0.78	-6.92	42.94	-8.84	-8.59	0.62	-0.65	-1.48	-0.35	-0.03	-0.28
Open Forest	0	-6.11	0.97	-0.40	-0.57	0.46	0.43	-26.54	12.29	6.17	1.89	0.08	0.46	-1.02	-2.24	-0.60
Total Forest	0	-2.45	1.82	-0.42	-0.32	0.53	-1.18	-2.36	2.61	0.68	1.47	-0.16	-0.17	20.56	-22.90	-0.50

Fig 7.9: Line graph showing forest cover change of Mizoram between 1987 – 2019 (in % per year).

Table 7.5 : Details of the rate of deforestation in Mizoram.

YEAR	Area in sq km		Change			Area in sq km	Change			Total Area in sq km	Change		
	Dense (>40% Canopy)	TT	Area	%	Rate	Open (10% - 40% Canopy)	Area	%	Rate		Area	%	Rate
1987	2938	2938			0	16154			0	19092			0
1989	3883	3883	945	32.16	13.94	14295	-1859	-11.51	-6.11	18178	-914	-4.79	-2.45
1991	4279	4279	396	10.2	4.86	14574	279	1.95	0.97	18853	675	3.71	1.82
1993	4238	4238	-41	-0.96	-0.48	14459	-115	-0.79	-0.40	18697	-156	-0.83	-0.42
1995	4281	4281	43	1.01	0.50	14295	-164	-1.13	-0.57	18576	-121	-0.65	-0.32
1997	4348	4348	67	1.57	0.78	14427	132	0.92	0.46	18775	199	1.07	0.53
1999	3786	3786	-562	-12.93	-6.92	14552	125	0.87	0.43	18338	-437	-2.33	-1.18
2001	8936	8936	5150	136.03	42.94	8558	-5994	-41.19	-26.54	17494	-844	-4.6	-2.36
2003	84+7404	7488	-1448	-16.2	-8.84	10942	2384	27.86	12.29	18430	936	5.35	2.61
2005	133+6173	6306	-1182	-15.79	-8.59	12378	1436	13.12	6.17	18684	254	1.38	0.68
2007	134+6251	6385	79	1.25	0.62	12855	477	3.85	1.89	19240	556	2.98	1.47
2011	134+6086	6220	-165	-2.58	-0.65	12897	42	0.33	0.08	19117	-123	-0.64	-0.16
2013	138+5900	6038	-182	-2.93	-1.48	13016	119	0.92	0.46	19054	-63	-0.33	-0.17
2015	138+5858	5996	-42	-0.7	-0.35	12752	-264	-2.03	-1.02	28748	9694	50.88	20.56
2017	131+5861	5992	-4	-0.07	-0.03	12194	-558	-4.38	-2.24	18186	-10562	-36.74	-22.90
2019	157+5801	5958	-34	-0.57	-0.28	12048	-146	-1.21	-0.60	18006	-180	-0.99	-0.50
	Average										-72.4	0.89	-0.19

Source : State of Forest Report, Forest Survey of India.

7.3.2 Deforestation in Tuirini Watershed

Assessing the condition of forest resources in the study area, NDVI analysis has been applied and makes thematic map of different time series for the years 1974, 1996 and 2018 keeping 22 years gap. Thematic maps of the forest cover changes were analyzed to identify the magnitude and direction of changes. The forest cover in the study area is 386.08 km^2, which is 93.85 % of the total geographical area in 1974. Very dense forest cover 9.76 km^2 (2.37%), moderately dense and open forest cover 169.31 km^2 (41.16%) and 207.01 km^2 (50.32%) respectively. The forest cover is slightly decreased in the year 1996, which is 380.69 km^2 (5.39 km^2 less than the previous year). Very dense forest and moderately dense forest also declined to 5.83 km^2 (1.42%) and 162.35 km^2 (39.47%). But the open forest is slightly increased to 212.51 km^2, which is 51.66 percent. In 2018, forest cover was improved to 383.93 km^2 (93.33%). Likewise the previous assessments, very dense and moderately dense forest continuously decreasing and open forest increasing. Very dense forest is only 2.26 km^2 (0.55%), 152.78 km^2 (37.14%) moderately dense and open forest is 228.89 km^2 (55.64%) respectively.

Table 7.6 : Distribution of forest resources in Tuirini watershed.

Sl no.	Forest Type	1974		1996		2018	
		Area in km^2	%	Area in km^2	%	Area in km^2	%
1	Very Dense Forest	9.76	2.37	5.83	1.42	2.26	0.55
2	Moderately Dense Forest	169.31	41.16	162.35	39.47	152.78	37.14
3	Open Forest	207.01	50.32	212.51	51.66	228.89	55.64
	Total	386.08	93.85	380.69	92.55	383.93	93.33

Source : LANDSAT Satellite Imagery

The study area has higher score of forest cover in percent than Mizoram (85.41% in SFR, 2019) in every assessment year and is very rich in forest resources. This is due to the presence of Tawi wildlife sanctuary in south east, Chalfilh forest reserve area in north east and Tuirini reserved riverine area along the river in the central part of watershed. Due to set up of settlements on the ridge of watershed demarcation line and steep slopes side, most of the settlement area covers only a small portion of the watershed.

Similar to the other parts of Mizoram, shifting cultivation is the main source of economy in the study area. Based on 2011census, 73 % of the total workers are the agricultural labourers / cultivators. They also practice excessive extraction of forest resources like fuel wood collection, lumbering, extraction of bamboo for commercial purposes and exploitation of non-timber forest products. Besides, unemployment problem and lack of awareness on the importance of environment boost the dependency of local community to forest resources. Contrast to the bad habits of exploitation, the forest resources gradually loses its uniqueness. Very dense forest mostly concentrated in remote areas of the inaccessible terrain.

Forest cover changes are determined significant changes particularly in the dense forest cover area. The changes on the land surfaces were not vast but highly changes in percentage. During the period of 1974 to 1996, the area of very dense forest cover lost is 3.93 km^2, which is 40.27% negative change. It continues to lose in the period of 1996 to 2018 and 3.57 km^2 (61.23%) have been lost. In study period of 1974 to 2018, the total loss of the very dense forest cover is 7.50 km^2, which is 76.84 % within 45 years. Saha *et al.* (2012) highlight that owing to practising shifting cultivation in the hilly region of north east India, there is a drastic reduction in dense forest cover (conopy density >40%) in most of the states. Along with the very dense forest cover loses, moderately dense forest lost its cover of an area of 6.96 km^2, (4.11%) during the period of 1974 to 1996. Between 1996 and 2018, 9.57 km^2 (5.89%) moderately dense forest cover was lost. During the study period of 45 years (1974 to 2018) the total moderately dense forest cover lost is 16.53 km^2 (9.76 %). In contrast to the very dense and moderately dense forest covers area, the open forest covers area changes goes in a positive way. The period of 1974 to 1996 have a positive change of 5.50 km^2 (2.66%) followed by 16.38 km^2 (7.71%) positive change during the period of 1996 to 2018. During the study period (1974 to 2018), 2.88 km^2 (10.57 %) forest cover has been increased. Regarding the total forest cover area, it decreased to 5.39 km^2 (1.40%) between 1974 and 1996 but increased to 3.24 km^2

(0.85 %) in 1996 to 2018. The total forest cover area change is in a negative way of 2.15 km^2 (0.56 %).

Table 7.7 : Forest change rate in Tuirini watershed.

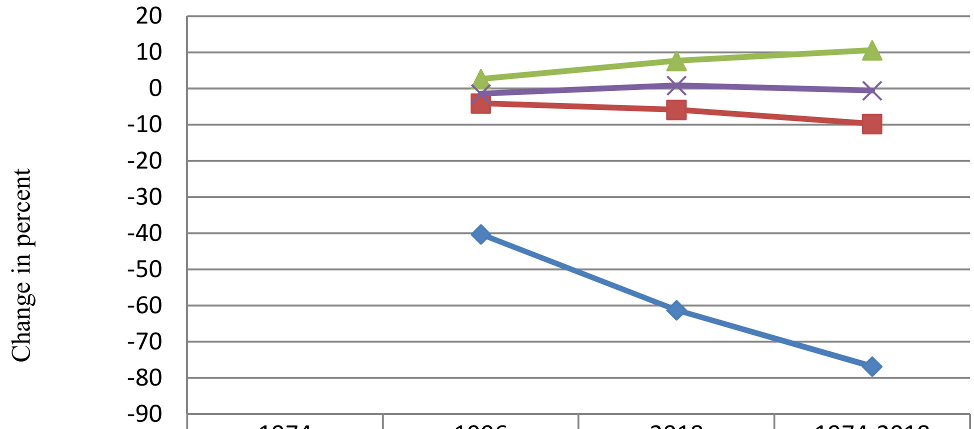
Sl no.	Forest Type	1974 - 1996		1996 - 2018		1974 - 2018	
		Area in km^2	%	Area in km^2	%	Area in km^2	%
1	Very Dense Forest	-3.93	-40.27	-3.57	-61.23	-7.50	-76.84
2	Moderately Dense Forest	-6.96	-4.11	-9.57	-5.89	-16.53	-9.76
3	Open Forest	5.50	2.66	16.38	7.71	21.88	10.57
	Total	-5.39	-1.40	3.24	0.85	-2.15	-0.56

Source : LANDSAT Satellite Imagery

In order to analyse deforestation, the annual rate of change in percentage (Puyravaud,2003) is calculated by comparing the area under forest cover in the same region at three different times interval. During the period of 1974 to 1996 of 22 years, very dense forest decreased to 2.34 % per year followed by moderately dense forest with 0.19% per year. But, the open forest was increased slightly with 0.12 % per year. With the very dense and moderately dense forest, total forest cover decreases to 0.06% per year. In 1996 to 2018, very dense and moderately dense forest still decreasing and the rate of lost percent per year is higher than the previous assessment, with 4.31% per year in very dense forest and with 0.28% per year in moderately dense forest. But found a higher positive change rate than the previous assessment in the open forest with 0.34% per year and also found total forest cover area gain to 0.04 % per year. For the total study period of 1974 to 2018, the lost rate of very dense forest cover is 3.32% per year, and also in moderately dense forest as 0.23% per year. The open forest covers has still positive change to 0.23% per year but the total forest cover declined to 0.01% per year with negative changes.

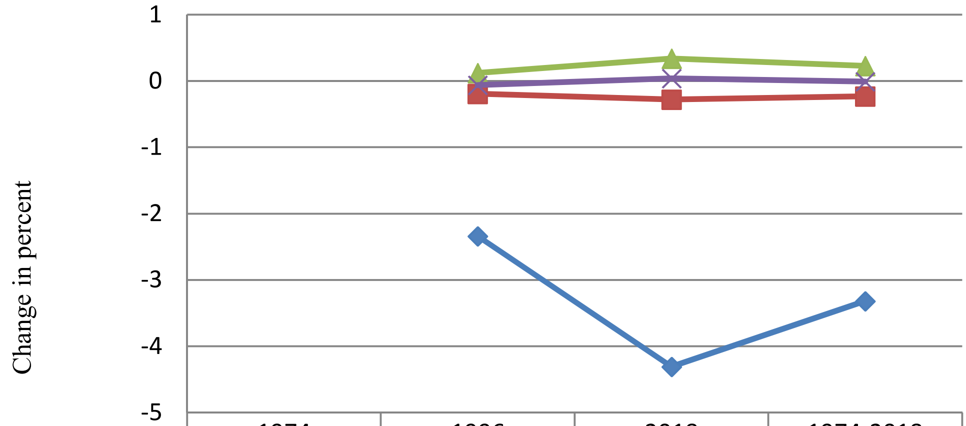
The result shows that the forest loses its quality (canopy density) during the study period and can be assumed that it will be continued further due to excessive exploitation of forest resources as going on. Regarding the total forest cover, it declined first but increased in the next assessment. During the first assessment period between 1974 and 1996, huge amount of fuel wood collection for commercial purpose and bulk lumbering introduced in an around Chalfilh virgin forest area in the mid 1970's. With the same period, the farmers started growing of ginger (Zingiber officinale) in the study area. This is one of the most important causes of deforestation perceived by the farmers because it needs to cut down the virgin forest for high rate of production. Above the destruction of virgin forest, the government of Mizoram introduced a sponsored land development project of Garden Colony scheme during the annual plan of 1977-78. It was expected to abandon the primitive style of shifting cultivation and improved horticulture. That was followed by New Land Use Policy (NLUP) in two phases, in the year 1984-85 for the first phase and 1990-91 to 1997-98 for the second phase. These two phases have direct impact on agriculture practices. Government has provided food in the form of money to the farmers to give full concentration in their farms for higher production. It enhanced the demand of land for agriculture practices like shifting cultivation, fruit plantation, wet rice cultivation, etc., and caused deforestation in the study area. The farmers' perceived that these extensions of agriculture area leads to deforestation and increases forest fires causing forest degradation. In 2000, the government introduced new scheme on Non-timber forest produce (Medicinal plants plantation) in and around Chalfilh forest area. It destructed the regenerating forest of Chalfilh area and lowered the quality as well as the quantity of the forest.

Along with the improvement of literacy rate and development of economic condition, the dependency of community on forest resources are gradually declined. The central government introduced National Rural Employment Guarantee Act (NREGA), later named Mahatma Gandhi National Rural Employment Act (MGNREGA) in 2008 (for particular study area) for the upliftment of rural economic condition and change the ration mode of public distribution system has slightly changed the tradition of agriculture system. Besides, the government implemented the NLUP for the third phase in 2011 addressing the issues of providing stable economy for the state along with the environment protection, land reforms and reclamation. This policy envisaged earmarking of 80% of the total geographical area of the state under forest or green cover. Out of which 70% will be protected dense forest and 10% for community reserve forest (ICFRE,2017). Therefore, the total forest cover was increased in the second assessment.



	1974	1996	2018	1974-2018
Very Dense Forest		-40.27	-61.23	-76.84
Moderately Dense Forest		-4.11	-5.89	-9.76
Open Forest		2.66	7.71	10.57
Total Forest Cover		-1.4	0.85	-0.56

Fig 7.10 : Line graph showing forest cover change of Tuirini watershed (in %)



	1974	1996	2018	1974-2018
Very Dense Forest		-2.34	-4.31	-3.32
Moderately Dense Forest		-0.19	-0.28	-0.23
Open Forest		0.12	0.34	0.23
Total Forest Cover		-0.06	0.04	-0.01

Fig 7.11 : Line graph showing deforestation rate of Tuirini watershed (in % per year)

Table 7.8: Deforestation rate in Tuirini Watershed

Year	Very Dense Forest	Change Area	%	Rate	Moderately Dense Forest	Change Area	%	Rate	Open Forest	Change Area	%	Rate	Total Forest	Change Area	%	Rate
1974	9.76				169.31				207.01				386.08			
1996	5.83	-3.93	-40.27	-2.34	162.35	-6.96	-4.11	-0.19	212.51	5.50	2.66	0.12	380.69	-5.39	-1.40	-0.06
2018	2.26	-3.57	-61.23	-4.31	152.78	-9.57	-5.89	-0.28	228.89	16.38	7.71	0.34	384.93	3.24	0.85	0.04
1974-2018		-7.50	-76.84	-3.32		-16.53	-9.76	-0.23		21.88	10.57	0.23		-2.15	-0.56	-0.01

7.4 Soil degradation

Soil is one of the most important natural resources and cannot regenerated within a short period of time. It takes about 200 years as a minimum for forming the top soil of 2.5 cm or 1 inch thick under cropland conditions, even longer under forest and other conditions (Pimentel, et al. 1995). Soil is a naturally occurring mixture of mineral and organic ingredients with a definite form, structure, and composition. The exact composition of soil changes from one location to another (USDA). According to Joffe (1949) "Soil is a natural body consisting a layer or horizons of minerals and organic constituents of variable thickness which differ from the parent material in their morphology, physico-chemical and mineralogical properties and their biological characteristics". Therefore, the changes of land use/land cover affect the processes and formation of the soil.

Soil degradation is a common problem occurs due to change in land use/land cover and soil erosion in the study area. It causes the change in physico-chemical properties of the soil and affects the decline of fertility and productivity of the soil leads to soil degradation. Many researchers reported that the conversion of land use/ land covers to other forms of land may directly or indirectly affects the physicochemical properties of soils which modify the fertility status and nutrient availability to plants and can provoke serious soil erosion. Researchers like Kenye *et al.* 2019, Sahoo *et al.* 2019, Manpoong & Tripathi, 2019 reported that land use change affects the soil properties in Mizoram. Saha *et al.* (2012), Shimrah & Rao (2015) have also reported that the soil property differs based on the land use/ land cover types in north east India. In other states of hilly region in India experienced this type of soil property variation based on land use change in Nagaland (Bier & Singh, 2018), Uttarakhand (Tewari *et al.* 2016), Jammu and Kashmir (Abassi *et al.* 2007). Besides India, tropical countries of the world experiencing the decline of soil fertility due to changing forest land into other forms of land. (Sombroek *et al.* 1993; Brown and Lugo, 1990; Piccolo *et al.* 1994; Tiessen *et al.* 1994; Fernandes *et al.* 1997; Neill *et al.* 1997; Dominy *et al.* 2002, Ramakrishnan, *et al.* 2003; Lugo *et al.* 1986; Lepsch *et al.* 1994 and Hartemink *et al.* 2008).

The process of soil degradation not only reduces the fertility and productivity, it also accelerates the process of transforming productive land into unproductive land or wasteland. The status of Physico-chemical properties of the soil were analysed through statistical tools like Mean (Average), Standard Deviation (SD), Analysis of Variance (ANOVA) and Multiple Correlation to highlight the soil degradation in Tuirini watershed.

7.4.1 Physical analysis – Bulk Density (BD), Soil Porosity

The analysis of the physical properties of the soil includes the bulk density (BD) and porosity in this study. These two physical properties change their characteristics based on land use/ land cover changes and they are inversely related to each other. This is also reported by Kenye *et al.* (2019), Abassi *et al.* (2007), Celik (2005) and Reiners *et al.* (1994). The study area has an average BD of 1.44 ± 0.12 and Porosity of 0.45 ± 0.04.Very dense forest has the lowest BD values with highest Porosity whereas tree plantations have highest value of BD but lowest Porosity. The soil bulk densities in all the land use / land cover classes were suitable for any agricultural purposes indicating that no extreme soil compaction in the study area.

The lowest mean bulk density of soil is in very dense forest area 1.39 ± 0.17 with a highest porosity value 0.47 ± 0.06. Abassi *et al.* (2007) reported that the forest has the lowest BD values at 0–15 cm depth. The highly significant correlation between BD and OM showed that change in BD is attributes to change in OM content. Kizilkaya & Dengiz (2010) and Gupta *et al.* (2010) also highlighted that natural forest land has high organic matter led to low bulk density and increasing total porosity. The concentration of OC, OM and available N are highest among the other land use / land cover classes and second highest in EC after current shifting cultivation. But, pH (5.74 ± 0.69) and Available K (237.00 ± 113.97) are in the second lowest following tree plantation area. Available P (8.85 ± 2.44) is in the third highest following the other two forest classes.

BD increased to 1.43 ± 0.09 with slightly decreasing porosity (0.46 ± 0.04) in moderately dense forest. The concentration of OC, OM, available N and available P are in the second highest and pH and available K are in the third highest class. But EC is in the second lowest among the other classes.

The open forest has almost similar bulk density and porosity with moderately dense forest, i.e., 1.43 ± 0.09 bulk density in moderately dense forest but has a little increase in SD, which is 1.43 ± 0.11. The porosity also slightly changes the SD from 0.46 ± 0.04 to 0.46 ± 0.03. OC and OM concentration are lowest among the other forest classes but higher than the other land use/ land cover classes. It has the highest value of available P and second highest in pH and available K among all the other classes. Available N is in the second lowest after tree plantation and EC is in the medium class. The similar sequence records of bulk density and porosity under forest covers were found in the study of Mizoram by Saplalrinliana (2016).

Besides the forest classes, current shifting cultivation has the lowest value of bulk density (1.44 ± 0.06) with a medium porosity among the other classes. It seems that the bulk density doesn't change much within a short period of one agricultural year. Current shifting cultivation has highest EC and available K among the land use/ land cover classes but lowest in pH and available P. Among the land use/land cover classes except forest, CSC has highest concentration of OC, OM and available N.

Tree plantations have highest and lowest value of bulk density and porosity due to the Teak tree (Tectona grandis) plantation. Sharma (2015) highlighted that Teak tree (Tectona grandis) plantation area has incomparable very high bulk density value due to having relatively less moisture content. Besides, it is found in the well drain very steep slope site. Therefore, the tree plantation area becomes highest and lowest in bulk density and porosity among the land use/ land cover classes. It has highest value of pH but lowest in Available N and available K. Concentration of OC, OM and available P are in the second lowest class and EC is in the third high.

Fruit plantation (Horticultural practice area) has the second highest bulk density value of 1.53 ±0.07 with a porosity of 0.42 ± 0.03 due to land management system under plantation activities like regular clearance of the land surface through weeding and removal of the fallen leaves and leads to intensity of soil erosion. Therefore, the concentration of OC, OM and EC are lowest among the studied land use/ land cover classes. Available NPK and pH are also in the lower class.

Similar result with the other reports inside Mizoram, NE India and other tropical countries, bulk density doesn't related with the OC and OM, they are highly negative correlated with a value of -0.791 and -0.790 respectively. EC also does not correlated with BD (-0.317) but the pH have significant correlation (0.551). The primary macro-nutrients (NPK) have also negative correlation with BD. Among these, available N have highly negative correlated with BD (-0.701) and the other available P and available K have -0.362 and -0.357 respectively. In contrast to bulk density, porosity has highly positive correlation with OC (0.811), OM (0.812) and available N (0.678). Low to moderate correlation found in EC (0.317), available P (0.443) and available K (0.345) (Table 7.11). The result of ANOVA highlight that there is a significant change (<0.05) of bulk density (0.036) and porosity (0.032) among the different studied land use/ land cover classes (Table 7.12).

The changing value of bulk density in different land classes reveals the soil degradation in the study area. The lowest bulk density of soil with highest porosity zone of very dense forest area has thick vegetative covers and rain water can penetrate easily. It enhances the infiltration rate and reduced the surface runoff. On the other hand, the soil having high bulk density and low porosity accelerates the intensity of surface runoff and caused high rate of soil erosion. Decline in porosity leads to reduced pore size distribution and diminish the infiltration rate. Besides, the increasing bulk density of soil disturbs the growth of plant roots and reduces the capacity of growth of plants. These have direct impact on productive capacity of the soil and lead to soil degradation.

Table 7.9: Changing the soil physical properties in Tuirini watershed.

Land use/ Land cover	BD (g/m^3)	Porosity (%)
Very Dense Forest	1.39 ± 0.17	0.47 ± 0.06
Moderately Dense Forest	1.43 ± 0.09	0.46 ± 0.04
Open Forest	1.43 ± 0.11	0.46 ± 0.03
Current Shifting Cultivation	1.44 ± 0.06	0.45 ± 0.02
Tree Plantation	1.57 ± 0.10	0.41 ± 0.04
Fruit Plantation	1.53 ± 0.07	0.42 ± 0.03
Overall	1.44 ± 0.12	0.45 ± 0.04

Values represent means ± SD

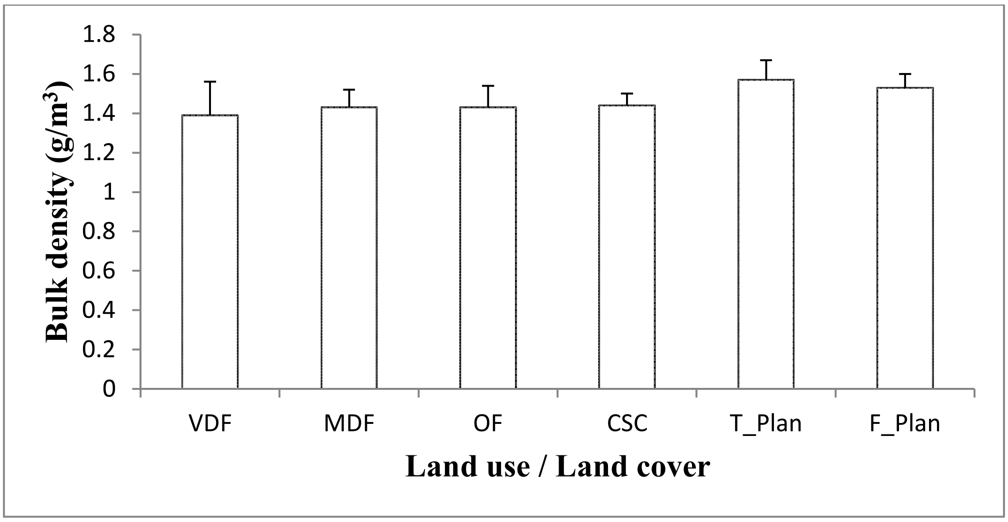


Fig 7.12 : Bar graph showing average and standard deviation of soil bulk density

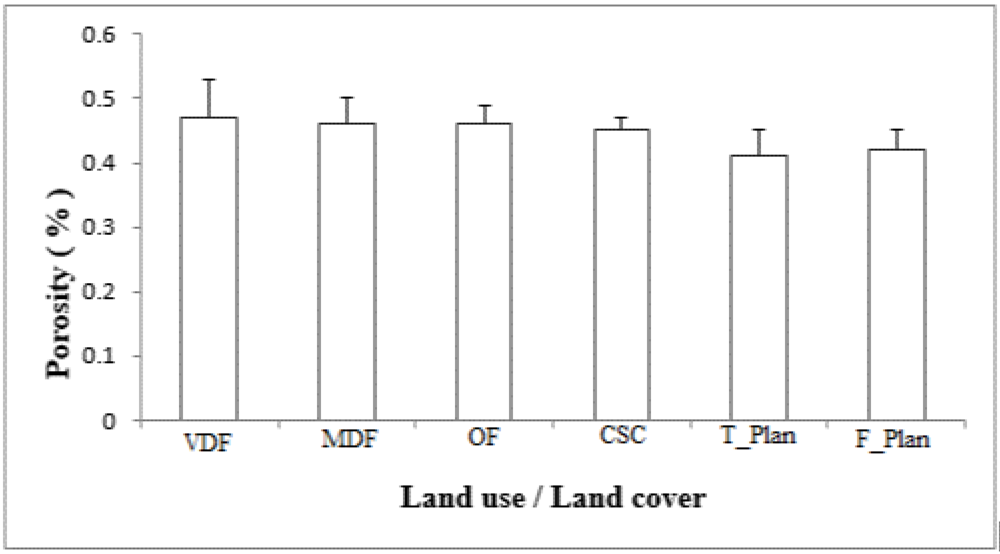


Fig 7.13 : Bar graph showing average and standard deviation of soil porosity

7.4.2 Chemical analysis

The chemical properties of the soil are the interactions of various chemical constituents among the soil particles and soil solution. The analysis of the chemical properties of the soil includes available carbon content like soil organic carbon (OC) and organic matters (OM), measure the concentration of dissolved salts in the soil as electrical conductivity (EC) and pH (Hydrogen ion concentration) and the primary macro-nutrients needed in greater quantities limiting plant growth like nitrogen (N), phosphorous (P) and calcium (K).

7.4.2.1 Organic Carbon and Organic Matter

Similar with the physical properties, the chemical properties of the soil also changes with changing the land use/land cover. Dengiz et al. (2006) ; Singh et al. (2009) ; Sahoo *et al.* (2019) highlighted that land use/land cover change is one of the key factors which affect the soil organic carbon. The reasons for this being the rate of input (e.g. plant litter) and rate of output (e.g. OC mineralization) of soil organic matter (OM) as a result of alterations in plant community and land management practice. Van der Werf *et al.*(2009) ; Chen *et al.* (2010) ; Lungmuana *et al.* (2016)

pointed out that soil organic carbon is the key indicator of soil health which acts as a store house for the plant nutrients, balancing of nutrients and maintaining physical condition of soil and support soil biota communities. Campbell *et al.* (1996) ; Horwarth (2005) reported that Soil organic matter plays an important role in soil physical, chemical and biological properties, which helps in creating a favourable medium for biological reactions and life support in the soil environment.

The concentrations of OC and OM go hand in hand and have a perfect positively significant correlation (+1). The average amount of OC and OM in the study area is 1.36 ± 0.18 and 2.34 ± 0.68 respectively. Very dense forest has the highest concentration of OC and OM (1.56 ± 0.55 & 2.69 ± 0.95) followed by the moderately dense forest (1.42 ± 0.40 & 2.45 ± 0.69) and Open forest (1.32 ± 0.35 & 2.28 ± 0.61). The three high amounts of OC and OM found in the classes of forest. Similar result was found by Saplalrinliana (2016); Sahoo *et al.* (2019); Kenye *et al.* (2019) in Mizoram, Bier & Singh (2018) in Nagaland, Kharal *et al.* (2018); Datta*, et al.* (1983); Khera and Kahlon (2005) in other areas.The highest concentration of OC and OM in the forest can be related to the presence of more vegetation generating more litter falls which are returned to the soils as organic matters and due to high level of inputs (leaf litter and root biomass) from the forest trees and its recalcitrant nature thus preventing microbial decomposition (Sahoo *et al.* 2019 and Kenye *et al.* 2019).

After forest area, current shifting cultivation has high amount of OC and OM content (1.29 ± 0.25 & 2.21 ± 0.42) rather than other tree and fruit plantation area. Sahoo *et al.* (2019) highlighted that may be attributed to the addition of burnt and partially burnt organic matter in the shifting cultivation area during slash and burn treatment. Similar results were also reported in shifting cultivations systems of Kangchup Hills, Manipur, North-East India (Binarani *et al.* 2010). But studies carried out in the study area reveals a decline in OC and OM on conversion of forests to shifting cultivation. As shifting cultivation involves slashing and burning of the natural forest, it has a damaging effect on the soil organic carbon, reduced nutrients and soil quality due to the huge biomass loss (Saha et al. 2012; Osman et al. 2013;

Guillaume *et al.* 2015; van Straaten *et al.* 2015; Singh *et al.* 2018; Kenye *et al.* 2019; Manpoong and Tripathi, 2019) Another reason might be due to the steep slope condition of the region combined with heavy rainfall which leads to incidence of more soil erosion consequently leading to loss of OC and OM of the surface soils.

Fruit plantation areas have 1.13 ± 0.18 and 1.94 ± 0.31 of OC and OM content in the study area respectively. Due to continuous land management system under plantation activities as regular clearance of the land through weeding and removal of the fallen leaves leads to high rate of soil erosion and limited time for decomposition to form huge concentration of biomass. Polyakov and Lal (2004) highlighted that continuous cultivation practices cause considerable losses of SOM and other nutrients. It minimizes the soil permeability by the destruction of soil structure and these changes have an effect on the soil quality status and the agricultural productivity (Bhuyan *et al.* 2013).

Tree plantations have the lowest concentration of OC and OM (1.25 ± 0.15 and 2.15 ± 0.26). It also has the highest value of bulk density and lowest value of porosity. In the studies of soil organic carbon stock of different land uses of Mizoram by Kenye *et al.* (2019) highlighted that the concentration of OC in teak plantation less than the natural forest and shifting cultivation. Tree plantation mostly found in well drained steep slope region which increase the runoff speed and may reduce the growth of small plants underneath leads to reduce the input of litter thereby affecting the soil carbon stock.

The result of changing the amount of OC and OM based on land use/ land cover reveals that the soil degradation happened in the study area. Through the analysis of variance (ANOVA), there is no significant variation of OC and OM among the different land use/ land cover classes (Sig. 0.168). The reason might be the short reforestation period and short term use of the land. But, it is possible to see the changing trends in different classes and can simply say that more than 80% of the confidence level found in soil degradation. Soil OC and OM have highly positive correlated with soil porosity (+0.81 and +0.81) and available N (+0.82) but highly negative correlated with Bulk density (-0.79 and -0.79). They also have a positive correlation with EC (+0.43 and +0.42) and available P (+0.33 and +0.35) but negative correlated with pH (-0.28 and -0.27) and available K (-0.23 and -0.23).

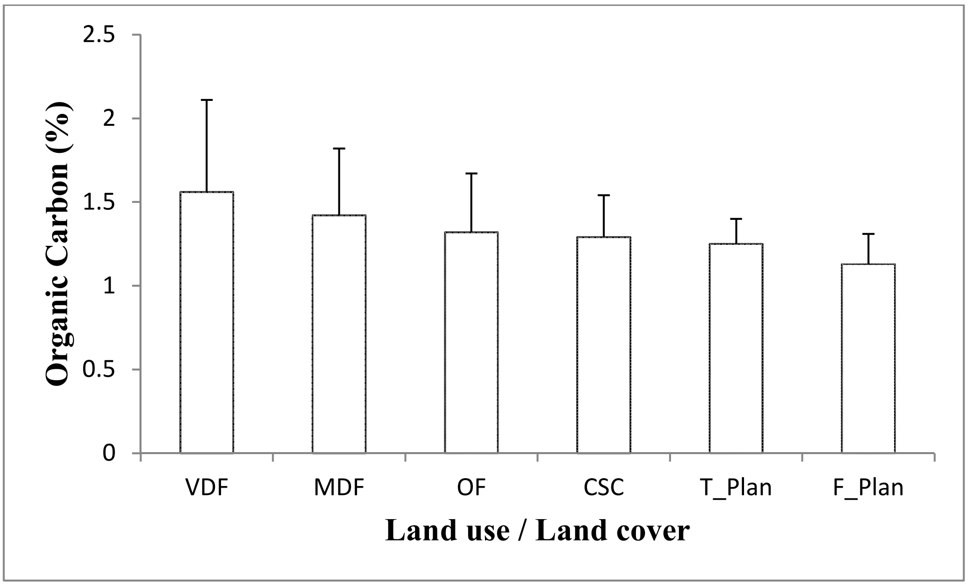


Fig 7.14: Bar graph showing average and standard deviation of soil organic carbon

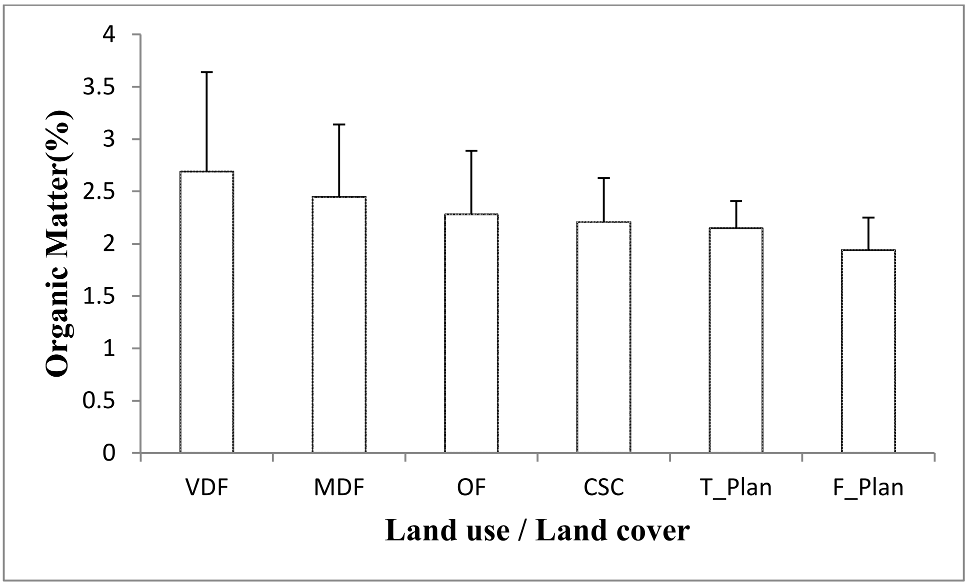


Fig 7.15: Bar graph showing average and standard deviation of soil organic matter.

7.4.2.2 pH and Electrical Conductivity (EC)

The average value of pH in the study area is slightly acidic in nature with a narrow pH ranging from 5.61 to 6.07 among the different land use/ land cover classes. The similar result is also reported by Lungmuana *et al.* (2016) and Manpoong and Tripathi (2019) in Mizoram and Sen *et al.* (1997) in northeast India. The highest value of pH found in the tree plantations area (6.15 ± 0.54) followed by open forest (6.07 ± 0.60). Fey *et al.* (1990) reported that soils under plantations typically become more acidic the effect usually being ascribed to the uptake of basic cations into the forest biomass. Moderately dense forest (5.86 ± 0.45) has similar value with fruit plantation area (5.86 ± 0.46) and very dense forest has 5.74 ± 0.69. In contrast to the other reports from tropical countries (Kharal *et al.* 2018; Islam and Weil, 2000; Abassi *et al.* 2007; Tewari *et al.* 2016) the current shifting cultivation has the lowest pH values of 5.61 ± 0.85 in the study area. The reason might be the period of soil sample collection, higher slope and usage of different chemical fertilizers. Another reason might be due to the penetration and percolation of surface material to the subsurface soil depths due to heavy rain during the monsoon season. But along with the other reports from the tropical countries and Mizoram (Manpoong and Tripathi, 2019) thick natural forest region have generally more acidity than the other land use/ land cover classes except current shifting cultivation. The lower pH in soil under forest is associated with the relative increase in OC and OM in these components of the soil and less evaporation from the surface in the study area. The correlation of pH with OC, OM, available N, available K and porosity indicated a negative correlation (–0.287, -0.27, -0.624, -0.305, -0.461) and available N and bulk density have positive correlation (0.388 and 0.551) (Table 7.11).

The average concentration of dissolved salts in the soil (Alkalinity) measured by EC in the study area is 1.23 ± 0.68 which is poor in seed emergence (G.O.M., 2009). Saha *et al.* (2016) reported a similar result that the soils of Mizoram are non-saline (Low EC). The result reveals that the current shifting cultivation has highest EC 1.58 ± 1.16 followed by the very dense forest (1.39 ± 0.91), tree plantation (1.31 ± 0.74), open forest (1.17 ± 0.57) and moderately dense forest (1.15 ± 0.42). Fruit plantation has the lowest EC in the study area. The correlation of EC with OC, OM, available N, available K and porosity have a positive correlation (0.436, 0.421, 0.225, 0.030 and 0.317) and has a negative correlation with available P and bulk density (-0.6 and -0.355).

The result shows that the pH and EC have negative correlation coefficient (-0.428) reveals that they are opposite to each other. Bier and Singh (2018) also found the similar result in Nagaland under the forest and shifting cultivation area. There is no significant variance in both of the results but some change can be seen on different land use / land covers.

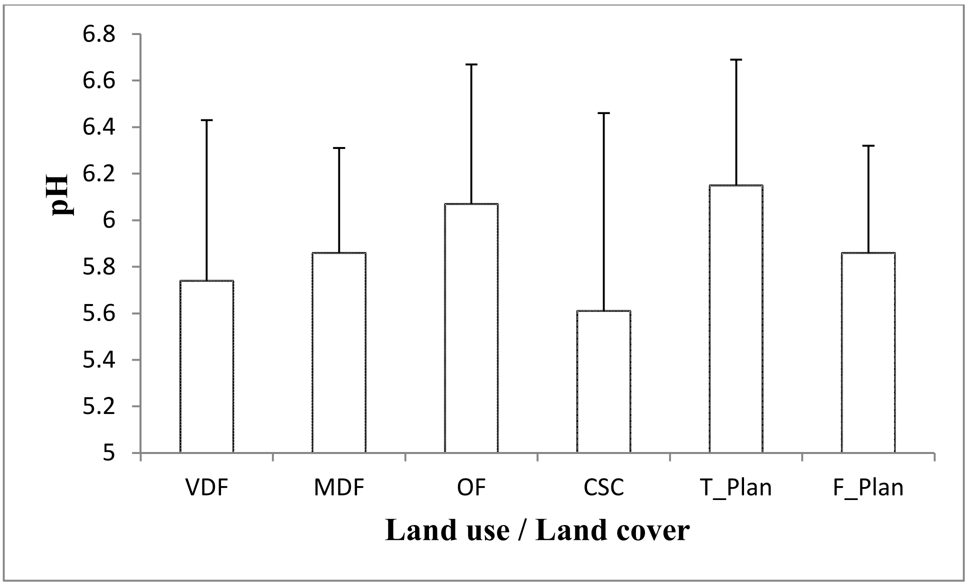


Fig 7.16: Bar graph showing average and standard deviation of soil pH

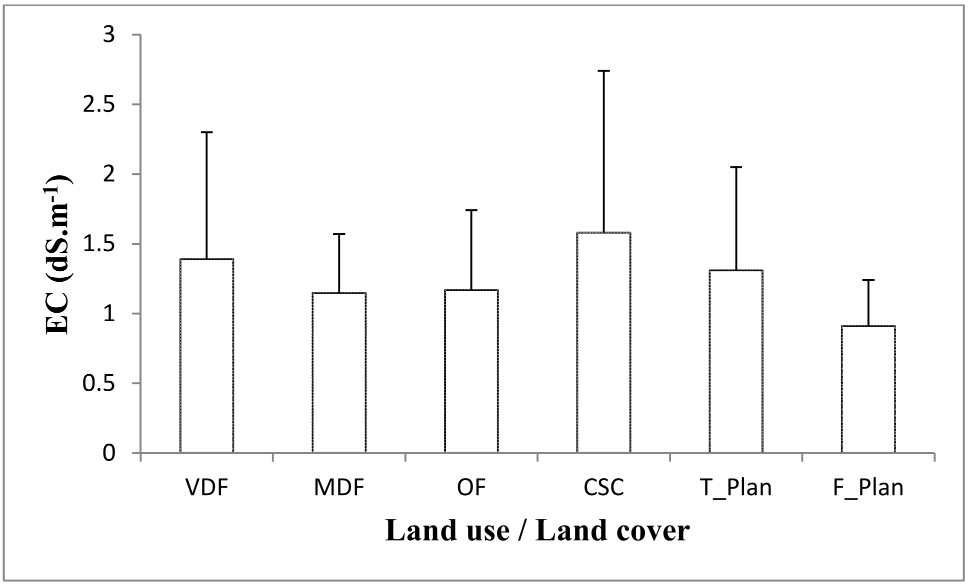


Fig 7.17 : Bar graph showing average and standard deviation of soil electrical conductivity

7.4.2.3 Available Nitrogen (N)

The average of available Nitrogen in the study area is 255 ± 93.82. Saha *et al.* (2016) pointed out that the available N is high in Mizoram. But in the study area, the available N is in a low class based on G.O.M. (2009) report. Natural forest areas of very dense and moderately dense have the two high accumulation of available nitrogen in the study area having 306.81 ± 126.55 and 279.02 ± 122.18 respectively. Researchers like Kharal *et al.* (2018) in Nepal and Bier & Singh (2018) in Jammu and Kashmir also recorded the highest accumulation of available N in soils of forested area. The value highly decreased to open forest area (226.63 ± 56.89) but third highest in current shifting cultivation (250.82 ± 80.48) among the different land use/ land cover classes. The result of high amount of available N in current shifting cultivation area might be due to the use of chemical fertilizer as reported by the farmers. This is also happened in the fruit plantation area (241.40 ± 77.81) and the lowest concentration of Nitrogen was found in the tree plantation area (222.59 ± 50.55).

There is no significant variation in the different land use/ land cover classes of the study area in available N using the ANOVA. But can say that around 85%

(Sig. 0.122) confidence of variation happened among the classes indicating land degradation by the removal of natural vegetation. The available N is highly correlated with OC, OM and soil porosity (0.824, 0.818 and 0.678). The similar result also founded by Kharal, et al (2018); Brady and Weil (2005) ; Abassi et al (2007); Bier & Singh (2018). The reason is that soil organic matter is a major source of nitrogen and along with other nutrients, available N is present in organic combination and are slowly released by the process of mineralization. But the available N has a high negative correlation with pH (-0.624) and BD (-0.701). Among the other nutrients, it has positive correlation with available P (0.188) but negative correlation with available K (-0.244).

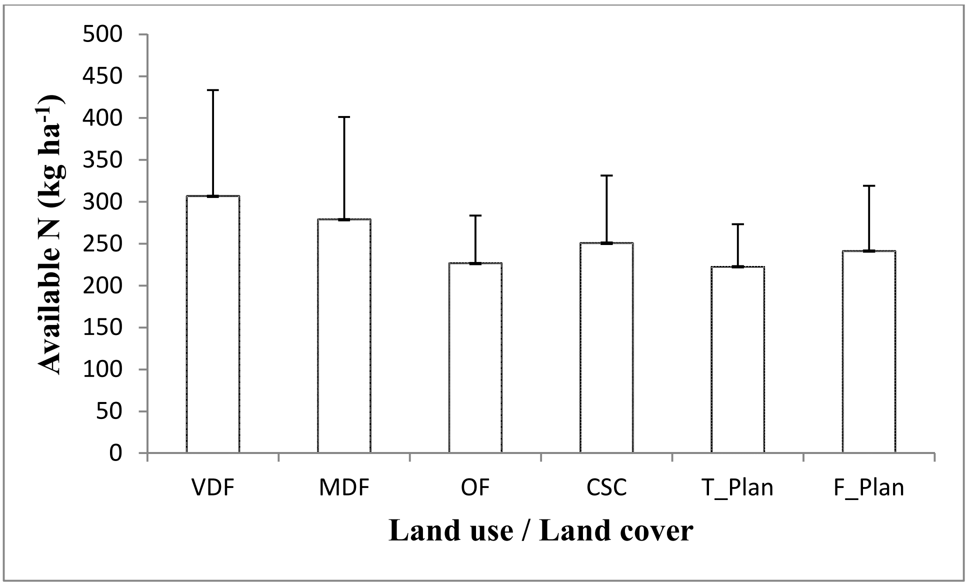


Fig 7.18 : Bar graph showing average and standard deviation of Available N

7.4.2.4 Available Phosphorous (P)

As reported by the previous papers of Kumar (2015) and Saha, et al. (2016) available P in Mizoram is low and along with that, the study area also has low content of available P with an average of 9.18 ± 4.90. The reason might be due to the high rainfall associated with the persistence of oxides of ion and aluminium fixation and the low value of pH (Tewari, et al. (2016). It might also be due to higher fixation of phosphorus by Fe^{2+}, Mn^{2+} and Al^{3+} (Laskar et al.1983). Open forest has the highest concentration of available P and followed by the moderately dense forest and very dense forest (10.11 ± 6.35; 9.79 ± 3.74; 8.85 ± 2.44) respectively. It indicates that the forest have highest concentration of available P among the studied different land use/ land cover classes. It might be due to the decomposition and recycling of old leaves or branches of vegetations enrich the available P. The similar result also recorded by Abassi, et al. (2007) and Bier and Singh (2018). Current shifting cultivation has the lowest concentration of available P in the study region (6.43 ± 2.27). The similar observation by Liu et al. (2002) that soils under cultivation had significantly less available P than soil under forest/vegetation and this change in P availability was associated with OM content. After forest classes, fruit plantation area have high available P (8.51 ± 6.07) and followed by the tree plantation (7.57 ± 3.10).

The land use/ land cover change does not have significant effects on the result of ANOVA. But can see a change that it decreases with decreasing vegetation cover and indicates a loss of nutrients leads to soil degradation. It has a positive correlation coefficient with OC and OM indicating that they are sources of available P in soil (Chenithung, et al. 2014). It has a high negative correlation with EC (-0.6).

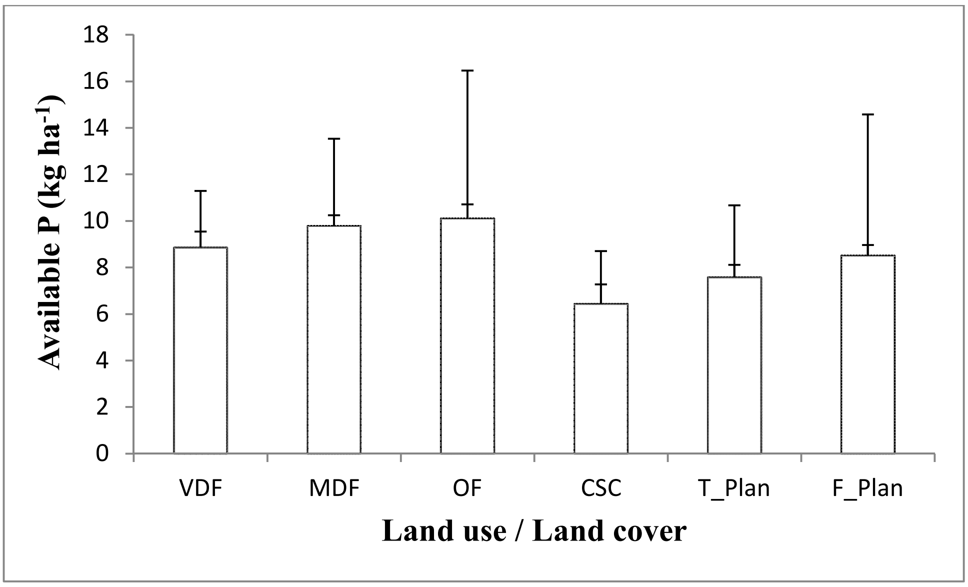


Fig 7.19 : Bar graph showing average and standard deviation of available P.

7.4.2.5 Available Potassium (K)

The concentration of available K is moderately high in the study area (246 ± 17.39). It is also highlighted by Saha, et al. (2016) that Mizoram has moderate to high available K. The concentration of available K in current shifting cultivation (399.94 ± 241.09) was found to be significantly higher than all other land use / land covers in the study area. The similar report also recorded by Sharma (2015) in Assam, Bier and Singh (2018) in Nagaland and Kharal *et al.* (2018) in Nepal. This might be due to the use of chemical fertilizers in and sufficient proportion of available K is conserved in the soil through the crop residues in the agricultural field. Open forest and moderately dense forest followed the shifting cultivation area (389.24 ± 250.43 and 342.10 ± 252.19) and fruit plantation area has 316.29 ± 251.15 stands in the fourth highest. Very dense forest has 237.00 ± 113.97 stands in second lowest and with having 225.17 ± 68.03, tree plantation area has the lowest available K. The similar record also founded that the teak plantation area has the lowest available K concentration in Assam (Sharma, 2015).

Similar to other nutrients, there is no significant variation of available K in the different land use/ land covers in the study area but changes amount of concentration in different land classes. It has a low negative correlation with available N (-0.244); pH (-0.305); OC and OM (-0.231 in both).

Table 7.10 : Details of the soil chemical properties of different land use / land cover class

Land use/ Land cover	SOC %	SOM %	EC ($dS.m^{-1}$)	pH	Available N ($kg\ ha^{-1}$)	Available P ($kg\ ha^{-1}$)	Available K ($kg\ ha^{-1}$)
Very Dense Forest	1.56 ± 0.55	2.69 ± 0.95	1.39 ± 0.91	5.74 ± 0.69	306.81 ± 126.55	8.85 ± 2.44	237.00 ± 113.97
Moderately Dense Forest	1.42 ± 0.40	2.45 ± 0.69	1.15 ± 0.42	5.86 ± 0.45	279.02 ± 122.18	9.79 ± 3.74	342.10 ± 252.19
Open Forest	1.32 ± 0.35	2.28 ± 0.61	1.17 ± 0.57	6.07 ± 0.60	226.63 ± 56.89	10.11 ± 6.35	389.24 ± 250.43
Current Shifting Cultivation	1.29 ± 0.25	2.21 ± 0.42	1.58 ± 1.16	5.61 ± 0.85	250.82 ± 80.48	6.43 ± 2.27	399.94 ± 241.09
Tree Plantation	1.25 ± 0.15	2.15 ± 0.26	1.31 ± 0.74	6.15 ± 0.54	222.59 ± 50.55	7.57 ± 3.10	225.17 ± 68.03
Fruit Plantation	1.13 ± 0.18	1.94 ± 0.31	0.91 ± 0.33	5.86 ± 0.46	241.40 ± 77.81	8.51 ± 6.07	316.29 ± 251.15
Overall	1.36 ± 0.18	2.34 ± 0.68	1.23 ± 0.68	5.78 ± 0.61	255 ± 93.82	9.18 ± 4.90	246 ± 17.39

Values represent means ± SD

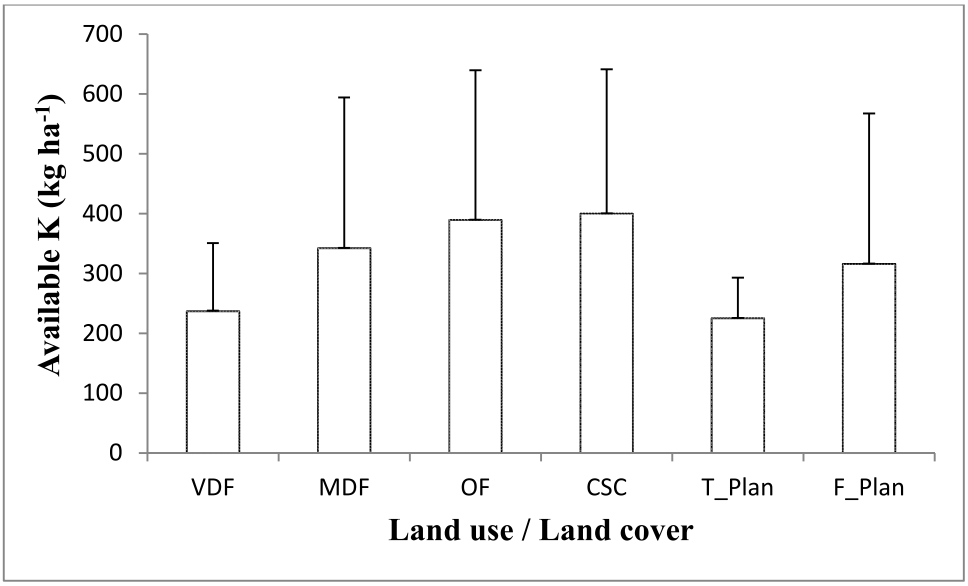


Fig 7.20 : Bar graph showing average and standard deviation of available K

Table 7.11 : Correlation Matrix of soil physico-chemical properties

		OC	OM	EC	pH	N	P	K	BD	Por
OC	Pearson Correlation	1								
OM	Pearson Correlation	1.000**	1							
EC	Pearson Correlation	0.436	0.421	1						
pH	Pearson Correlation	-0.287	-0.270	-0.428	1					
N	Pearson Correlation	0.824*	0.818*	0.225	-0.624	1				
P	Pearson Correlation	0.330	0.350	-0.600	0.388	0.188	1			
K	Pearson Correlation	-0.231	-0.231	0.030	-0.305	-0.244	0.067	1		
BD	Pearson Correlation	-0.791	-0.790	-0.355	0.551	-0.701	-0.362	-0.357	1	
Por	Pearson Correlation	0.811	0.812*	0.317	-0.461	0.678	0.443	0.345	-0.993**	1

**. Correlation is significant at the 0.01 le vel (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 7.12 : Anova table for significance test

		Sum of Squares	df	Mean Square	F	Significance
Organic Carbon	Between Groups	1.202	5	0.240	1.614	0.168
	Within Groups	9.980	67	0.149		
	Total	11.182	72			
Organic Matter	Between Groups	3.555	5	0.711	1.614	0.168
	Within Groups	29.524	67	0.441		
	Total	33.079	72			
Electrical Conductivity	Between Groups	2.143	5	0.429	.914	0.477
	Within Groups	31.417	67	0.469		
	Total	33.559	72			
pH	Between Groups	2.000	5	0.400	1.081	0.379
	Within Groups	24.801	67	0.370		
	Total	26.802	72			
Nitrogen	Between Groups	75509.784	5	15101.957	1.813	0.122
	Within Groups	558239.031	67	8331.926		
	Total	633748.815	72			
Phosphorous	Between Groups	89.485	5	17.897	.732	0.602
	Within Groups	1637.452	67	24.440		
	Total	1726.937	72			
Potassium	Between Groups	303328.638	5	60665.728	1.224	0.308
	Within Groups	3320796.662	67	49564.129		
	Total	3624125.301	72			
Bulk Density	Between Groups	0.161	5	0.032	2.539	0.036
	Within Groups	0.852	67	0.013		
	Total	1.014	72			
Porosity	Between Groups	0.024	5	0.005	2.619	0.032
	Within Groups	0.122	67	0.002		
	Total	0.146	72			

7.5 Soil erosion prone zone

Soil erosion has been an environmental concern and is a hazard traditionally associated with agriculture in tropical areas and it is important for its long-term effects on soil productivity and sustainable agriculture (Morgan, 2005). However, soil erosion is accelerated by the removal of vegetative cover and improper land management to become land degradation. The study area is highly vulnerable to soil erosion due to its undulating topography, steep slopes, high amount of rainfall and different human interventions on natural resources. The high vulnerable rate of soil erosion in this region calls for urgent attention for giving preventive measures to stop or at least to minimize soil erosion.

In the present study, weighted overlay technique has been used for generating soil erosion prone zone map to identify the areas and to take necessary preventive measures to stop or reduce the intensity and extent of soil erosion. Weighted overlay is a simple bi-variate statistical method wherein weights are assigned based on the relationship of eight soil erosion causative factors of different variables like drainage density, slope, dissection index, relative relief, absolute relief, land use / land cover, rainfall and soil texture. Numerical weightages are assigned to causative factors in percentage and then ranked the different classes on the basis of their relationships to the erosivity. Finally, the data layers were overlaid to produce erosion prone zone map. The overlay method has been done twice as weight 1 and weight 2, with and without the land use/ land cover for evaluating the importance of vegetative cover in soil erosion probability in the study area.

The final layer is classified into five different zones from very high, high, moderate, low and very low classes.

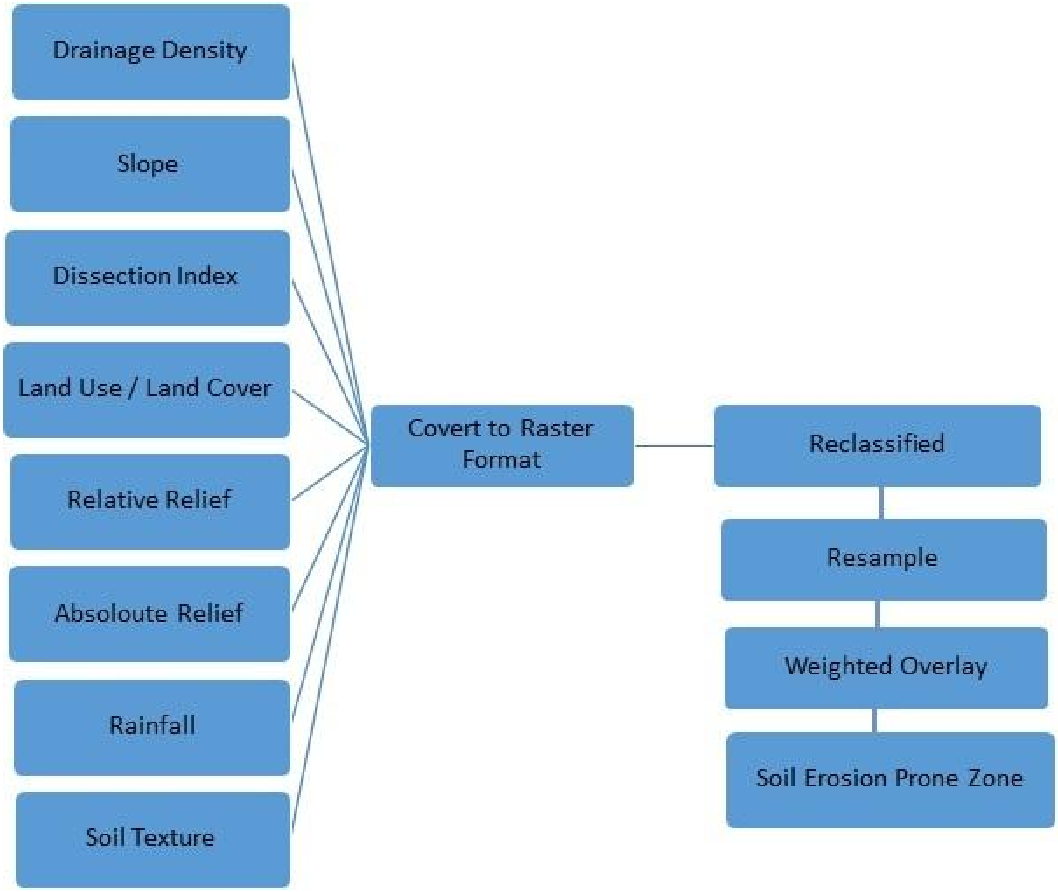


Fig 7.21 : Flow chart showing methodology of soil erosion zonation.

Table 7.13 : Details of the factors responsible for soil erosion prone zones

Sl No.	Factors	Class Name	Class Value	Area	%	Weight 1	Weight 2	Rank
1	Drainage Density	Very Low	< 1	93.40	22.70	10	10	1
		Low	1 to 2	133.52	32.46			3
		Moderate	2 to 3	117.23	28.50			5
		High	3 to 4	58.05	14.11			7
		Very High	> 4	9.18	2.23			9
2	Slope	Very Low	< 15	70.51	17.14	15	20	2
		Low	15 to 25	152.02	36.95			4
		Moderate	25 to 35	142.82	34.72			6
		High	35 to 45	41.56	10.10			8
		Very High	> 45	4.48	1.09			9
3	Dissection Index	Very Low	< 0.15	0.44	0.11	15	20	2
		Low	0.15 to 0.30	40.38	9.82			4
		Moderate	0.30 to 0.45	188.51	45.85			6
		High	0.45 to 0.60	143.26	34.85			8
		Very High	> 0.60	38.54	9.37			9
4	Landuse/Landcover	Very dense Forest		2.26	0.55	15	0	1
		Moderately dense Forest		152.78	37.14			3
		Open Forest		228.89	55.64			5
		Cropland		10.55	2.57			7
		Waterbodies		1.91	0.46			0
		Built-up		14.98	3.64			9
5	Relative Relief	Very Low	< 150	0.55	0.13	10	10	2
		Low	150 to 300	71.56	17.41			4
		Moderate	300 to 450	249.67	60.73			6
		High	450 to 600	83.28	20.26			8
		Very High	> 600	6.07	1.48			9
6	Absolute Relief	Very Low	< 400	56.29	13.69	10	10	2
		Low	400 to 800	217.58	52.92			4
		Moderate	800 to 1200	109.58	26.65			6
		High	1200 to 1600	21.69	5.28			8
		Very High	> 1600	5.99	1.46			9
7	Rainfall	Low	< 2300	32.11	7.80	15	20	6
		Moderate	2300 to 2500	43.21	10.50			7
		High	2500 to 2700	328.26	79.80			8
		Very High	> 2700	7.80	1.90			9
8	Soil Texture	Loam		2.16	0.53	10	10	7
		Very Fine Sandy Loam		6.84	1.66			9
		Fine Sandy Loam		51.84	12.60			5
		Sandy Loam		209.45	50.91			4
		Coarse Sandy Loam		129.63	31.51			3
		Loamy Sand		11.45	2.78			2

Table 7.14 : Results of the soil erosion prone zones

Sl No.	Class	Weight 1		Weight 2		Change	
		Area in km^2	%	Area in km^2	%	Area in km^2	%
1	Very High	1.86	0.45	1.95	0.47	0.09	4.84
2	High	3.69	0.9	36.14	8.79	32.45	879.4
3	Moderate	133.39	32.42	256.61	62.38	123.22	92.38
4	Low	255.46	62.1	113.42	27.57	-142.04	-55.6
5	Very Low	16.98	4.13	3.26	0.79	-13.72	-80.8
	TOTAL	411.38	100	411.38	100		

In the first weighted overlay method, the very low class covers 16.98 km^2 which is 4.13 % of the total geographical area. Low class covers the largest area with 159.97 km^2 (38.89 %) and the combination of these two classes covers 66.23% of the total geographical area. Very low to low zone of soil erosion are the areas covered by the thick vegetative cover with gentle slope and less human intervention areas. Moderate erosion prone zone covers 133.39 km^2 (32.42 %) of the total geographical area, which are found in the areas where less vegetative cover with steep slope and high relative relief. High and very high class covers only 3.69 km^2 (0.90 %) and 1.86 km^2 (0.45 %) respectively. They are generally found where the terrain is steep with high relative relief, thin vegetative cover and with high drainage density.

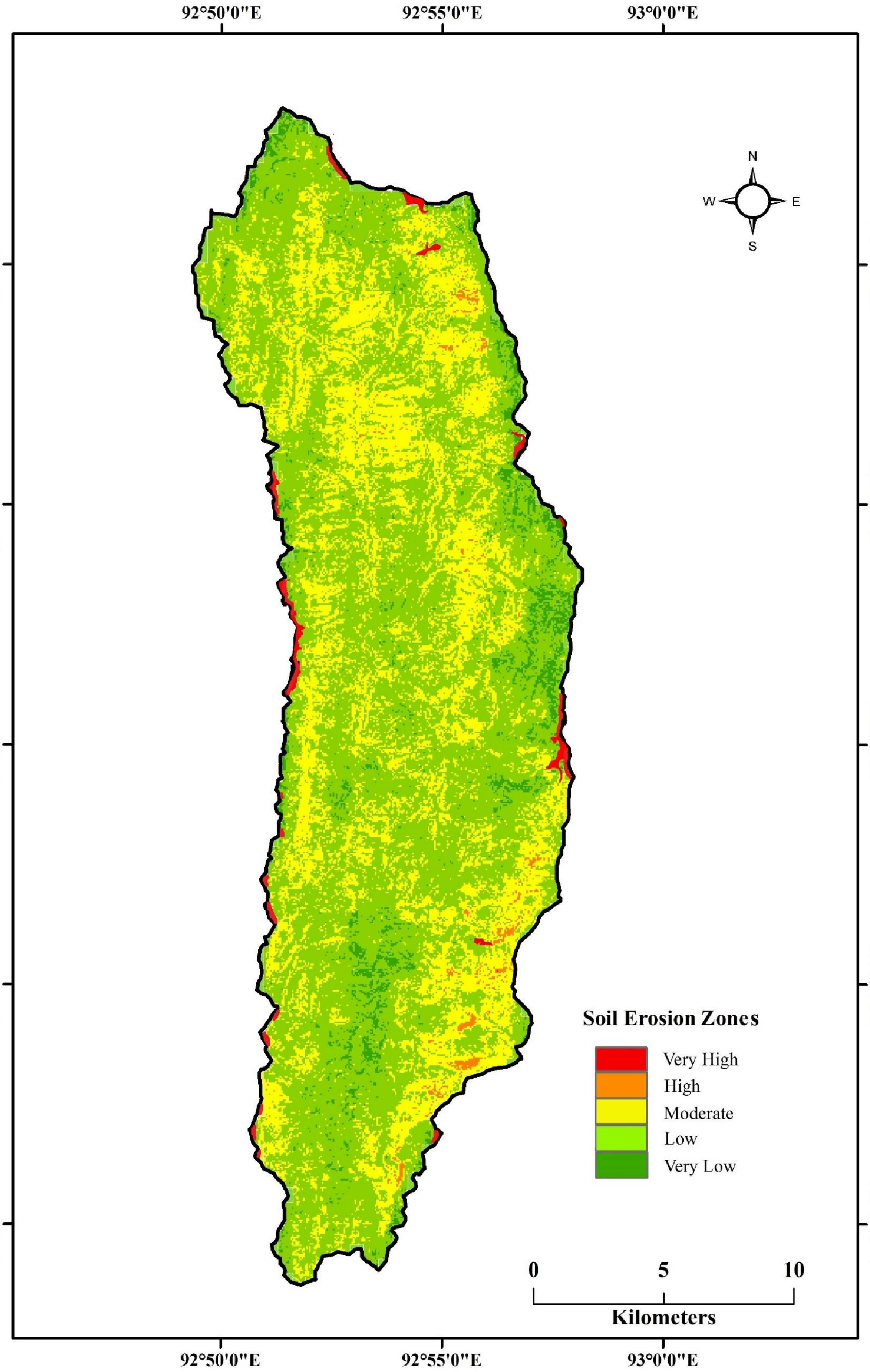


Fig 7.22 : Soil erosion zones in Tuirini watershed (Weight 1).

In the second weighted overlay method, very low and low class covers 3.26 km^2 (0.79%) and 113.42 km^2 (27.57 %) respectively, both of them are covering only 28.36 % of the total geographical area. They are found in areas where the terrain is gentle to steep slope with low relative relief and low dissection index. They are mostly concentrated in the upper river banks of Tuirini and the central eastern part around Saitual village. By comparing with the first weighted overlay result, very low zone found to loose 80.8% of its cover area and low zone lost 55.6% of its total area from the first weight. Moderate class covers 256.61 km^2 which is 62.38 %. It is highly increased than the area obtained in previous method with 92.38% increase. This zone covers almost the entire region without gentle slope with low relative relief area. High and very high classes cover 36.14 km^2 (8.79 %) and 1.95 km^2 (0.47 %) of the total geographical area respectively, and both of them covers occupy 9.26 % of the total geographical area. Comparing with the first weight, the high zone is unprecedented increase with 879.4 % and very high also increased with 4.84 %.

The result reveals that the vegetative covers play a very significant role in soil erosion probability. Due to vast vegetative cover in the study area, the area has low advantage to erosion probability. But, it is clear that if the vegetative cover lost its cover area and lowers canopy density, the soil erosion probability will rapidly increase in the study area. The probable intensity is very high in the areas where high degree of slope, high relative relief, high drainage density and higher value of dissection index exist.

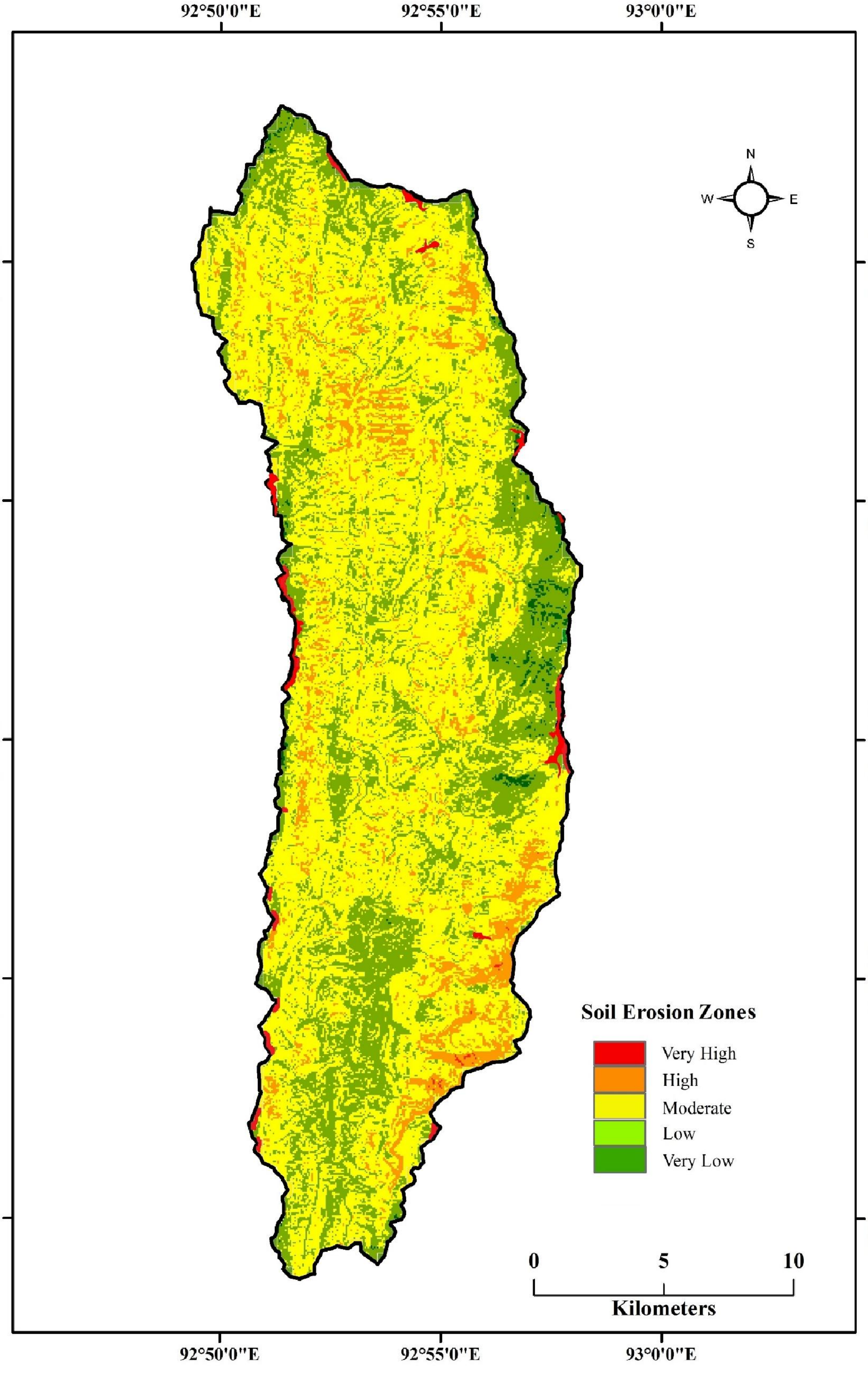


Fig 7.23 : Soil erosion zones in Tuirini watershed (Weight 2)

CHAPTER 8

SUMMARY AND SUGGESTIONS

Humans have considered our natural environment as virtually unlimited resource but subtle and gradual changes have altered our natural resources in many different ways like excessive exploitation of forest resources resulting to deforestation and forest degradation, extreme modification and over utilization of soil resources leading to soil degradation and rapid change of water demand meeting the needs of population explosion leads to water scarcity. The development of economy in the world, resulting exploitation of natural resources is a part of generating economic condition. Rapid expansion of built-up land and agriculture area triggered the intensity of deforestation and soil degradation, which also have a direct impact on water scarcity in the world leads to land degradation. Healthy land has a natural capacity to store and filter water, but this capacity is lost when land is degraded. Land degradation takes a number of forms, including the depletion of soil nutrients, high rate of soil erosion, vegetative degradation as a result of urbanization, and the cutting of forest for farmland, decline in fresh water sources, etc. All these types of degradation cause a decline in the productive capacity of the land.

Due to the deterioration of our environmental resources, acquiring information on land degradation conditions are essential for various developmental planning purposes to make implementation of reclamation programmes, rational land use planning for land resources management, etc. To achieve economic growth, improve agriculture productivity and attain sustainable development, it is needed to utilize the full potential of available land resources for meeting the basic needs of the growing population. Therefore, assessment of land degradation dynamics is essential to prevent further degradation and mitigation through the appraisal of potential and existing resources, assessing forest and soil deterioration, evaluating the problem of local people and gives suggestions of conservative measures.

Geographically, the study area of Tuirini watershed lies in the central part of Mizoram covering some parts of Serchhip and Aizawl districts. The watershed stretches in N-S direction in an area of about 411.38 km^2 of only 1.94% of the total geographical area of Mizoram. The area covers parts of survey of India topographical maps 84 A/13, 84 A/14 and 84 A/15 on 1:50,000 scale. Tuirini river is the major tributary of Tuirial river which flows from south towards north over a length of about 60 km including perennial and non-perennial streams. The river Tuirini originates near Chhingchhip village in Serchhip district, which is formed by adjoining two streams namely Zawngsih and Maudarh. The study area is composed of mountainous terrain with undulating topography and having an average altitude of about 709 metres above mean sea level. The highly undulated mountain ranges are inclined in north-south direction which run parallel each others. Geologically, the area is composed of various sedimentary rocks predominantly of arenaceous type and argillaceous type of the Surma Group. There are 30 sub-watersheds inside the Tuirini watershed and the neighbouring watersheds are Tuirial on the west and north, Mat on the south and Tuivawl on the east. The region has undulating topography with a high relative relief, high degree of slopes and the high drainage density. The lineament density is also quite high. Due to parallel high altitude mountain ranges obstructing the rain bearing winds, the study area receives high amount of rainfall during the rainy season with an average of 282.9 cm (2829 mm) per annum. The temperature of summer and the winter seasons range between 15ºC and 28ºC which is fairly comfortable weather means neither too hot nor too cold and relative humidity is moderately high (ranging between 61 % and 91%) indicating that the study area is a high humid region.

In the present study, the essential life supporting natural resources like water, soil and forest were assessed. The area receives an average annual rainfall of about 2891.81 mm for 20 years (1999-2018). The rainfall season starts from the month of April and ends up by the month of October. The months of May to September receives a good amount of rainfall of more than 390 mm in each month with 80.68 % from the total receiving annual rainfall whereas the remaining rainy season of April and October also receives more than 190 mm in a month with 14.07%. The total rainy season from April to October received 94.75 % of the average annual rainfall during 20 years. The dry season starts from the month of November and continues up to March and received 5.25 % of the total rainfall received for 20 years. During this period, the area received small amount of rainfall (Less than 80 mm). Due to this reason, most of the streams were dried up. But compared to other places, the area received high amount of winter rainfall. Therefore, excess rain water in the monsoon season has a good potential for rainwater harvesting to fill the gap of water scarcity and also insecure in the dry season.

Surface water in a general term describes any water body which is flowing or stagnant on the surface like streams, rivers, ponds, lakes, etc., and is available from various multi-sources. There are 30 perennial tributaries in the study area adjoining the main river, 13 streams from the eastern side and 17 streams from the western side respectively. The entire basin has the perennial stream drainage densitiy of 0.71 km / km^2. The drainage systems mostly exhibit trellis, parallel and dendrictic patterns with numerous tributaries. For delineation of the groundwater potential zones in the study area, geo-spatial techniques of remote sensing and GIS have been applied for generating and integrating the thematic layers such as drainage density, average slope, geomorphology, landuse/landcover, geology, Lineament density, average rainfall and soil texture. Analysis of groundwater potential zonation result reveals that the very high groundwater potential zone constitutes only 0.25% of the study area, which is 1.03 km^2 and high zone also covers only 6.46% (26.59 km^2). Moderate groundwater potential zone is predominant in the study area and covers 52.26%, which is 215 km^2. Low potential zone covers a vast area of rugged and steep sloping terrain with high drainage density zone. It constitutes 38.89 % (159.97 km^2) and very low zone covers only 2.14%, which is 8.79 km^2.

The knowledge of the physical and chemical properties of soil helps in managing resources for sustainable management. They need to study for agricultural purpose, to increase the productivity and to improve the workability of the soil mass. The analysis of relevant status of soil properties are very important to enhance production on a sustainable basis. The chemical analysis of the soil properties in this study involves that the characteristics of soil primary macronutrients like N, P, K, available of Organic Carbon (%), Organic Matter (%), Electrical Conductivity (EC) and pH of the soil. Among the primary macronutrients of the soil available N has low class, available P has intermediate class and available K has moderately high class. The soils are rich in OC and OM content. Generally, the soils of the study area are acidic in nature and the electrical conductivity is also low, which support poor seed emergence without modification. Among the physical properties of the soil, the average bulk density and porosity are fairly comfortable for moving air and water freely. There are no restrictions for the growth of roots, therefore, the plants can accommodate without any difficulties.

The soil texture analysis revealed that the soil particle size ranges from loam as a finest particle and loamy sand as the largest particle size. Loam soil covers only 2.16 km^2, which is 0.53% of the total area. Loam has the highest percentage of the clay and lowest in sand among the soil texture class. Very fine sandy loam covers 6.84 km^2 with a percentage of 1.66 of the total area. Fine sandy loam is the third largest area covering 51.84 km^2 (12.6%). Sandy loam covers the largest area with half of the total area (50.91%) which is 209.45 km^2. Coarse sandy loam holds the second largest area covering 31.51% (129.63 km^2). Loamy sand covers 11.45 km^2, which is only 2.78 % of the total area. It has highest concentration of sand percent and lowest clay percent. In general, the soil has high percent of the sand in every part of the study area. Soil Nutrient Index method has been applied to know the exact status of the soil fertility. The result reveals that high fertility in OC and OM, medium fertility in EC, pH and available K and low fertility status in available N and P.

The study area is rich in natural forest covering 383.93 km^2 (93.33 %) of the study area in 2018 assessment through the LANDSAT satellite imagery. Forests are mostly found in the river valley but very thick forests are found at the high altitude in the north eastern and the south eastern corners of the study area. Bamboos are mostly concentrated along the river valley and also in lower altitude region of the study area. The higher altitude regions are mostly dominated by different species of the trees and *Changel* (Musa paradisiaca L. var. Sylvestris) is common and evenly distributed in every parts of the region.

Thus, the first objective of the evaluation of land resources has been accomplished with the resource appraisal of water, soil and forest condition in the study area.

Responded to the questionnaire and interview on whether the study area is experiencing land degradation and its impact on their agricultural lands have been taken from farmers' perception of the study area. The result reveals that farmers in the study area associate with soil fertility decline and soil erosion, deforestation and water scarcity during the dry season.

Land use and land cover are changing over time due to various physico-environmental and human interferences, but the speed and distribution of changes differ from one place to another based on certain indicators. The data reveals that forest area covers a very vast area of 93.85 % in 1974 and decreased to 92.55% in 1996 but it increased to 93.33% in 2018. Very dense forest and moderately dense forest have continuously decreased during the study period but open forest has shown increasing trend. Due to agriculture as the mainstay of economy, cropland covers second vast area after forest. It covers 17.76 km^2 in 1974 and increased to 20.54 km^2 in 1996. Owing to the economic development and changing the mode of activities, cropland cover decreased to 10.55 km^2 in 2018. The covers of waterbody almost stable within the period, it covers 0.45 % (1.86 km^2) in 1974 and a little increase to 0.47% (1.94 km^2) in 1996 but declined to 0.46 % (1.91 km^2) in 2018. Built-up land covers increased rapidly from 1.38% (5.68 km^2) to 1.99% (8.20 km^2) in 1974 and 1996 respectively. It is again increased to 3.64% (14.98 km^2) in 2018.

Deforestation is one of the most important burning environmental issues that the world and study area is facing even today. For assessing the rate of deforestation in Mizoram, the rate of forest cover change has been computed since 1987 to 2019. The total forest has been reclassified into two classes based on the Forest Survey of India (FSI) guidelines, viz., Dense Forest (> 40% Canopy density) and Open Forest (< 40% Canopy density but more than 10 %). The data reveals that the total forest cover area decreases from 19,092 km^2 in 1987 to 18,006 km^2 in 2019, which means about 1,086 km^2 of forest cover area lost within the study period of 44 years. The average change during the study period is 72.4 km^2 lost in every assessments by 0.19 percent decreased per year.

In order to analyse deforestation in the study area, the annual rate of change in percentage is calculated by comparing the area under forest cover in the same region at three different times. During the period of 1974 to 1996, very dense forest decreased to 2.34 % per year followed by moderately dense forest 0.19% per year. But, the open forest increased slightly with an increased 0.12 % per year. With the very dense and moderately dense forest, the total forest cover decreases to 0.06% per year. In 1996 to 2018, very dense and moderately dense forest still showing decreasing trend and the rate of lost percent per year is higher than the previous assessment of 4.31% per year in very dense forest and 0.28% per year in moderately dense forest. But found a higher positive change rate than the previous assessment in the open forest, 0.34% per year and also found total forest cover area gain to 0.04 % per year. For the total study period of 1974 to 2018, the data reveals that very high lost rate of very dense forest cover found in the study area, which is 3.32% per year and also lost in moderately dense forest as 0.23% per year. The open forest cover has positive change with 0.23% per year and the total forest cover declined to 0.01% per year of negative changes. The trends of the land use/ land cover change and deforestation in the study area reveals that the deterioration of forest resources leading to land degradation.

The changing value of soil bulk density in different land use land cover classes reveals the soil degradation in the study area. The lowest bulk density of soil with highest porosity zone of very dense forest area has thick vegetative covers and rain water can penetrate easily. It enhanced the infiltration rate and reduced the surface runoff. On the other hand, the soil having high bulk density and low porosity accelerates the intensity of surface runoff and caused high rate of soil erosion. Decline in porosity leads to reduction in pore size distribution and diminish the infiltration rate. Besides, the increasing bulk density of soil disturbs the growth of plant roots and reduces the capacity of the growth of plants. These have direct impact on productive capacity of the soil and lead to soil degradation.

The result of changing the amount of OC and OM based on land use/ land cover reveals that soil degradation happened in the study area. It is possible to see the trends of changing in different classes and can simply say that more than 80% of the confidence level found in soil degradation. Soil OC and OM have highly positive correlated with soil porosity (+0.81 and +0.81) and available N (+0.82) but highly negative correlated with Bulk density (-0.79 and -0.79). They also have a positive correlation with EC (+0.43 and +0.42) and available P (+0.33 and +0.35) but found negative correlated with pH (-0.28 and -0.27) and available K (-0.23 and -0.23).

There is no significant variation in different land use/ land cover classes of the study area in available N but can say that around 85% confidence of variation happened among the classes indicating land degradation with the removal of natural vegetation. Forest classes have high concentration of available nitrogen but decreased to the other land use classes. Available P decreases with decreasing vegetation cover and indicates a loss of nutrients leads to soil degradation.

The study area is highly vulnerable to soil erosion due to its undulating topography with steep slopes, high amount of rainfall and different human interventions on natural resources. The high vulnerable rate of soil erosion in this region calls for urgent attention for giving preventive measures to stop or reduce soil erosion. Two times of weighted overlay have been analysed to discover the importance of land use / land cover change in erosion prone zone. The result reveals that the vegetative covers play a very significant role in soil erosion probability. Due to vast vegetative cover in the study area, the area has low chance to erosion probability. But, it is clear that if the vegetation lost its cover area and lowers canopy density, the soil erosion probability will rapidly increase in the study area. The probable intensity is more high in the areas where high degree of slope, high relative relief, high drainage density and higher value of dissection index.

Therefore, the second objective of assessing deforestation and soil degradation has been finished including the analysis of land use/ land cover change and farmers' perception of the study area regarding the land degradation.

The present investigation is only confined to the watershed of Tuirini, one of the smallest watersheds in the state of Mizoram. Similar investigation may be extended to the other watersheds if possible to provide more information on land degradation alongwith its causes and consequences to the state of Mizoram. Such studies will help in the formulation of appropriate conservation measures and policies for the sustainable development of natural resources.

8.1 Factors responsible for land degradation

Fulfilling the third objective of the study for giving suggestions to combating land degradation problems, understanding factors responsible for land degradation is necessary. It is fundamental for the development of policies and measures that aim to alter current trends in land use management system toward more effective sustainable development.

Depending upon the different reasons in the study, there are five different types of factors responsible for land degradation in the study area. All of the factors are either directly or indirectly related to anthropogenic activities and play leading role in land degradation.

8.1.1 Deforestation

Generally, the term deforestation has emerged as a result of various anthropogenic activities that contribute towards deteriorating the quality of forests and conversion of land use / land cover. Deforestation was not only confined to the agricultural expansion but also used for the excessive extraction of forest resources and increasing demand of built up land. Further it has caused over exploitation of land and water resources and ultimately reduced the quality of forests resources in the study area. Since shifting cultivation is still practiced in the study area, dense forest is converted into agricultural land every year, and causing a drastic reduction in very dense and moderately dense forest cover. It has been observed that anthropogenic activities are the major reasons towards forest degradation and the drivers of land use / land cover change. Majority of population living in the study areas are highly dependent on the forest for a variety of resources like food, fodder, agriculture, lumbering, housing, and non-timber forest products which have highly potential contribution towards the land degradation.

Forest plantation seems to be a positive effect and assist in reducing the rate of deforestation. But in the study area, the farmers opined that the forest plantations replace the trees of natural forest but doesn’t grow properly as the natural forest, it reduces the growth of small plants underneath and reduces the quality of forest in that plantation area. Besides, it degrades the soil fertility of physical properties as well as chemical properties.

8.1.2 Shifting cultivation

Shifting cultivation is the most traditional, dominant land use system and the backbone of economy in the study area. Most of the cultivators practice shifting cultivation, for rice and ginger, for both subsistence and for commercial purposes. The cultivation is confined to one time and often after one year for rice and two or three years for ginger. The cultivated area is abandoned and a new site is selected to repeat the process. Farmers further shift to new forest area which is causing land degradation and increasing the availability of degraded land in the study area. The shifting cultivation became an unsustainable practice today due to the increase in population that led to raise the demand of food and per capita income. The result of the farmer’s perception reveals that the fallow period in the same land has been reduced from 20-25 years in earlier days to 5–8 years now a days. They also opined that growing ginger is more vulnerable to land degradation because it needs to cut down the virgin or thick forest to increase the production. The soil with high nutrient content and low temperature is favourable for high production. Besides, the cultivating period of ginger is more than one year and needs to clear them regularly. It also needs to dig out for production. These continuous processes enhanced the soil erosion rate and leading to land degradation.

8.1.3 Soil erosion

Accompanying with the deforestation and expansion of agricultural land, soil erosion plays a significant role in land degradation. Due to the undulating topography, land use / land cover change and high amount of rainfall in the study area, the vulnerability of soil erosion chances is very high. More than 70 % of the total geographical area is under the moderate to very high intensity zone of erosion. About only 30 % area is under the low intensity zone of erosion. The farmers also perceived that most of them are experiencing the sheet and rill soil erosion in their agricultural land, rating them as a severe and only very few people applied the conservation practices. Gully erosion is also found extensively in the study area.

8.1.4 Population pressure

According to the census of India, the population of the study area is 18,712 persons in 1971 with a density of 45 persons per square kilometre. It rapidly increased to 27,231 persons (66 persons per square kilometre) in 1991 and again jumped to 37,378 persons with a density of 91 persons per square kilometer in 2011. Village Profile & Development Indicators, Government of Mizoram (2017-18) shows that the total population is 43,863 persons in the study area with a density of 106 persons per square kilometer. It increases to 6,485 persons after the last population census of India 2011. The high growth of population and population density trends are reflected in the per capita availability of the land. It increases pressure on the available arable land resulting to destruction for extending agricultural and built-up area. These land use conversion cause destruction of arable land into marginal land and reduced jhum cycle periods leading to land degradation in the study area.

Along with shifting cultivation, collection of non-timber forest products plays an important role towards local livelihood and economy in the study area. Increasing population led to rising demand of domestic necessities and since many persons are spending their daily time in collecting non-timber forest products from their nearby forest areas and selling them in the nearest markets for better livelihood. This causes serious biodiversity loss and leads to land degradation.

Table 8.1 : Population growth of Tuirini Watershed (1971-2018)

Year	Total population (No. of persons)	Change	Population Density
1971	18712		45
1981	19704	992	48
1991	27231	7527	66
2001	34978	7747	85
2011	37378	2400	91
2018	43863	6485	106

Source : Census of India, Village Profile & Development Indicators, GOM (2017-18)

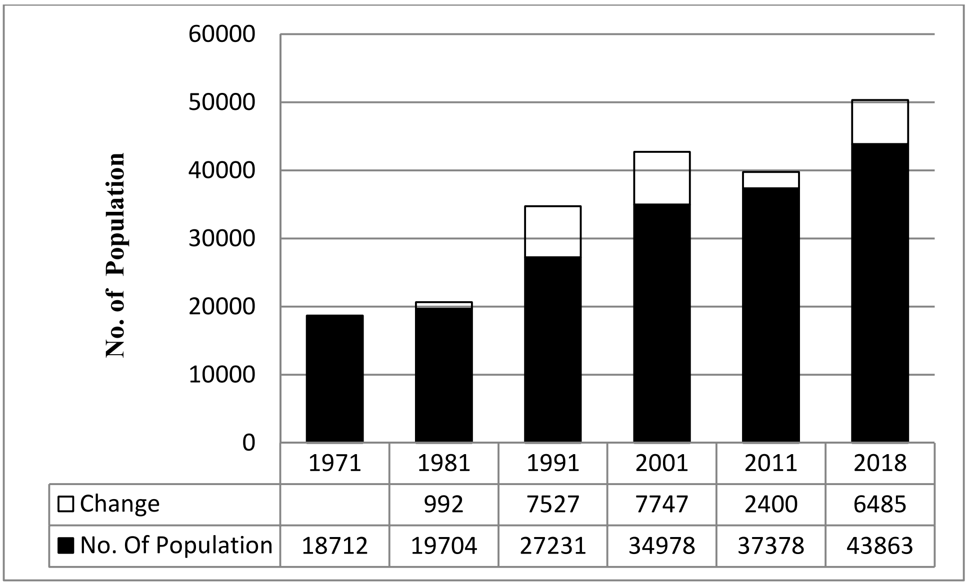


Fig 8.1 : Bar graph showing Population changes in Tuirini waterhed.

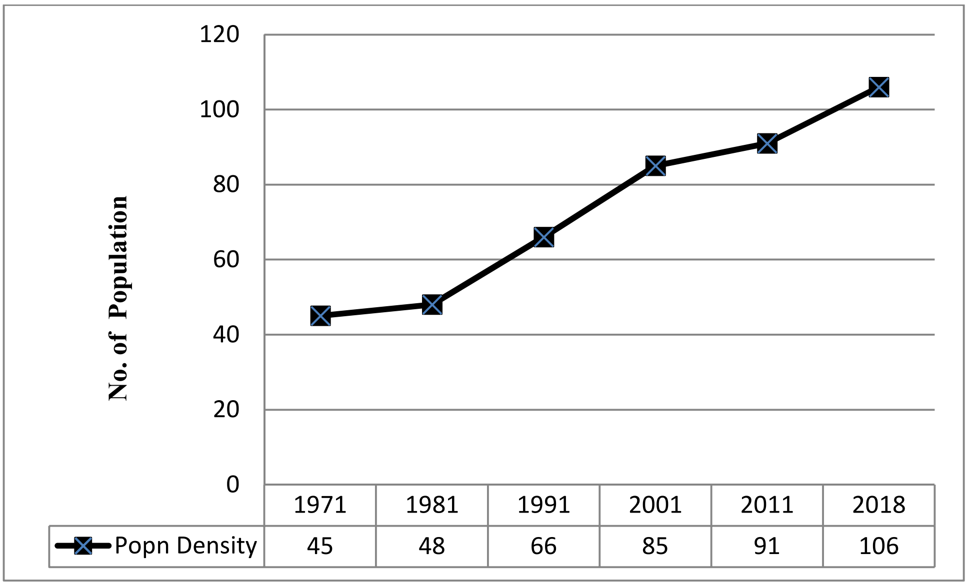


Fig 8.2 : Line graph showing Population density in Tuirini watershed.

8.1.5 Urbanization

Expansion of built up areas require land to establish the infrastructure necessary to support growing population which is done by conversion of land use / land cover. The construction of connecting roads and bridges gives opportunity to expand settlement area and agricultural land brings increasing number of people to the forest frontier and increases the exploitation of forest resources. Whether supported or not supported by the government, people started exploitation of natural resources for subsistence and commercial purposes. These caused a serious deterioration and lead to land degradation.

According to the census of India, number of settlements found in the study area is only 6 in 1971 but highly increased to 21 in the next decade of 1981. Households also increased from 2,817 to 3,051 within this decade. In the last census survey in 2011, the number of settlements increases to 29 and number of households are 7,777. From the assessment of the satellite imagery by the researcher, built up land is only 5.68 km^2 from the total geographical area. But it increased to 8.2 km^2 in 1996 and again increased to 14.98 km^2 in 2018. Village Profile & Development Indicators, Government of Mizoram (2017-18) highlighted that the no. of households increases to 8,769 from 7,777 in the last census with a change of 992 in number. The rapid expansion of built-up land and high rate of increase in settlement area and households number reveals the expansion of degraded land in the study area.

Table 8.2 : No. of Settlements and Households in Tuirini Watershed (1971-2018)

Year	No. of Settlements	Change	No. of Households	Change
1971	6		2817	
1981	21	15	3051	234
1991	25	4	4575	1524
2001	28	3	7860	3285
2011	29	1	7777	-83
2018	29	0	8769	992

Source : Census of India, Village Profile & Development Indicators, GOM (2017-18)

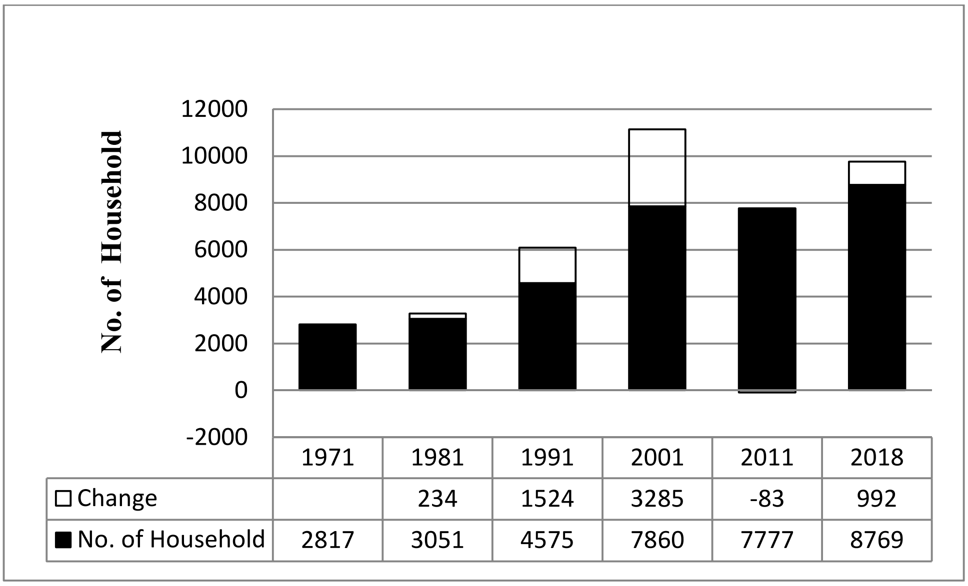


Fig 8.3 : Bar graph showing no. of Household changes in Tuirini watershed.

8.2 Suggestions:

8.2.1 Water resources

1) Rainwater harvesting by roof top for domestic uses in the rainy and the dry season:

The study area receives high amount of rainfall in the long rainy season. But, from the responses of local people through interview and questionnaire, only 25 % utilized the rainwater for domestic use and do not have water tanks for storage. This is the reason why they are experiencing water scarcity in dry season. Therefore, they must give priority to construct or buy water tanks for harvesting rainwater through the rooftop during the rainy season which will be utilized as domestic water use in the rainy season itself and even in the dry season.

Receiving good amount of water supply with regular interval in some villages, the people need to be given proper awareness of water consumption. Because they neglected rain water harvesting and highly depend only on pipeline water supply. This reflects the water condition in the stock point and reduces the water stock for dry season leads to irregular supply.

2) Construction of reservoir/pond/tank in the upper hilly area for the source of irrigation and domestic water supply:

Due to facing water scarcity in the study area especially in the dry season, the villager themself can construct reservoir or pond or tank in the upper hilly region where the water source is available, like banding the river or streams. It will also be fed by the rainwater in the rainy season. Then, they will take the water through pipeline in their stock point for distribution when needed.

3) Stop deforestation in the higher altitude of mountain for conserving and enhancing water resources:

Inside the study area, there are two prominent high mountains with thick vegetative cover like Chalfilh protected forest area in the northern and Tawi wildlife sanctuary in the southern sides. These mountains can become a store house of water resource for the study area. But, deforestation and forest degradation are prevalent linking with anthropogenic activities. This caused the decreasing water holding capacity of soil, slow rate of infiltration and intense speed with a high rate of runoff. So, the source of water for streams and rivers becomes dry when there is dry season. Therefore, it is essential to take necessary actions to stop the deforestation in the higher altitudes of mountains for conserving and enhancing the water resources in the study area.

4) Improving community based water management programme:

Community based water management programmes have been adopted in the study area in most of the villages. Government provide materials and tools and take the necessary actions for water supply. But it gives the management authority to local people in their respective villages. Generally, most of the villages run their management programmes successfully. But some villages receive less amount of water with irregular supply. Therefore, it is essential to improve the programme with the concerned government department for regular supply of water especially in the dry season.

8.2.2 Soil resources

1) Changing the cropping pattern and technique

The present study reveals that shifting cultivation dominated agriculture system and changes the physico-chemical properties of the soil which leads to soil degradation in the study area. But it is not possible to stop shifting cultivation practice immediately without proper assistance. So, there is a need to introduce a new cropping pattern for assisting sustainable agriculture system which support the slope topography in the study area.

It has been observed from the survey that some farmers practice horticultural crops on permanent basis besides the shifting cultivation. They mostly grow fruit items like Banana, Orange, Nimbu, etc. In some places especially in the eastern mountain ranges, they practice the plantation of tree like species, viz., Thingthupui (Dysoxylum procerum), Zawngtah (Parkia Speciosa), Khanghu (Acacia pennata), etc., for generating economy. Besides these, they also grow food items like cabbage at the higher altitudes and mustard along the banks of Tuirini river particularly in the winter season. They get surplus income by promoting horticultural crops and plantation can increase the income from a particular patch of land. This can further encourage farmers for choosing a regular source of income for sustainable agriculture development.

Another important suggestion is that the adoption of terrace farming and permanent farming for checking the expansion of shifting cultivation in the study area, which will automatically prevent the soil degradation.

2) Construction of soil erosion banding methods

In this study area, the agricultural fields are located in the hilly terrain with steep slopes with abundant supply of rainfall. These caused a serious erosion problem leads to soil degradation. The farmers' responses regarding soil conservation reveals that only 25% of the cultivators adopted conservation measures in their permanent agricultural land, but not practice in the shifting cultivation area. Therefore, it is essential to check the soil erosion for managing soil nutrient deterioration through the construction of erosion banding methods like Changkham technology (Lalramnghinglova, 2015), bunds, bench terraces and contour trenching which are successfully adopted in other hilly regions.

3) Establishment of the simple soil laboratory and experts to help the farmers in their respective region.

The farmers in the study area are utilizing the chemical fertilizer by their own management without consulting the concerned department and proper soil test. This can cause a serious problem for the existing soil properties in the field. Therefore, awareness about the judicious use of fertilizers based on the soil properties and cropping pattern is highly essential. Further, there is a needed to establish simple soil laboratory centre where easily accessible by the farmers and experts to give suggestions for proper management and judicious utilization of organic and chemical fertilizers.

8.2.3 Forest resources

1) Develop the community based forest management

Forest ecosystem plays an important role in providing various environmental benefits and life support systems to the human and wildlife animals. Development and implementation of forest management programmes specifically addressing the issues of livelihood of forest dependent communities and protection of environment can play an important role in conservation of forests.

If the policies are under the concerned department of the government, the local people usually ignore the precautions of forest conservation. But if it is maintained by the community, there is a chance to involve every person in that policy to takes action for conservation of forest management. This type of forest management is maintained in some villages of the study area and is very effective for forest conservation. Therefore, community-based forest management is necessarily develop for effective conservation of forest and wildlife protection against the land degradation.

2) Make a reserved/protected forest area in every village

In traditional style, every village allotted a reserve / protected forest in their village area. But due to the demand of increasing population and urbanization, those areas were used as settlements and agricultural area. Today, only few villages in the study area have reserved/protected forest. As already mentioned, the fallow period is only 5 – 8 years and no time for regenerating the thick forest cover. Therefore, it is mandatory to make a protected / reserve forest for every village for the sustainable management of the environment. Along with this, they can fix the fallowing period for managing the conservation of forest to reduce the increasing land degradation.

3) Proper awareness of forest conservation measurements

Most of the rural people in the study area are primarily depend on forest resources in different prospects. They cut down the forest for agriculture and also extract the forest resources like timber and non-timber forest products. These are the main factors of land degradation in the study area. Therefore, the local people need to be given the proper awareness of forest conservation measurements. It is better to inculcate the importance of forest ecosystem for protecting our environment and land degradation.

4) Banding deforestation in the river banks to reduce the intensity of soil erosion.

Due to rugged nature of the terrain with high steep slopes, large extent agricultural land found near the river banks where slope is moderate. Besides, trees and bamboos along the river banks are highly extracted for commercial purposes. Associated with high speed of run-off from the topof the hills, these types of forest degradation caused a serious soil erosion problem in the down side of the land causing bulk loss of soil nutrients thereby reduction in the fertility of the soil. Therefore, banding of deforestation along the river banks must be implemented to check or at least to reduce further erosion with high rates and degrading the soil fertility.

Appendix

Schedule for the Dynamics of land Degradation in Tuirini Wathershed, Mizoram

Thank you for agreeing to take part in this important survey of perceptions regarding the dynamics of land degradation. We will be gaining your thoughts and opinions in order to better serve for the future. Be assured that all answers you provide will be kept in the strictest confidentiality.

Vanlaltanpuia
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Soil Erosion

1. Erosion faced in own farm Yes [ ] No [ ]
2. Prevailing form of erosion

a. Sheet erosion
b. Rill erosion
c. Gully erosion

3. Severity of soil erosion

a. Severe
b. Moderate
c. Minor

4. Impact of erosion on crop yield

a. Severe
b. Moderate
c. Minor

5. The rate of erosion over time

a. Increasing
b. Same
c. Decreasing

6. Causes of soil erosion

a. Erosive rains
b. Slope steepness
c. Damaged conservation structures
d. Tillage

7. Causes of Crop productivity decline

a. Heavy Rainfall
b. Rainfall shortage / drought
c. Fertility decline
d. Continuous cultivation
e. Soil erosion
f. Shortening of jhum cycle
g. Others

8. Soil fertility status in own plots

a. High fertility
b. Medium fertility
c. Poor fertility

9. Causes of Soil fertility declining

a. Soil Erosion
b. Repeated cultivation
c. Lack of manure
d. Lack of fertilizer
e. Other

10. Changes in fertility over time

a. Improving
b. Declining
c. No change

11. Any soil conservation measure applied

a. Yes
b. No

12. Type of conservation measure applied/adopted

a. Contour Ploughing
b. Changkham
c. Terrace
d. Other : ……………….

Deforestation

1. Deforestation faced in own land (Village area)? Yes [ ] No [ ]

2. Causes of Deforestation?

a. By local activities
b. By Govt. activities
c. By company or organization activities
d. Others: ………………………………

3. If local activities

a. Fuel wood
b. Shifting cultivation
c. Raw material for building construction
d. Commercial Timbering

4. If Govt. activities

a. NLUP
b. Road Construction
c. MIP
d. Commercial Forest Plantation

5. Type of Agriculture practice

a. Shifting cultivation
b. Terrace Farming
c. WRC
d. Plantation

6. Land use change

a. Severe
b. Moderate
c. Minor

7. Growing distance of collecting raw materials from forest?

a. Increasing
b. Decreasing
c. Same

8. Period of Jhum cycle in the recent past year?

a. 15 years
b. 10 years
c. 5 years
d. Below 5 years

9. Type of Crop

a. Rice
b. Ginger
c. Chili
d. Others:……………………………………………….

10. Type of fruit plantation and year

	Type	Year
a.	Banana	……….
b.	Oranges	……….
c.	…….	
d.	…….	

11. Type of tree plantation and year

	Type	Year
a.	Teak	………
b.	Tung	………
c.	……..	………
d.	……..	………

Water Scarcity

1. Which of the following sources of drinking water does your household use? (Multiple responses are possible)

a. Bore well/ hand pump
b. Public tap
c. Spring
d. Household water supply (piped)
e. Other

2. What is your main source of water? Single response

a. Bore well/ hand pump
b. Public tap
c. Spring
d. Household water supply/ piped
e. Other specify _________________

3. Is the quantity of water that you receive (from your main source of water) adequate?

Yes ☐ No ☐

4. Is water available (from your main source) throughout the year?

Yes ☐ No ☐

5. Which months do you face scarcity? Multiple

January		April		July		October	
February		May		August		November	
March		June		September		December	

6. Generally, how does the water smell?

No smell ☐ Foul smell ☐

7. Generally, does the water have a taste?

Yes [ ] No (tasteless) [ ]

8. Generally, what does the water look like?

Clear [ ] Cloudy/ dirty [ ]

9. Do you pay for water?

Yes [ ] No [ ]

10. How much do you pay a month? Rs. [ ]

11. Have you made a complaint related to your drinking water service in the past one year?

Yes [ ] No [ ]

12. To whom did you complain?

____

13. What was the result of the complaint?

a. Prompt action taken
b. Delayed action taken
c. No action taken

14. Overall, are you satisfied with your drinking water service?

Satisfied [ ] Dissatisfied [ ]

15. What are the reasons for your dissatisfaction? (list up to three)

a. ____
b. ____
c. ____

16. Changing rainfall pattern

a. Severe
b. Moderate
c. Same

17. Is the rivers/streams volume of water is decreasing or increasing in your land?

Decreasing Increasing

Bore well/ hand pump

18. How far (in meters) is the bore well/ hand pump that you use?

19. How long (in minutes) does it take to fetch water and return home?

20. Is the water is safe for drinking? Yes No

21. Has the bore well / hand pump broken down in the past one year?

Yes No

22. How frequently has the bore well/ hand pump broken down during the past one year?

a. Once a week
b. Once a fortnight
c. Once a quarter
d. Once in six months
e. Once a year

23. Is the bore well/ hand pump fixed promptly when it breaks down?

Yes No

Public tap

24. How far (in meters) is the public tap that you use?

25. How long (in minutes) does it take to fetch water and return home?

26. What is the frequency of water supply?

a. More than once a day
b. Once a day
c. Once in two days
d. Once in three days
e. Once a week
f. Other

27. Is this frequency sufficient for your needs?

Yes ☐ No ☐

28. Has the public tap broken down in the past one year?

Yes ☐ No ☐

29. How frequently has it broken down?

a. Once a week
b. Once a fortnight
c. Once a quarter
d. Once in six months
e. Once a year

30. Is the public tap fixed promptly when it breaks down?

Yes ☐ No ☐

Open well/ Spring

31. How far (in meters) is the open well/ Spring from which you get water? ☐

32. How long (in minutes) does it take to fetch water and return home? ☐

33. What is the frequency of cleaning the Spring?

a. Once in a quarter
b. Once in six months
c. Once a year
d. Not cleaned in the last year

Household water supply (piped)

34. What is the frequency of water supply?

a. 24 hour supply
b. More than once a day
c. Once a day
d. Once in two days
e. Once in three days
f. Other

35. Is this frequency sufficient for your needs?

Yes [ ] No [ ]

36. How often would you like to get water?

a. More than once a day
b. Once a day
c. Other

37. On the days that you get water, how many hours or liters do you usually get water for? [ ]

Rainwater Harvesting

38. Do you harvest the rain water? Yes [ ] No [ ]

39. Do you have a water tank for harvesting the rain water? Yes [ ] No [ ]

40. How do you consume the rain water?

a. For Cooking and Drinking
b. For Cleaning
c. For Plants and Crop
d. Both A and B

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Plate No.1

Photo A **Photo B**

Photo C **Photo D**

Photo A & B : Soil sample collection for testing physico – chemical properties.

Photo C : Drying soil sample under room temperature for the preparation of testing.

Photo D : Mortar and sieve soil sample for the preparation of testing.

Plate No.2

Photo A **Photo B**

Photo C **Photo D**

Photo A : At Mount Chalfilh peak

Photo B : At Mount Tawizo peak

Photo C : At the confluence of Tuirini river and Tuirial river

Photo D : At water divide of Tuirini watershed and Mat watershed

Plate No.3

Photo A: Resource inventory survey, interviewing farmers and elders regarding their perceptions on land degradation.

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2005	MBSE	X	44.4
2007	MBSE	XII	50.4
2010	Mizoram University	B.A (Geog)	50.6
2012	Mizoram University	M.Sc (Geog)	65.78
2014	NEHU	PGD Geoinformatics	77.4
2015	UGC	NET	-
2016	IGNOU	PGD Disaster Management	74

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(a) Teacher in Highland Public School, Chaltlang, Aizawl (2013-14)

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Paper presented in National Level

1. *Remote sensing and GIS application in planning* on National Level Interaction Programme for Ph.D. Scholars, organized by University Grant Comission, Academic Staff College, Mizoram University during 5th -25th November, 2014.
2. *Shifting cultivation and its Environmental Impact in North-East India* on National Seminar, organized by Department of Geography, Pachhunga University College during 15th – 16th March, 2018.
3. *Application of Remote Sensing and GIS* on National Workshop on Geospatial Technology, organized by Department of Geography, Pachuunga University College, Aizawl, Mizoram during 10th – 14th February, 2020.
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5. *Environmental Degradation as a risk factor for Landslide Hazard in Mizoram* on One Week National Webinar organized by Department of Geography, Govt. Hnahthial College during 1st – 7th October, 2020.

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1. *Landslide Hazard Zonation (LHZ) of Aizawl District, Mizoram using refined Weighted Overlay Method* on 9th International Geographical Union (IGU) Conference, Saheed Bhagat Singh College, University of Delhi, New Delhi, 18th -20th March, 2016.
2. *A study on Relief Characteristics of Tuirini Watershed, Mizoram* on International Conference on Natural Resources Management for Sustainable Development and Rural Livelihoods organized by Department of Geography and Resource Management, Mizoram University during 26th – 28th October, 2017.

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4. *Vulnerability of Earthquake Disaster in Mizoram: A GIS perspective* on One Week International Webinar on Natural Disaster with Special Emphasis to Earthquake and its Implications organized by IQAC, Govt. Champhai College during 20th – 24th July, 2020.

Paper Published in Journal

1. Identification of Food Security Region for Balanced Development in Mizoram, North East India, *Geographic,* 2016, Vol. 11, pp. 32-45, ISSN 0975-4121
2. Rural-urban Disparity in Nutritional Efficiency Attainment and Infant Mortality Rate in District Saiha, Mizoram, *Geographic,* 2017, Vol. 12, pp. 29-37, ISSN 0975-4121
3. Farmers Perception on Land Degradation in Tuirini Watershed, Mizoram, *Geographic,* 2020, Vol. 15, pp. 1-10, ISSN 0975-4121

Paper Published in Edited Book

1. A Study on Relief Characteristics and Erosion status of Turini Watershed, Mizoram, *Natural Resource Management for Sustainable Development and Rural Livelihoods*, Today and Tomorrow's Printers and Publishers, New Delhi, 2017, Vol. 3, Chapter 96, pp. 1241-1251, ISBN 81-7019-584-1 (India), ISBN 1-55528-434-5 (USA).
2. Shifting Cultivation and Food Security, A spatial comparison of Shifting Cultivation and Wet Rice Cultivation in Mizoram, *Natural Resource Management for Sustainable Development,* Today and Tomorrow's Printers and Publishers, New Delhi, 2019, pp. 45-56, ISBN 10: 81-7019-654-2, ISBN 13:9788170196549.
3. Evaluation of Groundwater potential in Mat river basin, Mizoram through GIS analysis, *Natural Resource Management for Sustainable Development,* Today and Tomorrow's Printers and Publishers, New Delhi, 2019, pp. 603-619, ISBN 10: 81-7019-654-2, ISBN 13:9788170196549.

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