The Use GIS and Remote Sensing in the Assessment of Magat Watershed in the Philippines

A thesis presented in partial fulfilment of the requirements for the degree of
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Abstract

The Philippine watersheds are continually being degraded— thus threatening the supply of water in the country. The government has recognised the need for effective monitoring and management to avert the declining condition of these watersheds. This study explores the applications of remote sensing and Geographical Information Systems (GIS), in the collection of information and analysis of data, in order to support the development of effective critical watershed management strategies.

Remote sensing was used to identify and classify the land cover in the study area. Both supervised and unsupervised methods were employed to establish the most appropriate technique in watershed land cover classification. GIS technology was utilised for the analysis of the land cover data and soil erosion modelling. The watershed boundary was delineated from a digital elevation model, using the hydrological tools in GIS.

The watershed classification revealed a high percentage of grassland and increasing agricultural land use, in the study area. The soil erosion modelling showed an extremely high erosion risk in the bare lands and a high erosion risk in the agriculture areas. This supports the need for effective conservation strategies and a land use plan in the study area. The use of remote sensing and GIS could assist watershed environmental planners and managers to achieve this objective.

Dedication

I dedicate this thesis to my mother Nanang Luring

My wife Jennifer

And my two daughters

Katreena and Karla

Acknowledgements

Acknowledgement is due to Sylvia Hooker, Olive Pimentel, Natalia Benquet and Dianne Reilly. Without their assistance, my family and I would not have been able to fully utilise the benefits that NZAID have made available to us. I am deeply indebted to NZAID and their assistance and caring approach should not be underestimated. I am sure that the generous support my family and I have received from the New Zealand government will enable me to make a contribution to the Philippines – a gift that will forever be a small part of New Zealand.

I am also very grateful to my supervisor, Mr Mike Tuohy, for his advice regarding the direction, analysis and delivery of this project. In addition, I would like to thank Dr John Holland and all the staff in the Institute of Natural Resources, who have assisted in the process of my study and the completion of my research report. Special thanks are also due to the following: Dr Evelyn Ame and Rafael Umbrero, who were supportive in the gathering of my research data in the Philippines and without their assistance, the research would not have been made possible.

Furthermore, I would like to extend my thanks to my fellow NZAID scholars, who have sat alongside me for nearly two years now — I will miss them all. To the local Philippine community, who have become my family — my thanks to you. To all the New Zealanders who made this a memorable moment in my life — Kia Ora.

Special mention is due to my wife, Jennifer and my two lovely daughters, Katreena and Karla — they made my stay in New Zealand more fulfilled. The same accolade is given to my loving Mother — Nanang Luring, and to my brothers and sisters. The list would not be complete if I were not to convey my special thanks to my nieces, nephews, grandsons and in-laws. Each of them has made a sacrifice, in order for me to reach my potential and I thank them all.

Above all I give thanks, glory and honour to the Divine Providence, for all the blessings we have received, especially during the course of my study.

List of Abbreviations

Abbreviations

asl	above sea level
BAR	Bureau of Agricultural Statistics
DEM	Digital Elevation Model
DENR	Department of Environment and Natural Resources
ETM	Enhance Thematic Mapper
GCS	Geographical Reference System
GIS	Geographical Information Systems
IWMP	Integrated Watershed Management Plans
LGUs	Local Government Units
MLC	Maximum Likelihood Classification
RUSLE	Revised Universal Soil Loss Equation
RS	Remote Sensing
STRM	Shuttle Radar Topography Mission
USGS	United States Geological Survey
USLE	Universal Soil Loss Equation
UTM	Universal Transverse Mercator
WEPP	Watershed Erosion Predication Project
WGS	World Geographical System

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Chapter 1

Background of the Study

1.1 Introduction

This thesis is concerned with the application of recent technologies - remote sensing and the Geographical Information Systems (GIS) - in the assessment and monitoring of watersheds, in the Philippines. These technologies are being increasingly applied, in various fields of natural resources management and particularly in area of data generation and environmental modelling. The capability of remote sensing to capture up- to-date information for large areas and the ability of GIS to store and manage data from various sources mean these technologies are an important tool, in the field of natural resource management. This study will explore the usefulness of remote sensing and GIS, in the various areas of watershed management. The study begins with a brief discussion on the general background of the research.

1.2 General background

Watersheds are land areas which catch and drain water to a particular location, such as a stream, river, lake, ocean or other body of water (DeBarry, 2004). They vary in size, depending on their structural characteristics. For example, a large river has its own watershed and the streams or tributaries which feed to a river also have their own watersheds. Therefore, a large river watershed is an aggregation of smaller watersheds. These watersheds are a very important resource, because they supply water for agricultural and industrial use, including water for domestic consumption.

Watersheds are vulnerable to changes, because they form an integrated network and they are continuously being subjected to various disturbances (DeBarry, 2004). These changes can be brought about, either by natural processes, or - human influence activities - or both. Examples of natural agents are climate, tectonic movements or earthquakes and erosion whilst human-influenced activities are agriculture, deforestation and urbanisation (Keefe, et al.). The majority of cases occur as a result of several agents of change which act together. However, changes often result from interactions between natural and human-induced disturbances and these changes concern watershed managers and environmentalists. The cumulative effects are usually detrimental to a watershed's ecological balance, particularly if human induced activities are not controlled.

In the Philippines, approximately 70% of the country's total land area consists of watersheds (Cruz, 2005). According to various studies, Philippine watersheds have been subjected to extreme human activities, especially the forestlands. Forest trees play a significant role in maintaining the quantity and quality of water, in the catchment areas. The forestlands, which are generally found in the watersheds, account for a total area of 15.88 M hectares (Forest Management Bureau, 2003). In the mid 1990s, however, the land area, with natural forest cover was reduced to only 5.59 M hectares (Paragas, et al.). The rapid rate of deforestation, over the past fifty years, was attributed to rampant logging activities, both legal and illegal, which paved the way for forestland conversion into agricultural lands and settlements (Simbulan, 2003).

The high growth of population has also exerted extreme pressure on the country's watershed areas. More areas have been utilised for agricultural farming and settlements, in order to support the requirements of growing populations. This increase in land disturbances has aggravated the capability of the watershed areas to control the flow of water and it has further elevated the rate of soil erosion (Barbosa, 2006, Brath, et al, 2005). Blanco and Nadaoka (2006) mentioned that eroded soils were usually deposited in lakes, river and other water bodies, resulting in the degradation of water quality and the siltation of river systems which could then lead to flooding. In 1988, it was estimated that 18 million people were already residing in the now fragile upland watersheds, which at a growth rate of more than 2% would have risen to 25 million by the year 2000 (Heaney and Regalado, 1998).

The implementation of the Local Government Code, 1991 provided autonomy for local government units (LGUs) to sustainably manage resources, within their area of jurisdiction (Cruz, 2005). Amongst the functions devolved to the LGUs were the management of communal forests and watersheds. Whilst some LGUs were able implement projects, the majority were not successful or sustainable, mainly due to poor planning and monitoring.

The management of watersheds necessitates a better understanding of the different physical factors and processes, which influence changes in watershed area. These factors, which affect the dynamics of land cover/ land use change and rates of soil erosion, are critical to effective watershed management. Local authorities are tasked to provide updated land use classification; inventories of various physical and economic factors in their area; identification of current areas, which are highly susceptible to erosion; and the provision of appropriate land use management recommendations.

1.3 Aims of research

The main objective of this research is to explore the applicability of remote sensing and Geographical Information System (GIS) technologies, in generating quality data and assessing risk vulnerability, in watershed areas in the Philippines.

Specifically the project aims are as follows:

1. To collect maps and prepare available data in order to meet requirements for analysis.

2. To determine the most appropriate method, in classifying multiple land cover/land use classes, in watershed areas.

3. To create a land cover map for inclusion in the GIS analysis of erosion risk potential, in watershed areas.

4. To estimate soil erosion rates in the Magat Watershed area using the USLE model.

5. To determine the relationship of land cover and other watershed physical attributes, in connection to its susceptibility to erosion.

1.4 Limitations of the Study

This research project, on the assessment of watersheds using remote sensing and GIS, relies mainly on the quality of data input for analysis. The satellite images used were already taken some years ago and therefore it could be expected that of the information could have already changed. Moreover, the study only utilised a single data set image which could have been better if more images were considered for more accurate results. Detailed information on soil and rainfall in the area are also not available and, hence some of the data, used in the modelling analyses, were based on assumptions.

1.5 Contribution to Knowledge

The output of this study especially the land cover and erosion maps will be valuable for environmental planners, government agencies and other stakeholders, in the area. These maps could serve as inputs or guides in the planning and formulation of sustainable management strategies. The data collected and generated, in this project, could be utilised in other remote sensing and GIS related studies, within the Magat watershed. Similarly, the methods applied in this study could be replicated, or serve as model for other resource management studies.

1.6 Thesis Structure

This thesis report comprises seven chapters, which provide a background to the study. They describe the theories, methodologies and analysis pertaining to the application of remote sensing and GIS, in watershed assessment. The report discusses in detail the application of these technologies, on land classification and soil erosion modelling. The chapters of the report are as follows:

Chapter 1 provides an introduction to the study, including background and the research aim, in addition to a description of how the thesis is presented. This chapter also describes the areas, where remote sensing and GIS would be needed, in order to support the establishment of an effective and sustainable watershed management framework.

Chapter 2 describes the physical characteristics of the study area in detail. The location, climate, geological features, hydrology and other attributes are explained together with maps and photographs. It also provides a brief background on the socio-economic profile of the study area and the current status and issues confronting the use of the Magat watershed.

Chapter 3 presents the different maps and imagery used in the study. This chapter describes the metadata of Landsat images, DEM and the other thematic maps, including their sources. It also explains the procedure used in the preparation of the data and the cropping of study area, in order to speed up the processing.

Chapter 4 presents the procedure for delineating the watershed from the digital elevation model. It also explains the importance of determining the watershed boundaries and other physical characteristics, which are critical for watershed management. An analysis of area distribution and slope classification is also discussed.

Chapter 5 provides an analysis of land cover/land use of the Magat watershed area. This chapter discusses some of the methods and techniques of remote sensing, which has been employed in previous studies. The analysis presented in this chapter includes a determination of area, for each land cover class and their distribution, based on slope and elevation.

Chapter 6 presents a GIS based modelling of soil erosion risk, in the Magat watershed. This chapter discusses the basic factors that contribute to erosion and it provides some explanations on their effects, based on the results of previous studies. The procedure used in preparation of factor maps: rainfall, soil, slope steepness, slope length and vegetative coverage, are described in detail.

Chapter 7 summarises the conclusions of each chapter and it provides recommendations for the improvement of study and further research. Conclusions on the preparation of data, methodology and results are enumerated. Recommendations, for the implementation of the methods and results of the study, are also provided.

Chapter 2

Description of the Study Area Magat Watershed

2.1 Introduction

The Magat Watershed is a forest reservation area declared under Proclamation 573, dated June 26, 1969 (Elazegui and Combalicer, 2004). It is classified as a critical watershed in Region II, due of its contributions towards maintaining the ecological balance and in addition it is of economic importance to the people living in the area and to the Philippines in general. Figure 2.1 shows the catchment area of the Magat watershed and the Magat dam structure.

Figure 2-1 Magat catchment area and dam structure

The watershed pictured above, in Figure 2-1 supports the Magat multi-purpose dam and other vital infrastructures. These physically supporting structures are very essential for the provision of irrigation, flood control and hydroelectric power generation within the study area. Magat Watershed is the topic/study area of this thesis and this section provides a description of the important physical attributes and socio-economic background of the Magat Watershed and the provinces where it is located.

2.2 Geographical Location

The Magat watershed covers a total land area of approximately 426,000 hectares and whilst it is predominantly situated within the region of Nueva Vizcaya, it also includes part of two other provinces: Ifugao and, Isabela. It is located between latitudes 16 ^{o} 05' and 17 ^{o} 01' and longitudes 120 ^{o} 51' and 121 ^{o} 27'. Figure 2.2 below, is a map showing the location of Magat Watershed, with respect to the major places mentioned previously and also other places, in the Philippines.

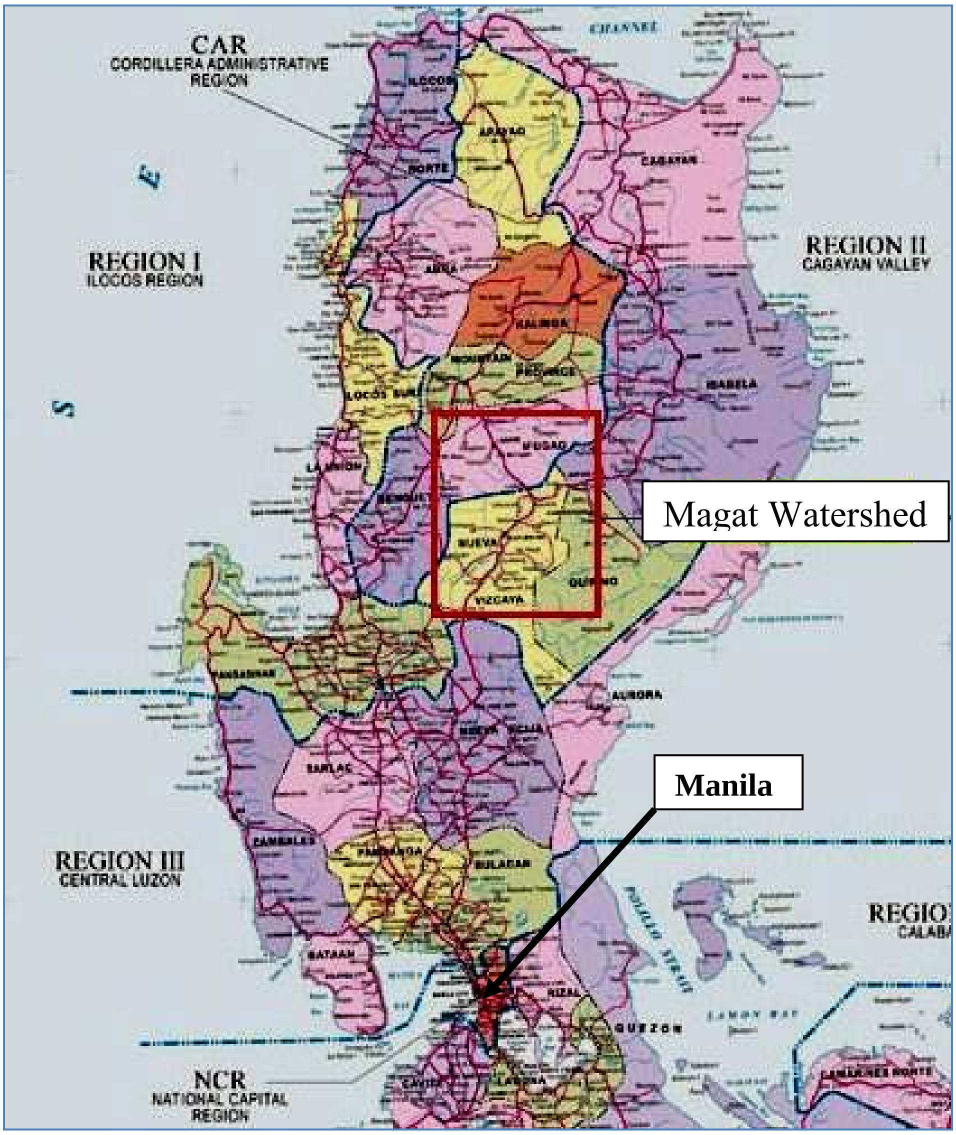


Figure 2.2 Location map of the study area

As seen in Figure 2.2, the watershed is approximately 200 kilometres north of Manila city and it is accessible by land through a National Highway, which traverses the area from south to north, starting from Sta. Fe, Nueva Vizcaya, through to Santiago City, Isabela. It can also be reached through provincial and municipal roads, which link Ifugao and Mountain Province in the western side and Isabela on the eastern side. Likewise, the watershed is also accessible by air transportation, through the airport in Cauayan, Isabela and small airstrips for light planes in Ramon, Isabela and Bagabag, Nueva Vizcaya.

2.3 Topography

The Magat watershed is surrounded by several mountain ranges. The south and eastern parts of the watershed are bordered by the Mamparang Mountains, Palali range and Sierra Madre range whilst the Cordillera Mountains are located on the west and southwest (LUCC, 2001). The terrain in the watershed generally ranges from 100 metres to 2,900 metres above mean sea level. The Magat River, which is the longest river in the area, crosses the watershed from south to north and its tributaries cross mountains and valleys. The floodplain is located in the middle areas of the watershed and it occupies the major portion of the province of Nueva Vizcaya, particularly the municipalities of Bagabag, Villa Verde, Solano and Bayombong. On the other hand, mountainous regions are located in the municipalities of Ifugao and Isabela and also within a major portion of the municipalities of Ambaguio, Diadi, Kayapa and Sta. Fe, in Nueva Vizcaya.

The slopes of the Magat watershed are predominantly very steep. These hilly and very steep areas surround the flood plain region and they are located on the northwest and southern side. The floodplain region, found in the central portion of the Magat watershed has flat to gentle slopes.

2.4 Soils and Geology

The dominant soil texture in the study area is clay loam. Clay loam is composed of soil material with a more or less even distribution of sand, silt and clay. This type of soil dominates the area, due to the abundance of fine-grained volcanic rocks, sedimentary and pyroclastics (Lasco, et al.) Other types of soil present in the watershed are complex soil, gravelly loam and silt loams, which are generally found along the river area. With the exception of areas, which have been developed from limestone and covered mostly by rocks, the majority of the area is classified to have a moderately deep soil.

Apart for those areas situated along the river terraces and sedimentary hills, the majority of the areas have a moderate-to-high water holding capacity (www.nvizcaya.gov.ph). The upland soils are considered well drained, both internally and externally, except for the 'clayey' alluvial plains. The infiltration rate varies from slow to moderate in all the uplands and soil fertility is considered to be generally high.

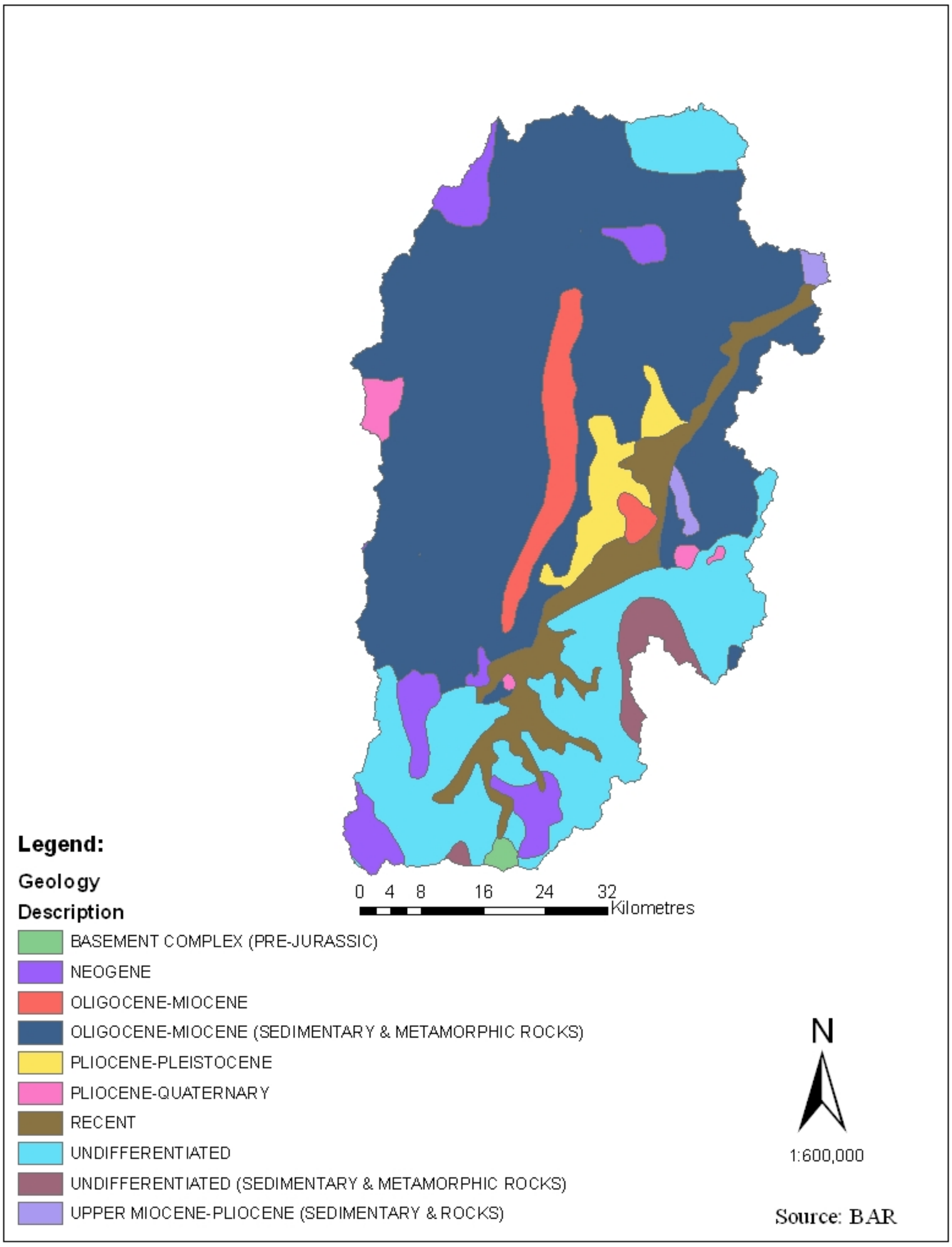


Figure 2. 3 Geological feature of the study area

The Magat watershed geological feature is generally composed of rocks, which are metamorphic and sedimentary, as shown in Figure 2.3. Metamorphic rocks constitute the largest deposits in the area, whilst sedimentary rocks are found only in the northern portion of Nueva Vizcaya. According to Bato (2000), the sedimentary rocks in the watershed are comprised mainly of unconsolidated conglomerates, sandstone, shale and siltstone, or pyroclastic rocks and limestone, as chemical deposits. These rocks are believed to have been deposited and consolidated during the Oligocene to Miocene periods.

The most common sediment in the area is recent alluvium. As shown in the figure above, the deposits are generally concentrated along main streams, particularly in the Magat River, and they are laid down with the older materials. Alluviums are characterised as loose, unconsolidated soil or sediments, which are eroded and then deposited by water (FFTC, 2005).

2.5 Climate

The climate of the Magat watershed falls under Type I and Type III categories based on the Coronas classification. The western section belongs to the Type I climate, which is defined by a dry season from December to May and a wet season from June to November. This section is exposed to the Southwest Monsoon and it receives a fair share of the rainfall, which is brought about by the tropical cyclones that occur, from June to September.

The eastern section, on the other hand, falls within Type III climate. The type III climate season is characterised by a relatively dry period during the November to April season, but there is no pronounced maximum rain period. The Magat climatic conditions are greatly influenced by southwest monsoons and the South Pacific trade winds (PAGASA). These two air masses contribute approximately seventy-five percent of the annual rainfall in the area.

The annual rainfall, in the watershed, ranges from 1,400 millimetres in low elevation areas to about 2,400 millimetres in high elevation areas (LUCC, 2001). The average minimum temperature is 23 degrees Celsius, whilst the average maximum temperature is 34 degrees Celsius. The average relative humidity is 83% and the months, June to November, are more humid than other months (PAGASA).

2.6 Hydrology

The Magat vast area of mountains and valleys is traversed by a network of rivers, streams, springs and creeks. The Magat River and its tributaries, which originate from the headwaters of the Caraballo and Cordillera ranges, in the Province of Nueva Vizcaya, have a combined drainage area of approximately 1784 square kilometres (LUCC, 2001). Its major tributaries are the Matuno River, Sta Cruz River and Sta Fe and Marang Rivers. The Magat River flows through its flood plain, and merges with its other tributary rivers from the provinces of Ifugao and Isabela towards the Magat High Dam at Ramon, Isabela. These rivers drain the plains and valleys of the watershed and they also provide water for domestic and irrigation purposes.

The stream flow for the Magat River is usually at its maximum from July to November, due to high precipitation brought about by the occurrence of several typhoons or storms, during this period. This often results in the spilling of water over the Magat high dam and this causes flooding in the downstream areas. The Magat watershed is considered to be well drained, except for some low lying areas. Flooding also occurs in the municipalities of Sta. Fe, Aritao, Dupax, Bayombong, Solano and Bagabag, during the rainy seasons due to the overflowing of the heavy silted rivers (LUCC, 2001, Ortiz, 2006).

2.7 Land Cover / Land use

The Magat watershed is comprised generally of wooded lands, grass and agricultural areas. Wooded lands combine with shrubs and grasses to comprise the largest land area which covers almost half of the watershed land area. The forest areas, classified as either closed or open, are composed of coniferous and broadleaf trees and plantation forest. The land cover/land use distribution, in the study area, is illustrated in Figure 2.4 below.

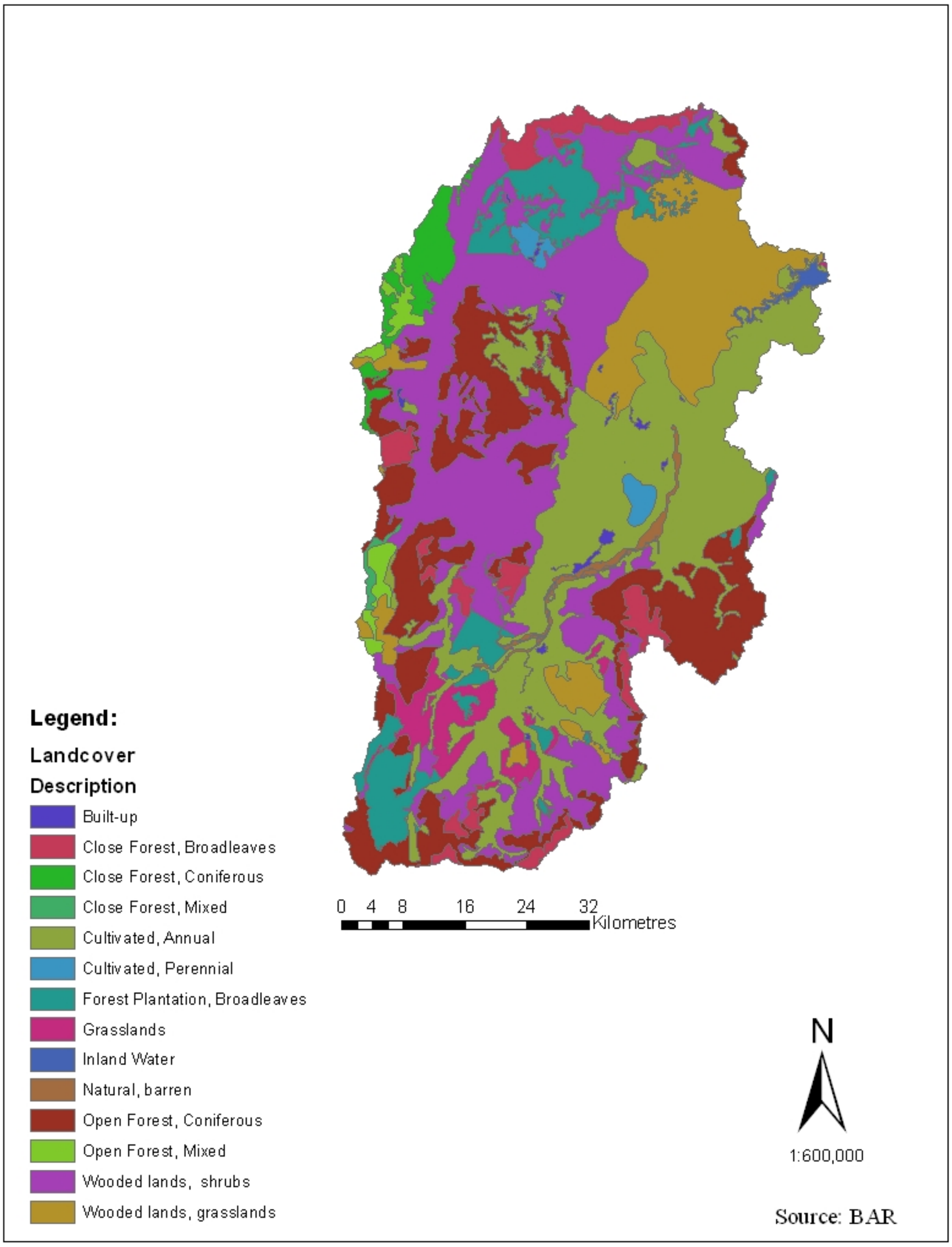


Figure 2.4 Land cover /land use of the study area

The central portions of the watershed, along the flood plain region, are generally used for agriculture and settlement. The agriculture area is divided into two classes: the annually cultivated and the perennially cultivated. Annual cultivated areas are generally devoted to rice and vegetable production, which are supported by irrigation infrastructures, whilst perennially cultivated areas are only utilised during the rainy season, when a sufficient amount of rainfall is available. Identified inland water generally represents the Magat River catchment.

Table 2.1, below, shows the area and percentage distribution of the different land cover/ land use, within the study area. The forest areas, which include closed forest, open forest and plantation forest, cover approximately 28 % of the Magat watershed. The broadleaf forests cover a combined area of 47,765 hectares whilst the area for coniferous forest totals to 82,434 hectares. The coniferous forest type are occupies the largest area, amongst the forest classes.

Table 2.1 Area and percentage of land cover in the Magat watershed.

Land cover/land use class	Area	Percentage
Closed Forest: Broadleaf	18091	3.80
Closed Forest: Coniferous	9538	2.00
Closed Forest: Mixed	989	0.21
Forest Plantation, Broadleaf	28704	6.02
Inland Water	2501	0.52
Open Forest: Coniferous	72896	15.29
Open Forest: Mixed	5078	1.07
Built-up	1844	0.39
Cultivated: Annual	109226	22.91
Cultivated: Perennial	3603	0.76
Natural: Barren	3251	0.68
Grasslands	33359	7.00
Wooded lands: Shrubs	118298	24.82
Wooded lands: Grasslands	69286	14.54
Total	**426664**	**100.00**

This table also shows that cultivated areas, both annual and perennial, cover an aggregate area of 113,000 hectares, or approximately 24% of the watershed area. The mixed wooded lands, shrubs and grasslands constitute approximately 40%, or a combined area 187,584 hectares. The built up class, which include, residential and commercial, covers a total area of 1844 hectares. The majority of the built up areas are located in the low lying municipalities of Nueva Vizcaya.

Figure 2.5 Areas covered with grass and shrubs

The above Figure 2.5 shows some areas which are covered with grasses and shrubs. Some of these areas have previously been covered by forest. However, due to deforestation; this land has transformed into grass and shrub land. Similarly, due to the increasing demand for agriculture areas, grass lands are being utilised for pasture and orchard production.

Figure 2.6 Mixed land use showing terraces planted with grains

Another example of mixed land use, in the Magat watershed, is upland farming. Figure 2.6 shows some of the rice terraces area found in the Magat watershed. Upland farming, particularly the construction of terraces for rice production, has been practiced for hundreds of years and it is firmly embedded as part of the culture of the people living in the province of Ifugao. These terraces serve as a catchment area for collecting water and they minimise the impact of water flow runoff, on the soil.

In general, the majority of the agriculture fields in the Magat watershed can be found on the flat areas. These areas are located in the central and eastern part of the watershed and along the floodplain regions, in the province of Nueva Vizcaya. These agriculture areas depend on a network of streams and river for irrigation. Figure 2.7, below, shows an example of rice paddy area, which is the most prevalent agriculture activity, in the floodplain region of the watershed.

Figure 2.7 Flat areas are predominantly use for rice farming

Aside from agriculture, the flat lands are being used for road construction, which connect the different provinces and municipalities within the Magat watershed (Figure 2.8). The majority of the residential and commercials are concentrated in these flatlands. Approximately 23% of the land area has been classified into alienable and disposable land and it is utilised mainly for agriculture and settlement purposes.

Figure 2.8 Mixed forest areas

The closed and plantation forest areas are found on the western and southern part of the watershed. Figure 2.8, above, is an example of a mixed forest area in the watershed. The rolling and hilly areas are planted with upland crops, fruit trees and vegetables. These areas characterise by steep and/or highly elevated areas, which are generally dipterocarp forests and some pine forests

2.8 Soil erosion and sedimentation

Soil erosion is considered to be a very serious problem, which threaten the sustainability of the Magat watershed and the life expectancy of the multipurpose dam. According to Ortiz (2006), the watershed experienced severe erosion, due to landslides caused by the 1990 earthquake. This was further exacerbated by rampant logging and the slash and burn practices, used by some people in the area, as shown in the figure below.

Figure 2.9 Soil erosion resulting from deforestation and slash and burn practices

The above photo illustrates an example of a deforested area, which was converted for agricultural purposes. The excessive removal of the natural cover and tilling exposes the soil to extremely erosive factors. Figures 2.10 and 2.11 illustrate other environmental problems, within the Magat watershed, which have resulted from natural and human influenced activities.

Figure 2.10 Erosion caused by mining activities in the watershed

The prevalence of mining activities has also contributed to an increase in erosion and the siltation of water bodies. Figure 2.11 shows rock extraction activities, which disturb the landscape and causes erosion on hill slopes. Soils from these areas are then detached and they usually end up in the river systems: Such is the case of Magat River, in Figure 2.12 below.

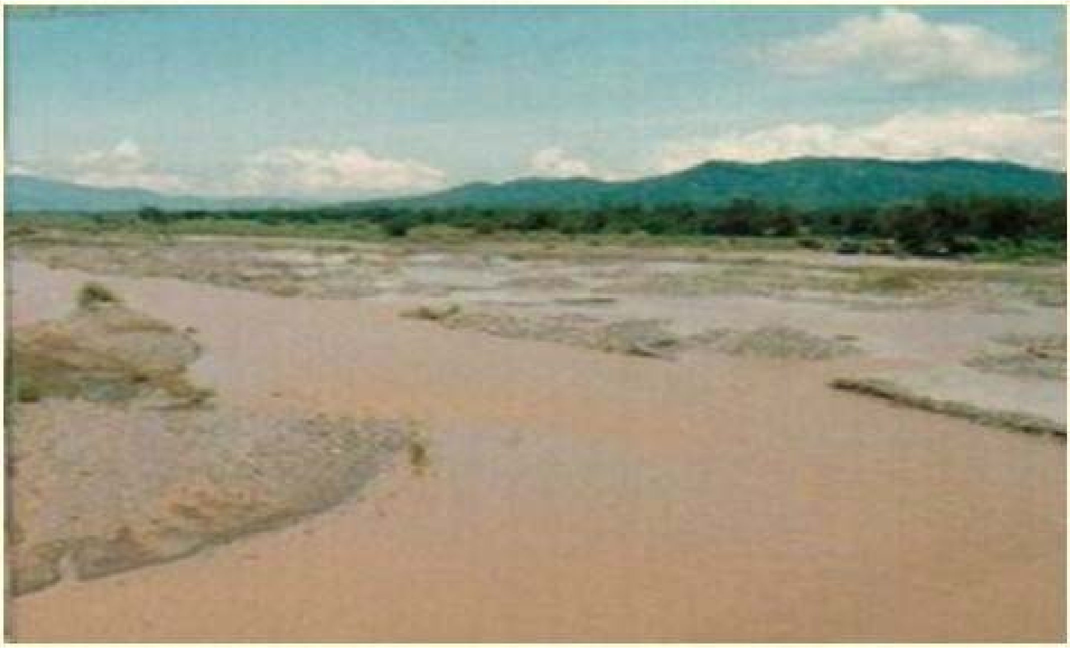


Figure 2.11 Heavily silted portion of Magat River at Nueva Vizcaya

The deposition of soil, primarily coming from the upland areas of the watershed, affects the quality of water in streams and rivers (Figure 2.12). It also has a negative impact on the production and survival of fish and other biotic organisms. A vast amount of siltation has also caused the overflowing of the river and streams, which have flooded agricultural and settlement areas, in some low lying areas of Nueva Vizcaya.

2.9 Socio-economic background

The provinces of Nueva Vizcaya, and Ifugao, which encompass most parts of the Magat watershed area, have combine population of 578,500, which is an increase of approximately 95,000, from 1995 (NSO, 2008). The annual population growth rate, in the area, is estimated to be 1.5%. Based on the 2007 Census report, the median age for a household population was 22 years and therefore half of the population were below 22 years of age. Approximately 27% of the population live in the urban areas of

Bayombong, Solano and Bambang. The literacy rate, for the population living in the watershed area, is about 92%.

The economy of the study area is basically agricultural based, with approximately 110,000 hectares allocated for various agricultural activities (NSO, 2008). Primary products include crops, such as rice, corn, root crops, vegetables and fruits. Farmers are also engaged in swine and cattle production. The grassland areas are utilised for pasture farming, particularly cattle and goat farming. Aquaculture is also a thriving economy, with a large portion of the Magat dam water area used for fish cage farming of tilapia. Similarly, there is an increase in the conversion of agricultural and idle lands into tilapia fishponds, especially in the provinces of Ifugao and Nueva Vizcaya, wherein the supply of fish is limited and people generally rely on obtaining fish from neighbouring areas.

The road network in the area varies from concrete roads, gravel type and trails. Concrete roads connect major municipalities, which are generally located in the lower part of the watershed. Gravel type or rough roads and mountain trails, on the other hand, are the access routes to municipalities and villages located in the highlands, or areas that are separated by physical barriers, such as rivers and very steep mountain ridges. Mountain trails are also numerous in the watershed. Native folk and some minor ethnic groups live in very remote and steep areas, which are only accessible by days of walking on these trails.

2.10 Summary

This chapter has considered, in detail, the Magat Watershed in Nueva Vizcaya, a forested reservation area of the Philippines. Magat is a critical watershed in Region II and it has some outstanding features, which are of great importance to human survival in the area and the provision of environmental balance, in general. This watershed supports the Magat multi-purpose dam and it supplies the infrastructure necessary for irrigation, flood control and hydroelectric power generation. The task of this chapter was to introduce the reader to the key physical attributes of the study area. The focus now changes to the next stage of the study – the collection of data – which is the focus of Chapter 3.

Chapter 3

Data Collection and Preparation

3.1 Introduction

This chapter will provide a description of the different data gathered for this study. It will discuss the processing of the data collected in preparation for its inclusion in the analysis. This includes the preparation of different thematic maps, satellite imagery and a digital elevation model. The discussion begins with a brief overview of satellite images.

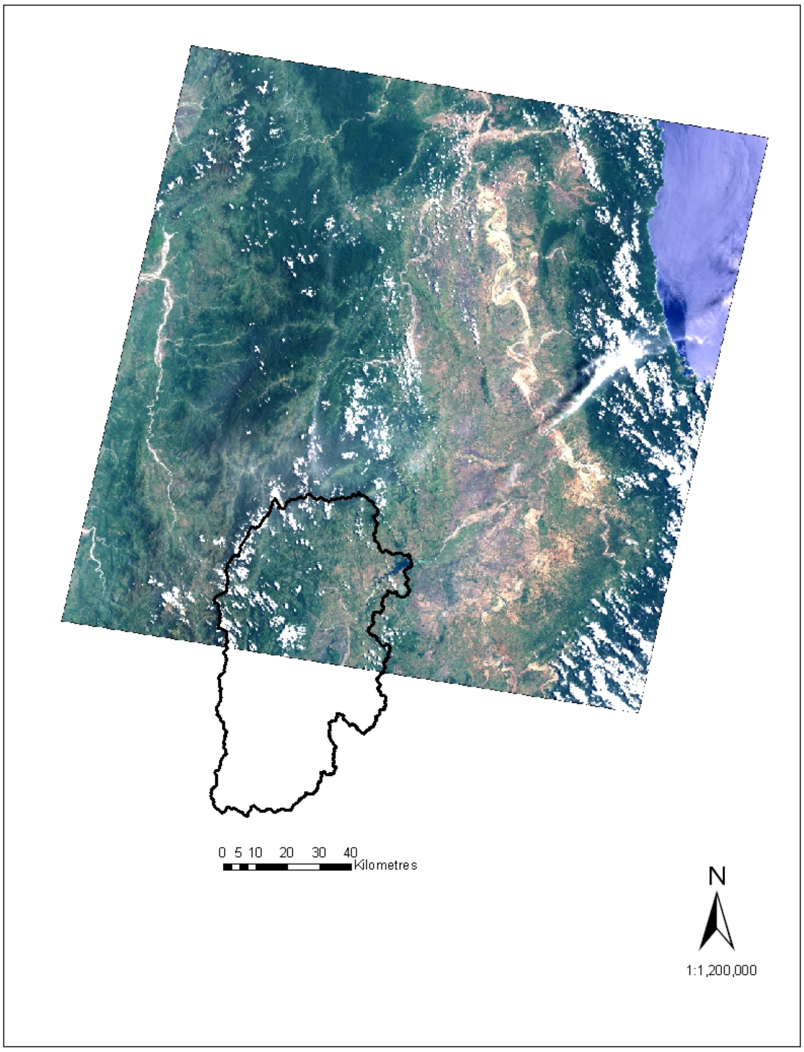


Figure 3.1 Landsat image of the study area

3.2 Satellite Image

The satellite image shown in Figure 3.1 below was acquired on the 3rd June 2001 by Landsat 7 using the ETM+ sensor. The whole image covers the area between 16.34 ^{0} and 18.34 ^{0} N and between 120.29 ^{0} and 122.65 ^{0} E. The reference datum of this image was WGS 1984 and the map projection was UTM zone 51N.

The satellite image data set has six multi-spectral bands with 30 metre resolution and a panchromatic band of 15 metre resolution. Landsat 7 is the latest of a series of NASA satellites, which provides an uninterrupted multispectral record of the Earth's land surface, to assist in the monitoring and managing the Earth's resources. Table 3.1 below, describes some of the characteristics and principal applications of the spectral bands, within the satellite image.

Table 3.1 Landsat 7 spectral band characteristics

Band Number	**Spectral Range(*um*)**	**Ground Resolution**(m)	**Principal application**
1	.45 to .515	30	Determining water body and coastal mapping
2	.525 to .605	30	Vegetation and cultural feature identification
3	.63 to .690	30	Plant species differentiation and cultural feature
4	.75 to .90	30	Determining vegetation type, water bodies and soil moisture
5	1.55 to 1.75	30	Vegetation moisture content
6	10.40 to 12.5	60	Thermal mapping
7	2.09 to 2.35	30	Determination of rocks and minerals
Pan	.52 to .90	15	Higher spatial resolution for more detailed features

Source: Lillesand et al,(2005)

Table 3.1 describes the main applications of the different Landsat spectral bands, which could be very useful, especially for a new user of the data. Since the satellite images would be used mainly for land cover identification, it was important to know which bands would be useful for that particular purpose. For this study, only bands 1-5 and 7 were used for the classification. The panchromatic band was used for improved resolution of composite maps. The image was cropped in order to cover the boundaries of the study area and to reduce the amount of data. This action was taken to speed up the processing of the data, in the computer.

3.3 Digital Elevation Model

The Digital Elevation Model (DEM) used for the study was sourced from the Bureau of Agricultural Research, a government agency in the Philippines (Figure 3.2). It is a Shuttle Radar Topography Mission (SRTM) DEM with a resolution of 90 metre and it has a reference coordinate system of GCS_Luzon_1911. The DEM contained the whole region and hence it occupied large data storage.

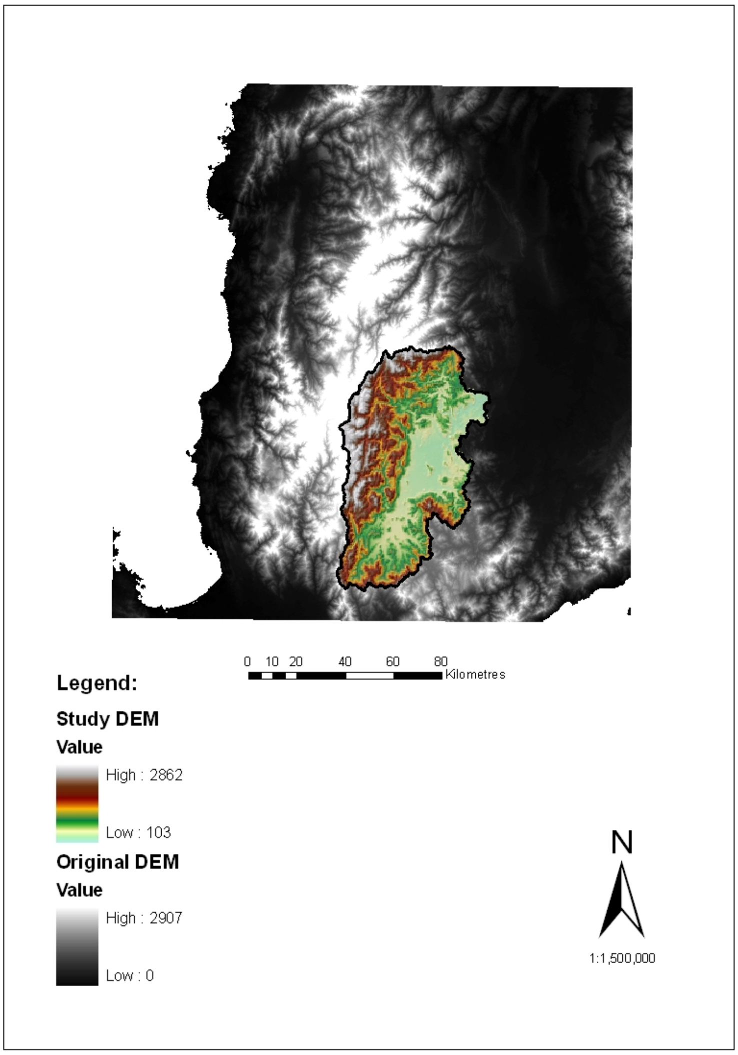


Figure 3.2 DEM of the study area extracted from the original data set

Using the spatial analysis function in ArcGIS, the study area DEM was extracted by mask as shown in Figure 3.2 above. Re-sampling of the extracted study area DEM, to 30 m resolution was performed and re-projected to WGS_1984, in order to obtain a unified coordinate and projection system, with the satellite image. The DEM would be used in the demarcation of the watershed boundaries, the extraction of slopes and elevation data and in the calculation of slope steepness and slope length factors, for the soil erosion modelling.

3.3 Rainfall data

The rainfall data was collected from National Irrigation Authority Magat Reservoir Station, in the Philippines. The data available covers the rainfall amount for the period, from June 2008 to May 2009. Figure 3.3, below, shows the total erosive rainfall and monthly rainfall, within the study area.

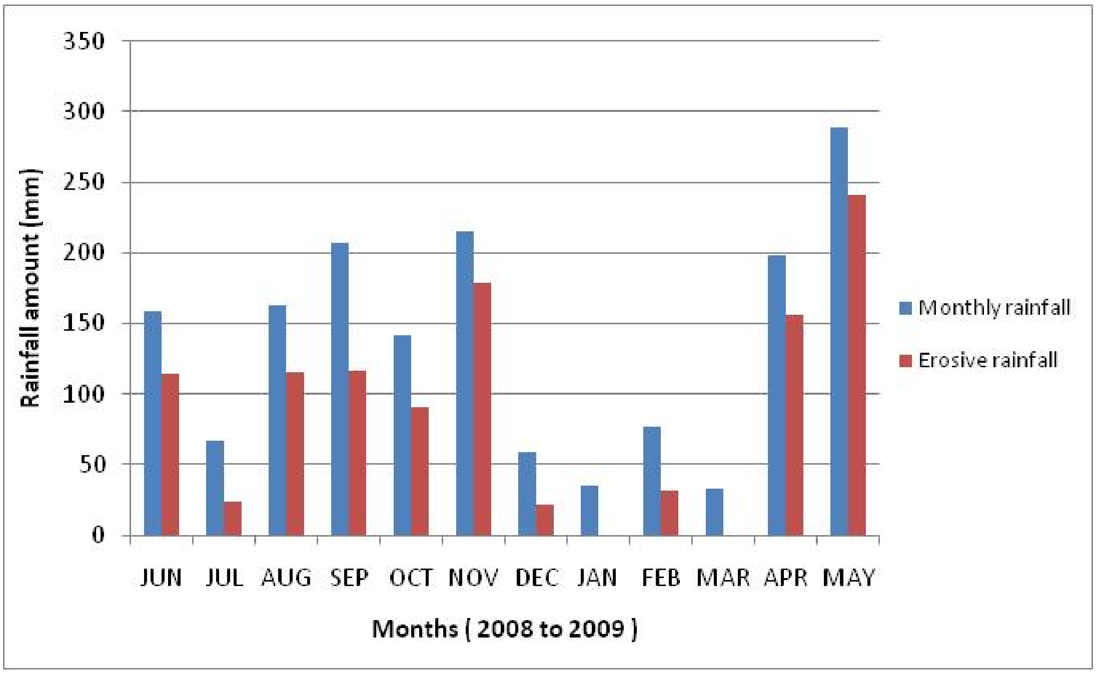


Figure 3.3 Monthly rainfall at Magat watershed

The graph shows that the highest rainfalls were observed during the months of September and November 2008, and April and May 2009. The high amounts of rainfall, during these months, could be attributed to the occurrence of several typhoons. The total rainfall recorded from June 2008 to May 2009 was 1640 mm whilst the total amount of erosive or intense rainfall was 1090 mm.

3.4 Soil

A soil map, showing the textural characteristic of soil in the study area, was also collected (Figure 3.4). Soil texture has an important effect on soil properties. A soil's water-holding capacity, drainage class, consistency and chemical properties are affected by soil texture. Soil texture refers to the percentage of sand, silt, and clay particles in a soil.

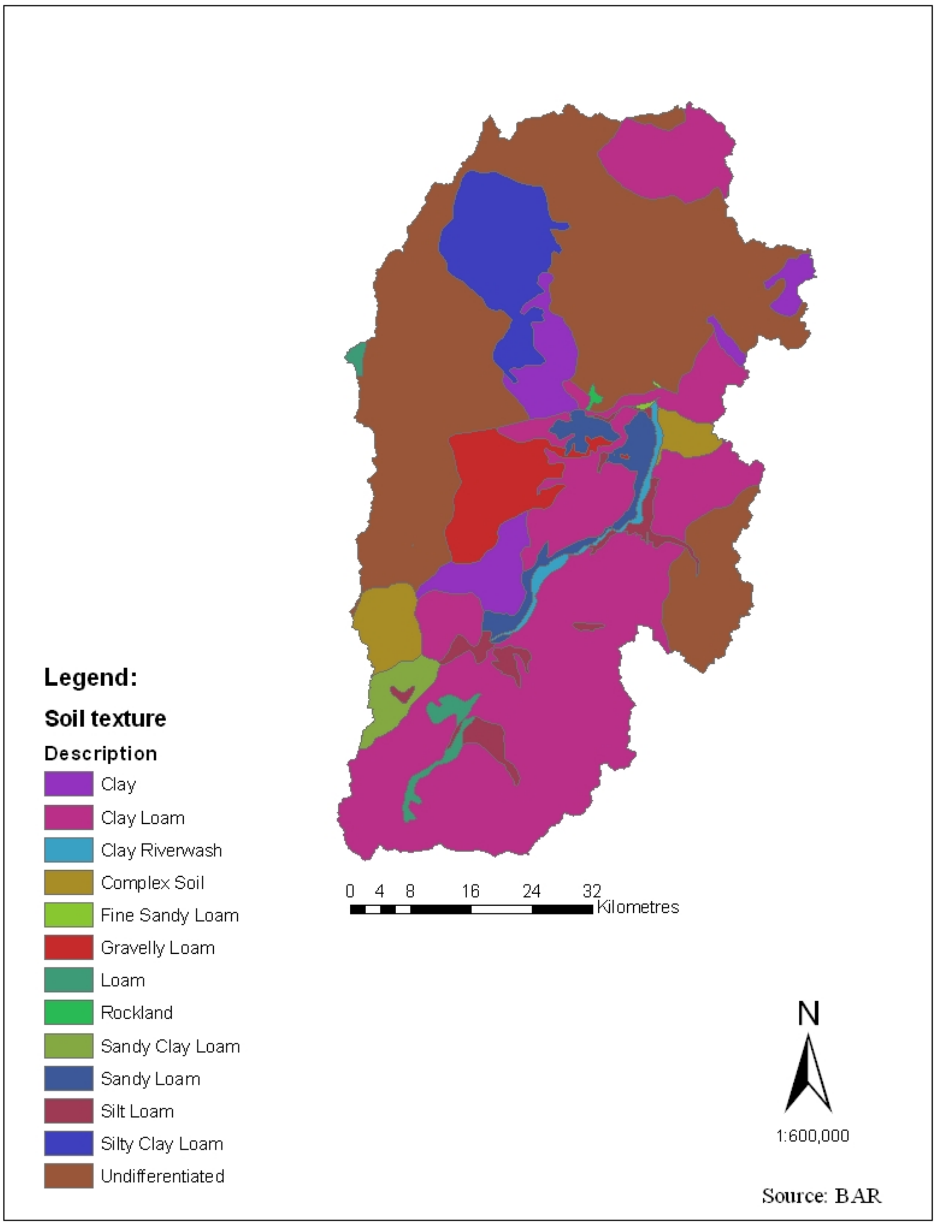


Figure 3.4 Soil texture map of the study area.

The dominant soil texture in the study area is clay loam. Clay loam consists of soil material with a more or less even distribution of sand, silt, and clay. Other types of soil, present in study are silty loam, complex soil and gravelly loam.

Table 3.2 below shows the size of soil particles, according to the U.S. Department of Agriculture classification system. A clayey soil has a high resistance to natural erosive factors, due to its small texture size particles (Breiby, 2006, Renard, 1997). Fine-textured soils, generally, are more fertile and they contain more organic matter. They are known to have better moisture and nutrient retention and they are less permeable. The size of clay soil particles is 0.002 mm or less.

Table 3.2 Soil texture size particles.

Soil texture	size
Very coarse sand	2.0-1.0 mm
Coarse sand	1.0-0.5 mm
Medium sand	0.5-0.25 mm
Fine sand	0.25-0.10 mm
Very fine sand	0.10-0.05 mm
Silt	0.05-0.002 mm
Clay	<0.002 mm

In contrast, sandy soils are less fertile and they have low organic matter content. Due to their larger size particles, they exhibit less water retention and they are rapidly permeable. Sandy soil size particles vary, from very fine sand of 0.05 mm to very coarse sand of 2.0 mm. Silt loam size particles are in an intermediate range between clay and sand and they range from 0.002-05 mm.

3.5 Photographs

Photos illustrating land cover, land use and issues relating to soil erosion, in the study area, were also collected. These photographs were used in identify land cover categories and also to describe the study area. High resolution images, from online sources, were also utilised in order to identify land cover and counter check accuracy of the classification.

3.6 Spatial correlation of data from various sources

The project utilised remote sensing and GIS technologies, when generating spatial datasets. Different classification methods were explored, in order to determine the most suitable approach for land cover classification, in the watershed areas. The effects of various physical attributes of the watershed, on the erosion process, were also investigated in the project.

3.6.1 Remote Sensing

The remote sensing component of this study involved the generation of spatial datasets, which contained land use and land cover conditions. Image processing and an analysis of Landsat data were performed, in order to generate a land cover and land use classification, within the watershed area. The land cover classification maps, generated for the study sites, served as inputs in the analysis of areas vulnerable to soil erosion. The land-cover maps were generated using image processing tools in ArcGIS software.

3.6.2 Geographic Information System (GIS)

This component included the development and maintenance of digital spatial databank, generation of thematic maps and spatial analysis. The preparation of the data such as the cropping of the study area and inputting of attributes were performed using some GIS functionality. GIS was utilised in preparation of the all the inputs for the soil erosion and land cover change analysis in the Magat watersheds. The Magat watershed was delineated using the hydrology tools in ArcGIS. Areas of the classified land use were also computed. The calculation of erosion rates using USLE model was also performed in the ArcGIS software.

3.7 Summary

The data collected and used in the analysis have been described in this chapter. The satellite images, elevation model and other thematic maps were cropped, in order to delineate the study and reduce the storage of data. This chapter provided a brief description on the spatial attributes and sources of the data. The application of remote sensing and GIS methods in the study were also briefly explained.

Chapter 4

Watershed Delineation

4.1 Introduction

The previous chapter discussed how elevation data, satellite images and thematic maps-of the Magat watershed, were obtained from various sources. This chapter illustrates how to use the major functionality available in the ArcGIS hydrology tools for Raster analysis and how to perform drainage analysis on a terrain model, using the Digital Elevation Model. The ArcGIS hydrology tools were used, in order to derive several data sets, which collectively described the drainage patterns of the catchment area. Raster analysis was performed, to generate data on flow direction, flow accumulation, stream definition, stream segmentation and watershed delineation. These data were then be used to develop a raster and vector representation of catchments and drainage lines, from selected points.

4.2 Geographical Information System (GIS)

Geographical Information System (GIS), a computer-based, geographically referenced information system, is widely utilised in the field of natural resources management. Lovett and Appleton (2008) stated that, amongst the various applications of GIS in environmental management are resource mapping and modelling, hazard and risk analysis, planning and resource assessment. GIS is an information system, which has been designed to work with data referenced by spatial/geographical coordinates (Maantay and Ziegler, 2006). It has the capability to integrate and organise geo-referenced information into one system: it provides accurate data collection for better decision making; and it models and visualizes impact of different environmental factors. GIS provides planners, resource managers and researchers with a very powerful tool, for analysis and decision making.

The application of GIS, in the area of natural resource management, offers several advantages. It provides the integration, overlaying and analysis of various environmental data, in order to determine their cause and effect relationships, but more importantly it allows a visualisation of these relationships, through output maps (Palmer, 2008). This technology also allows the modelling of these factors which reveals potential changes and trends that may result from variations in these factors. These capabilities make GIS application very suitable for environmental modelling, which inherently requires spatial data.

Whilst GIS has been widely practiced within environmental management, in developed countries, it has been still sparsely used in developing countries, such as the Philippines. Government agencies still rely on traditional methods of surveying and sampling methods, for data generation and resource assessment. Usually, these activities require a great deal of manpower and time, especially in relation to the geographical distribution of resources in an area. The development of GIS, in the Philippines, is being held back by a lack of interest in GIS and also the availability of trained personnel. This lack of interest could be due to inadequate knowledge on the extent of its use and application of GIS in resource assessment and decision making. Such a situation may warrant a demonstration of its application and also the undertaking of further studies on GIS capabilities, to encourage use and investment in the system, for watershed management.

4.3 Digital Elevation Model (DEM)

A digital elevation model (DEM) is a digital representation of the terrain elevation, or topographic surface (Lovett, 2008, Shamsi, 2005). It is a major component of a GIS, because it enables elevation data to be used for modelling and analyses and it can also display phenomena, related to topography. DEM are widely used in determining terrain attributes, such as slope, aspect and elevation values, at any point. There are various applications, such as the delineation of watersheds and streams and the generation of isometric projections of terrain profiles (Cochrane and Flanagan, 2000, Shamsi, 2005).

DEM can be obtained and created through the interpolation of contour data from topographic maps, or it can be acquired through remote sensing satellites. Amongst the most popular and widely available elevation data sets are those produced by Shuttle Radar Topography Mission (SRTM) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) projects undertaken by United States National Aeronautics and Space Administration (NASA). The STRM elevation data set has a global resolution of 90 metres and 30 metres a resolution over the USA and it has covered approximately 80% of the Earth's surface (www2.jpl.nasa.gov. 2009). On the other hand, the ASTER GDEM covers the planet from 83 degrees North to 83 degrees South, which is larger than SRTM coverage of 56 degrees S to 60 degrees N (www2.jpl.nasa.gov. 2009). The ASTERGDEM has a global terrain elevation measurement or resolution of 30 metres interval.

4.4 Digital Elevation Model Data in Drainage Delineation

The determination of watershed and catchment boundaries is important, in hydrological studies. These watersheds are used in various studies involving water availability and quality projects, flood forecasting programmes and public policy applications. Traditionally, watersheds are delineated manually from a topographic map, by locating and analysing contour lines (CRWR). This procedure involves the drawing of arrows, which represent the flow directions perpendicular to each contour, in the direction of the steepest descent, as shown in Figure 4.1.

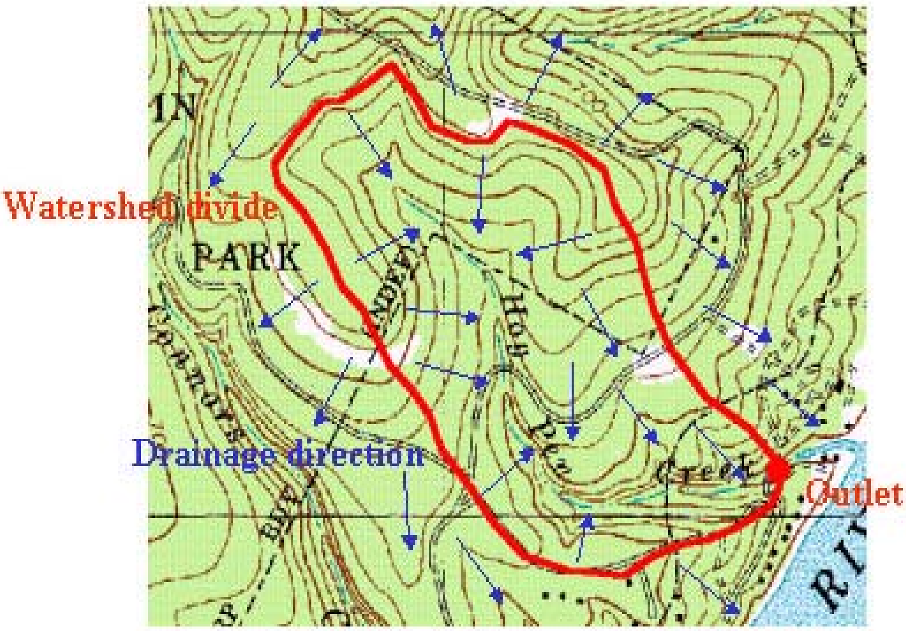


Figure 4.1 Manual delineation of watershed areas from topographic map (CRWR).

The boundaries of the watershed or catchments are determined by identifying where the flow directions separate, or where the arrows point in opposite directions (Figure 4.1

above). This manual procedure is very difficult and prone to human errors and in addition it is time consuming and requires some degree of skill.

However, with the advent of GIS, functionalities such as ArcGIS Hydro, have automated the delineation of watershed and drainage areas. The use of DEM entails the analysis of grids, in order to identify flow directions and accumulation areas, which are then easily processed with GIS hydrology tools (Melancon, 1999). Comparatively, automated delineation, with the use of DEM, provided more accurate results and it could be easily repeated (Kraemer and Panda, 2009). Precise drainage boundaries are essential, for accurate modelling studies.

4.5 Methodology

4.5.1 Watershed delineation

The delineation of watershed, from the DEM, involved several procedures. The process was performed, using the hydrology tools in ArcGIS. The steps are discussed as follows:

1. **Filling of the DEM**: The filling of the DEM, using the Fill feature in the hydrologic tools is first step in watershed delineation. This procedure is necessary, in order to correct any small imperfections in the DEM, which may affect the proper delineation of the watershed and streams.

2. **Determining flow direction**: The direction of flow is determined by finding the direction of steepest descent or maximum drop, from each cell. The output filled DEM is process with the Flow Direction function, in order determine the direction of flow, from every raster.

3. **Determining of flow accumulation**: The Flow Accumulation function calculates the accumulated flow, as the accumulated weight of all cells flowing into each, down the slope cell, in the output raster. The step is important when identifying stream channels and ridges. The output flow direction grid is used as input, to the flow accumulation function.

4. **Setting watershed parameters:** This step is undertaken using the CON function. The threshold number of cells is set, in order to establish the minimum area of watershed to be delineated.

5. **Stream link grid identification:** Using the stream link function, the stream grid cells are identified. The output flow direction and con flow accumulation are the inputs for this function.

6. **Watershed determination**: Finally, the last step is the watershed delineation with the stream grid and flow direction grid as input. The stream area could be extracted and converted to a feature file, using the stream to feature file.

The Magat watershed was determined by following its stream link network. The sub-watersheds, which were connected to the stream network, were selected and aggregated to form the Magat watershed. The area of the Magat watershed and its sub-watershed was calculated and classified.

4.5.2 Extraction of geo-morphological characteristics.

Topographical features, such as slope and elevation of the Magat watershed, were also determined. Using the Surface tool in Spatial Analyst, the slope feature of the watershed was calculated. The elevation levels of the watershed were then extracted. Geo-morphological features were essential inputs in the characterisation and vulnerability assessment of the watershed.

4.6 Results and discussion

This section will discuss the procedure and the analysis conducted in the delineation of the Magat watershed boundaries, using the hydrology tools in ArcGIS.

The first step involved in the processing of the DEM was the filling of DEM, using the Fill function in ArcMap. Since, the DEM used was re-sampled to 30m resolution, this step was important to correct any depression in the re-sampling process. After correcting the DEM, the direction and accumulation of flow were extracted. These steps helped to determine the location of streams and ridges. The threshold size for the watershed area was set at 5000 cells. A much lower threshold size would give more detailed watershed and stream features, — however, this would have required a longer processing time.

The final procedure, in the delineation of the watershed and stream features, was to delineate the boundaries of the Magat watershed (Figure 4.2). In defining the area, the raster file of the watershed was first converted into a polygon file. The stream network file was then overlaid onto the watershed polygon file. The watershed area and boundary were delineated, by following the stream network connected with the Magat River system.

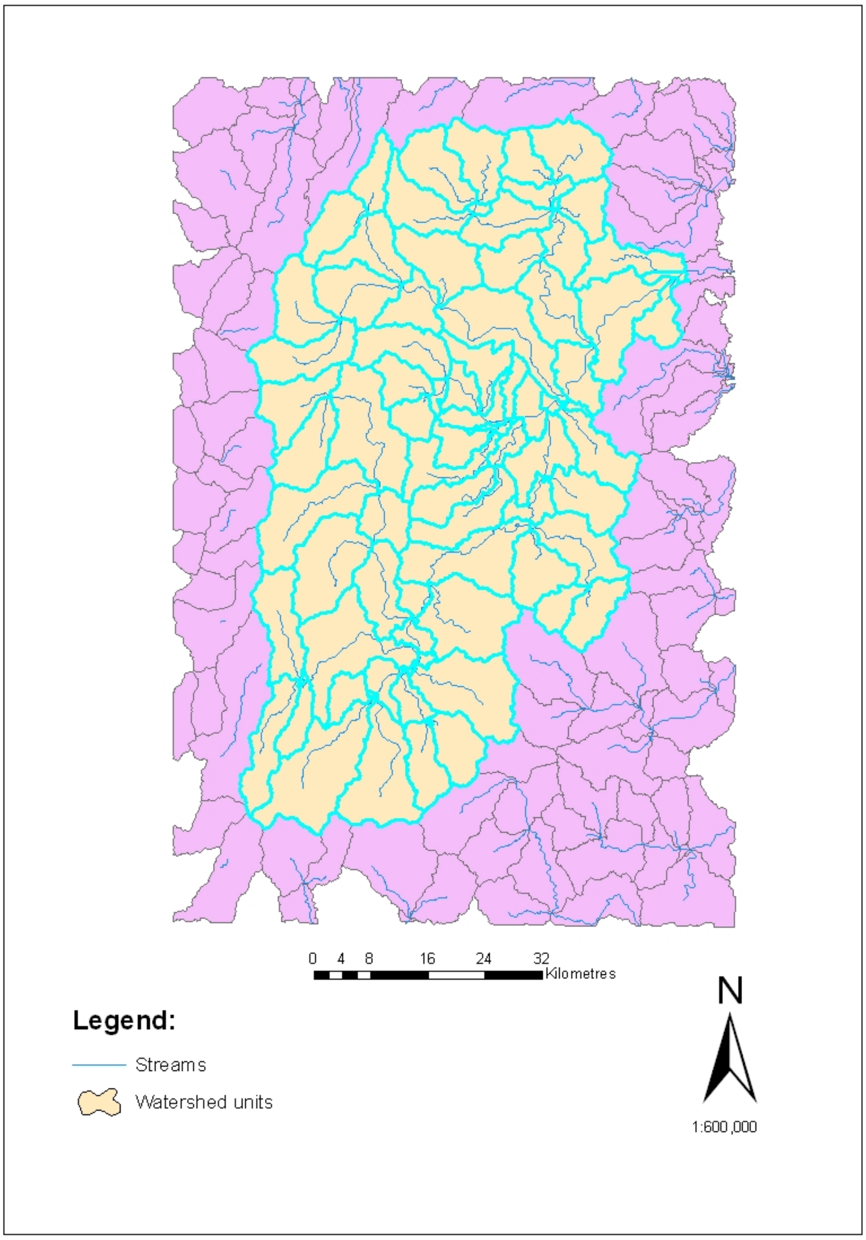


Figure 4.2 Magat watershed boundary delineated from DEM

The Select function in the analysis tools, in ArcMap, was used to extract the Magat watershed boundary, which is represented by the highlighted shape in Figure 4.2. The stream file was clipped using the boundary of the delineated watershed. The outputs were the vector files of the watershed and the network of streams found in the area.

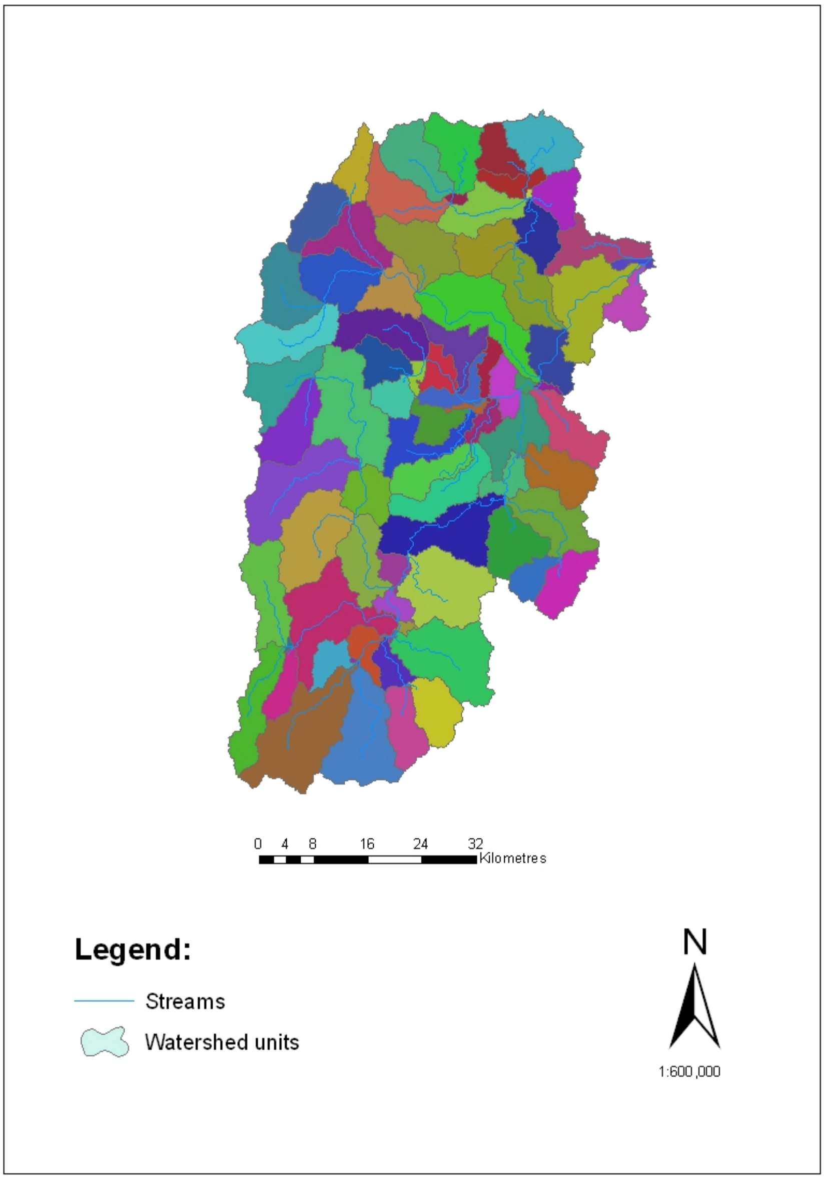


Figure 4.3 Magat sub-watersheds and stream network

Figure 4.3 above, presents the delineated sub-watersheds and stream network of the Magat watershed. The map shows the aggregated sub-watersheds, which form the entire Magat watershed area. The sub-watersheds of Magat range from small (<10000 hectares) to medium sizes (10,000-50000 hectares). The stream line represents the Magat River and its tributaries.

The total area of the delineated watershed of the Magat area, shown in Figure 4.3 above, is 426,459 hectares, encompassing the provinces of Nueva Vizcaya, Ifugao and Isabela. The total number of sub-watersheds extracted is 80. The smallest sub-watershed has an area 43.23 hectares and the largest sub watershed is 15,490 hectares.

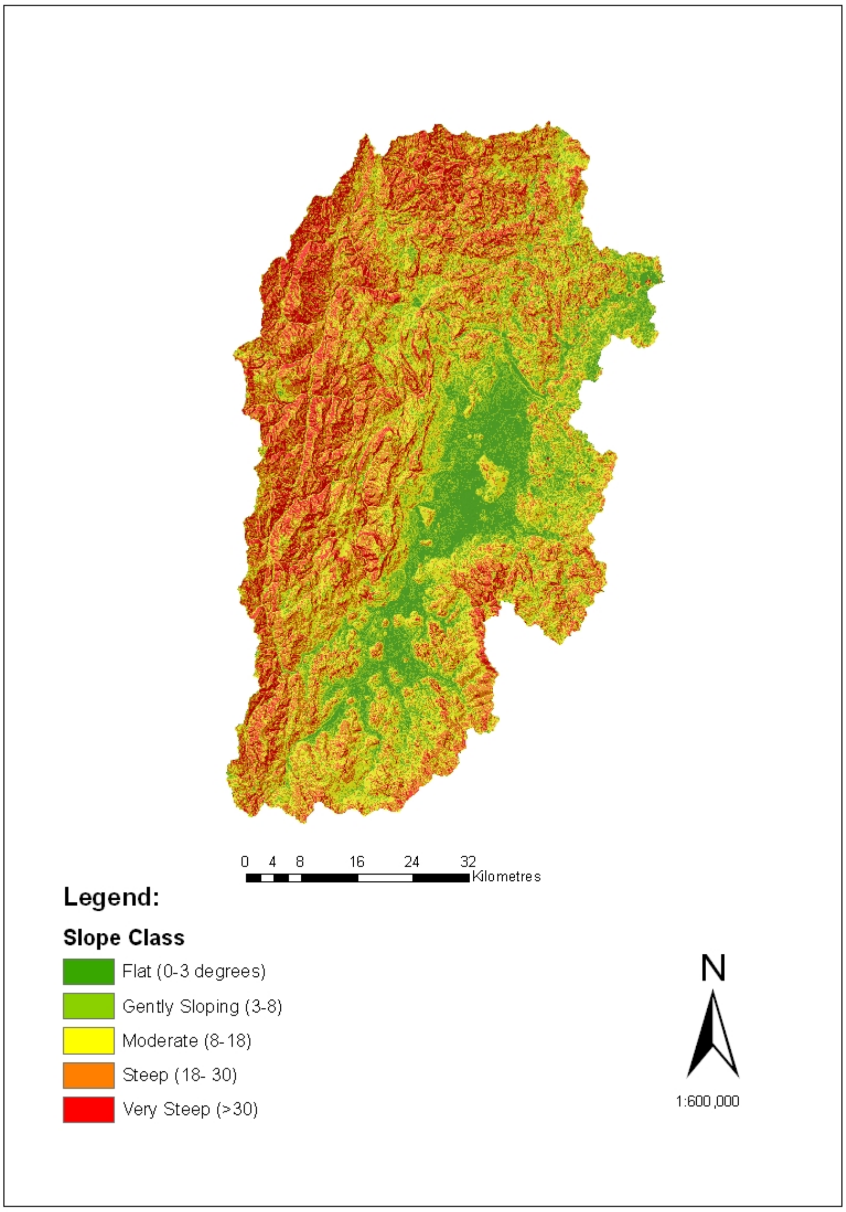


Figure 4.4 Slope classification of Magat watershed

Figure 4.4 above, shows the slope levels of the Magat watershed. The slope varies from level to gently sloping to very steep. The slope in Magat watershed is expected to be predominantly steep, due to its mountainous and rugged terrain. The level and gently sloping areas are located adjacent to the main channel of the Magat River. The figure above reveals that the slope class of Magat watershed has a high potential risk of erosion. According to Morgan (2005) erosion rates usually increased as slope steepness increased. Thus, slope factor should be considered significant when developing areas within the watershed.

The percentages of the different classes of slopes are shown in Figure 4.5 below. Approximately 24% of the total land was classified as level to gently sloping (0 to 8 degrees). These areas were generally located along the flood plain region. The moderate steep and steep regions constituted about 62% of the land area whilst the remaining 14% were classified as very steep.

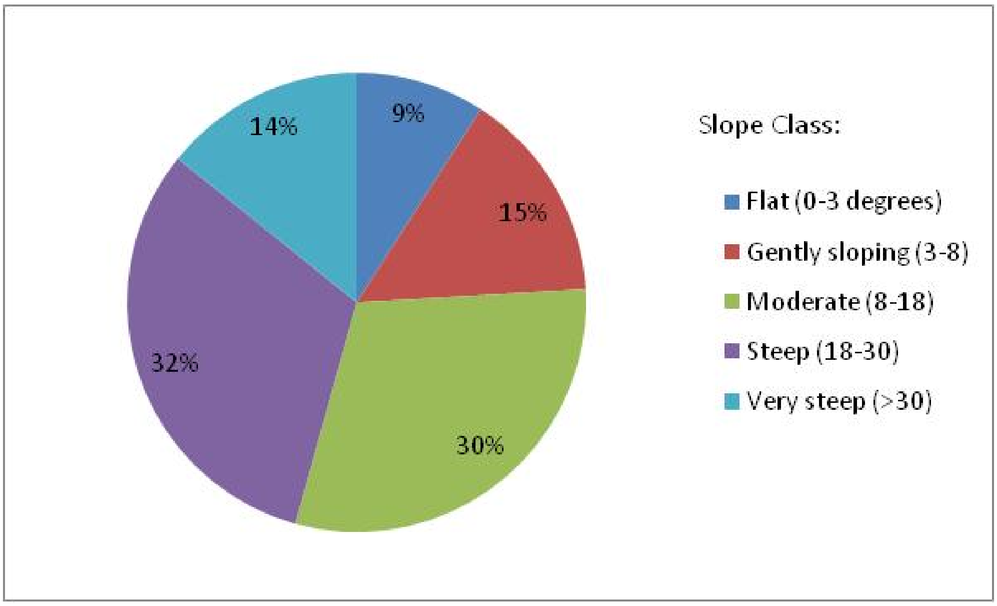


Figure 4.5 Percentages of slope class at Magat watershed

The slope classification of the Magat watershed indicates the suitability of current land use in the area. The flat to gently sloping areas are mainly used for agriculture and settlement. The moderately steep to steep are being utilised for plantation forests. However, these areas are also increasingly being developed for upland farming and other production areas. The very steep areas are still covered with natural forest, particularly coniferous and broadleaved.

4.7 Conclusion

A determination of the Magat watershed and catchment boundaries is necessary, in hydrologic modelling. It is important, in relation to hydrology, because the catchment size, location and its characteristics such as slope, soil types, geology and land use govern the amount and rate of runoff into and along the streams. These watershed characteristics have been used in various studies involving the ecology of streams, water availability and quality projects, flood forecasting programmes, and also in public policy applications. The delineated boundaries of the Magat watershed, from the digital elevation model, were more accurate and more detailed. The maps and other data, which were generated on the physical attributes of the watershed, could provide environmental planners and managers with additional information for better planning and management. The ecological processes, involved in the watershed, were considered to be interrelated with each other.

Chapter 5

Land cover classification

5.1 Introduction

Land cover identification and classification is one of the most popular applications of remote sensing, in the gathering of information relating to the Earth’s surface. Several classification methods have been developed, to suit the wide array of data needed. This chapter will present a procedure used in identifying and classifying land cover and land use in a watershed environment. The study will investigate the land cover/land use characteristics of the Magat watershed, where both supervised and unsupervised techniques of classification have been employed.

5.2 Remote Sensing and GIS in Land Classification

The technology on remote sensing has become a very important method of data collection, in relation to the environment. Remote sensing has been extensively used to collect information on areas, which are difficult to reach for field-work. Remote sensing involves the collection of information on objects, places or natural occurrences without having contact with the subject of the investigation (Campbell, 2007, Lillesand, et al, 2008). According to Grossman and Forrester (2001), data collection has been made more accurate and fast and larger areas of interest can be encompassed, with remote sensing. This technology has become a cheaper alternative to field survey, which is laborious and time consuming.

One of the major applications of remote sensing is the identification and monitoring of land coverage. Land cover features, such as water, soil, vegetation, cloud and snow, are identified and classified, through remote sensing, as a result of their different reflectance to visible and infrared lights. Accurate mapping of land cover/land use assists planners and decision makers, to develop better management strategies and policies. Several methods of classification have been developed, depending on the objectives of the classification and the requirement for information. Amongst the most common methods are supervised and unsupervised classification techniques (Campbell, 2007).

5.2.1 Supervised and unsupervised of classification

Supervised classification schemes require knowledge of the land cover types to be mapped (Barret and Curtis, 1999). It is most often used when knowledge of the area to be mapped is extensive and land cover types are easily recognisable. This method involves the identification of representatives of each known class in the image called training sites, which are then applied to the whole image (Mather, 2004, Eastman, 2009). Supervised classification methods rely heavily on both the quality and representation of the training area (Campbell, 2007). This means that there should be sufficient training areas identified, in order for a particular class to produce more homogenous cell values and to have a more superior representation in the output map.

In contrast, the unsupervised methods aggregate images cells into natural groupings or clusters, which are already present in the mapping variables and they require no prior knowledge of the study area (ESRI, 2006, Eastman, 2009). These different clusters are then interpreted into meaningful classes, based on the understanding of the analyst. There are also many approaches to clustering classes in the unsupervised method. One of those commonly used is the ISOCLUST. The ISOCLUST module is an iterative self-organising module, wherein each cell is assigned to the cluster with the closest mean, in every iteration (ESRI, 2009). The means of each class are then recalculated during the iteration.

Campbell (2007) listed the advantages and disadvantages of these two classification methods. In the supervised classification, the categories could be easily matched with classified images and errors could also be easily detected, primarily because of the analyst's prior knowledge of the image location. The disadvantages of this supervised method were that the identification of training could be difficult and time consuming and the training areas might not be properly selected and digitised, thus resulting in poor classification output.

The advantages of the unsupervised method included the following: knowledge of the study area was not required, human errors were minimised and the repeatability and consistency of the classification, such as the same result, could be obtained for the same data set, even if it was performed by a different analysts (Campbell, 2007). On the other hand, one of its disadvantages was the difficulty when matching categories, with classes derived from the images. Lunetta and Lyon (2004) stated that unsupervised classification could overlook a very small but possibly significant class in the data set, which might not be missed by supervised classification, if the analyst were aware of them.

Decision techniques, which are used to group the cells are categorised into soft and hard classifiers. Hard classifiers assigned class to a particular cell, based on a definitive decision, whilst soft classifiers provided some uncertainty on the membership of cell, in a particular class (Eastman, 2009). An example of hard classifiers was the maximum likelihood classifier (MLC). This classifier used band means and a variance of the signature classes, to estimate the probability that a cell or pixel belonged to each class (Lillesand, et al., 2008). The unclassified pixels, from the images, are clustered to the class in which they have highest membership probability, or the class to which they are closest.

5.2.2 Integration of remote sensing and GIS

Advancements in computer technology have allowed the integration of data produced from GIS and remote sensing. Available GIS software packages now allow remotely sensed data to be imported and integrated with spatial and non-spatial data generated from GIS. GIS is responsible for the integration, analysis and manipulation of the data generated from remote sensing (Navalgund, et al., 2007). The application of GIS includes the overlaying and cross-referencing of remotely sensed data with other spatial attributes of the study area. Likewise, GIS can facilitate the modification and integration of non-spatial data, such as socio-economic statistics on remotely sensed data (Price, 1994).

6.3 Methodology

Land cover classification was performed on four sub-watersheds of the Magat watershed. A satellite image, acquired by Landsat 7, was used in the classification. The sample areas were extracted by mask, using the vector file of the sub-watersheds created from the watershed delineation, in the previous chapter. The preparation of data and classification was carried out, using the functionalities in ArcMap.

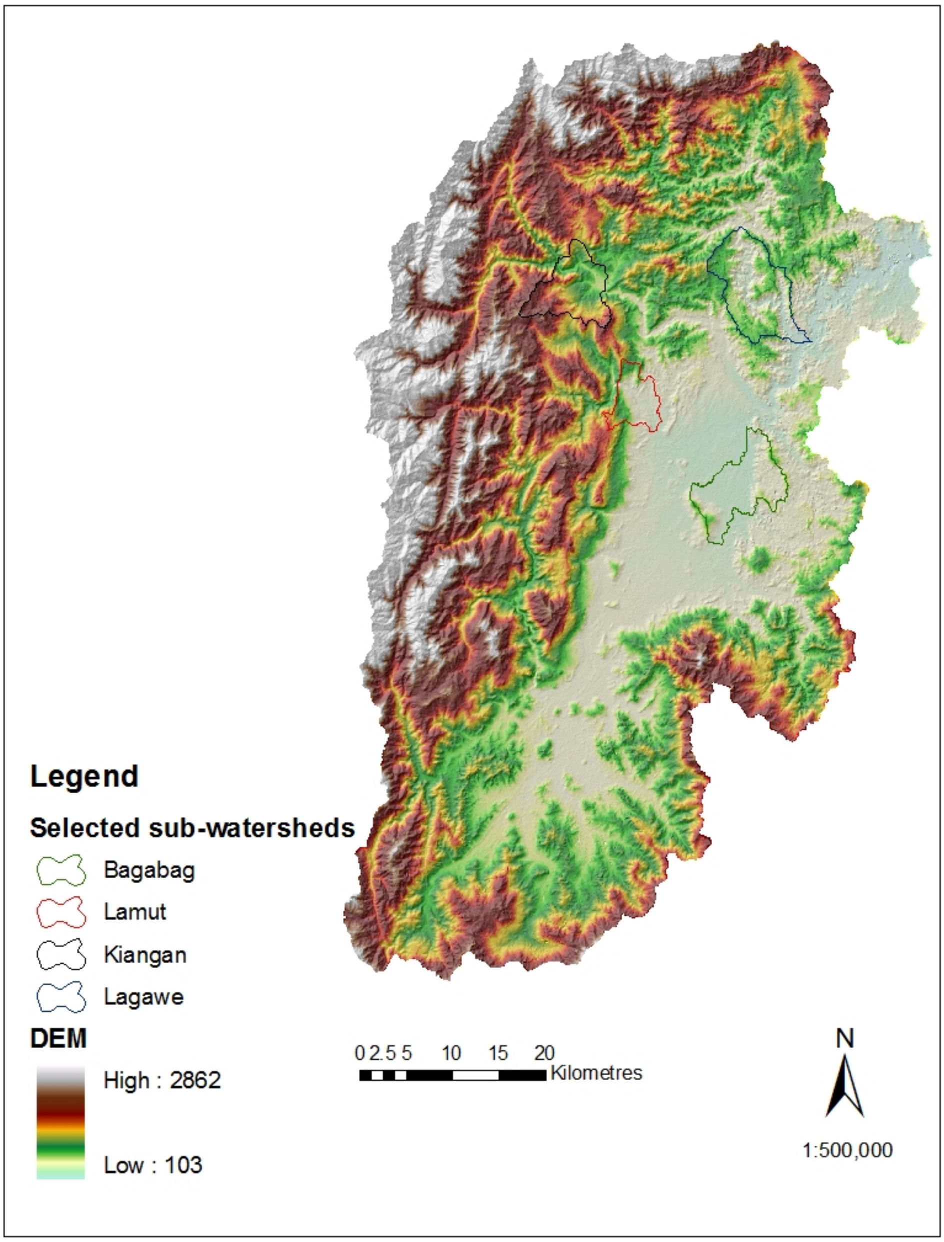


Figure 5.1 Location of selected sub-watershed areas.

The sub-watersheds were selected, based on location and on the variability of identifiable existing land cover types. The Bagabag and Lamut subwatersheds are located on the flat and lower part of the Magat watershed, whilst the Kiangan and Lagawe sub-watersheds are situated on higher elevations and steeper areas of the watershed (Figure 5.1). Moreover, the sub-watersheds were chosen base on the presence of human related activities, such as agriculture, logging and other land conversion activities, which are of significant concern for the management and conservation of the Magat watershed.

Supervised classification was first performed on the images with the easily separable classes as output. These classes were as follows: forest, grassland, water body, bare land, agriculture, clouds and cloud shadows. The first step was the creation of composite images of the selected sites. This was followed by the identification and digitisation of the training areas, for each class. The training areas were stored in a shapefile format. High resolution images from Google maps were used to counter check the identified land cover types. The shapefiles were converted into raster format, to suit the requirement for the creation of a signature file.

Using the Create Signature, under the Multivariate function, signature files were created, which represented each known class and these were used in the supervised classification. The Maximum Likelihood Classification (MLC) method was performed, in order to create a land cover classification. All six spectral bands were combined, during the creation of the signature file and during the classification. The resulting images were analysed, in order to determine overlapped classes. Sample areas were identified and compared, with high resolution images from Google maps. The land cover categories description, in Table 5.1, served as a guide during the classification.

Table 5.1 Description of Land cover class categories

Land Class	Description
Built-up land	Areas covered much by structures include residential, roads and industrial and commercial areas.
Agricultural land	Land used primarily for production of food and fibre. Categories under this class are: cropland, pasture, orchards and other agricultural lands.
Herbaceous rangeland	Includes lands naturally covered by grass and shrubs, in addition to areas which have been modified to grass as their principal cover.
Forest land	Lands, which have a tree-crown areal density (crown areal density) of more than 10% are classified in this class. Forests are divided into three categories: deciduous, evergreen and mixed forest
Water	Areas which are persistently covered with water such streams, rivers, lakes, reservoirs , estuaries and wetlands
Barren land	Land with limited ability to support life and on which less than one-third of the area has vegetation or other cover

Source: USGS Land Classification System

Table 5.1 shows some of the land class categories, under based on the USGS classification system. The description column provides the type of land cover, which can be classified under the different categories.

Unsupervised classification was performed on the imagery, in order to further refine the classification of a certain land use class, into more specific classes — and to separate overlapping classes. The ISO CLUSTER tool was used to create a signature file, which represented different classes or clusters, with the same set of spectral bands used in the supervised classification. Two sets of ISO CLUSTER signature files were created composed of 10 and 15 classes. The purpose of having two signature files was to determine which number of classes would provide a better classification result. Dendrogram analysis was conducted on both signatures, to determine which classes were closely related and they could then be merged.

To limit the extent of the classification, each overlapping class was used as a mask. The resulting classes of the supervised and unsupervised classifications were compared, in order to produce a refined classified image. The resulting classes were: built-up, agriculture, forest/tree plantations, grassland, bare land and water body. The clouds and cloud shadows were reclassified into land cover classes that were dominant in the location.

The area and percentages of the different land cover classes were calculated. A cross-tabulation of the land cover class layer, with elevation levels and slope classes, was also conducted to determine the distribution of different land cover in the watershed area. The statistical analysis was carried out using the Zonal Statistics function in ArcMap.

5.4 Results and discussion

The land coverage of the four sub-watershed areas of the Magat are namely: Bagabag, Lamut, Kiangan and Lagawe, which were classified by supervised and unsupervised techniques. Classification methods were carried out using the Multivariate tools in ArcMap. The supervised classification was performed on the easily identifiable land cover classes: water, forest, grass, bare lands, built-up, and agriculture or paddy fields. The outputs of the classification are the maps and tables which are presented on this section.

Illustrated in Figure 5.2 are the composite images, for the Bagabag sub-watershed, used in the identification of training areas. The images were created using the Composite tool in ArcMap. The first image, RGB 321m was a combination of bands 1, 2 and 3, whilst the second image was a combination of bands 4, 3 and 2.

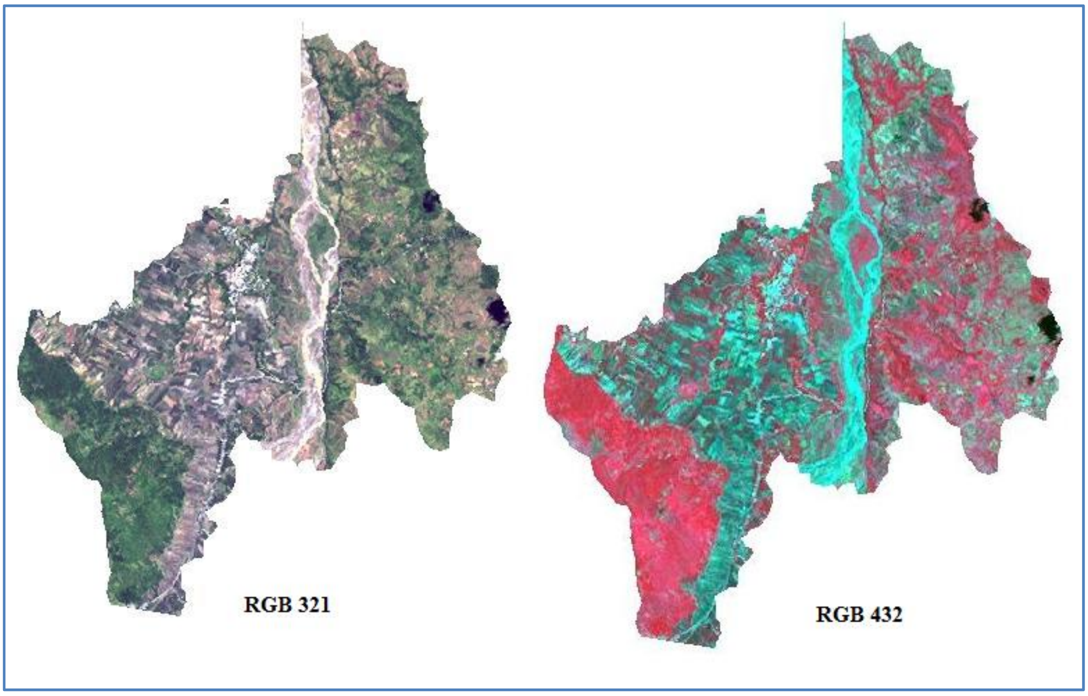


Figure 5.2 Composite maps of Bagabag sub-watershed area.

The training areas were identified from the composite images, primarily based on known land cover types in the area. The dark green, in RGB321 or dark red in RGB432 were identified as forest, whilst grasses were identified as a light green colour. In addition, the clouds and cloud shadows were identified, based on their white and black colours respectively. The water area was visible and based on its shape. Training areas, for the paddy fields and bare lands, were distinguished, with the aid of high resolution images from Google maps. The paddy field areas are more structured and rectangular in shape and sometimes greenish, such as the case of RGB 321, whereas, the bare lands were brown in colour and irregular in shape.

The signatures for the abovementioned classes were generated from training areas, whereas, with the unsupervised method, the signature class was created through the ISO CLUSTER function. ISO CLUSTER creates the signatures, by grouping cells with similar spectral responses (ESRI). Land cover/ land use classes for the unsupervised method, were identified, utilising images from Google maps. The Maximum Likelihood classifier was used, as the decision technique for the supervised method. The raw classification output for the two methods are displayed in Figures 5.3 and 5.4

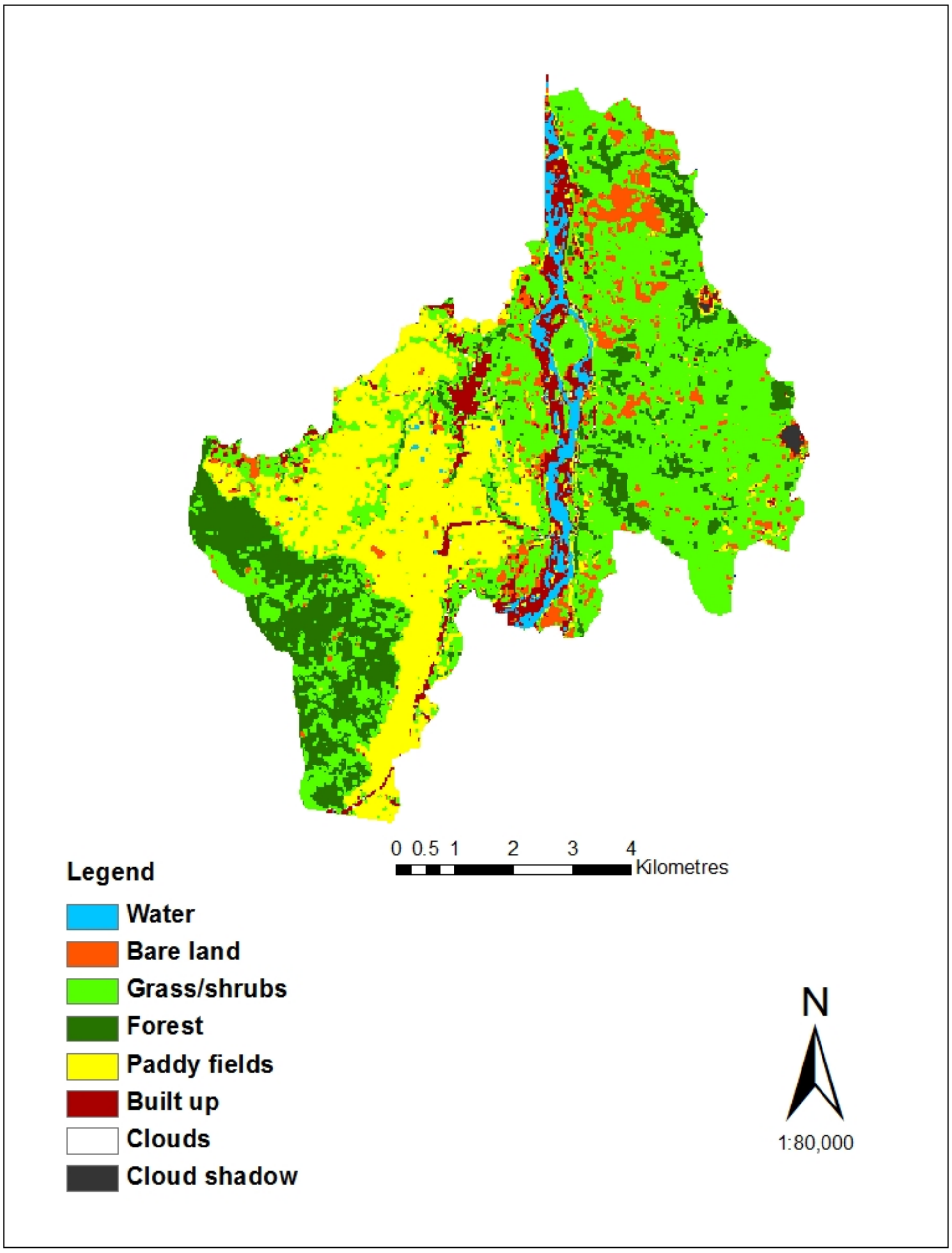


Figure 5.3 Land cover classification output with supervised method.

The classification output, using the supervised method for the Bagabag sub-watershed is presented in Figure 5.3. The sub-watershed was categorised into eight groups, namely: water, bare lands, grass/shrubs and forest lands, agriculture/paddy fields, built up areas, clouds and cloud shadows. It can be observed from this figure that known signature classes were clearly classified, except for built up areas. Under the intended groupings, areas that were classified under built up areas only include the residential and commercial areas. However, in the output map, areas adjacent to the river characterised by the stony and sandy portion of the river banks exhibited the same spectral response as the land cover /land use of built up areas.

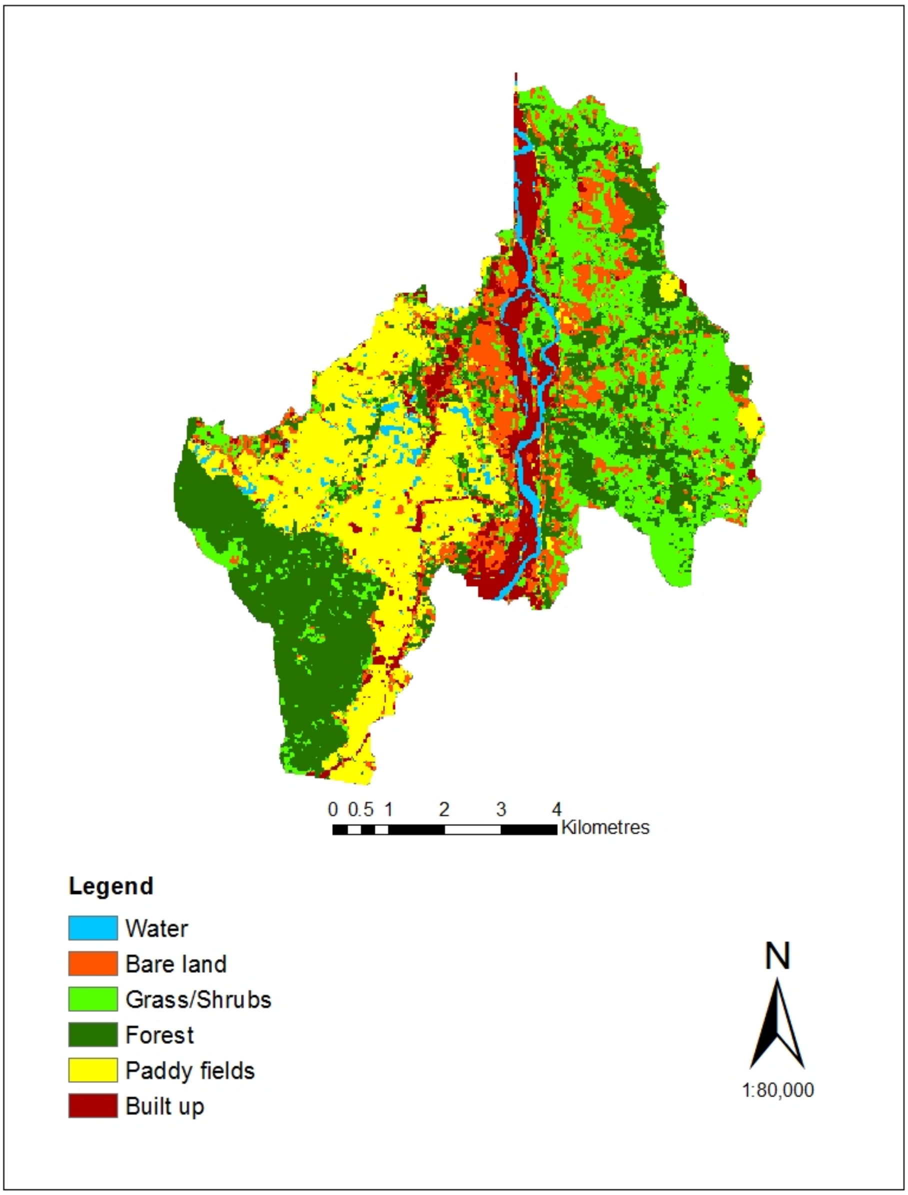


Figure 5.4 Land cover classification output with unsupervised method.

On the other hand, the classification output for the unsupervised method showed several overlapping classes. Figure 5.4 shows that some paddy fields were classified under the water category. This may be attributed to the provision of irrigation water in the rice fields, during planting. The satellite image was acquired in the month of June, which is when rice planting season in the area begins. The clouds also displayed a similar spectral response as the water, whilst the cloud shadows overlapped with the agricultural classes. Again, since the image was taken in the month of June, some of the grasslands were still very dry and they exhibited a similar spectral response as the bare lands.

Six (6) land cover classes, as shown in Figure 5.4 were produced from the merging of closely related signature classes. These signature classes were combined, based on the distances of their means and variances computed, using the Dendrogram tool (Appendix 1). The Dendrogram tool calculated the distances between each pair, and then it iteratively combined classes to each other until all classes were grouped into a single class (ESRI, 2009).

The two classification outputs were evaluated with the aid of high resolution images from Google maps. It showed that the supervised method produced more accurate classification output, than the unsupervised method. The final classification output for the sub-watershed, is shown in Figure 5.5. Areas covered by clouds and cloud shadows were reclassified into the nearest dominant land cover within the area. Likewise, areas adjacent to the river were considered to be part of the water to distinguish them from the built up category. For the purpose of this study, three other sub-watersheds were classified and evaluated for comparison. The results of the land cover classification and analysis for the four selected sub-watersheds are presented and discussed below.

In the Bagabag sub-watershed, six land cover/land use classes were identified as illustrated in Figure 5.5. Since Bagabag is located along the floodplain region, a large portion of the area is used for agriculture, particularly rice farming. The irrigation water supply for farms is sourced from the Magat River which constitutes most of the water class of the sub-watershed. Grasses and shrubs dominate the hilly areas on the eastern part, whilst forests are generally found in the mountains, located in the southern portion of the sub-watershed.

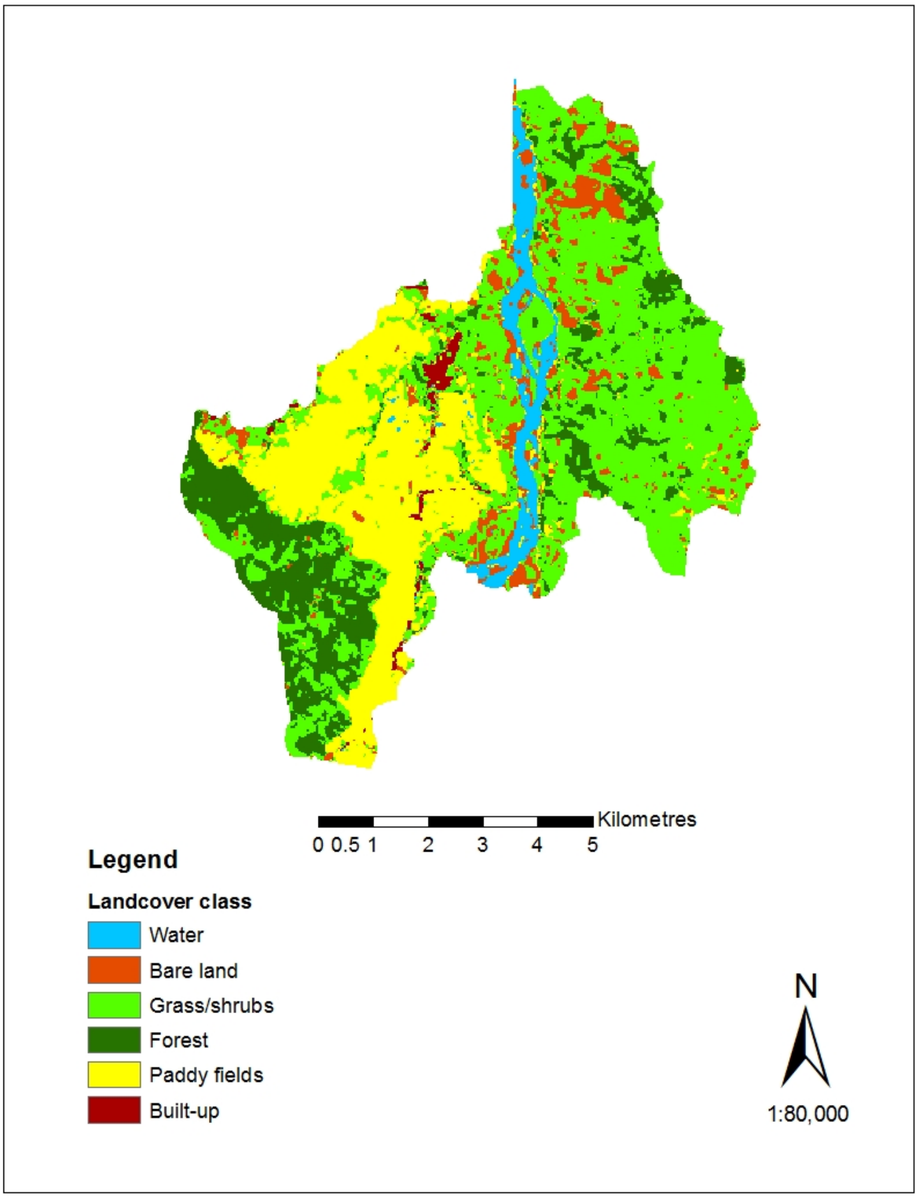


Figure 5.5 Land classification map for the Bagabag sub-watershed.

Also shown in the map above are patches of bare land found in hilly areas, which may indicate disturbed lands. The built up class represents the residential and commercial areas and these are located particularly in the municipality of Bagabag. The forest cover is generally found on Mt. Singian in the south-west of the sub-watershed.

The percentages for different land cover type, for the Bagabag sub-watershed are shown in Figure 5.6 below. Grass cover has the highest percentage covering 45% of the total area followed by paddy or agriculture at 25 %. The forest cover and bare lands comprise approximately 16% and 8%, respectively. The major water body in the area, the Magat

River, occupies 5% of the catchment. Identified built-up areas constitute a small portion of the study area and this is mainly residential and commercial properties.

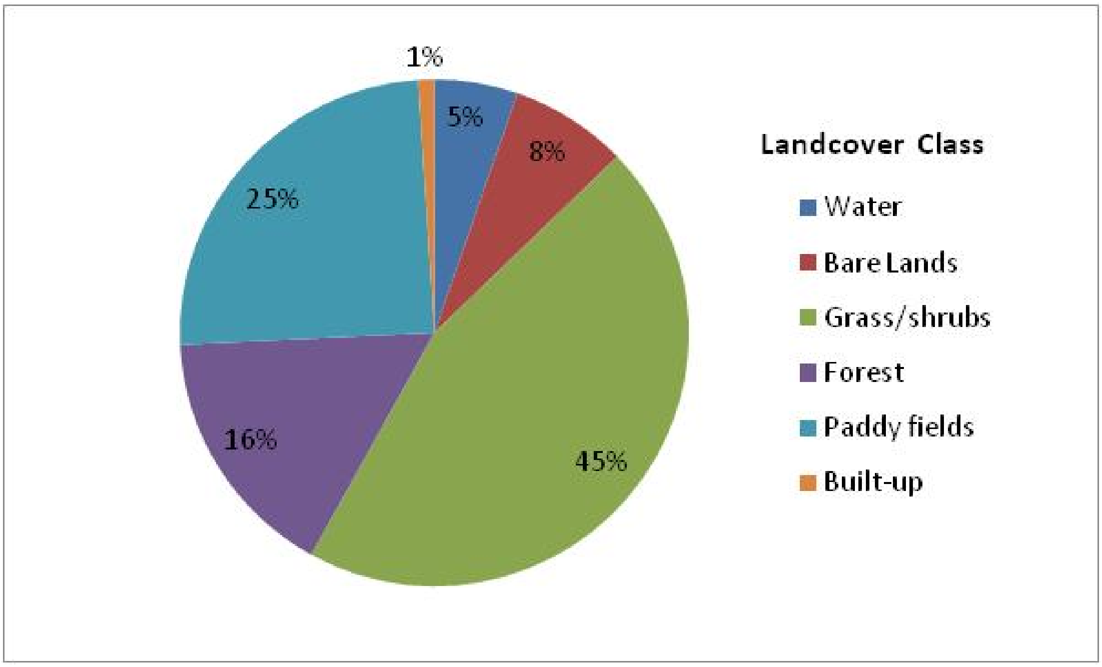


Figure 5.6 Percentage distribution of land cover for the Bagabag sub-watershed.

The classification pattern of Bagabag indicates a dynamic land cover/land use. It can be observed that there is a reduction in the forest cover particularly on Mt Singian located at the south western part. The small patches of grass/shrubs and bare land areas may be evidence of some ongoing land conversion activities in the area. The flat areas, which are mainly used for agriculture, are susceptible to conversion for settlement areas to address the requirements of the growing population.

The land cover distribution for the second site, the Lamut sub-watershed is presented in Figure 5.7 below. The dominant land covers are grass/shrub lands and forest. Lamut sub-watershed still possesses a large forest cover, although small areas of grasses and shrubs can be found in the surrounding areas. The large number of grassy areas in the mountainous portion dominated by forest cover is evidence of logging activities.

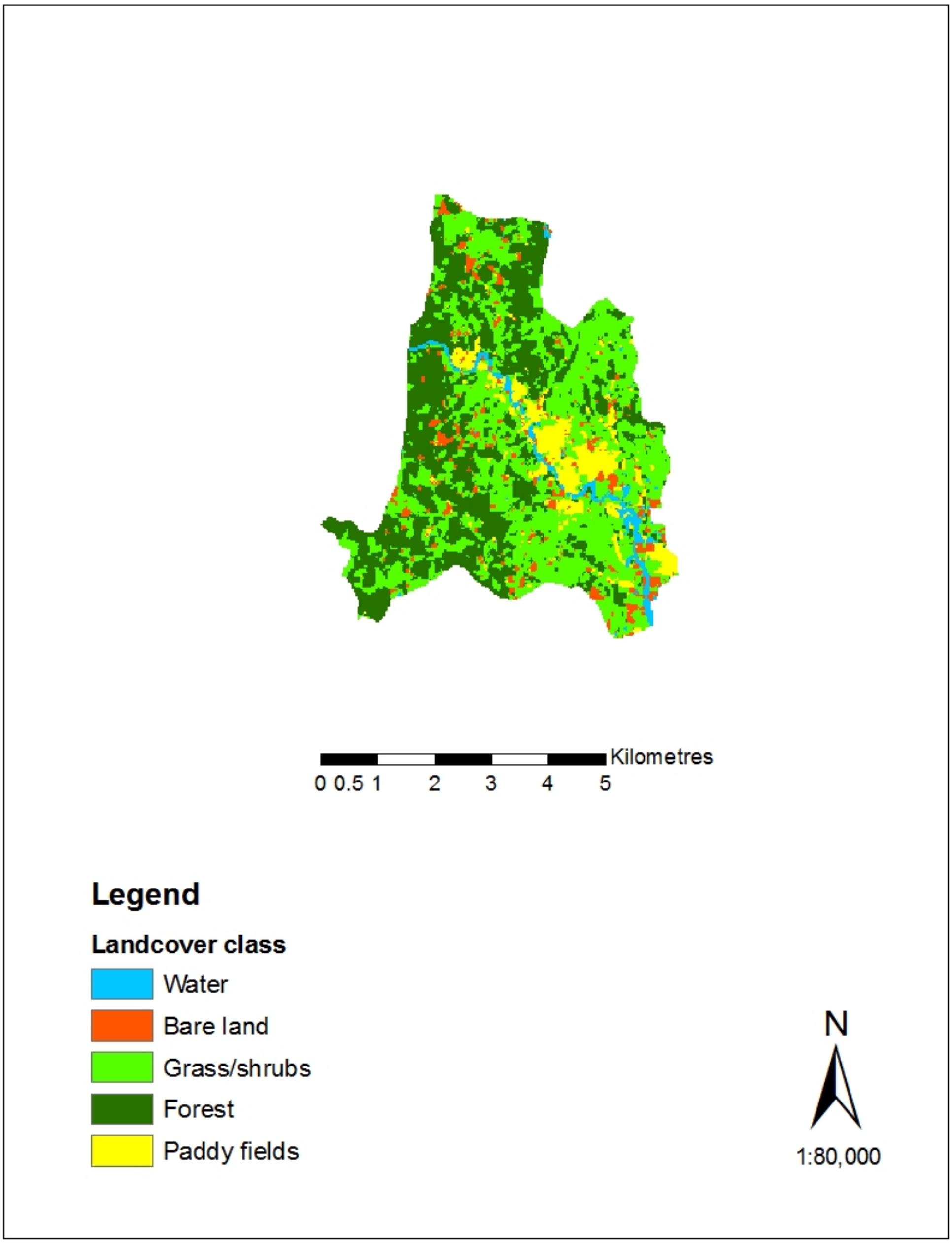


Figure 5.7 Land classification map for the Lamut sub-watershed

On the other hand, bare lands identified in the figure above, may indicate newly deforested and converted areas. Slash and burn activities for charcoal production is common in the area. The flat areas of Lamut site are also utilised for rice paddy field production and other agricultural activities. These are located in the central portion of the sub-watershed and they are adjacent to the river.

Figure 5.8 below, shows the percentage distribution of land cover in the Lamut area. Forest and grass lands occupy approximately 82% of the total area. The percentage of paddy field area is approximately 9%, whilst the remaining 9% is divided between the bare lands and water.

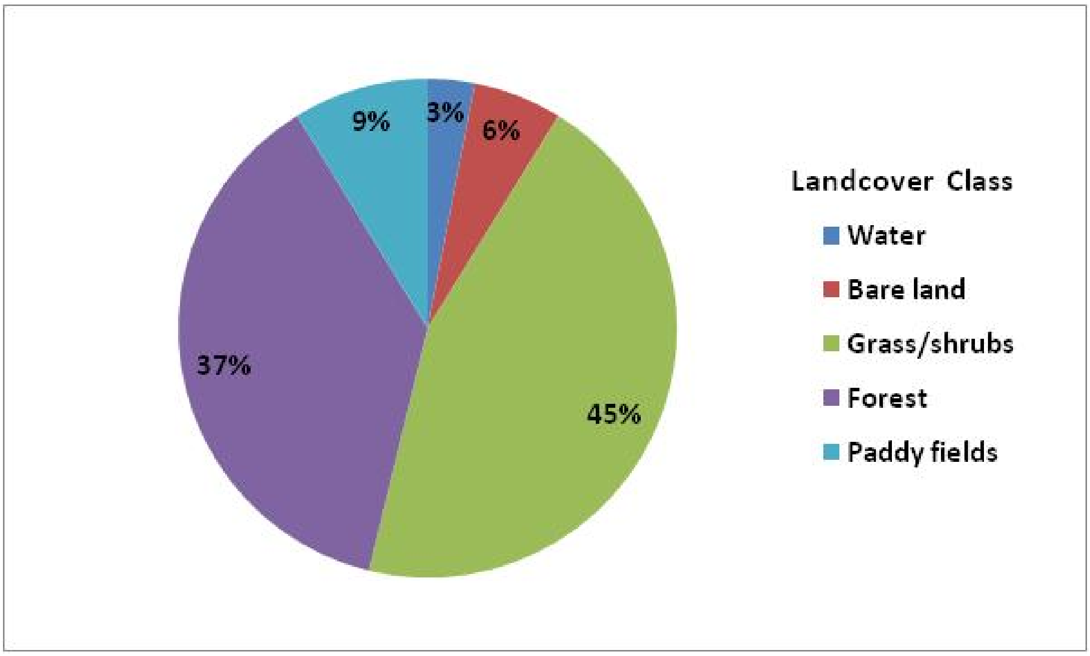


Figure 5.8 Percentage distribution of land cover for the Lamut sub-watershed.

The graph shows that the forest cover is still high compared to other areas of the watershed, despite the threat of logging activities and slash and burn practices. This could be attributed to the terrain, which renders some of the forest area inaccessible. Rainfall in the area is also high, which promotes the growth and regeneration of forest trees. Although some villages exist in the area, they were not identified, due to the dominance of other land cover types.

The third site, the Kiangan sub-watershed, has six land cover classes identified, similar to the Bagabag site. As shown in Figure 5.9, majority of the area is still covered with forest, and then followed by grass and shrubs cover type. A significant area of paddy fields and built up were also identified. Rice farming in sloping areas or on terraces is a common agriculture practice in the area. The built up areas represents the residential and commercial areas in the municipality of Kiangan and in some areas of Lagawe.

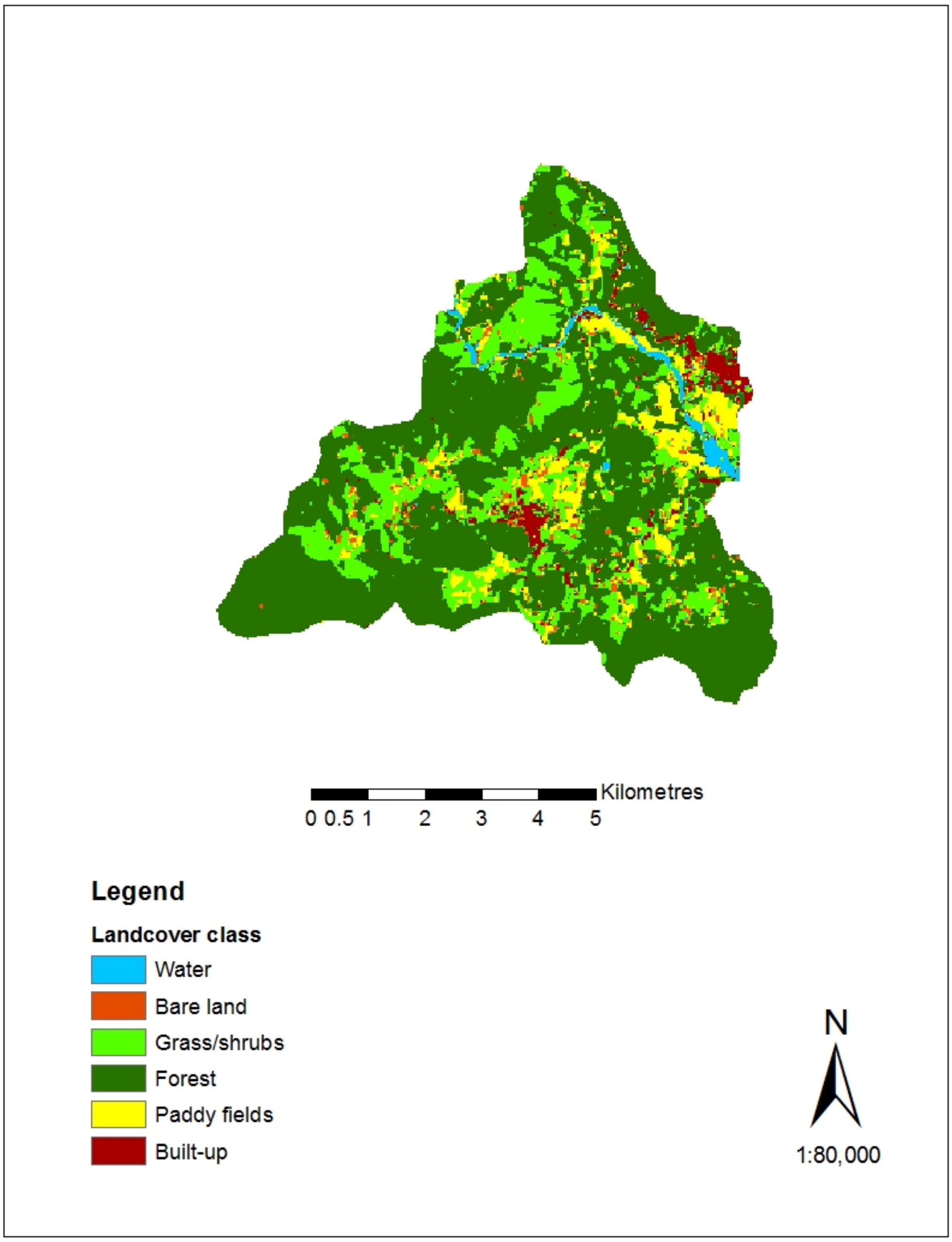


Figure 5.9 Land classification map for the Kiangan sub-watershed

The percentages for different land cover type, for the Kiangan sub-watershed, are shown in Figure 5.10. Forest covers approximately 45% of the total area followed by grasslands at 22 %. The paddy fields and bare lands comprise approximately 8% and 3%, respectively. Identified built-up areas constitute 3 % of the study area and this is mainly residential and commercial properties.

The land cover classification of the Kiangan sub-watershed suggests, that there is a high land disturbance or conversion activities, in the area. The grasslands, which are located mostly on the mountain slopes and adjacent to forest cover, indicate that these are deforested areas. There are also large areas for paddy fields and built up, mainly for settlements areas, develop due to the increasing population in the area.

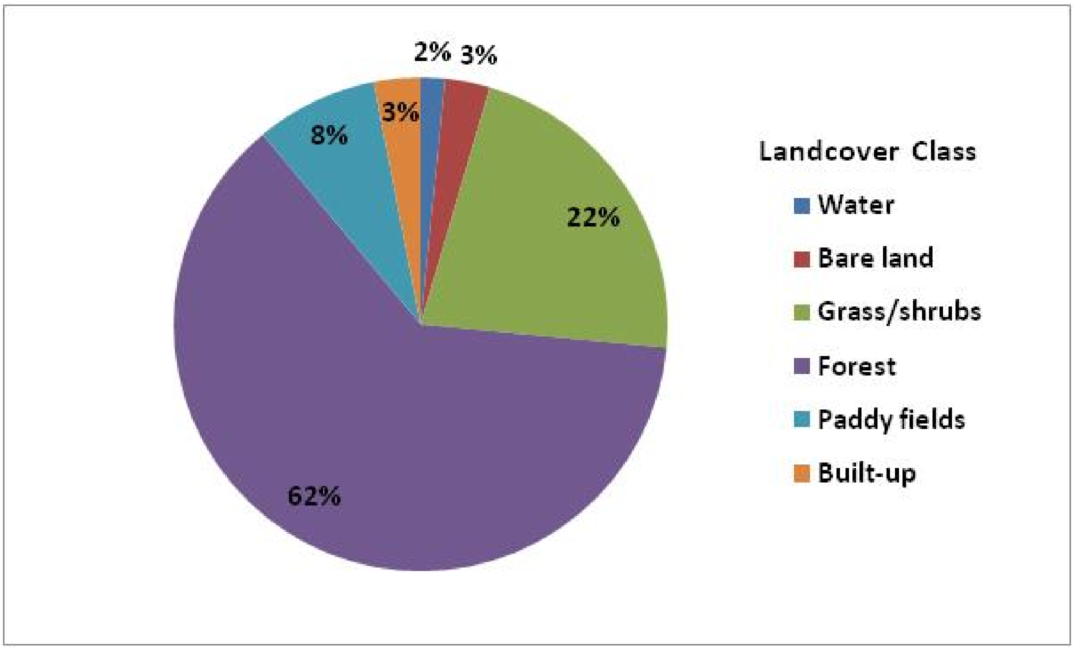


Figure 5.10 Percentage distribution of land cover for the Kiangan sub-watershed.

Figure 5.11 below shows the classified land cover for the Lagawe sub-watershed. There were four land cover types identified, namely, forest, grass, bare lands and water. The sub-watershed is predominantly covered with grass, followed by forest cover which is scattered in patches and generally found on the edges of the mountain. The meandering river traverses the central portion of the sub-watershed. The bare lands are found in the lower portion of the watershed.

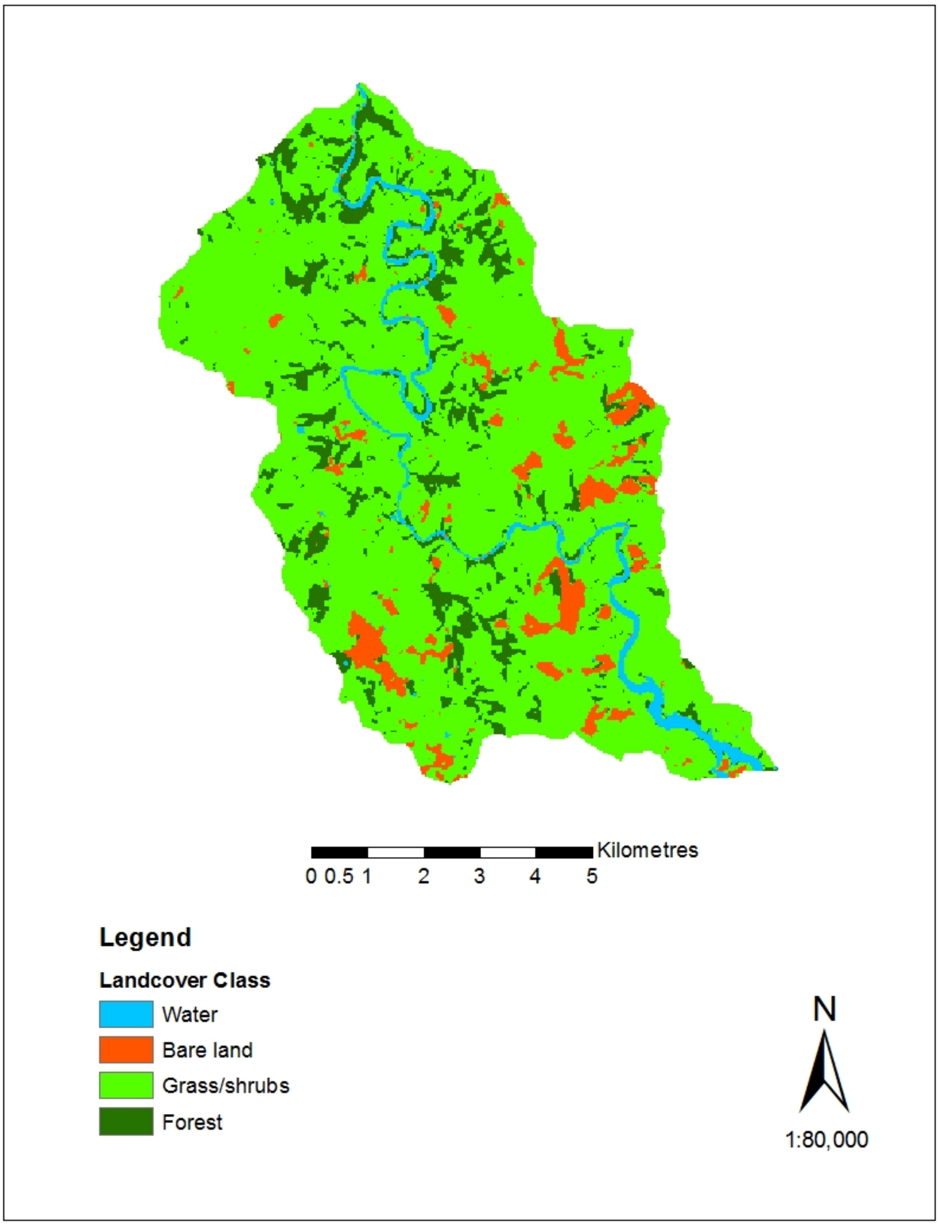


Figure 5.11 Land classification map for the Lagawe sub-watershed

The percentages of the different types of land cover, in Lagawe sub-watershed, are shown in Figure 5.12 below. Grasslands occupy approximately 79% of the total land area of the sub-watershed. The forest cover is approximately 11%, whilst the remaining 10% is divided between water and bare land. The high percentage of grass or shrubs in the Lagawe sub-watershed suggests that the land characteristics and other physical attributes of area favour the growth of grasses. The rugged terrain of the sub-watershed also limits the land use potential of the area especially for agriculture

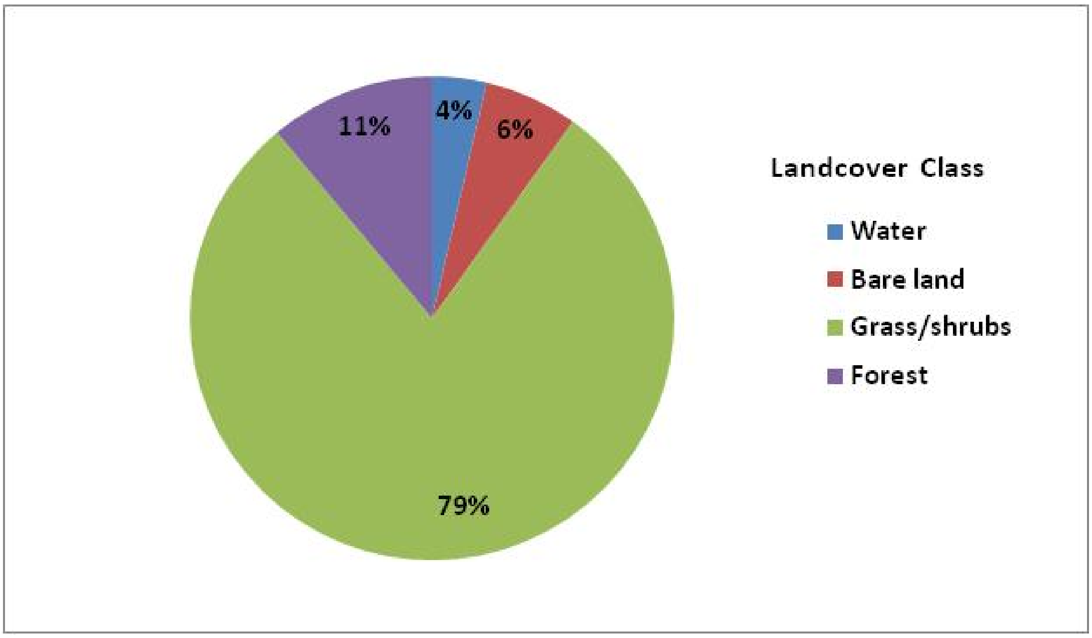


Figure 5.12 Percentage distribution of land cover for the Lagawe sub-watershed.

Table 5.2 below shows a summary of the area of land cover types in the four sub-watershed sites. The grass land cover class has the largest area in all four locations followed by the forest type except in Bagabag area. The water class for the four sites generally represents the Magat River and its tributaries. The area of bare land, which is considered to be highly susceptible to erosion, totals 1201 hectares, in the four sub-watershed areas.

Table 5.2 Land cover class distribution in hectares

	Sub-watersheds			
Landcover class	**Bagabag**	**Lamut**	**Kiangan**	**Lagawe**
Water	311	83	75	266
Bare lands	460	159	143	457
Grasslands/shrubs	2701	1218	1060	5774
Forest	966	1005	3014	807
Paddy fields	1458	234	386	0
Built-up	42	0	148	0
Total	**5944**	**2688**	**4825**	**7304**

The distribution of land cover/ land use, in the four sub-watersheds shown in Table 5.2 above, is influenced by topographical and other physical attributes of the area. Agricultural land use depends primarily on the existence of flat areas and the availability of water for irrigation. Forest and grasslands covers mainly the hilly and mountainous areas of the watersheds. The built up areas, which have been classified only on the Bagabag and Kiangan sites, cover an area of 190 hectares. Potential expansion for this class is expected, however, there may be conflict with other land cover/ land use.

5.5 Conclusion

The study investigated the land cover composition of the Magat watershed, employing both supervised and unsupervised techniques, of classification cover. The procedure used, to identify and classify land cover and land use in the watershed environment was presented. Results of the study show the land cover composition and distribution in the Magat watershed. The four sub-watersheds possessed different land cover compositions and percentage of cover, which may lead to differences in response to environmental forces. The maps and other information generated could serve as guides during planning and as a reference for related studies. This study has shown that remote sensing and GIS is a useful tool, for the gathering of information and also the monitoring of changes in watershed land cover and land use.

Chapter 6

Soil erosion modelling

6.1 Introduction

Soil erosion is considered one of the worst environmental problems in developing countries (Pimentel, 1995). In the Philippines, it was estimated that between 64 and 76 million tonnes of soil were eroded from the country's agricultural and upland areas every year (Philippine Forest Management Bureau 1998). The Magat watershed, due to its strategic location, is experiencing various disturbances, particularly from land conversion for agriculture and settlement purposes. This chapter will investigate the erosion risk potential in the Magat watershed, based on land use extracted from satellite images, in addition to other factors, which contribute to soil erosion, such as slope, rainfall and soil characteristics.

6.2 Soil erosion modelling

In soil erosion modelling, it is necessary to understand how the processes of soil erosion occur and the different factors which affect it. According to Morgan (2005), soil erosion was a process, which started with the detachment of soil particles and their corresponding transport caused by erosive agents, such as wind and water. Soil erosion, by water, is largely attributed to rain splash. Soil particles are detached from the soil mass as result of continuous bombardment by rain drops. The soil particles are then transported by surface runoff. There are four major factors that affect soil erosion, namely: climate, soil erodibility, slope terrain and land cover or land use (Lal, 1990).

6.2.1 Factors Influencing Erosion

1. Rainfall

Rainfall is considered a major cause of soil erosion, due to soil detachment resulting from raindrop impact and runoff shear (Angulo-Martinez, et al., 2009).The amount, intensity and frequency of rainfall influence the rate of erosion (Lal, 1990). During periods of frequent rainfall, a greater percentage of the rainfall will become runoff. According to Morgan (2005) the amount of soil loss increased as the intensity of rain increased.

2. Soil Characteristics

The soil's physical characteristics affect erodibility, or its natural resistance to erosive factors. Soil properties, which affect erodibility include texture, structure and cohesion (Lal, 1990). Soil texture depends on the sizes or combination of sizes of the soil particles which are classified as clay, silt and sand. Morgan (2005) mentioned that soils with a large quantity of silt-sized particles were the most vulnerable to erosion, from both wind and water, due to ease in detachment and difficulty in forming aggregates.

Clay textured soils, whose particles are the smallest within a soil mass, are less susceptible to erosion, than silt textured soils, primarily because of their soil structure property, or ability to form aggregates. The formation of aggregates improves water infiltration on clay textured soil, due to an increase in the number of larges pore spaces. Soils with stable or well cemented aggregates have stronger resistance to the forces of water and wind. Soil structure influences both the ability of the soil to absorb water and its physical resistance to erosion (Hudson, 1993). Sandy soil particles are also less prone to erosion due to high infiltration rates and drainage.

Cohesion refers to the binding force between soil particles and its influence on soil structure (Morgan, 2005). Clay soils are very cohesive, whilst sandy soils are not. Highly cohesive soils are usually more resistant to water and wind erosion, because the soil particles are tightly joined (Wikipedia, 2009).

3. Land cover

Vegetation is considered as the most important physical factor, which influences soil erosion. The vegetative cover has a significant control over the rate of detachment and transport (Lal, 1990). According to Thornes, (1990), a reasonable cover of vegetation shielded the soil from the impact of rainfall. This ground cover helped to bind the soil together, making it more resistant to runoff. Crown cover or above ground cover intercepts the rainfall and reduces its impact on the soil. The impact of ground cover, on erosion, could be clearly observed, particularly on sloping areas. The presence of vegetation reduces the velocity of surface run-off and the roots underneath provide some mechanical strength to the soil. It is considered that areas with a dense and robust cover of vegetation are greatly protected against soil erosion.

4. Topographical condition

Slope steepness and slope length are also significant factors, which affect soil erosion. Soil erosion is usually expected to increase with an increase in slope steepness and slope length (Bonilla, et al., 2007, Morgan, 2005). Soil erosion increases with an increase in slope steepness, due to higher runoff velocity and the area where runoff the concentrates, whilst an increase in slope length allows a greater accumulation of runoff, which results in higher soil erosion. Water flow is expected to be faster on steeper slopes and consequently, the result is a higher erosion risk and an increase in sedimentation (Morgan, 2005).

6.2.2 Erosion Models

Erosion models are used to represent events that describe the process of soil erosion. Several erosion models have been designed, to predict soil loss and they are continuously being improved. The Universal Soil Loss Equation (USLE) is the most common quantitative model, for the computation of soil erosion. USLE is an empirical model, which has been developed and based on 10,000 plot-years of basic runoff and soil loss data, from 49 locations across the United States (Wischmeier and Smith, 1978). It is designed to compute long term average soil erosion rates, from sheet and rill erosion under specified conditions.

The soil loss equation is as follows:

$$A = RKLSCP$$

Where:

- **A = Estimated average annual soil loss:** units are expressed ***in tonnes/hectare/ year.***

- **R = Rainfall erosivity factor:** The erosive power of rainfall, expressed in ***MJ mm ha-1 h-1 year-1.***

K = Soil erodibility factor: Soil resistance against erosive forces expressed in ***t ha h MJ-1 h-1 mm-1***

L = Slope Length Factor: The ratio of soil loss from the field slope length to soil loss from a 22.1 m length, under identical conditions.

S = Slope Steepness Factor: The ratio of soil loss from the field slope gradient to soil loss from a 9% slope, under otherwise identical conditions.

C = Cover Management Factor: The ratio of soil loss from an area with specified cover and management to soil loss from an identical area with no vegetative cover.

P = Support Practice Factor: The ratio of soil loss with a support practice, such as contouring, strip cropping, or terracing to soil loss with a straight row farming up and down the slope.

The units of average annual soil loss (*A*) are based on the *R* and *K* factors. The R factor, which represents the erosive power rainfall, is considered as the main cause of soil erosion, whilst the soil erodibility or K factor embodies the effect of soil erosion. The *K* factor represents the soil erodibility, or the capability of a particular soil type resistance to erosive forces. The other USLE factors (*L, S, C, and P*) are considered as adjustment factors and are they dimensionless.

6.3 Application of GIS in Erosion models

Soil Erosion models are now being integrated in various Geographical Information Systems (GIS) software. The capability of GIS to integrate and analyse different layers of spatial data complement the setting of soil erosion models, which combine the influence of various factors that affect the erosion process. The Universal Soil Loss Equation (USLE) model is incorporated as a tool in IDRISI software. The main input of the USLE model, in IDRISI, is the DEM, which is used for the calculation of slope steepness and slope length factor (Eastman, 2009) On the other hand, erosion models, such as USLE, could be performed in ArcGIS using the Map Calculator function. The

LS factor is determined from the flow accumulation and slope, which has been, extracted from DEM using the Spatial Analyst tools. Factor maps are prepared, by adding necessary values in the attribute table, in the factor vector files. The vector files are converted to a raster file to suit the data format requirement for the Map calculator.

6.4 Methodology

Soil loss in the four sub-watersheds mentioned in the previous chapter, was determined and compared. The Universal Soil Loss Equation (USLE) was used in the soil modelling component of this study. The factors included in the computation of soil erosion are land cover, soil characteristics, rain erosivity and conservation practice. The USLE equation model is as follows:

$$A = RSLSCP$$

Preparation of factor maps

The first part of the modelling was the preparation of the different factor maps. The factor maps were extracted from the data collected and generated, described in the previous chapters.

1. R- factor

The USLE factor, which stands for the erosive power of rainfall, is called the rainfall erosivity factor (R factor). The R factor is calculated as the product of the kinetic energy of a storm, times the maximum 30 minute storm intensity (Morgan, 2005). Another method of calculating the R-factor is by summing all the storm events within certain periods of years and dividing this by the number of years. For this study, the R-factor was calculated based on the total erosive rainfall collected from the period of June 2008 to May 2009, which is the data available for the study area. The R factor was calculated using the following formula:

$$R = 38.5 + .35P$$

The P in the formula for this study represents the total erosive rainfall. The calculated value was added to the table of attributes in the rainfall vector map and it was converted into a raster file, in order to create the R factor map.

2. K- factor

The susceptibility of soil, to external erosive forces, is described by the soil erodibility factor (K factor), in the USLE. Generally, the K factor is determined by referencing a soil monograph index (Wischmeier and Smith, 1978, Yitayew, et al., 1999). The determination of the K value is based on the relative percentages of silt, sand, organic matter and, soil structure and soil permeability. Clayey and sandy soils have low K values, primarily due to clay soils' resistance to detachment — whilst sandy soils although easily detached, have low runoff (Renard, et al., 1997). Soils, which are high in silt, are the most erodible and they have high K values. However, due to insufficient information on the soil characteristics, the K values adopted for the soil, in the study area, were based on values used in previous studies. Below is the summary of K values adapted for the study, based on the soil's textural characteristics.

Table 6.1 Summary of K factor values for the Magat watershed land cover

Soil Type	K- values
Clay	0.100
Clay loam	0.300
Sandy loam	0.250
Complex soil	0.300
Silty clay loam	0.350
Rock land	0.150

3. *LS* factor

The slope steepness factor was combined with the slope length factor, during the preparation. The computation for the combined *LS* factor was adapted from the procedure presented by Mitasova, et al. (1999). The *LS* factor was computed in the Map Calculator using the following formula:

LS = ([Flow Accumulation grid] * Resolution / 22.13) ^ 0.4 * (Sin [Slope grid] * 0.01745) / 0.09) ^ 1.4

The slope grid and flow accumulation grid were extracted from the DEM, using the slope function and hydrological tools in ArcGIS. The slope of the three sites was calculated with the slope tool in Spatial Analyst. On the other hand, the flow accumulation grid was created by first calculating the flow direction. The flow direction grid served as input in determining the flow accumulation area. The *LS* factor was computed using the formula above, together with the Map Calculator tool. Slope length is described as the distance beginning from the point of origin of overland flow, to the point where deposition starts, or where the flow connects to a river system (Wischmeier and Smith, 1978).

4. C –factor

The *C* factor is used in the erosion model to indicate the effect of vegetation cover, on the erosion rate. It represents the ratio of soil loss occurring on field plots with vegetative cover, compared to field plots with no vegetative cover and this ratio of soil loss could be used to forecast the extent that soil loss can be reduced. The C values, used in the study were based on related erosion modelling studies, in tropical countries. The map for the cover factor was prepared, by adding the values corresponding to the different land cover/land use features, to the table of attributes of land cover shapefiles. Then this was converted into a raster file using the C values, to create a factor map.

Table 6.2 Summary of C factor values for the Magat watershed land cover

Type of land cover	C factor values
Forest	0.001
Grass land	0.015
Barren land	1.000
Water	0.000
Agriculture (paddy fields)	0.015
Built-up	0.010

5. P –factor

Some areas in the Magat watershed practices rice farming in sloping areas or on terraces. According to Morgan (2005) terraces were built in sloping areas, in order to interrupt surface run-off velocity. In this study, a P factor value of 0.5 was assigned for the conservation strategy.

Using the USLE soil erosion equation, the different factor maps were combined to determine the erosion rates. The resulting maps were classified, using the classification system used by Morgan (1995), as shown in Table 6.3 below. This classification system is grouped into six erosion vulnerability or risk classes, from very slight erosion (<2 tonnes/ha/year) to severe erosion (>100 tonnes/ha/year).

Table 6.3 Erosion risk classification (Morgan, 1995)

Erosion risk class	Erosion rates tonnes/ha./year
Very slight	0 - 2
Slight	2 -5
Moderate	5 -10
High	10 -50
Severe	50 -100
Very severe	> 100

6.5 Results and discussion

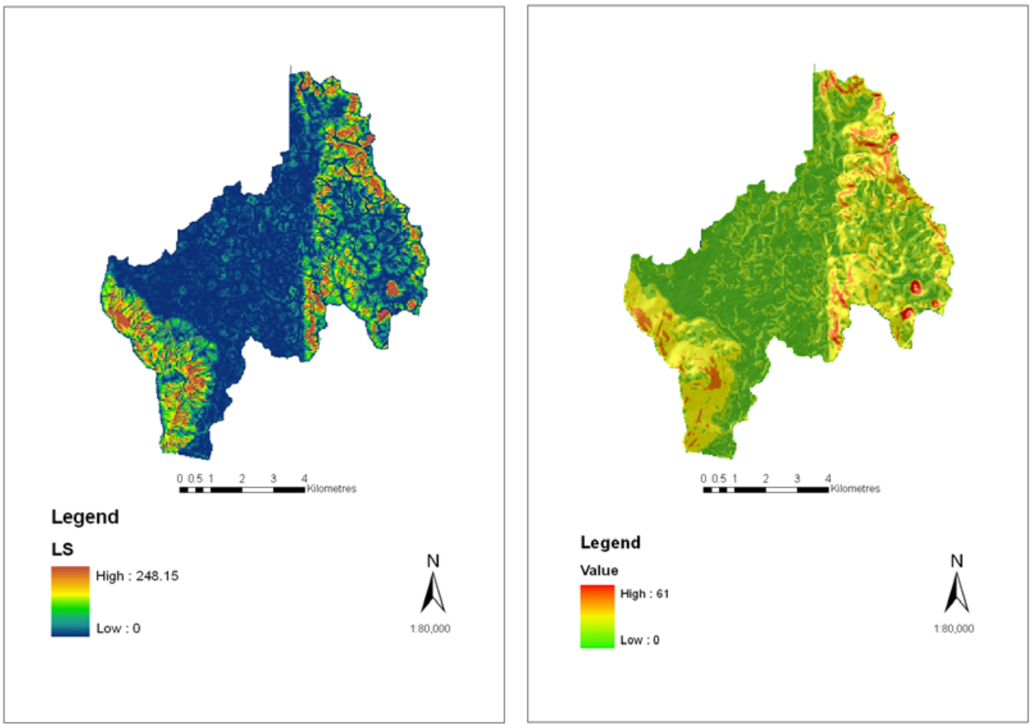
This section presents the results of the soil erosion modelling, conducted at Magat watershed. The erosion rates, in the three selected sites were compared. The influence of land cover/ land use, and slope steepness were determined and discussed.

Factor maps

Different factor map were created for the USLE soil erosion modelling. The annual R factor calculated for three sites range from 420 to 525. The total of the high intense or erosive rainfall precipitation during the period June 2008 to May 2009 was 1090 millimetres. However, rainfall amount in high altitude areas, are generally higher than at low altitudes and, hence, the variability of the R factor.

The K-values assigned for the watershed soil type range from 0.1 to 0.35. Lower K-values indicate less susceptibility to erosion. These values were assigned to clay type soils which are known to have better natural resistance to erosive forces. The highest K value was allotted to silt clay loam soil type at 0.35.

The LS factor computed values range from 0 to 397. The output *LS* factor map, for the Magat watershed, reveals that the mountainous regions of the watershed have the highest values. The Magat watershed has many hill slopes, which equal or exceed 30 degrees and the highest *LS* factor values are concentrated in these areas. The calculated mean LS factor for the four sites ranges from 4.7 to 17.



LS factor | Slope in degrees

Figure 6.1 LS factor and slope steepness in the Bagabag sub-watershed.

The slope in degrees for one of the selected sub-watersheds is shown in Figure 6.1. The slope of this sub-watershed is generally smooth, in most areas. However, some areas exhibit abrupt increases, particularly along the hilly areas on the eastern side.

A comparison of the *LS* factor map with a map displaying slope steepness as degrees rise (Figure 6.1) indicates that the *LS* factor is sensitive to steep slopes and it rises in value accordingly. The map shows that areas, which are generally flat, have a lower *LS* factor. On the other hand, areas with steep slopes result in high *LS* factors. Erosion rates are directly related to the LS factor. High *LS* factors would indicate high potential rates for erosion.

The C factor values, which represent, the vegetative cover of the area, vary from 0 to 1. The highest value of 1 was assigned to bare lands (Morgan, 2005) whilst the 0 value was designated to the water area. The forest cover was given the value of 0.005. In some studies (Breiby, 2006), the C factor values varies from 0.001 to 0.010 depending on the type and condition of the forest.

Erosion Vulnerability

The erosion rates for the four sub-watershed areas of the Magat watershed was determined and compared. Calculation of soil erosion rates was undertaken using the USLE empirical model. Table 6.4 below is a summary of the erosion risk areas in hectares in the four selected sub-watershed. The erosion vulnerability or risk class was based on the erosion classification coding by Morgan (2005). The erosion vulnerability class ranges from very slight with erosion rates between 0-2 tons/hectare/year to severe erosion for erosion rates above 100 tons/hectare/year.

Table 6.4 Soil erosion risk class in hectares by site

Erosion risk class	**Erosion rates t/ha./yr.**	**Area in hectares**			
		Bagabag	**Lamut**	**Kiangan**	**Lagawe**
Very slight	0 - 2	2561	963	1086	2082
Slight	2 - 5	560	520	400	380
Moderate	5 - 10	711	455	550	640
High	10 - 50	1604	544	1997	3028
Severe	50 - 100	217	68	385	740
very severe	> 100	251	139	401	434
Total		**5905**	**2688**	**4819**	**7304**

The table above shows that considerable areas in all four sites have a high erosion risk potential. At Kiangan and Lagawe, the high erosion risk category covered the largest area with 1972 hectares and 3028 hectares, respectively. Moreover, a total area of approximately 829 hectares and 1174 hectares were classified to have severe erosion to very severe risk potential. Areas with a very slight erosion risk occupy the largest area at Bagabag sub-watershed. This may be attributed to the slope characteristics of the site, which are generally flat and smooth compared to the other three sites.

The percentage of the vulnerability or erosion risk category, at each site, is shown in Figure 6.2. The percentages for very to slight erosion range between 25-40%, whilst for high erosion risk, the area classified varies from 20-40%. Areas identified as having very severe erosion potential are all below 10 % in the four sub-watersheds.

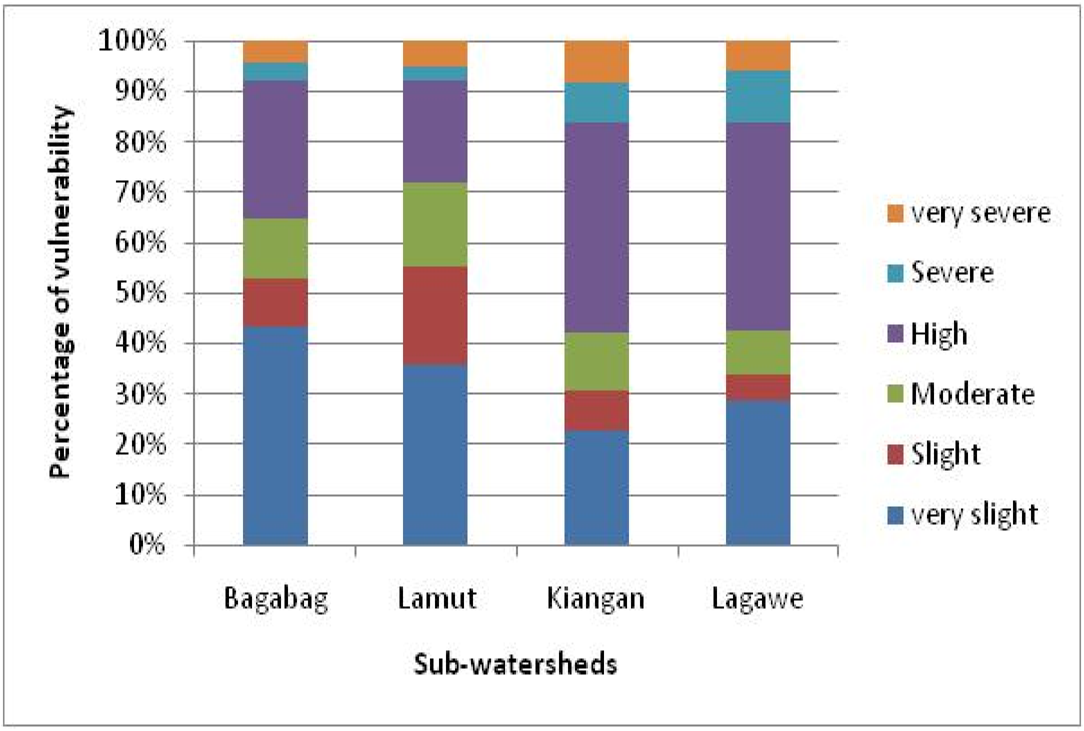


Figure 6.2 Percentage of erosion risk level per site

A comparison of the percentage of erosion risk in the four sub-watersheds shows that Kiangan and Lagawe has the highest susceptibility, or potential risk of soil erosion (Figure 6.2 above). Areas with high, to very severe erosion risk, at Kiangan and Lagawe sites, comprise approximately 58% and 57% of the total area respectively, compared to 35% and 28%, for Bagabag and Lamut sub-watersheds. Areas with very slight, to slight erosion risk, are also lowest at Bagabag and Lamut sites.

The high percentage soil erosion potential, at Kiangan, and Lagawe areas can be attributed to their steeper slopes. Moreover, the Kiangan sub-watershed is in close proximity to populated areas, which makes it more subject to land conversion and disturbances. The results of the erosion modelling, for the four sub-watersheds, are discussed in detail, in the succeeding part of this report.

The soil erosion vulnerability map, for the Bagabag sub-watershed is shown in Figure 6.3 below. Areas classified as severe, to very severe erosion risk, account for a total area of 215 and 645 hectares, respectively. The moderate to high erosion risk accounts for 2315 hectares, whilst the areas classified as very slight, to slight, are estimated at 2561 and 560 hectares, respectively. Areas with very slight, to slight erosion risk, are located in the flat areas, along the floodplain regions. Whilst a moderate to high erosion risk is generally found in the hilly areas and in some parts of the agriculture areas.

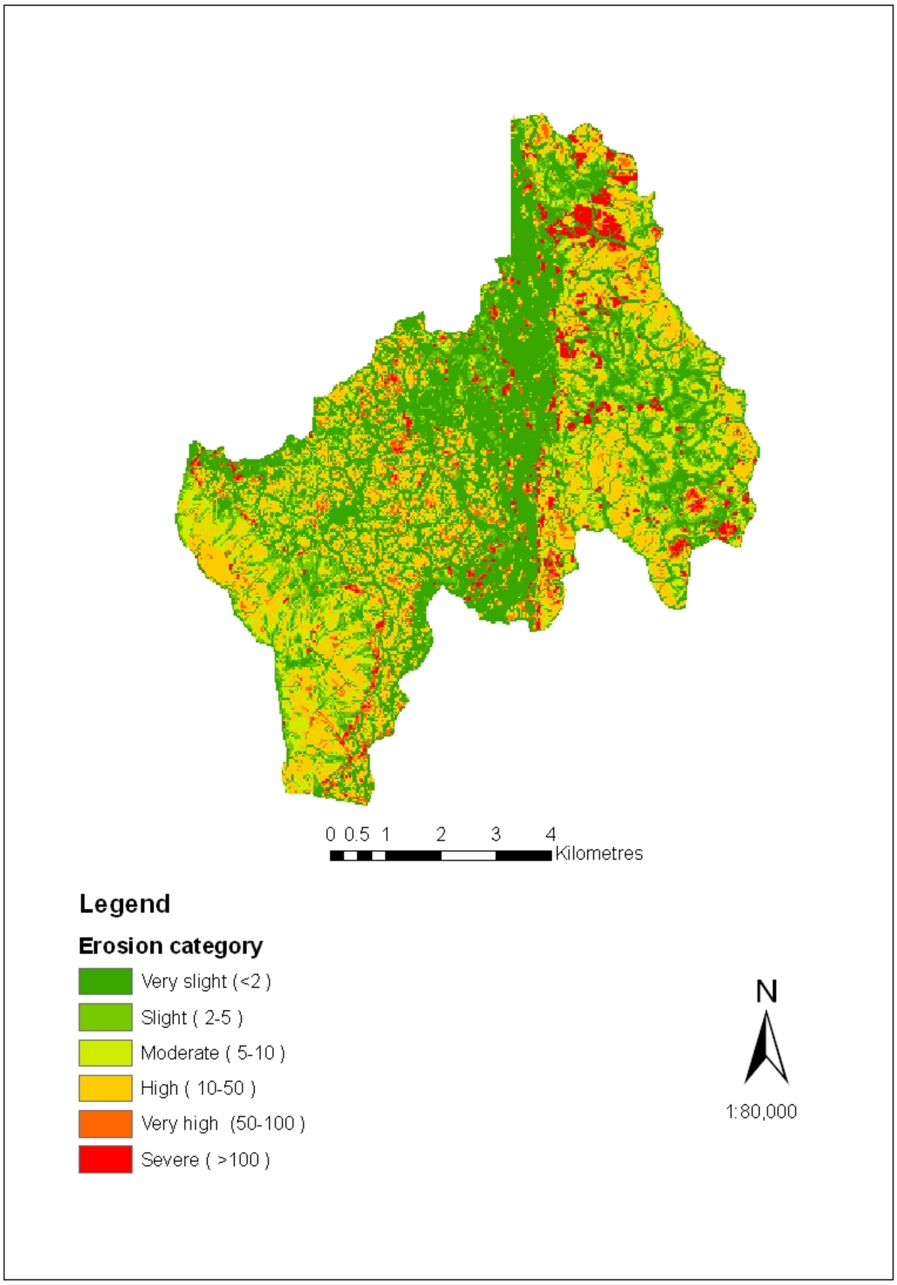


Figure 6.3 Erosion risk map in the Bagabag sub-watershed.

As illustrated in Figure 6.3 above, areas with severe to very severe erosion risk are generally found in bare lands. These erosion classes constitute approximately 8% of the sub-watershed area, whilst areas with very slight, to slight, account for approximately 53% of the area and they are generally located on the lower flat lands. It could be observed that the majority of the severe to very severe erosion vulnerable areas are found in bare lands and very steep areas.

The erosion rates by land cover, at Bagabag sub-watershed, are shown in Table 6.5. Average erosion for the bare land areas is 383 tonnes /hectare/ year, which is considered very severe. Erosion rates for forest and grasslands are classified as moderate. The agriculture or paddy field areas also exhibit a high erosion risk potential, at 25 tonnes /hectare/year, whilst the built up areas showed negligible erosion, at 0.6 tonnes /hectare/year.

Table 6.5 Erosion rates by land cover in Bagabag

Land Class	Area (ha)	Erosion rates (tonne/ha/yr)	Soil loss (tonnes)	Soil loss Percent (%)
Water	311	0	0	0
Bare land	460	383	176389	72
Grass	2701	10	26588	11
Forest	966	6	5880	2
Paddy field	1458	25	36220	15
Built-up	42	0.6	27	0
Total	**5939**		**245103**	**100**

The erosion values attained for Bagabag are higher than the erosion rates reported in other studies, except for agricultural and built up areas. According to Morgan (2005) the average annual erosion rates for cultivated areas, ranges from 0.1 to 200 tonnes /hectare/year, with the highest erosion rate average reported in China between 150-200 tonnes/hectare/year. The values for forest and grassland are also higher, compared to values attained from other studies.

The erosion vulnerability map, for Lamut site, is presented in Figure 6.4. This map reveals that, apart from bare lands, paddy field areas also exhibited severe to very severe erosion potential. The total area classified as severe and very severe, at Lamut sub-watershed are 68 hectares and 138 hectares, respectively. Areas with a high erosion risk potential are also significantly high, totalling to approximately 829 hectares, which is approximately 35 % of the sub-watershed areas.

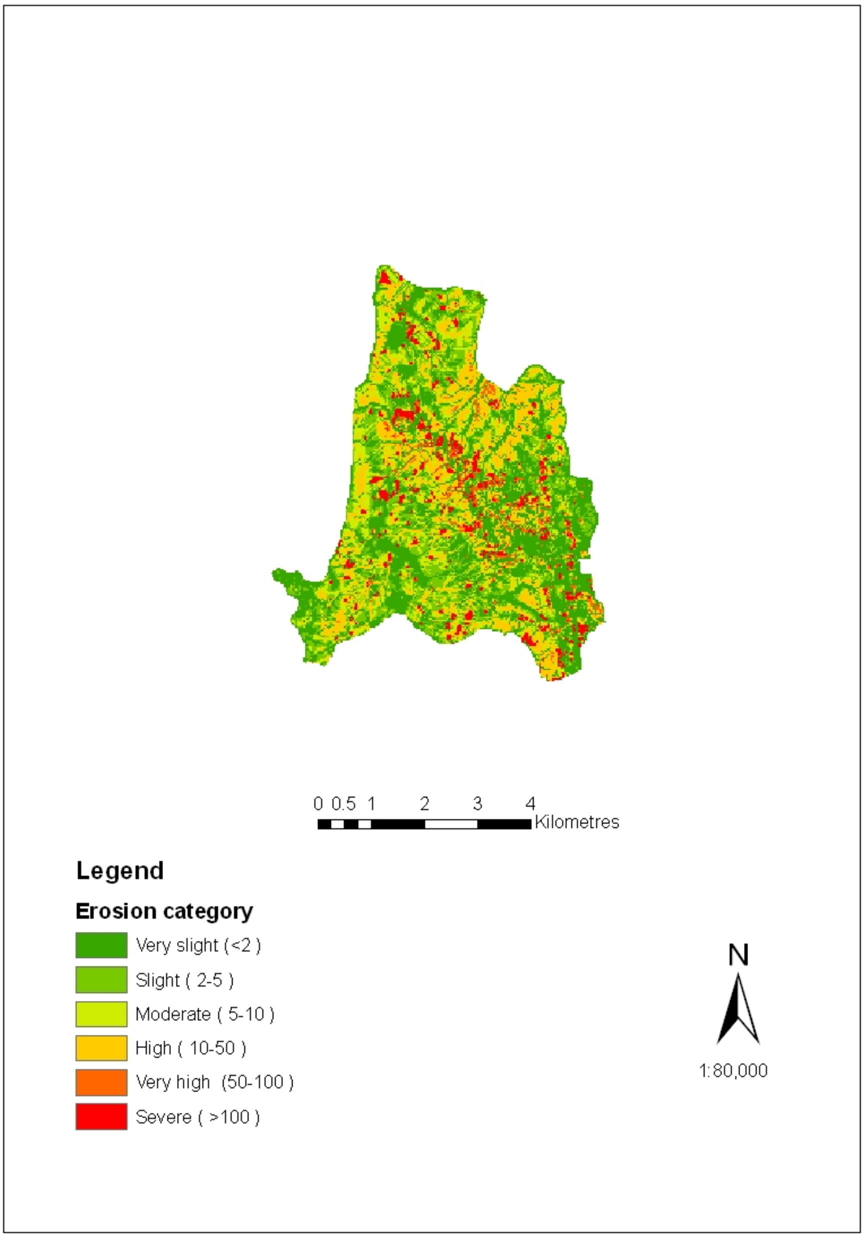


Figure 6.4 Erosion risk map in the Lamut sub-watershed

The figure above reveals the significant contribution of topographic factors in erosion rate values. Some of the forest cover, which is expected to have lower erosion rate values, is classified as having higher erosion potential, compared to grassland. This may be attributed to the steeper slopes within forest area location. The steeper slopes, at Lamut site might also be the reason for the higher average erosion in the paddy field area, compared to Bagabag site.

Table 6.6 shows erosion rates by land cover in the Lamut sub-watershed. The estimated annual soil erosion, for the site is 103,452 tonnes. Bare lands contribute approximately 75,917 tonnes, or approximately 73% of the total soil loss. The average erosion rate for bare lands is 479 tonnes /hectare/year which is higher than the erosion rate at Bagabag sub-watershed, but substantially lower, in relation to the other sub-watersheds. The erosion rate for paddy field areas is significantly higher at 51 tonnes /hectare/year.

Table 6.6 Erosion rates by land cover in the Lamut sub-watershed

Land Class	Area (ha)	Erosion rates (tonne/ha/yr)	Soil loss tonnes/yr	Soil loss Percent (%)
Water	83	0	0	0
Bare land	159	479	75917	73
Grass	1218	9	11499	11
Forest	1005	4	4211	4
Paddy field	234	51	11825	11
Total	**2698**		**103452**	**100**

The values calculated for bare lands and paddy field areas at Lamut sub-watershed, are extremely high compared to figures achieved in other studies. The average erosions rates for grass and forest are likewise higher, than the values reported by Morgan (2005). Similar to Bagabag site, the difference in figures could be due to the topographical characteristics of the area and the variation in other factors used. However, the erosion rates, particularly for bare lands and paddy field areas, should be a cause for concern which would warrant immediate conservation measures, in order to reduce the rates and minimise damage from soil erosion.

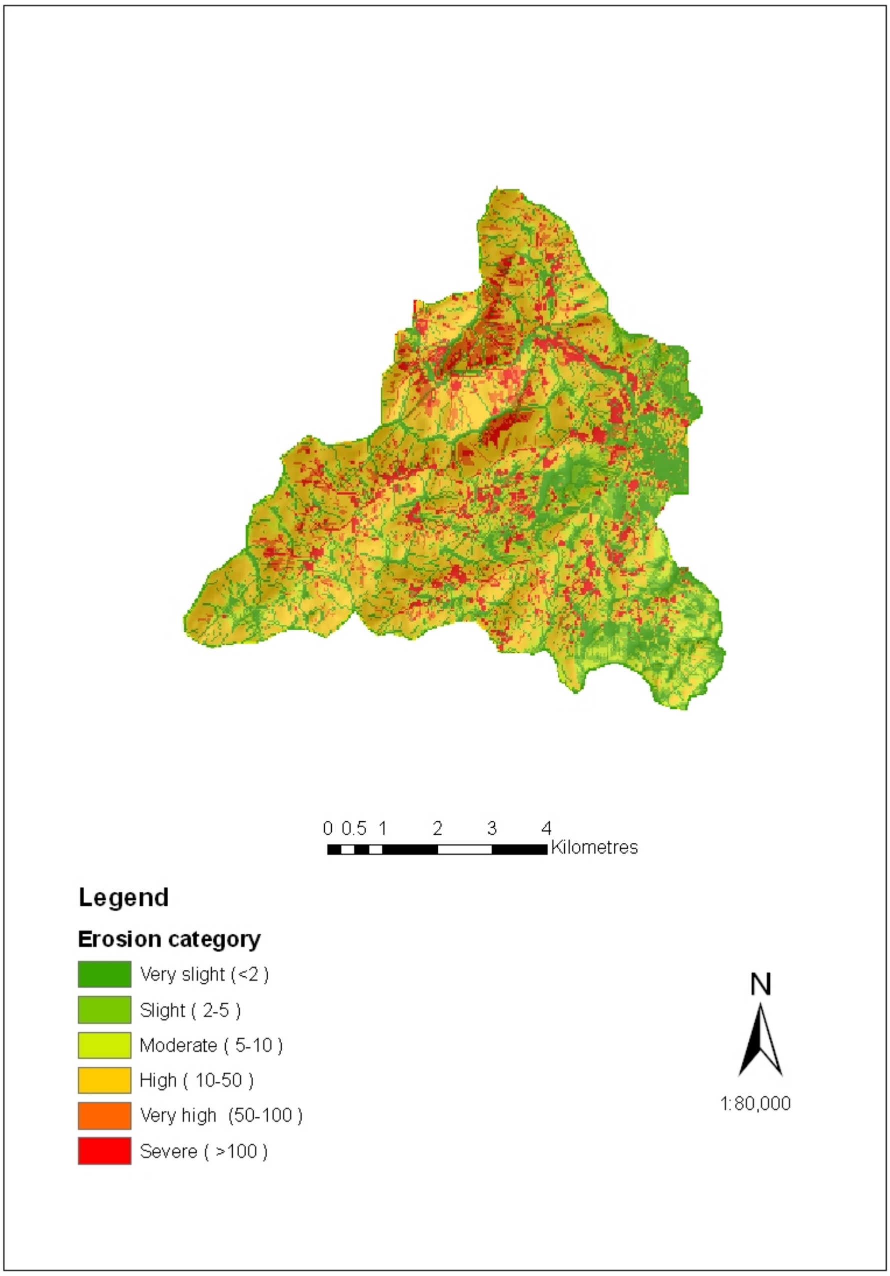


Figure 6.5 Erosion risk map in the Kiangan sub-watershed

The Kiangan sub-watershed has large areas with high, to severe potential of erosion risk, at approximately 58% of the total area. As shown in Figure 6.5, the high to severe erosion risk, are evenly distributed in the area. Areas classified as severe, to very severe erosion risk, account for a total area of 385 and 401 hectares, respectively. The high erosion risk accounts for the largest area, with 1997 hectares, whilst the areas classified as very slight, to slight, are estimated at 1086 and 400 hectares, respectively. The Kiangan sub-watershed, because of its strategic location, is vulnerable to various disturbances, particularly from land conversion for agriculture and settlements purposes.

The erosion rates by land cover, at Kiangan sub-watershed, are much higher compared to the rates at the other sites, as determined in Table 6.7. Average erosion for the bare land areas is 909 tonnes /hectare/ year, which is considered very severe. Erosion rates for forest and grasslands are classified as high. The agriculture or paddy field areas also exhibit a severe erosion risk potential, at 213 tonnes /hectare/year, whilst those of the grass, forest and built up areas are classified as high. Erosion rates amongst the different land cover classes are high due to the steeper slopes of the area.

Table 6.7 Erosion rates by land cover in the Kiangan sub-watershed

Land Class	**Area (ha)**	**Erosion rates (tonne/ha/yr)**	**Soil loss tonnes/yr**	**Soil loss Percent (%)**
Water	75	0	0	0
Bare land	143	909	129661	43
Grass	1060	42	44282	15
Forest	3014	15	43882	15
Paddy field	386	213	82087	27
Built-up	148	14	2107	1
Total	**4825**		**302019**	**100**

Figure 6.6 shows the erosion risk potential map for Lagawe sub-watershed. Areas with very slight or no apparent erosion totalled 2408 hectares, whilst those affected by slight erosion cover 479 hectares. These two erosion risk classes account approximately 40% of the area.

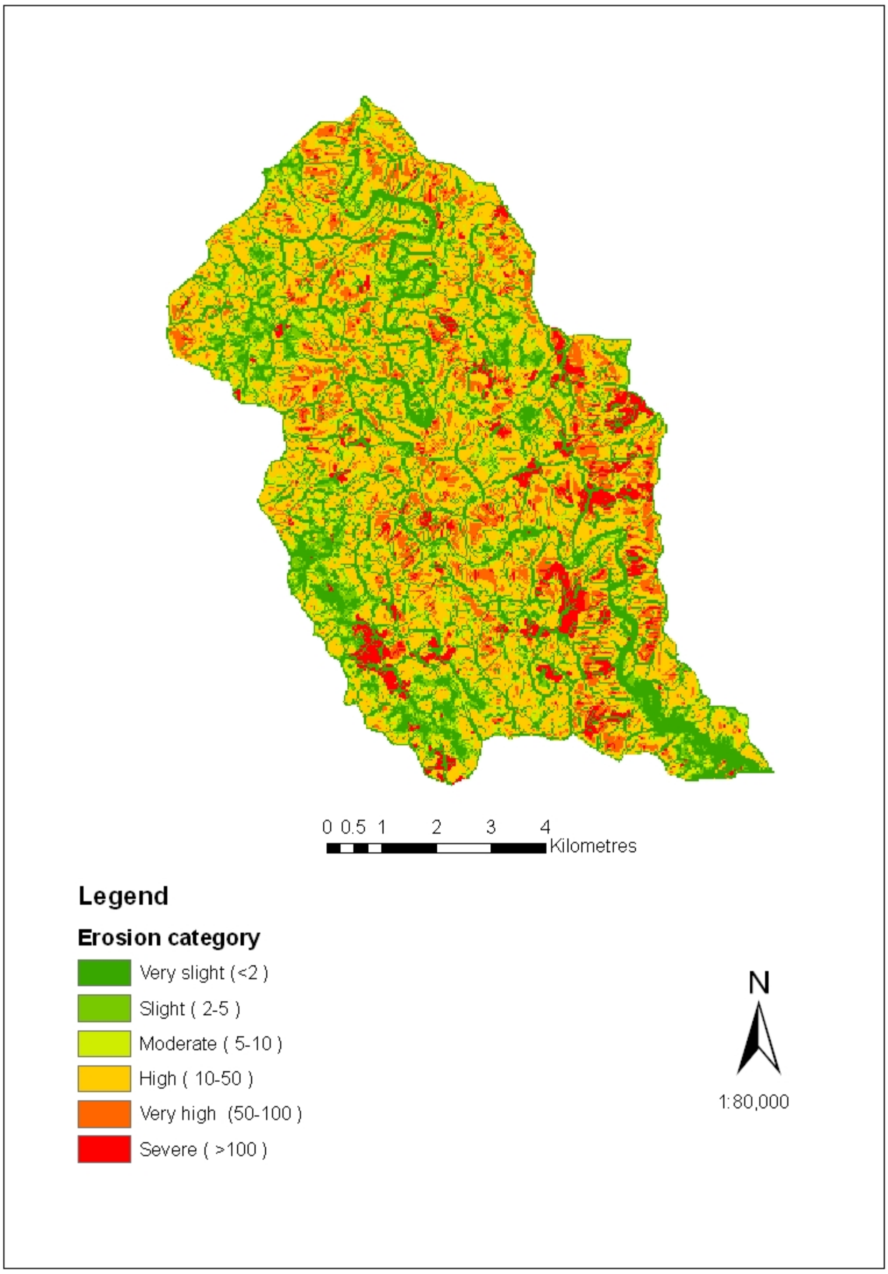


Figure 6.6 Erosion risk map of the Lagawe sub-watershed

Areas affected with severe, to very severe, erosion summed up to 740 hectares or approximately 12% of the total area. As seen on the map above, the severe, to very severe, erosion vulnerable areas are located in bare lands and very steep areas. This indicates that the aforementioned factors make the highest contribution to soil erosion rates in the area.

The average erosion rates by land cover at Lagawe site are displayed in Table 6.8. It can be observed that bare lands have the highest erosion rates, at 1435 tonnes/hectare, followed by the grass land at 24 tonnes /hectare. The erosion rate for forest cover is 13 tonnes /hectare. The total annual soil erosion for the area is 781,618 tonnes.

Table 6.8 Erosion rates by land cover at the Lagawe sub-watershed.

Land Class	Area (ha)	Erosion rates (tonne/ha/yr)	Soil loss tonnes/yr	Soil loss Percent (%)
Water	267	0	0	0
Bare land	458	1391	636874	81
Grass	5769	23	134475	17
Forest	809	13	10268	1
Total	**7304**		**781618**	**100**

The values calculated for bare land are extremely high compared to figures achieved in other studies (Shi, 2003). The average erosion for grass and forest are likewise higher, when compared to values reported by Morgan (2005). Reported values for natural vegetation range between 0.5- 5 ton/hectare/year. This difference in values may be attributed to the topographical characteristics of the area and other factors used.

Erosion rates per slope classes

Erosion rates, in the different slope classes, for the four sub-watershed areas, were also determined. As shown in Figure 6.7, average erosion rates at Bagabag and Lagawe sub-watersheds increases, as the slope increases. The average erosion rates are lowest in flat areas, which range from 5 to 24 tonnes /ha/year, and the highest rate is found in the very steep classes, between 16 to 320 tonnes /ha/year (Table 6.9 below).

Proud (1999) reported that average soil erosion losses for mountain slopes in the southern part of Philippines, ranged from 218 tonnes /hectare/year to 508 tonnes /hectare/year. This report also further noted that soil erosion rates, in particular cultivated cassava plantation areas, significantly increased, with increases in the slopes. It was reported that erosion rates, for slopes between 1- 15 % varied from 3tonnes /ha/yr to 221 tonnes /ha/yr. Soil erosion rates increased with an increase in slope steepness, as a result of faster water flow (Morgan, 2005).

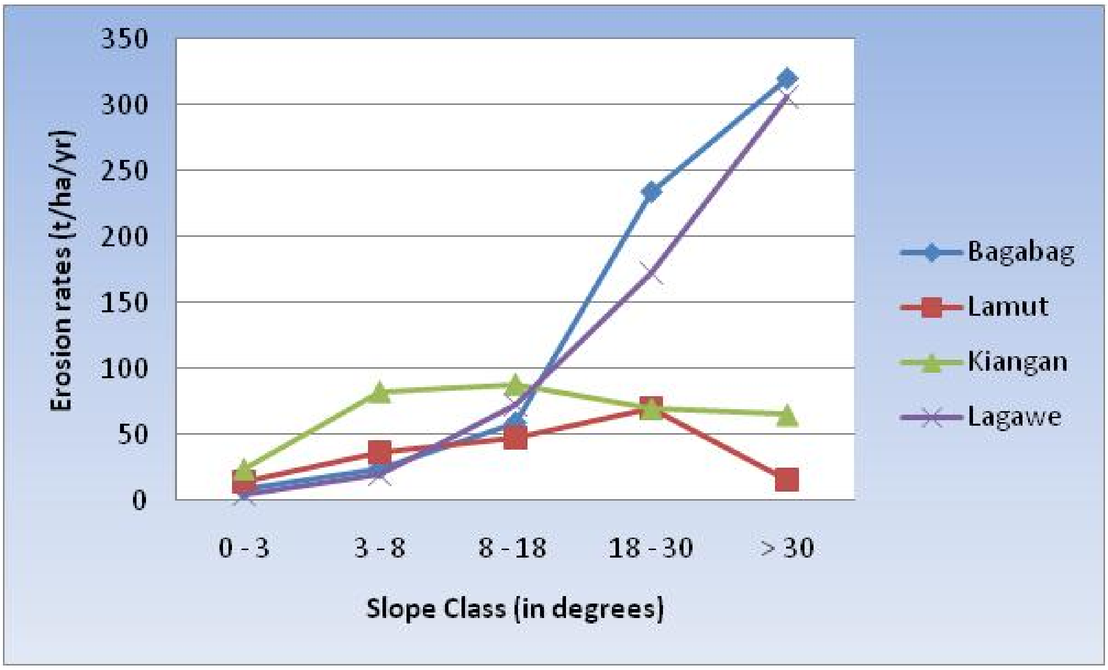


Figure 6.7 Average erosion rates per slope class

At the Lamut sub-watershed, averages erosion rates show an increasing pattern, from flat to steep classes, whilst at the Kiangan sub-watershed, the average erosion rates increases from flat to moderate classes. However, a drop in the average soil loss can be observed for the very steep class at the Lamut area, and for the high and very steep classes, at the Kiangan area. These drops in average erosion rates for Lamut and Kiangan sites could be attributed to land cover. The land cover, for the very steep areas at Lamut and for the high and very steep areas at Kiangan sites, are predominantly forest. This has mitigated the impact of other factors, such as the LS factors which are usually higher on steep areas.

In contrast, the extremely high erosion rates, at the high and very steep areas of Bagabag and Lagawe sub-watersheds could be ascribed to the presence of bare lands, which are likely to have a high potential risk of erosion. This disparity in the results illustrates the importance of vegetative cover, to protect the soil from excessive erosion.

Furthermore, erosion rates are expected to be higher as slope steepness rises and thus land disturbances should minimised or prevented.

Table 6.9 Erosion rates per slope class

	Erosion rates (tonne/ha/yr)			
Slope class	**Bagabag**	**Lamut**	**Kiangan**	**Lagawe**
Flat (0 - 3)	9	14	24	5
Gently sloping (3 - 8)	25	36	83	19
Moderate (8 - 18)	59	48	88	72
Steep (18 - 30)	234	70	70	172
Very steep (> 30)	320	16	73	306

Correlation analysis

A statistical analysis, on the relationship between the different factor layers and erosion rates, is shown in Appendix 2. Amongst the factors influencing erosion, the cover factor is shown to have the strongest relationship with erosion rates that have with positive correlation coefficient values of 0.43-0.65. Positive correlation indicates a direct relationship between two layers, which means that as cover factor values increases, the erosion rates also increases. The LS and slope steepness factor layers also a show positive correlation with the erosion rate layer, albeit with lower values. A correlation coefficient value, closer to positive or negative 1, indicates a stronger correlation between two variables (Brase, 2006).

The correlation matrix shown, in Appendix 2, was calculated using the Band Collection Statistics tool in ArcMap. A correlation value represents the ratio of the covariance between two layers, divided by the product of its standard deviations (ESRI, 2009). Basic statistical parameters, such as mean, standard deviation and the minimum and maximum values for every layer were also calculated. The mean erosion rates for the three sites range from 42 to 110 tonnes/hectare/year. The mean slope varies 7 degrees for Bagabag site to 16 degrees for the Lagawe site.

Conservation practice

This study also simulated the effect of conservation practices on agriculture land use. Morgan (2005) stated that terraces were built in sloping areas, in order to interrupt surface run-off velocity by shortening the slope length and thus reducing surface run-off erosive capacity. The computed soil erosion rate for agriculture land, at Kiangan and Lamut sites where terracing are employed are 220 tonnes /hectare/year and 83 tonnes /hectare/year respectively, whist in areas without terracing the erosion rate is 367 tonnes /hectare/year, and 51 tonnes/hectare/year. This suggests that the agriculture lands contribution to the annual soil erosion in the sub-watershed area would be reduced by half, with the application of the mechanical measure.

Table 6.10 Soil loss for terraced and non-terraced land

Sub-watershed	Total Soil loss (tonnes)			% Difference
	Non terraced land	Terraced land	Difference	
Lamut	363,494	303,859	59,634	16
Kiangan	108,683	99,856	8,827	8

Table 6.10 shows the effect of terraces on soil conservation at Kiangan and Lamut sub-watershed. A total of 59,634 tonnes and 8827 tonnes of soil was conserve from erosion with the employment of terracing at two sub-watersheds. This demonstrates the importance of incorporating conservation practices in lands being develop for agriculture and other land uses. In a study conducted by Poulder, et al. (1999), in the upland areas of the Philippines, the annual soil loss in cultivated areas , where conservation practices were applied, such as contouring and strip cropping, were considerably lower, compared to areas cultivated with more usual farmers' practices. The annual soil loss for areas with conservation practices ranges from 37-44 tonnes/hectare/year, whilst areas those without the use of these practices resulted in a soil loss of 65 tonnes/hectare/year (Poulder, et al. 1999).

Sloping lands in the Magat watershed are subjected to land conversion to meet the increasing demand for food from agriculture and to shelter the growing population, in the area. However, if the erosion trend in an area is left uncontrolled, it could result in low productivity of land and a poorer condition of the watershed. Hence, terracing and other conservation measures should be promoted and practiced, in order to control soil loss in the watersheds.

6.6 Conclusion

This study has determined the erosion risk potential in the Magat watershed area based on land use extracted from satellite images and factors such as slope, rainfall and soil texture. Some areas in the Magat watershed exhibited a moderately high to extremely high potential for erosion risk, which is comparable to other critical watersheds in the Philippines. This situation necessitates immediate and sustainable conservation strategies.

The results of this study show the influence of different factors, on the erosion vulnerability of the watershed. It reveals, the importance of vegetative cover for soil protection and the need for conservation strategies to control or minimise soil erosion. The Magat watershed, due to of its strategic location has experienced various disturbances particularly from land conversion for agriculture and settlement purposes. Map outputs showing the spatial distribution of both natural and human related erosion factors, could be of great value, in the development of a comprehensive land management plan for the Magat watershed.

Chapter 7

Conclusion and Recommendations

7.1 Introduction

This thesis is concerned with the application of recent technologies: remote sensing and the application of Geographical Information Systems (GIS) in the assessment and monitoring of watersheds in the Philippines. These technologies are recognised as being increasingly applied in the field of natural resources management, particularly, in the area of data generation and environmental modelling. The capability of remote sensing to capture up to date information for large area and the ability of GIS to store and manage data from various sources, has made these technologies an important tool, in the field of natural resource management — and this research has recognised this fact. This study has explored the usefulness of RS and GIS, in the various areas of watershed management, in the Philippines. The results/findings and recommendations from the work are now discussed.

7.2 Conclusions

This study shows that a remote sensing and geographical information system could be useful in the generation of information and the assessment conditions, within watershed areas. The analysis of satellite images and topographical, soil and rainfall data, using remote sensing and GIS techniques, has resulted in the production of maps showing land cover/ land use dynamics and erosion risk hazards, in the watershed environment. These maps, which have been produced, could assist watershed planners and managers to generate an effective and sustainable watershed management plan. Technical issues, regarding the data preparation, analysis and the results are now discussed.

7.2.1 Data preparation

Watershed delineation

The use of digital a elevation model (DEM) has resulted in more detailed and accurate watershed and catchment boundaries. The procedure involved was simple to follow and it allowed the repetition of the procedure, with relative ease. Since the determination of watershed boundaries was performed with the computer, it eliminated human error factors, which are common in manual methods of delineation.

7.2.2 Data Analysis

Supervised Classification

The supervised classification method produced a more suitable digital image classification, for the selected sub-watersheds. Prior knowledge of training areas resulted in more superior land cover groupings. It was also observed that inclusion of more training areas for certain land cover types allowed better representation of the particular class in the output image. Supervised classification was performed, based on easily identifiable land cover classes: water, forest, grass, bare lands, built-up, and agriculture or paddy fields. Similarly, separate classification for each of the selected sub-watersheds, rather than a combined classification, gave a more divergent land cover/ land use classes.

Unsupervised Classification

Unsupervised classification provided a poor classification for the selected sub-watersheds. A conflict in the groupings was observed for the water and paddy field areas. Some paddy fields, during the acquisition of the satellite image, were flooded with water, in preparation for planting and, hence this resulted in a similar spectral response, for the two separate classes. Lyon and Lunetta (2004) noted that some classes might be missed in an unsupervised classification.

LS factor

LS factor was observed to be sensitive to slope steepness and it rose in value accordingly. The value of LS factor, in all four sub-watersheds, is generally lower in flat and gently sloping areas, whilst high LS factor values are achieved in steep areas. Erosion rates are directly related to the LS factor. According to Morgan (2005) increases in slope and slope length would result to higher in a higher surface run-off velocity. Erosion rates would likely to be high in areas with a high LS factor.

7.2.3 Results

Erosion vulnerability by site

A comparison of the percentage of erosion risk in the four sub-watersheds shows that Kiangan and Lagawe sub-watersheds have the highest susceptibility or potential risk of soil erosion. The site, with lowest susceptibility is the Bagabag sub-watershed. The high percentage of soil erosion potential, at Kiangan and Lagawe sites, may be attributed to topographical characteristics and its proximity to populated areas, which makes it more subject to land conversion and disturbances.

The Magat watershed exhibited a moderate high, to extremely high potential of erosion risk, which is very similar to other critical watersheds in the Philippines. This condition necessitates immediate and sustainable conservation strategies. The Magat watershed because of its strategic location has experienced various disturbances, particularly from land conversion for agriculture and settlements purposes. The results of this study show that soil erosion could be a vast environmental problem in the watershed area, if left uncontrolled.

Erosion rates by land cover

The erosion rates with land cover, in all four sites, followed a similar pattern, with bare lands having the highest average annual erosion rates, followed by paddy fields, grass lands and forest, respectively. Average annual erosion rates, for the bare lands and paddy fields, range from 383 - 1391 tonnes /hectare/ year and 25 - 213 tonnes/hectare/year respectively. The erosion rates of the different land cover classes show the importance of vegetation, in minimising soil loss.

Erosion rates by slope classes

The soil erosion modelling also reveals the contribution of topographic factors in erosion rate values. Erosion rates are significantly higher in steeper areas. The difference in values, amongst land cover in the four sub-watersheds is attributed to elevation and slopes. Erosion rates of the different land cover classes, at Kiangan and Lagawe areas are higher compared to the Bagabag and Lamut sub-watershed due to their steeper slopes.

Conservation practices

The simulation of P-factor in the erosion modelling revealed its importance in controlling or minimising the soil loss. This result shows that the application of conservation practice, in agricultural areas, significantly reduces the soil erosion rate. As a consequence, this results in a lower soil nutrient and productivity loss.

7.3 Recommendations

Although this study has attained its objectives, further improvements on the quality of data and methods used, must be undertaken, in order to achieve more accurate results.

For Data Collection

The data used in this study should be further improved and be more comprehensive. The satellite images need to be of recent collection dates and the DEM, used in the study, need be improved to a higher resolution. The data and maps for soil and rainfall should be more detailed, if more accurate analysis is conducted. Soil surveys needs to be conducted and rainfall data needs to be established, in strategic locations of the watershed.

For Data Analysis

The land classification performed included only easily identifiable land cover/ land use in the Magat watershed. A more detailed land classification, involving more classes, such as the different forest types, could be conducted in order to obtain a more comprehensive representation of the area. Further analysis could include satellite images acquired on different periods, for comparison and better classification. This could also provide more accurate information on land cover/ land use changes in the watershed area.

The results of the soil erosion modelling were based on the physical factors available in the selected sites of the Magat watershed. However, the study only considered in detail the effect of land cover and slopes on erosion risk potential. The contribution of factors, such as rain erosivity, soil and conservation practices, needs to be further analysed.

For Policies

The results of this study show that erosion rates in bare lands are extremely high, in the study area. The study also revealed that erosion rates in forest and grass lands are much less, than other land cover types. Conservation strategies, such protection and restoration of vegetative cover, needs to be established in order to reduce the rate of soil erosion. Priority should be given to areas with high, to very severe, erosion risk.

The rate of erosion was observed to be higher in steeper and higher elevation areas. Land disturbance, such as conversion and deforestation, should be minimised or disallowed, in these areas. Agriculture activities, such as rice farming also show higher erosion rate values, than those established in flat lands. Policies should be established to incorporate conservation practices such as contouring, no-tilling technology and, selective planting amongst others, in order to minimise soil erosion and preserve soil fertility.

This study has demonstrated the usefulness of remote sensing and Geographical Information Systems, in the assessment of the Magat watershed. These technologies need to be incorporated in the assessment and management tools of agencies that are concerned with Magat watershed. Since there are many stakeholders in the area, there needs to be sharing and agreement with the information generated.

For Future Studies

This study only included four sub-watersheds, in the analysis. Evaluation of other sub-watershed areas could be conducted in order to obtain a more comprehensive assessment of the overall condition of the Magat watershed. Any future study could include other processes and activities, which may affect the state of the Magat watershed.

In addition, this study has only focussed on the application of remote sensing and GIS, on land cover classification and soil erosion. Further studies need to be conducted, in order to explore other applications of remote sensing and GIS, in watershed assessment and management.

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Appendices

Appendix 1. Dendrogram of signature classes created from Iso Cluster Tool.

Distances between Pairs of Combined Classes
(in the sequence of merging)

Remaining Class	Merged Class	Between-Class Distance
5	7	3.121022
6	9	3.589943
5	8	4.205451
5	10	4.350745
1	2	4.440706
1	3	5.658060
1	4	6.060027
5	6	6.714499
1	5	8.276275

Dendrogram of d:\emerson\landsat\isoclus_ext2_101.gsg

```
C   DISTANCE
L
A
S  0    0.9196  1.8392  2.7588  3.6783  4.5979  5.5175  6.4371  7.3567  8.2763
S  |-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|

  7 --------------------------|
                              |--------|
  5 --------------------------|        |-
                                       ||
  8 -----------------------------------||--------------------|
                                        |                    |
 10 ------------------------------------|                    |-------------|
                                                             |             |
  9 ------------------------------|                          |             |
                                  |--------------------------|             |
  6 ------------------------------|                                        |
                                                                           |-
  2 -------------------------------------|                                 |
                                         |----------|                      |
  1 -------------------------------------|          |--|                   |
                                                    |  |                   |
  3 ------------------------------------------------|  |-------------------|
                                                       |
  4 ---------------------------------------------------|

   |-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
   0    0.9196  1.8392  2.7588  3.6783  4.5979  5.5175  6.4371  7.3567  8.2763
```

Appendix 2. Statistical analysis for soil erosion modelling.

Statistical parameters for Bagabag sub-watershed.

```
#               STATISTICS of INDIVIDUAL LAYERS

#    Layer            MIN          MAX         MEAN          STD
#   --------------------------------------------------------------
        1            0.0000    3974.3130      42.8089     231.8617
        2            0.0000       1.0000       0.1445       0.2642
        3            0.0000     248.1501       4.7143       8.5815
        4            0.0000      61.9049       6.9150       6.5657
#   ==============================================================


#                    COVARIANCE MATRIX

#    Layer              1             2             3             4
#   --------------------------------------------------------------------
        1       23980.75930      11.72604     195.38820     161.99137
        2          11.72604       0.03138      -0.12481      -0.10899
        3         195.38820      -0.12481      33.04213      18.34621
        4         161.99137      -0.10899      18.34621      19.38032
#
=======================================================================


#                    CORRELATION MATRIX

#    Layer              1             2             3             4
#   --------------------------------------------------------------------
        1             1.00000       0.42744       0.21950       0.23762
        2             0.42744       1.00000      -0.12257      -0.13976
        3             0.21950      -0.12257       1.00000       0.72499
        4             0.23762      -0.13976       0.72499       1.00000
#
========================================================================
Legend:
   1- Erosion rates
   2- Landcover
   3- LS factor
   4- Slope
```

Statistical parameters for Lamut sub-watershed.

STATISTICS of INDIVIDUAL LAYERS

Layer	MIN	MAX	MEAN	STD
1	0.0000	4694.5010	41.6942	198.3382
2	0.0000	1.0000	0.0888	0.2371
3	0.0000	140.4108	9.0222	11.6767
4	0.0000	53.8975	10.7335	7.9696

COVARIANCE MATRIX

Layer	1	2	3	4
1	21605.16267	14.70449	187.66972	42.91102
2	14.70449	0.03114	-0.13417	-0.15050
3	187.66972	-0.13417	75.14204	35.34190
4	42.91102	-0.15050	35.34190	35.12282

CORRELATION MATRIX

Layer	1	2	3	4
1	1.00000	0.56687	0.14729	0.04926
2	0.56687	1.00000	-0.08770	-0.14390
3	0.14729	-0.08770	1.00000	0.68795
4	0.04926	-0.14390	0.68795	1.00000

Legend:

1- Erosion rates
2- Landcover
3- LS factor
4- Slope

Statistical parameters for Kiangan sub-watershed.

```
STATISTICS of INDIVIDUAL LAYERS

#    Layer           MIN          MAX         MEAN         STD
#   --------------------------------------------------------------
        1           0.0000    7498.4390     110.3767     522.8271
        2           0.0000       1.0000       0.0751       0.2392
        3           0.0000     260.4634      13.3098      15.8501
        4           0.0000      65.6438      16.1473       9.8146
#   ==============================================================


#                    COVARIANCE MATRIX

#    Layer             1             2             3             4
#   --------------------------------------------------------------------
        1       143810.53658      43.11056     787.70919     475.11872
        2           43.11056       0.03013      -0.02455       0.04468
        3          787.70919      -0.02455     132.19076      50.59585
        4          475.11872       0.04468      50.59585      50.65259
#
=======================================================================


#                    CORRELATION MATRIX

#    Layer             1             2             3             4
#   --------------------------------------------------------------------
        1            1.00000       0.65492       0.18066       0.17604
        2            0.65492       1.00000      -0.01230       0.03617
        3            0.18066      -0.01230       1.00000       0.61832
        4            0.17604       0.03617       0.61832       1.00000
#
=======================================================================
Legend:
   1- Erosion rates
   2- Landcover
   3- LS factor
   4- Slope
```

Statistical parameters for Lagawe sub-watershed.

STATISTICS of INDIVIDUAL LAYERS

Layer	MIN	MAX	MEAN	STD
1	0.0000	6927.9189	77.6949	356.2948
2	0.0000	1.0000	0.0431	0.1304
3	0.0000	397.7955	17.2135	19.5838
4	0.0000	57.0031	17.0041	9.4304

COVARIANCE MATRIX

Layer	1	2	3	4
1	64871.94444	14.59820	537.34232	-8.73592
2	14.59820	0.00871	-0.11684	-0.11645
3	537.34232	-0.11684	196.70861	45.72371
4	-8.73592	-0.11645	45.72371	45.61312

CORRELATION MATRIX

Layer	1	2	3	4
1	1.00000	0.61423	0.15042	-0.00508
2	0.61423	1.00000	-0.08928	-0.18478
3	0.15042	-0.08928	1.00000	0.48271
4	-0.00508	-0.18478	0.48271	1.00000

Legend:
1- Erosion rates
2- Landcover
3- LS factor
4- Slope