Evaluation of Development and Land Use Change Impacts on Stream Flow and Sediment Yield in Margalla Hills

By

Muhammad Shahid
(2011–NUST–MS WRE&M–03)

This thesis is submitted in partial fulfillment of

The requirements for the degree of

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In

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(2014)

This is to certify that the

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DEDICATED TO

MY PARENTS

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LIST OF ABBREVIATIONS

AVHRR:	Advanced Very High Resolution Radiometer
CDA:	Capital Development Authority
DEM:	Digital Elevation Model
DMC:	Double Mass Curve
DN:	Digital Number
DR:	Distance to Roads
DS:	Distance to Shoreline of the Lake
DV:	Distance to Village
EMR:	Electromagnetic Radiation
ERDAS:	Earth Resources Data Analysis System
ETM:	Enhance Thematic Mapper
EL:	Elevation
FAO USA:	Food and Agriculture Organization United States of America
GDP:	Gross Domestic Product
GIS:	Geographic Information System
GLOVIS:	Global Visualization Viewer
GPS:	Global Positioning System
GWLF:	Generalized Watershed Loading Function
ISODATA:	Iterative Self-Organizing Data Analysis Technique
IUCN PAK:	International Union for Conservation of Nature Pakistan
MSS:	Multi-Spectral Scanner.
MUSLE:	Modified Universal Soil Loss Equation
NERC-UK:	Natural Environment Research Council United Kingdom
PEPA:	Pakistan Environmental Protection Agency
PMD:	Pakistan Meteorological Department
RS:	Remote Sensing
SDR:	Sediment Delivery Ratio
SG:	Slope Gradient
SPOT:	Satellite Pour L 'Observation De La Terre

ST:	Soil Texture
SWAT:	Soil and Water Assessment Tool
TM:	Thematic Mapper
USGS:	United States Geological Survey
USLE:	Universal Soil Loss Equation
WAPDA:	Water and Power Development Authority

ABSTRACT

Water resources are affected by development activities and land use change which is undeniable and most significant. Land use change can alter the hydrology of a watershed. The present study has been carried out for Rawal and Simly Dams 'watershed. This study analyzed the historical land use changes which had taken place in catchment area for the period 1975-2012 (38 years) for Rawal Dam and for period of 1983-2012 (30 years) for Simly Dam. The main objectives of this study were to identify the land use change pattern over time, to obtain land use information from satellite imagery classification using GIS and Remote Sensing and to analyze its effects on rainfall-runoff and runoff-sediment relationships for the catchment areas of Rawal and Simly Dam. In this study the catchment area of the Rawal and Simly Dam was delineated on topographic sheets and using Planimeter the catchment area of Rawal Dam was computed as270 km^2 and the catchment area of Simly Dam was computed as150km^2. Using digital elevation model the catchment area of Rawal Dam was computed as 272.8km^2 and Catchment area of Simly Dam as 153.5km^2.To check the effect of land use changes on rainfall-runoff and runoff-sedimentation relationship for Rawal and Simly Dam Double Mass Curve analysis was performed. Double Mass Curves with trend curves of annual rainfall-runoff, Monsoon month's rainfall-runoff were drawn for both Rawal and Simly Dam site. It can be concluded that slope of the trend curve is changing for both Rawal and Simly Dam, which shows that land use changes have affected the rainfall-runoff and runoff-sedimentation relationship. To quantify land use change in catchment, the satellite imageries of 1992, 2000 and 2010 were used. The unsupervised classification was performed and 6 land use classes water body, forest, vegetation & agriculture, rangeland, built-up area and bare land were made. Land use analysis of 1992-2010 for Rawal catchment has shown 2.4 km^2decrease in water bodies' area, 13.6km^2 decrease in forest area , 37.4km^2 decrease in vegetation and agriculture, 28.3km^2 increase in range land, 16.6km^2 increase in built up area and8.5km^2increase in bare land. Similarly land use analysis of Simly Dam from 1992-2010 has shown 0.6 km^2 decrease in water bodies area ,18.7 km^2 decrease in forest, 4.1km^2 decrease in vegetation and agriculture,6.8 km^2increase in rangeland,6.5km^2 increase in built-up area and10.1km^2 increase in bare land. It is recommended that more meteorological stations should be installed in both catchments to monitor meteorological conditions, sediment data should be collected on yearly basis. GIS and remote sensing with Double Mass Curve Analysis should be used for watershed management.

CHAPTER 1

INTRODUCTION

1.1 Background

Pakistan's Agriculture Industry is the backbone of the country's economy and provides country's basic food security (90 % of food production). Agriculture contributes about 25 % to Pakistan's GDP but the sustainability of this production is subject to environmental threats. Pakistan's water resources are under considerable stress due to extent of agricultural activities, domestic and industrial uses. The major issues being faced include sedimentation, soil and water salinity, environmental degradation of lower river reaches, vulnerability to drought and supply, inefficiency and low productivity. Therefore developing and managing water resources in a sustainable way poses many and major challenges. Climate changes further complicate the water resources management in the country. Water resource management is practiced to fulfill water demand and sustainable future water use.

Water resources are affected by development activities and land use change which is undeniable and more significant of them. Land use change can alter the hydrological factors such as infiltration, interception and evaporation which have effect on runoff generation and the balance which exist between stream discharge, evaporation and ground water recharge in the watershed. The changes of agriculture land and forest into urbanization directly affect overland flow due to increase in overland flow flooding may occur. The increase in built-up area reduces ground water recharge because water retention capacity in landscapes increases due to forest and vegetation. Land use change impacts notably affect hydrology of Small basin (Jones and Grant, 1996). According to Schumann and Schultz (2000), land use change effects on hydrology also depend on spatial distribution of land cover types. Due to human alteration and development activities in catchment area changes occur in process of runoff generation because infiltration rate is reducing. Land use changes can alter the timing and size of flood peak (Tali 2011). Studies using different climate models have shown that land use alter global hydrological cycle by affecting the pattern of precipitation and temperature. Since 1900 river discharges has increased prominently in all over the world and study suggests that land use change may be responsible for this increase (Berga, 2011). The present study has been carried out on Rawal and Simly Dams watershed areas in which land use changes occurred due to urbanization and agriculture activities. Rawal and Simly Dam's watershed areas are located in Murree hills and Margalla Hills. The Murree hills are located in Punjab province and Margalla Hills are located north of Islamabad which is Capital of Pakistan. The Margalla hills are a part of Murree hills. Rawal Dam is constructed on Kurrang River and Simly Dam is constructed on Soan River and Khad Nullah respectively. From Rawal Dam drinking water is supplied to Rawalpindi and its Cant area (PEPA, 2004). The growing population and increasing development activities in catchment area of Rawal Dam are badly affecting the regime of water which comes in it. The ineffective management of forests accelerates deforestation. The sediments which originate from its catchment area due to land development and agriculture activities have reduced 35% of its storage capacity (IUCN PAK, 2005). Simly Dam is main source of drinking water for Islamabad. In Rawal and Simly catchment mostly precipitation occurs in December to January and July to September. Due to rainfall erosion of soil and soft rocks take place over the areas which have steep slope (IUCN PAK, 2005). Evaluation of Land use change and its effect on runoff and sedimentation of watershed is essential for management of water resources.

1.2 Statement of Problem

Due to deforestation, agricultural activities, development activities and sedimentation land use changes occurred in Rawal and Simly Dam. The actual capacity of Rawal Dam was 47230 acre-feet when it was developed and its current storage capacity is 31000 acre-feet. From comparison of these values it can be observed that 34.74 % of total storage of Rawal Dam is lost due to land use changes. Similarly the storage capacity of Simly Dam was 23000 acre-feet in 1982 which was increased up to 33000 acre-feet in 2005 but now the storage capacity of Simly Dam is 32219 acre-feet. Comparing these values it can be observed that 2.36 % storage capacity of Simly Dam is lost due to land use changes (IUCN PAK, 2005). Therefore it is strongly needed to evaluate land use change impacts for sustainable management of water resources.

1.3 Research Hypothesis

The state of the art latest tools Remote Sensing & GIS have been used to detect land use change and its effects on hydrology. Double Mass Curve is plot of accumulated values of one quantity against the accumulated values of quantity during same time period. When accumulation of two quantities are plotted the data will show a straight line, and the slope of this line shows the constant of proportionality between these quantities. The break in slope indicates change in proportionality constant. In this study for evaluation of land use change effect on rainfall-runoff and runoff-sedimentation relationships Double Mass Curve is used with trend curve.

1.4 Objectives of the Study

The main objectives of the study were:

a. To develop a procedure for satellite imagery classification into land cover classes to obtain land use information in GIS environment.
b. To determine the change in land use change pattern over time.
c. To analyze land use change effects on rainfall-runoff and runoff sediment relationships.

1.5 Scope of the Study

In Rawal and Simly catchment mostly precipitation occurs in the form of rainfall and snow. Mostly the rainfall takes place from July to September. Due to rainfall erosion of soil and soft rocks take place over the areas which have steep slope. The surface runoff volume generated from rainfall and snowmelt is affected by the development, deforestation and agricultural activities in Rawal and Simly watershed areas. Therefore, there is a strong need to analyze hydrology and hydraulic data to find out the correlation between the developmental activities in Margalla Hills and incoming flows & sediment yield rate in order to understand which type and which extent of activities lead to how much impact on stream flow and sedimentation. This interrelationship can show the loss of storage capacity and hence the actual need of cost of watershed management.

1.6 Organization of the Thesis

The thesis contains 6 chapters outline of which is given below.

Chapter 1 present's background of the study in this chapter land use change and their effects on water resources are described. Also the land use changes effect on Rawal and Simly Dam catchment area are described shortly. The hypothesis, objectives of the study and scope of the study are explained.

Chapter 2 is composed of literature review. In this chapter land use change impacts on stream is explained. Overview of GIS and Remote Sensing, principle of Remote Sensing, Remote Sensing data for land use classification and methods for land use change detection is explained. Satellite imagery classification, Double Mass Curve and previous studies are also explained.

Chapter 3 presents the details of study area i.e. study area map, location map of Rawal and Simly Dam, catchment area map of both Rawal and Simly Dam. Salient features of Rawal and Simly Dam are discussed. Meteorological conditions temperature, precipitation of catchment area is explained graphically. Geological map and details of River basin are explained in this chapter.

Chapter 4 is composed of data source methodology & analysis, in this chapter data source and the details of data List of meteorological stations and their location are explained. Also flow data, topographic sheets, sediment data and remote sensing data is explained with detail. In methodology and analysis details of graphical relation carried out for this study is given. Digital Elevation Model (DEM), selection of spectral bands for image formation, list of satellite from where data of remote sensing was acquired, radiometric characteristic of Landsat-5 and Landsat 7 is given. The procedure for area of interest selection and images of area of interest extracted from Landsat scene are given. The image classification methods supervised, unsupervised classifications and their algorithms and criteria for selection of classification method is explained. The unsupervised classification which was carried out on images of 1992, 2000 and 2003 for both Rawal and Simly Dam and land use classes which were made for both Rawal and Simly Dam are given in detail.

Chapter 5 presents results and discussions, in this chapter land use change patron in Rawal and Simly Dam catchment is explained with the land use change maps of 1992, 2000 and 2010 along with their histograms. Rainfall-runoff and runoff-sedimentation relation is explained for both Rawal and Simly catchment, also the rainfall-runoff is given in heaviest rainfall months i.e. July, August and September. The effect of land use changes on rainfall-runoff relation of Rawal and Simly Dam catchment is explained using Double Mass Curve and the Double Mass Curve is explained for both Rawal and Simly catchment.

Chapter 6 is composed of conclusion drawn from this study and recommendations proposed from the drawn conclusion to indicate the direction for future studies.

CHAPTER 2

LITERATURE REVIEW

2.1 Hydrological Process

The central focus of Hydrology is hydrological cycle which occurs continuously and it has no beginning or end. Earth's water is circulating continuously, Hydrological process has fallowing stages:

Precipitation

It is the fall of moisture from atmosphere to earth surface which may be in liquid or frozen form.

Evaporation

In this process water from the oceans, earth surfaces escapes in the form of vapors to the atmosphere evaporation increases with the increase of temperature.

Condensation

Water in the form of gaseous molecules goes from earth surface to atmosphere and in atmosphere these vapors are cooled this process is called condensation.

Transpiration

It is the process in which water from the surface of vegetation escapes into the atmosphere.

Runoff

It is the portion of precipitation which is not evaporated is known as runoff it goes to ocean through surface or subsurface stream.

Interception

Precipitation water which is absorbed by the vegetation is called interception.

Infiltration

Some of precipitation water goes to ground surface which is called infiltration.

Depression Storage

Some of precipitation water is stored in depression on the catchment area which is called depression storage.

The hydrologic cycle is shown in **Figure 2.1** and it illustrates about all the process which occur in a hydrologic cycle.

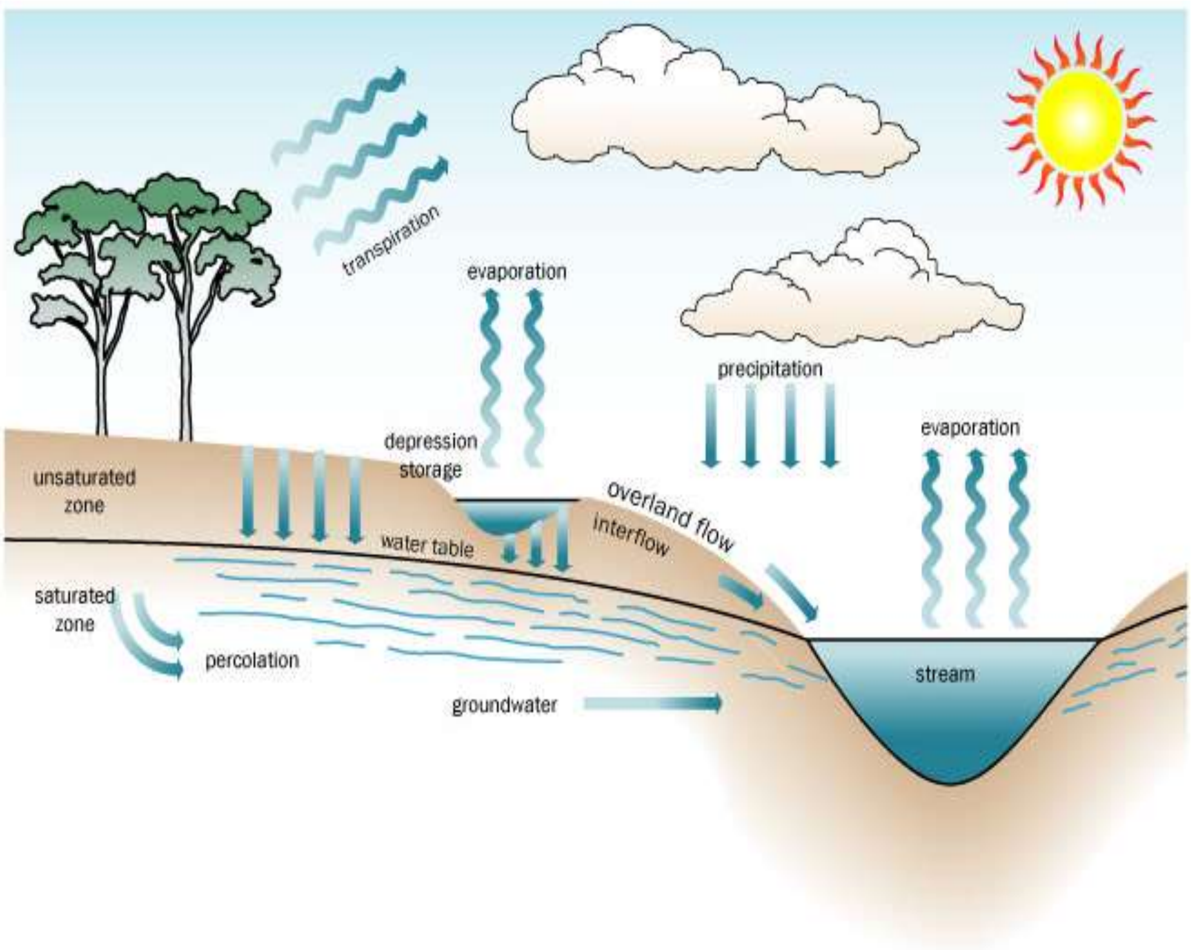

Fig-2.1: Process of Hydrologic Cycle (Google Images)

2.2 Land Use Change Impact on Stream Flow

Many years ago Guttenberg (1959) wrote that "'Land use' is a key term in the language of city planning". Sekliziots (1980) defines land use as the human function of a given area. Exploitation of land for residential, industrial, agriculture, recreational activities is called Land Use Change. The important factor in the runoff process is land use change; it affects erosion, evapotranspiration, infiltration, base flow and ground water recharge due to which water supply is affected. Due to rapid development activities land use changes and soil surface become impervious which leads to decrease in soil infiltration rate and increase in runoff rate. The seasonal and annual distribution of stream flow can significantly alter due to development activities, deforestation, agriculture, land degradation and landscape. Land use change can contribute to drought and flooding (Mustafa et al, 2005). Base flow is reduced due to Watershed development activities because path of groundwater flow changes with surface water bodies (Lin, et al 2006). Impact of vegetation is significant on infiltration because it produces organic matters which binds particles of soil tightly and increase its porosity due to which water holding capacity of soil and its percolation rate increases which increases the infiltration rate (Maidment 1993a). Rawal and Simly Dam are major drinking water sources for Rawalpindi and Islamabad. Since 1990 widespread construction activities has taken place in catchment areas of Rawal and Simly Dam. In addition to this for tourists a mega city of international standard has been planned by New Murree Development Authority which includes removal of 8 % forest. Due to construction of Islamabad Murree dual carriage way N-75 many water channels are affected badly. Murree hills makes up an attractive and picturesque resort and every year thousands of tourists flock to it. In the catchment areas of Rawal and Simly Dam there are many poultry forms, the solid waste of which has no proper disposal and management. This land use change is critical for Rawal and Simly Dam, hence investigation of the relationship between stream flow and land use change in catchment areas of Rawal and Simly Dam is strongly needed.

2.3 Concept of GIS and Remote Sensing

The selection of reference data is important in any study these data can be derived from a number of sources and it may be in different form. For land use change detection different maps i.e. topographic maps, soil survey maps are used as data. Also data can be collected from survey, field visit, sampling and modeling. Using maps, sampling and survey data land use changes can be accessed at smaller scale and it is costly and time consuming (Lillesand, 2004). The conventional methods for data collection and analysis are costly and low efficient that’s why for assessment of human activities on earth viewing the earth from satellite is essential. For efficient and quick assessment, monitoring and analyzing of land use change planners need a reliable mechanism and remote sensing technology is reliable and less costly. Remote sensing is a technique used for obtaining information about any feature while still at distance from it. Using remote sensing information can be obtained about the areas which are inaccessible for ground survey (Lesschen et al 2005, Berga 2011).

2.3.1 Principle of Remote Sensing

In remote sensing energy source transmit energy in the form of electromagnetic radiation through space. The profile of electromagnetic radiation is given in **Figure 2.2.**

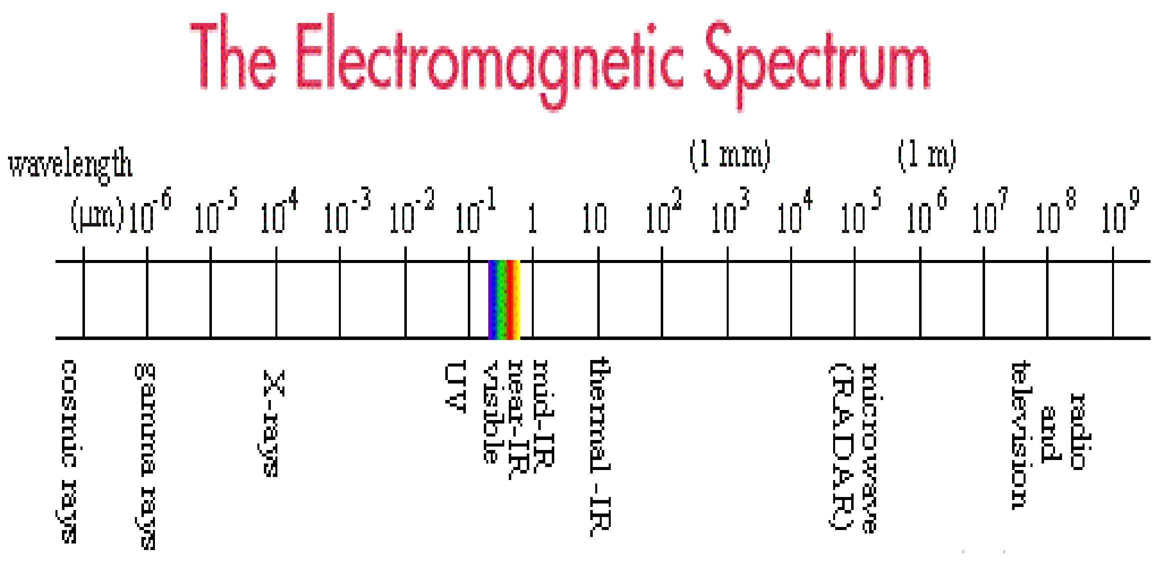

Fig-2.2: Electromagnetic Radiation (Lillesand, 2004)

The electromagnetic energy which energy source transmits through space reflects back toward the sensor after striking the objects on earth. The objects on earth returns different kind and amount of the energy and the study of this difference enable us to identify them **Figure 2.3** illustrates the process remote sensing.

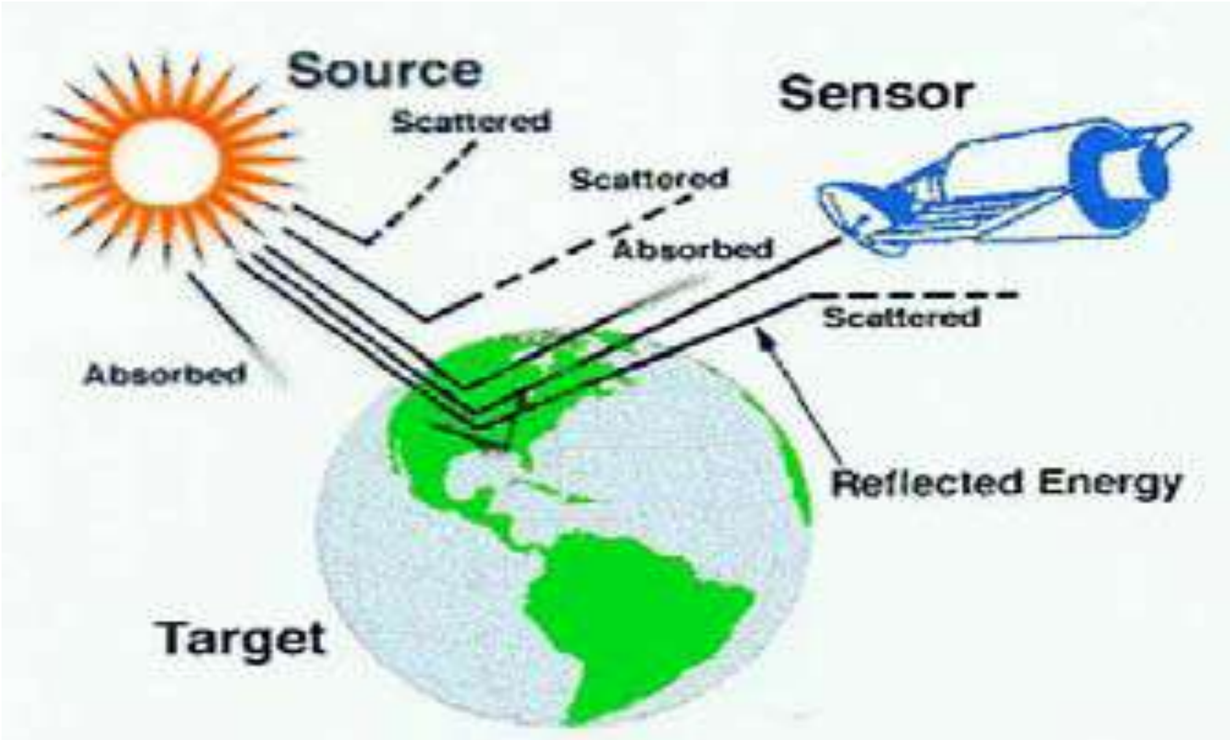

Fig-2.3: Process of Remote Sensing (Lillesand, 2004)

There are two types of sensors

1 Active Sensors

This type of sensor emits microwave from satellite these microwave strikes with the land surface and reflect back to the sensor. Active sensors are suitable for observation of mountains and valleys.

2 Passive Sensors

Passive sensor is the sensor which observes microwaves radiated naturally from land surface. These are suitable for observation of temperature on sea surface, accumulation of snow and for ice thickness.

The part of the system which is out in front of sensor is called scene. Particles in atmosphere Strikes with the electromagnetic radiation and divert their path this process is called scattering. The extent of scattering depends upon many factors which are particle abundance, gasses, radiation wavelength and the distance which radiation travels in the atmosphere. The process in which Molecules present in atmosphere soak up energy at different wavelengths is called absorption. The detectors in sensor record the wavelength of electromagnetic radiation and this energy is converted into digital number (DN). The range of DN value is from 0-250 and each pixel has unique DN value.

2.3.2 Erdas Imagine

Erdas Imagine is a remote sensing application used for geospatial applications. It was released in February 1992 as ERDAS IMAGINE 8.0. It is a toolbox which is used for mapping, image display & analysis and image enhancement. From image analysis in Erdas Imagine invisible features of image can be seen, from the brightness level of image features of image can be observed it also help in vegetation, forest and mineral analysis. It is used to locate geo positions of features, linear feature extraction and import export of data for variety of formats (Erdas Field Guide, 2005).

2.3.3 Remote Sensing Data for Land Use Classification

Aerial photographs and satellite imageries are used in remote sensing. Many model use raster data for land use change detection because grid cells have equal size in raster data. In most frequently used raster data Remote Sensing data is the suitable and excellent data for land use change evaluation. Remote sensing data can be acquired from different satellites as the sensors of these satellites obtain data. There are many satellites in the space which can be used for collection of remote sensing data. The applications of these satellites vary with their mechanism of data collection, sensor, bands, special and spectral resolution, sun rise, sun set and height of the flight. Landsat is the most popular satellite among the other satellite operating in space. Landsat has operated since 1970-2005 its 8 mission were sent in space. Landsat 1 started its work in 1972 and terminated in January 1978 , Landsat 2 started its work in 1975 and terminated in January 1981, Landsat 3 was launched in March 1978 and terminated in March 1983 , Landsat 4 was launched in July 1982 and terminated in 1993, Landsat 5 started its work in 1984 and decommissioned in December 2012 ,Landsat 6 started its work in 1993 but it failed to reach its orbit Landsat 7 started its work in 1999 in which scan line off problem was observed in 2003 and Landsat 8 started its work in February 2013. In Landsat satellite data can be downloaded freely. Landsat is very important for analysis of environmental system because of its long period operation. There are many other satellites working in space and their features are given in **Table 2.1**.

Table: 2.1 Characteristics of Satellites

Satellite/sensor	**Repeat rate**	**Area of image**	**Pixel dimension**	**Frequencies**
Landsat/MSS	16–18 days	150x150 km	80 m	Green, red, infrared
Landsat/TM	16–18 days	150x150 km	30/15 m	Blue, green ,red, near infrared, mid infrared, thermal
AVHRR	0.5 day	800x800 km	1.1 km	Green, red infrared, lower frequencies
IKONOS	1–3 days	Variable	1–4 m	Green, red, infrared
Quick bird	1–3 days	16x16 km	0.6 m	Blue, green, red, near infrared
SPOT	3–6 days	60x60 km	10–20 m	Green, red, near infrared

Source: Nelson and Geoghegan 2002

2.4 Methods Other than Remote Sensing For Land Use Change Detection

Land use changes can be studied from various approaches and it depends on the availability of information some of them are explained below.

Field Survey

The traditional means to get information about the characteristic of land is field survey. The field survey varies in methodology and objectives but is based on observing and mapping in field. To find land use changes field survey can be done and land use classes and land use map for some specific area can be made through field survey. These types of survey are costly and take too much time and limited information can be obtained through this type of survey (NERC-UK - 1990).

Socio Economic Survey

Information about land use change can be gathered through socio economic surveys. Household regional survey gives information about land use change information about population growth can be obtained, death rate, agricultural area, built up area of some specific area for which land use change study is being carried out. Then through trend analysis of Population growth, death rate, land use changes can be predicted.

Estimation of Area Change

The change in land use can be evaluated using estimation of area change. The information about Area change can be achieved from statistical books, agriculture and environmental reports. Area change may be increase or decrease of agricultural used areas, certain crop, and forest area (Eiden et al, 2002)

Analysis of Land Use Flows

Land use flow means which land use class is expanding and which land use class is being replaced. Land use flow matrices can be used to find land use change, Flows are analyzed by means of simple tables or matrices, and where land use information coming from different years is crossed (Eiden et al, 2002).

Aerial Photography

Aerial photography is an important additional source for land use information. There are many types of aerial photographs generally they are 23 cm square and they are taken with a camera pointed vertically from an airplane flying. The principle advantage of Aerial photograph is that they provide permanent record for detailed analysis. The land use evaluation using aerial photography is costly and the major disadvantage of aerial photography is that the information may be lost during the conversion of photography from analog to digital format (NERC-UK -1990).

2.5 Satellite Imagery Mapping

The best way to find land use change is satellite imagery mapping it is a latest and cheap tool. Using satellite imagery mapping land use map of large area can be observed. Land sat data can be computer classified to get accurate map of land use. Land use is being mapped using thematic mapper (TM) images; thematic mapper is advanced multispectral scanning.TM of Land sat record the digital numbers which represent the scores of reflected light from 30 m cells on the ground. There are 7 wave bands of spectrum which are between the blue and thermal wave lengths. Scanning of land use through satellite is done reflectance data for 185 km swath is collected through different orbits full cover of earth in 16 days can be obtained. The data which represent 185 km section of a path is called scene. From path and row value of a given area Images of that area can be observed then using suitable classification method land use changes for this area can be fined (NERC-UK -1990).

2.6 Double Mass Curve

Hydrological data is the sequence of observation of any phase of hydrological cycle which is made at a particular site. This data maybe the record of rainfall of an area recorded by a particular rain gauge, and it may be record of discharge data of a stream at a particular point. In most hydrological studies long term record is preferred but user should recognize that for long term data there are chances of error due to any change in physical condition of the basin or in method of data collection. The inconsistency in any hydrological data can be checked by the basic analysis tool which is Double Mass Curve. Mass and Double Mass Curves can be used in many hydrological and hydraulic studies. Mass curve and Double Mass Curves are defined below:

Mass curve:

The Mass curve is the plotting of cumulative values of a hydrological quantity verses time.

Double Mass curve:

The Double Mass Curve is defined as the plotting of cumulative value of one quantity verses the cumulative value of other quantity while the time duration should be same.

In Double Mass Curve straight line can be observed while plotting commutation of two quantities with same time period. The slope of this line will show the constant of proportionality between these two quantities and the break in the slope of line will show the change in the proportionality constant between quantities. Double Mass Curve can be visualized and it is mostly used to check consistency and trends of hydrological data and meteorological data. The Double Mass Curve can be used to identify missing precipitation data it is used to check the consistency of data with respect to the time. From the changes in slope the change in trend of data can be identified and also consistency or inconsistency of the data can be checked. Double mass can be applied in the analysis of sediment transport data and reservoir sedimentation data. The change in slope may be due to many factors. Change in a precipitation Double Mass Curve may occur due to instrument error or due to human error. If there are no breaks in slopes then the correlation between values of the two variables which are plotted has not been changed with the change in time. The double mass can give us the significant information about the time in which changes occurred in those variables for which Double Mass Curve is plotted. In general it is a rule that if the break in slope persists for the duration less than five years then the breaks in slope is ignored also if breaks are for more than 5 years then it can be considered a trend and it can be analyzed and investigated (Searcy and Hardison 1960, Albert 2004). Merriam (1937) used Double Mass Curve to check the consistency of precipitation data in Susquehanna watershed

USA. Recently Chinese scholars used using Double Mass Curve for analyzing the effect of soil & water conservation also for detection of land use change effect on runoff and sedimentation and got good results (Mu, et al., 2010).

2.7 PREVIOUS STUDIES

The land use change in a catchment can be accessed using field survey, socio economic survey, analysis of land use flows and GIS and Remote Sensing tool. GIS and Remote Sensing is mostly used for land use assessment and studies have been discussed in which this tool was used for land use change assessment.

In 2012 Efe et al carried out a study for land use change detection in Karinca River catchment Turkey using GIS and remote sensing. This study period was 1979-2007. Satellite imageries of year 1979 and 2007 were analyzed for 1979 Land use data was derived from historical topographic and land use map of the study area after transferring them in digital format and Landsat ETM+ satellite image of 2007 was used. Unsupervised classification method was used and Iterative self-organizing analysis technique (ISODATA) was used for Landsat ETM+ image. The classification of 1979 image showed 43.4 % forest, 26.5% grass land, 18.3 % olive groves, 10 % agriculture and 1.2 % built up area similarly land use data of 2007 Image consisted of 44.2% forest, 20.7 % grass land, 25.4% olive and 7.9 % agriculture areas. Changes occurred from 1979 to 2007 were 2.7 % decrease in cropland, 7.1 % increase in olive groves, 0.8% increase in forest and 0.7 % increase in built-up area.

In 2008 Coskun et al used GIS and remote sensing for evaluating urbanization and land use change in the Kucukcekmece Water Basin (Istanbul, Turkey). The study was carried out for 15 years from 1992 to 2007. Satellite images of year 1992, 1993, 2000 and 2007 were analyzed. These images were taken from different satellites i.e. image of 1992, 1993 were TM images of Landsat5, image of 2000 and 2007 were from Spot-Pan. The resolution of images were 10 m, 20 m, 5.8 m, 23.5 m and 30 m and study area maps of scale 1:25,000, 1:5,000 and aerial photos of scale1:5,000 were used for ground truth were used. Different classification method were applied to enhance spectral data in unsupervised classification method ISODATA algorithm was applied for all images the threshold value was .95 and number of iteration was 20 and 50 clusters were obtained. Due to similarity of reflected values of different classes unsupervised classification efficiency was poor due to which supervised classification was applied and maximum likelihood algorithm was applied and numbers of clusters were increased from 50 to 80. The classes of water, forest evergreen, forest deciduous, forest intermixture, barren land, agriculture, grass land, soil, urban, road were made. The results of classification were evaluated 100 random pixels were compared with fieldwork results the user accuracy was 84% ,84%, 83.33% and 86% for 1992,1993,2000 and 2006 respectively.

In 2012 Singh and Dubey carried out a study on land use mapping in Naina -Gorma Basin (Rewa District India). The study was carried out from 1975 to 2008, for 1975 Topographic sheet No 63 H/9, H/10, H/13, H/14, L/1, and L/2 and for 2008 scene of IRS LISS III with scale 1:50,000 were used. Geo-referencing was done through topographic maps and unsupervised classification was performed for Image analysis. In Unsupervised classification spectral classes were grouped on the basis of numerical information unsupervised classification involve clustering algorithm which arrange unknown pixels in number of classes based on their natural grouping. The ISODATA algorithm was used for unsupervised classification. The number of classes was 60 and iteration was 10 and 95 % convergence were selected for unsupervised classification. After classification of image 9 land use classes i.e. agriculture, forest, dense scrub, open scrub, river, other water bodies, waste land, sandy area and settlement were recorded. There were 6 % forest, 6% agriculture, 7% dense scrub, 12 % open scrub, 4 % river, 1 % water bodies, 21 % rock , 10 % sandy area, 33 % settlement.

Malik et al used GIS and Remote Sensing to evaluate deforestation in Margalla hills. The satellite images of 1990 and 1998 were classified and supervised classification method was used. The satellite image of 26 may l990 (TM) and 8 June 1998 (SPOT XS) were used. Four classes dense forest, sparse vegetation, agriculture land, settlements were developed. The results showed that between 1990 and 1998 forest cover decreased 0.6% at annual rate, sparse vegetation increased 11.8% at annual rate and 70.6% of total area remained unchanged.

Saed et al in 2011 used GIS and Remote Sensing to evaluate deforestation and urbanization in Rawal watershed. The Landsat- ETM+ images of 1992, 2000 and 2010 were used. NDVI classification was performed and seven land use classes, Conifer, shrub, agriculture, rangeland, rocks, settlements, and water were made. Conifer decreased 34% shrub decreased 29% agriculture increased 32%, rangeland increased 21%, rocks increased 292%, settlements increased 231% and water decreased 45%.

Land use change effect at catchment runoff can be found using experimental studies of catchment, hydrological modes and numerical methods. These approaches are explained below.

Yu et al, (2008) in china evaluated land use change efficiency to control flood by using experimental plotting. Fohrer et al. (2001) used SWAT model for predicting land use change impacts. Lorup et al (1998) evaluated land use change effect on catchment area of Zambezi River Zimbabwe by using numerical methods and hydrological modeling.

Zhao et al, (2004) from china evaluated effects of land use change on hydrological relationships of Zichang catchment. For land use mapping the land sat TM data was used from 1986 and 1997 with 30 x 30 m resolution. Different land use classes were made which were terrace farmland, woodland, sparce woodland, grass land, shrub, residential areas and water bodies. Due to small area residential land and water bodies classes were omitted. The rainfall, runoff and sediment data of period 1980-1986 and 1991-1997 was used. The digital topographic map of the study area and DEM was used for land use change pattern classification was done. To check land use change effects on rainfall-runoff relationship Double Mass Curve was drawn for two different periods i.e. 1980-1986 and 1991-1997 from slope trend curve change was observed and slope trend curve was less in 1980-1986 which shows that runoff increased from 1991-1997. Similarly the Double Mass Curve was drawn between rainfall and runoff of June, July, August and September. It was observed that in June, July, August and September the runoff was increasing in 1991-1997. To check land use impacts on runoff and sedimentation relationship the Double Mass Curve in two different periods i.e. 1980-1986 and1991-1997was drawn between runoff and sedimentation the slope trend curve was more for 1991-1997 which shows that sediment increases in this period. Similarly the June, July August and September Double Mass Curve were drawn between runoff and sedimentation and in 1991-1997 July August and September the slope curve was observed maximum which shows sediment was increasing in this period.

In 2011 Gao et al carried out a study using Double Mass Curve to find the changes on flow of stream and sedimentation and change of land use on Yellow River China. The precipitation data, flow data and sedimentation data was collected for period (1950-2008). Double Mass Curve was prepared for precipitation verses flow and precipitation verses sediment. The results showed that in late 1950s the stream flows and sedimentation trend was decreasing. It was observed from 1985-2008 cumulative stream flow was reduced 17.8% and cumulative sediment discharge was reduced 28%.

In 2009 Alansi et al from Malaysia used double mass curve for land use evaluation on rainfall-runoff and runoff sedimentation relationship. This study was carried out on Bernam watershed. In this study land use change effect were compared for two periods 1980s and 1990s. The results showed that land use change was major reason of increase in runoff and sedimentation in the study area. Slope trend curves were higher for 1990s as compared with 1980s this shows that sedimentation and runoff were more for 1990s.

Santillan et al (2010) used GIS & RS to quantify the impact of land use changes in tropical Taguibo watershed Philippine. A rainfall-runoff model based on the US Soil Conservation Number and sediment yield model based on Modified universal soil Loss Equation were constructed to estimate the impact of land cover change on the volume of runoff and sediment yield during rainfall events. Landsat ETM + and MSS images covering the study area acquired on 17 April 1976 and May 2001 with pixel resolution of 57-m and 28.5 respectively were obtained from GLFC i.e. Global Land Cover facility and these images were analyzed to obtain land cover map needed for model parameterizations. Rainfall-runoff modeling was performed using the Soil Conservation Service-Curve Number (SCS-CN) model (SCS 1985).The SCS-CN model was implemented using HEC-HMS. The HEC-HMS model was calibrated rainfall events recorded at the inner portion of the watershed and discharge Hydrograph measured at the main outlet for the June 25-27, 2007 period. Sediment yield was constructed using Modified Universal Soil Loss Equation (MUSLE). A sediment transport model based on sediment routing equation of Soil and Water Assessment tool (SWAT) model was used to route the computed sediment concentration at sub-watershed outlet through the channel until the main outlet of the watershed is reached. The analysis showed a 6.52 % reduction in forest cover a 13.69 % reduction in mixed vegetation a 4.46 % increase in barren areas and 15.54 % increase in grassland in the study area from 1976-2001. Landsat image analysis also provided a very quick identification of the areas that needed rehabilitation strategies for the reduction of surface runoff and sediment yield.

Fashtali, (2003) carried out a study to find land use changes in Uromieh Lake which is a salt lake in north western Iran and its catchment Shar-chi catchment exist in west Azerbaijan province. To determine land use changes Topographic map of the study area scale 1:50000 (1998) and aerial photograph of the area scale 1:50000 (1956) were used. Satellite images ETM 9 June 2000 & TM 9 August 1990, ASTER 24 July 2000 were used. Hydrological data, sediment data of the catchment area of 26 years duration (1974-1999) were used. To determine Land use different method were used for image classification i.e. Principal component classification, normalized density value index, false color classification, hue saturation Intensity classification, and accuracy assessment for land cover map. During the image processing phase geometric correction and image enhancement and image supervised and unsupervised classification was done. Maximum likelihood classification of Principal component gave unsatisfactory results and overall accuracy was 73.49 %. Maximum likelihood classification of normalized density value index using band 2 and 3 ETM Landsat gave good results and overall accuracy was 76.31%. Hue saturation Intensity classification gave unsatisfactory results and accuracy was 72.42 %.

In 2013 Badar et al carried out a study to evaluate the impact of land use changes on Dal lake which is located in north of Srinagar. GIS and remote sensing were the assessment tools. Due to increase in tourism activities large number of residential buildings, hotels, and restaurants are constructed in the catchment area at alarming rate. Due to these activities runoff is affected also these land use changes may affect the catchment area. For simulating hydrological response under changed land system conditions lumped parameter watershed model GWLF was used. The GWLF computes runoff by using SCS curve number equation i.e. Soil Conservation Service Curve Number, erosion is computed using USLE (Universal Soil Loss Equation) and sediment yield is the product of erosion and SDR (sediment delivery ratio). To check the land use changes multi-sensor satellite data in the form of Landsat, multi-data and Thematic Mapper and satellite data in the form of Landsat Thematic Mapper (TM) and Indian Remote Sensing satellite data was used Landsat image of October 1992 with spatial resolution of 30 m and image of 5 October 2005 with a spatial resolution of 23.5 was used Digital Elevation Model (DEM) was used. For identification of hydrological response land use data is very important in order to determine the changes supervised classification is used and analysis of color tone texture shape size was done. Daily precipitation and temperature data are required for simulation of hydrologic process by GWLF model. The classification of satellite images was done and 16 classes were made which were deciduous, coniferous forest, forest, grasslands, sparse forest, plantation, agriculture, agriculture fallow, snow, and water channel area, bare land, aquatic vegetation, and horticulture, scrub lands, built up and bare exposed rocks. The results showed that from 1992-2005 significant changes occurred in Dal Lake catchment area. Prominent of them were horticulture, built up, bare land, agriculture, grasslands, scrub lands and forests. From 1992 to 2005 a record increase of 12.08 km2 occurred in built up class and agriculture class decreases 1.84 km2 while horticulture that include fruit crops decreased 7.57 km2. The study showed that area of coniferous tree was reducing 5.67 km2 and deciduous tree area was reduced to 1.8 km2 also .96 km2 area of sparse forest was decreased. Similarly large scale decrease of (−7.89 km2) in grassland area, 12.9 km2 decrease in plantation cover was seen. There was also observed an increase of (+11.97 km2) in scrub lands. The overall accuracy of the classification was found to be 93%.

Ali, (2009) carried out a study to find effect of land use changes on surface runoff of Lai Nullah Basin. HEC-HMS model was used and it was calibrated for five-storm events. Results showed the efficiency of consistency between simulated and measured hydrograph was 76-98%.

CHAPTER 3

METHODOLOGY

3.1 Study Area

The study area consists of catchment areas of Rawal and Simly Dam. Rawal Dam is Located in Capital of Pakistan along Murree Road at about 3 km from Faizabad interchange in Park area of Islamabad territory. Simly Dam is located about 30 kilometers east of Islamabad and Rawalpindi in Rawalpindi District Punjab Province Pakistan. The catchment areas of both Simly and Rawal Dam lie in Murree Hills Punjab Province of Pakistan. The location map of the study area is given in **Figure 3.1.**

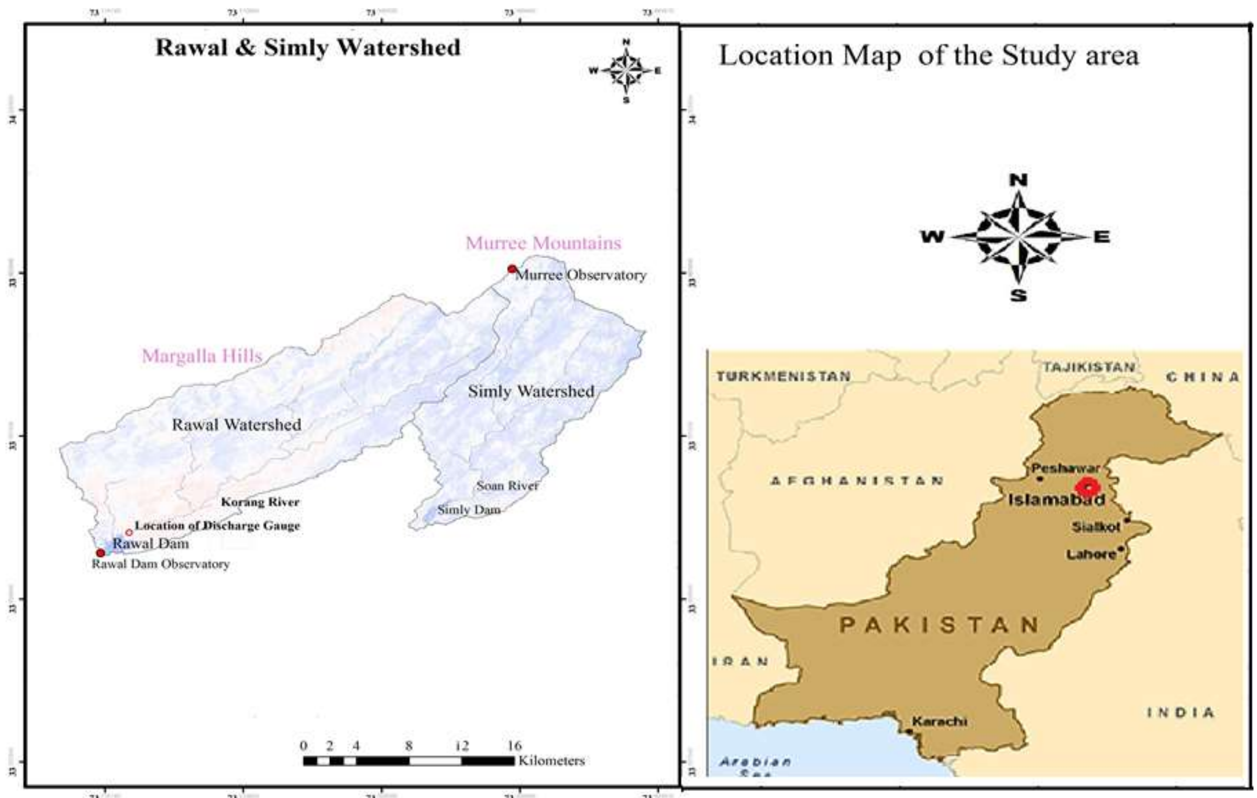

Fig-3.1: Location Map (Landsat-2010)

Rawal Dam is the main source of water supply for Rawalpindi city and cantonment. Similarly Simly Dam is the main source of water supply for Islamabad. The map of study area is given in **Figure 3.2**.

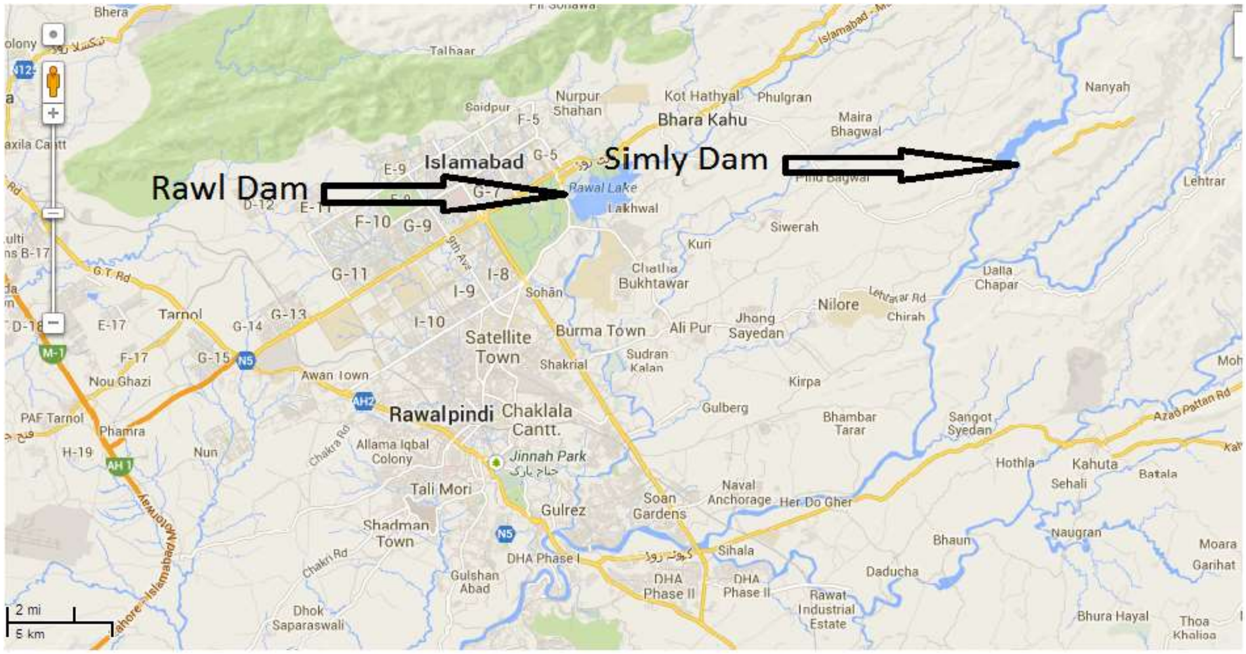

Fig- 3.2: Study Area location Map (Google maps)

3.2 Rawal Watershed

The characteristics of Rawal Watershed are given in **Table 3.1**

Table: 3.1 Characteristics of Rawal Watershed

Name of river	Korang River
Catchment area	273 km^2
Latitude / Longitude	Latitude 33° 42' N & Longitude 73° 7' E
Main tributaries	Main Korang and its tributaries, Shahdara & its tributaries Noorpur & its tributaries.
Meteorological Stations	Rawal dam observatory located at Rawal Dam site Latitude 33° 40' 40″N & Longitude 73° 6' 36″ E & Elevation 543.7 m
Discharge station	Located at Rawal Dam site Latitude 33° 43' 15″N & Longitude 73° 8' 12″E

3.2.1 Location

The Rawal watershed extends from north east of Islamabad to Murree hills. The location map of Rawal Watershed is shown in **Figure 3.3**.

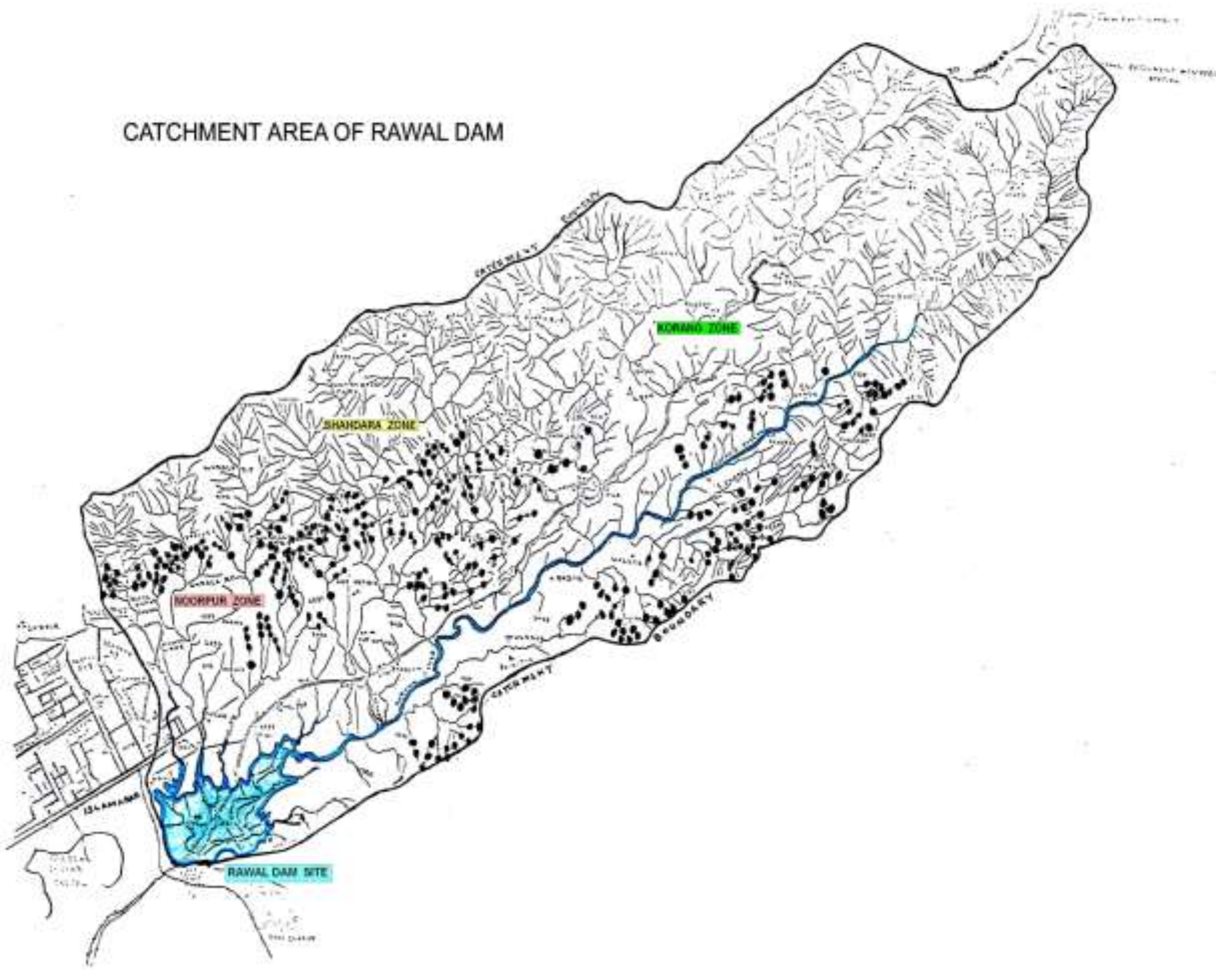

Fig-3.3: Rawal Dam Catchment Area Map (Small Dam Organization Punjab)

3.2.2 Climate

The Rawal Dam has tropical climate in upstream catchment. It has cold snowy winters, cool summer with escalated rain. The downstream catchment has four seasons, these are winter (December – February), hot weather (March-May) Monsoon (June-September) and transition period (October-November).

Precipitation

The catchment area of Rawal Dam is situated in the Outer Himalayas retaining high altitude. Precipitation is received year around winter and summer is the season in which maximum precipitation is received. The heavy rainfall months are July August and September and the average annual precipitation in catchment area of Rawal Dam is 1435 mm. The details of precipitation data is given in **Appendix A.**

Temperature

The temperature data of catchment area of Rawal Dam for duration of 38 years i.e. 1975-2012 was analyzed and it was observed that average annual maximum temperature is 21^0 C and average annual minimum temperature is 11^0 C the details of yearly temperature is given in **Appendix A**.

Humidity

In catchment area of Rawal Dam humidity is high during the period of Monsoon and moderate during the non-monsoon period. The relative humidity in the catchment of Rawal Dam ranges from 36-76 %.

3.2.3 Geology and Physiography

The geology of Rawal Dam catchment area is loosely cemented sandstone and friable sandy shale the soil here is sand, silt and clay. The physiography of the catchment area is hilly. The hills range between elevation of 500 m at western end and 2200m on its east end and it has average height of 1000 meters. The irrigation here is rain fed and ground water is sweet. Wheat, millet and maize are the crops which yield here.

3.2.4 Rawal Dam

Rawal Dam was completed in 1962 by WAPDA and later it was handed over to Punjab Irrigation Department in 1967 for operation and maintenance. Rawal Dam is located at Latitude 33^0 $42^'$ N and Longitude $73^0 7'$ E in Park area of Islamabad. The catchment area of Rawal Dam extends 15 km From Rawalpindi town up to the Murree Hills. The location of Rawal Dam is shown in figure 3.3 and salient features of Rawal Dam are given in **Appendix B.**

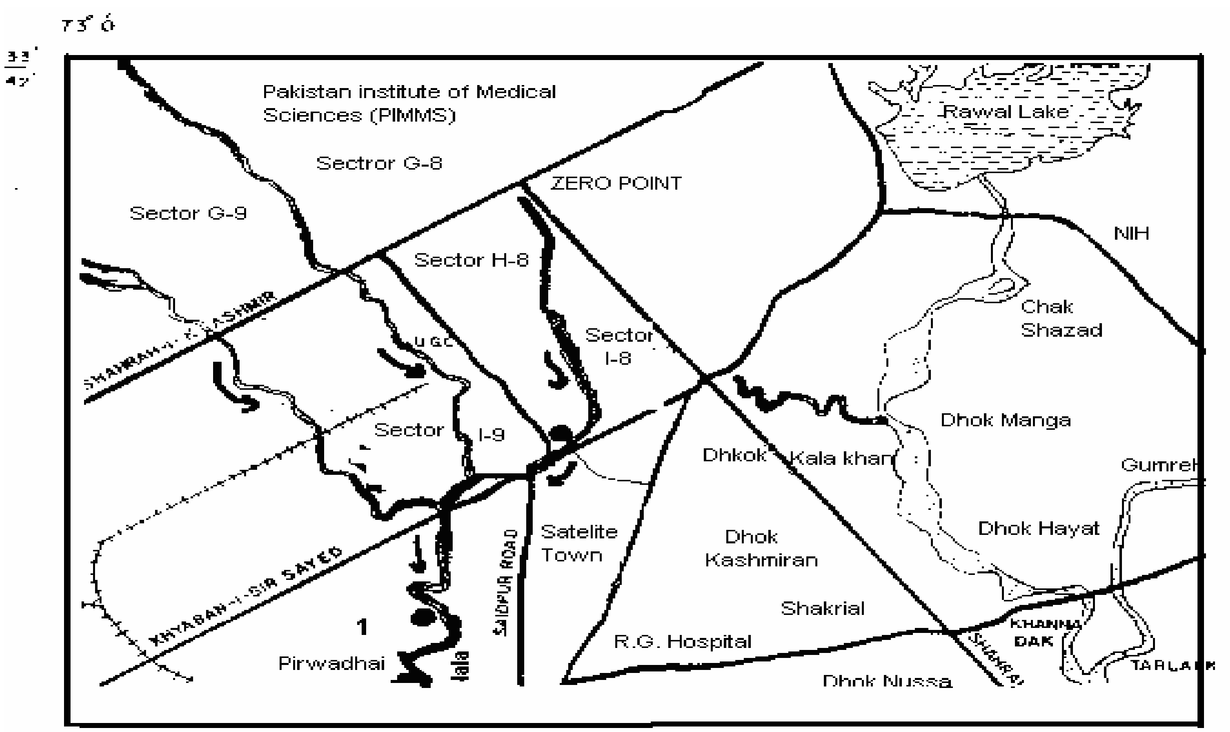

Fig- 3.4: Location Map of Rawal Dam (WAPDA)

3.3 Simly Watershed

The characteristics of Simly Watershed are given as:

Table: 3.2 Characteristics of Simly Watershed

Name of river	Soan River
Catchment area	154 km²
Latitude / Longitude	Latitude 33° 43' 8″ N & Longitude 73° 20' 25″E
Main tributaries	Soan Nullah, Khad Nullah,
Meteorological Stations	Murree observatory located at Murree Latitude 33° 55' 12″N & Longitude 73° 22' 48″ E & elevation 2167 m

3.3.1 Location

The Simly Dam is located 35 km northeast of Islamabad. The location map of Simly watershed is shown in **Figure 3.5**.

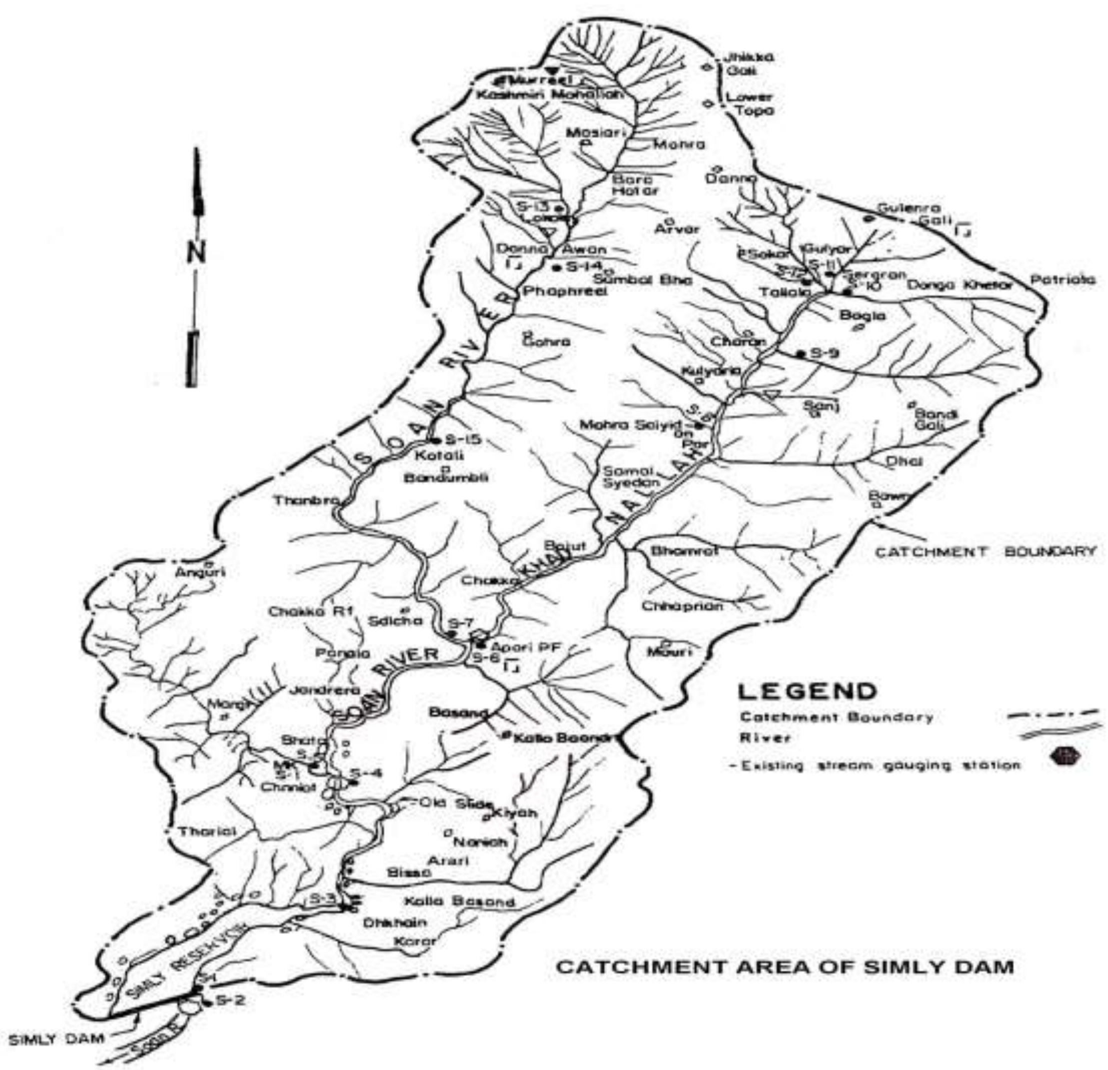

Fig- 3.5: Catchment area of Simly Dam (WAPDA)

3.3.2 Climate

The climate of upper Soan basin can be divided into four seasons as are experienced over the whole of Pakistan. These are the winter monsoon (December-February), the hot weather (March-May), the summer monsoon (June- September) and the transition period (October-November). It is summer monsoon rainstorms that give rise to the major floods. The Simly basin is an un-gauged catchment. The only available record is the meteorological data of Islamabad and Murree.

Precipitation

In the catchment area of Simly Dam precipitation is received year around, winter and summer is the season in which maximum precipitation is received. The heavy rainfall months are July August and September the average annual precipitation in catchment area of Simly Dam is 1757 mm. The detail of precipitation data is given in **Appendix A**.

Temperature

The average annual maximum temperature in Simly Dam catchment is 16^0 C and average annual minimum temperature is 8^0C the detail of yearly temperature is given in **Appendix A**.

Humidity

In catchment area of Rawal Dam humidity is high during the period of Monsoon and moderate during the non-monsoon period. The relative humidity in the catchment of Rawal Dam ranges from 36-76%.

3.3.3 GEOLOGY AND PHYSIOGRAPHY

In catchment area of Simly Dam most of the Murree and Kotli Sattian areas are composed by the sand-, silt- and clay-stones of the Murree formation. Mesozoic limestone and marl rocks with subordinate shale are only present along the western margin of the Main Boundary Thrust. Regionally the rocks of the Simly Dam Project area belong to the Siwalik System of Mio-Pliocene age. Physiography relates the details of elevation of different parts of the watershed for describing watershed. The Murree and Kotli Sattian areas are located in the Siwaliks and the Middle Mountains regions of the Himalayan Mountain Range. The Siwaliks extend from the planes around the cities of Islamabad and Rawalpindi up to 900m ASL. Shrub, bushes and small trees mainly form the vegetation of this area. Very little grass cover is present and soil cover is minimal. The Middle Mountains range in elevation from river bottoms at about 900m ASL to the top of the Murree and Patriata mountains (less than 2000 m ASL), which corresponds to the highest cultivable land in the area (Borgia, 2002). The Geological map of Simly Watershed is given in **Figure 3.6**.

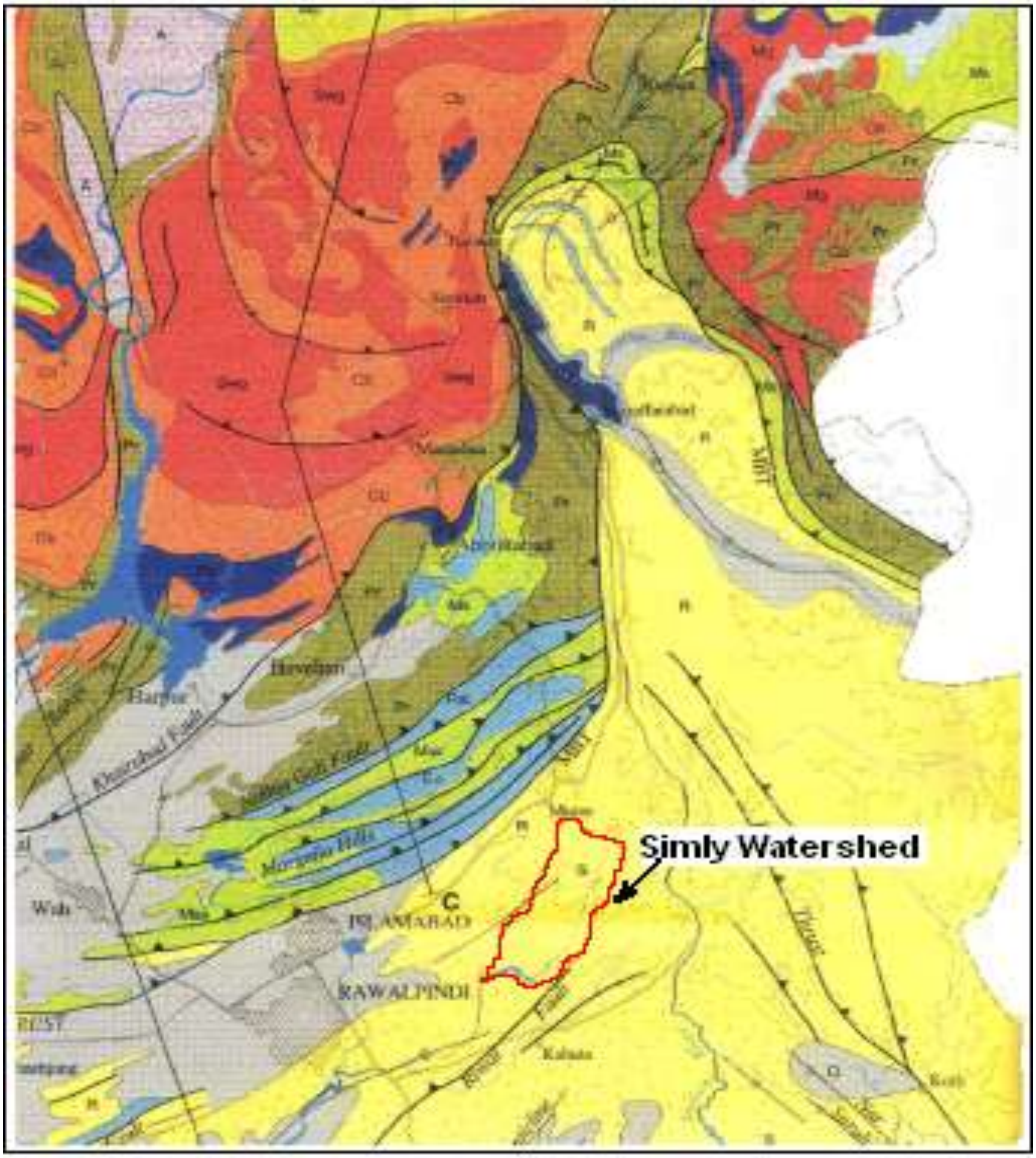

Fig- 3.6: Geological Map of Simly Watershed (WAPDA)

3.3.4 Simly Dam

The construction of Simly Dam was started in 1972 and it was completed in 1982 .Simly Dam is located in 30 kilometers East of Islamabad and Rawalpindi. It is the largest reservoir of drinking water to people living in Islamabad capital of Pakistan. Simly Dam is located at Latitude 33$_0$ 43' 8'' N and Longitude 73$_0$ 20' 25" E. The Simly watershed extends from 35km North-East of Islamabad up to the hill stations of Murree, Patriata and Lower Topa. The location map of Simly Dam is given in **Figure 3.7** and Salient features of Rawal Dam are given **Appendix B**.

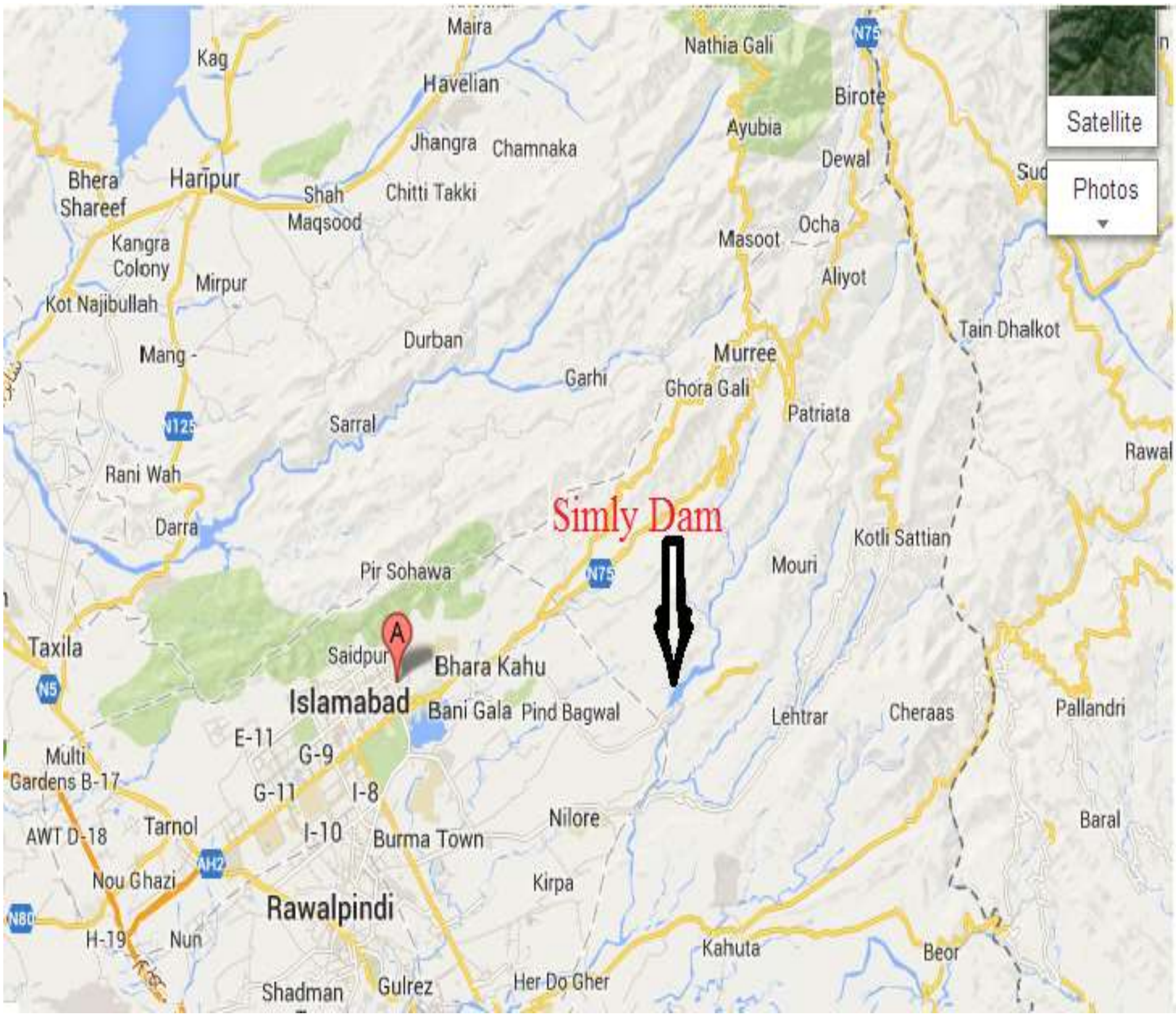

Fig- 3.7: Location Map of Simly Dam (Google maps)

3.4 Data Acquisition

Data used for this study were, Topographic sheets, Hydrological data, Meteorological data and remote sensing data. These data were collected from different organization the detail of which is given in **Table 3.3**. Detail of data is given in **Appendix A**, **B** and **C**.

Table: 3.3 Details of Data Used

Sr.No	Data Type	Period	Source
1	Topographic sheets	43G1,43G2, 43G5, 43G6,	Survey of Pakistan
2	Rainfall data of Rawal Dam	1975-2012	Pakistan Meteorological Department
3	Rainfall data of Simly Dam	1983-2012	Pakistan Meteorological Department
4	Temperature data of Murree	1975-2012	Pakistan Meteorological Department
5	Temperature data of Islamabad	1975-2012	Pakistan Meteorological Department
6	Flow data of Rawal Dam	1975-2012	Small Dam Organization Punjab
7	Flow data of Simly Dam	1983-2012	Capital Development Authority
8	Sediment data of Rawal Dam	1975-2005	Small Dam Organization Punjab
9	Sediment data of Simly Dam	1983-2005	Capital Development Authority
10	Satellite Imageries	1992,2000,2010	USGS GLOVIS

3.4.1 Hydro-Meteorological Data

There are five Meteorological Stations in catchment area of Rawal Dam and Simly Dam, installed by Pakistan Meteorological Department (PMD) and Small Dam Organization Punjab. Meteorological data on monthly and annual basis was collected from these organizations for the period of 1974-2012. The details of monthly and annual rainfall data, temperature data are given in **Appendix A**.

Flow Data

The gauging station of Small Dam Organization Punjab is installed on Rawal Dam. The inflow data of Rawal Dam on monthly and annual basis was obtained from Small Dam Organization Punjab for duration 1975-2012. The inflow data of Rawal watershed is presented in **Figure 3.8** and the detail of data is attached at **Appendix B**.

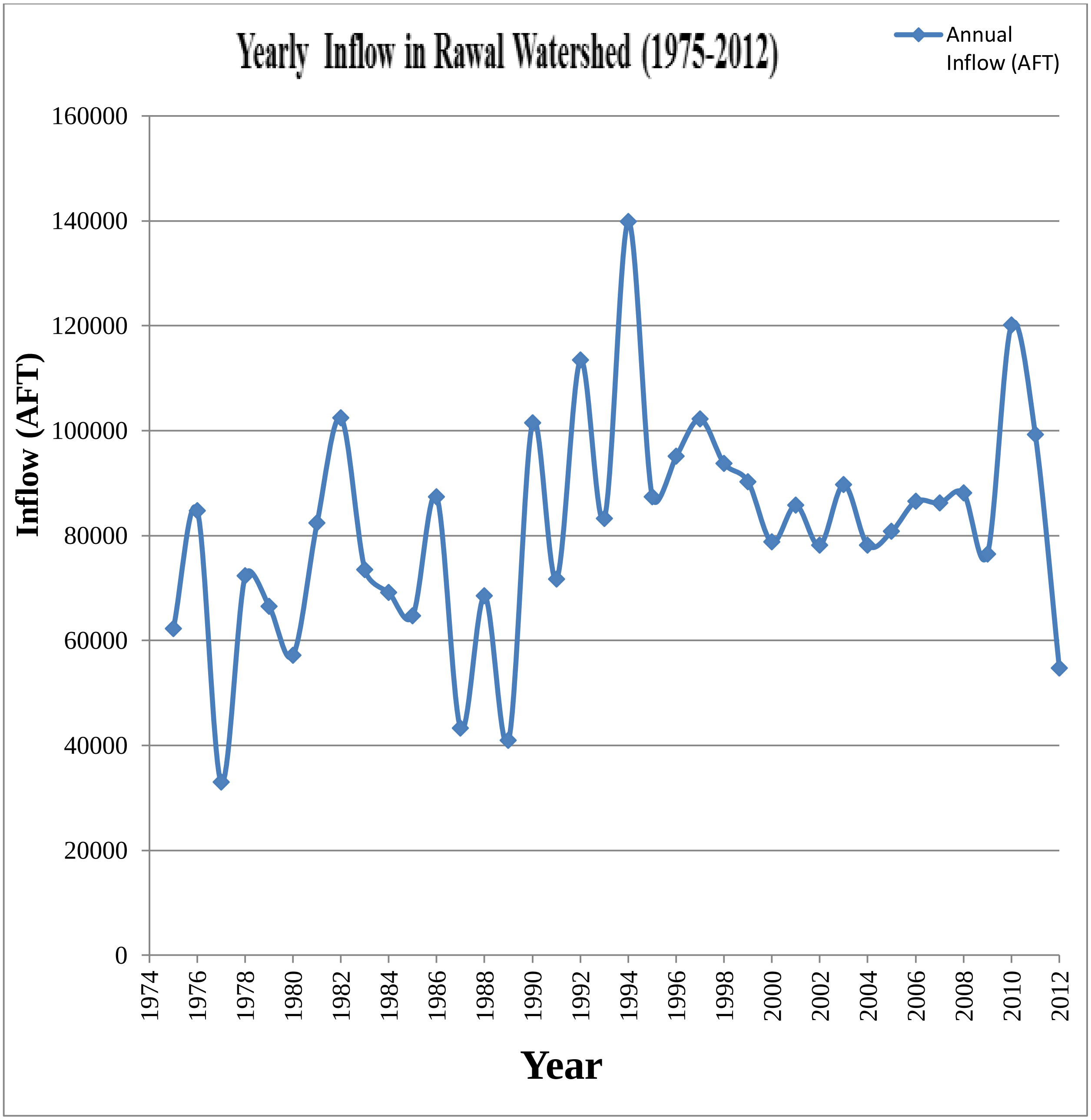

Fig-3.8: Average Annual Inflow in Rawal Watershed (1975-2012)

Similarly for Simly Dam initially the data was collected from a gauging station named Chinot gauging station which was installed at 5 miles upstream of Simly watershed but later on it was revealed by JICA Study that there was a problem in Gauging station position. The Chinot gauging station has been discarded since 1993 and now a day's inflow data is being calculated using empirical relationship. The inflow data for Simly watershed is presented in **Figure 3.9** and the detail of data attached at **Appendix B**.

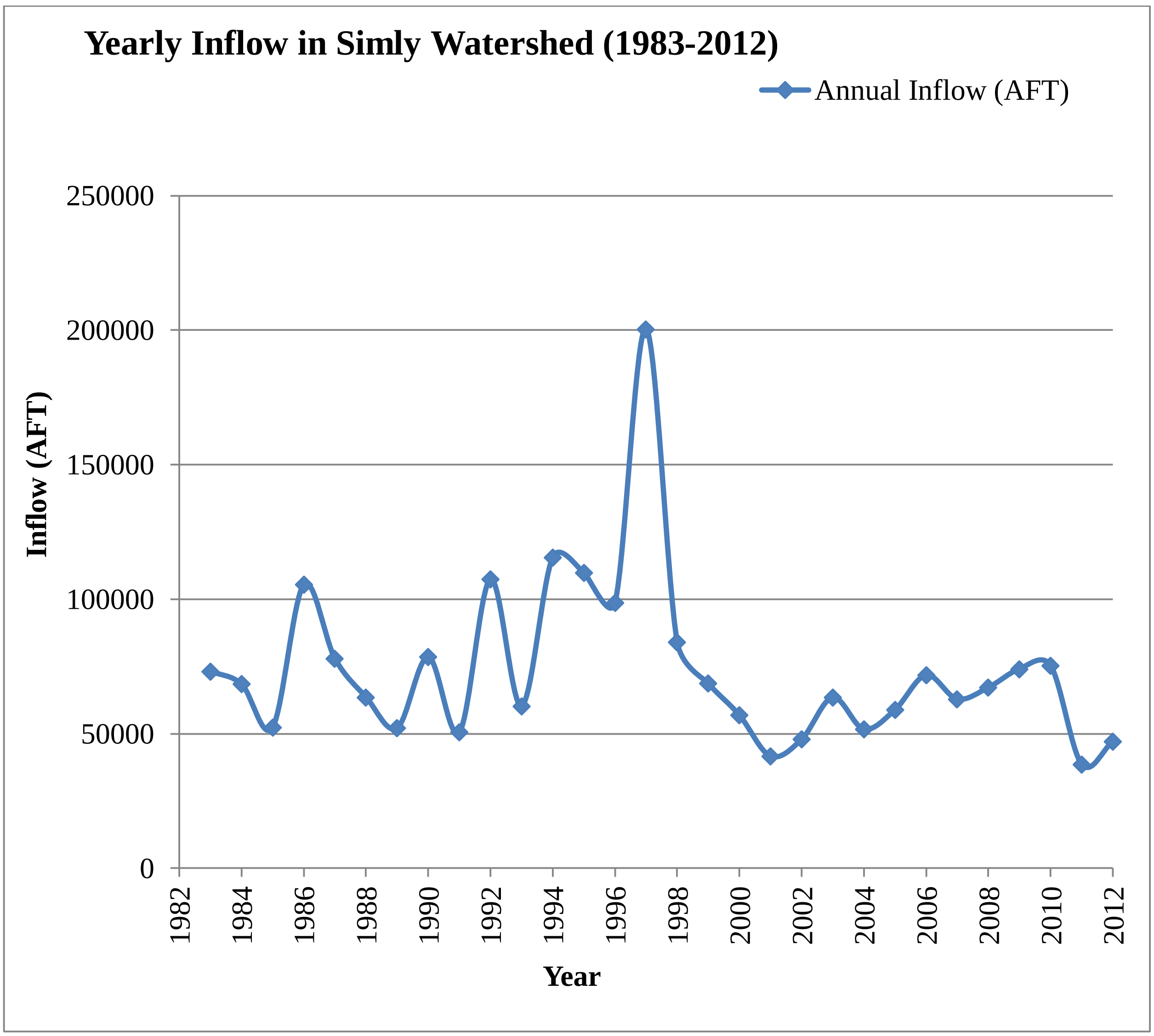

Fig-3.9: Average Annual Inflow in Simly Watershed (1983-2012)

SEDIMENT DATA

The sediment data of Rawal Dam for duration 1975-2005 was collected from WAPDA. The sedimentation rate at Rawal Dam is given in **Figure 3.10** and the details are attached at **Appendix B**.

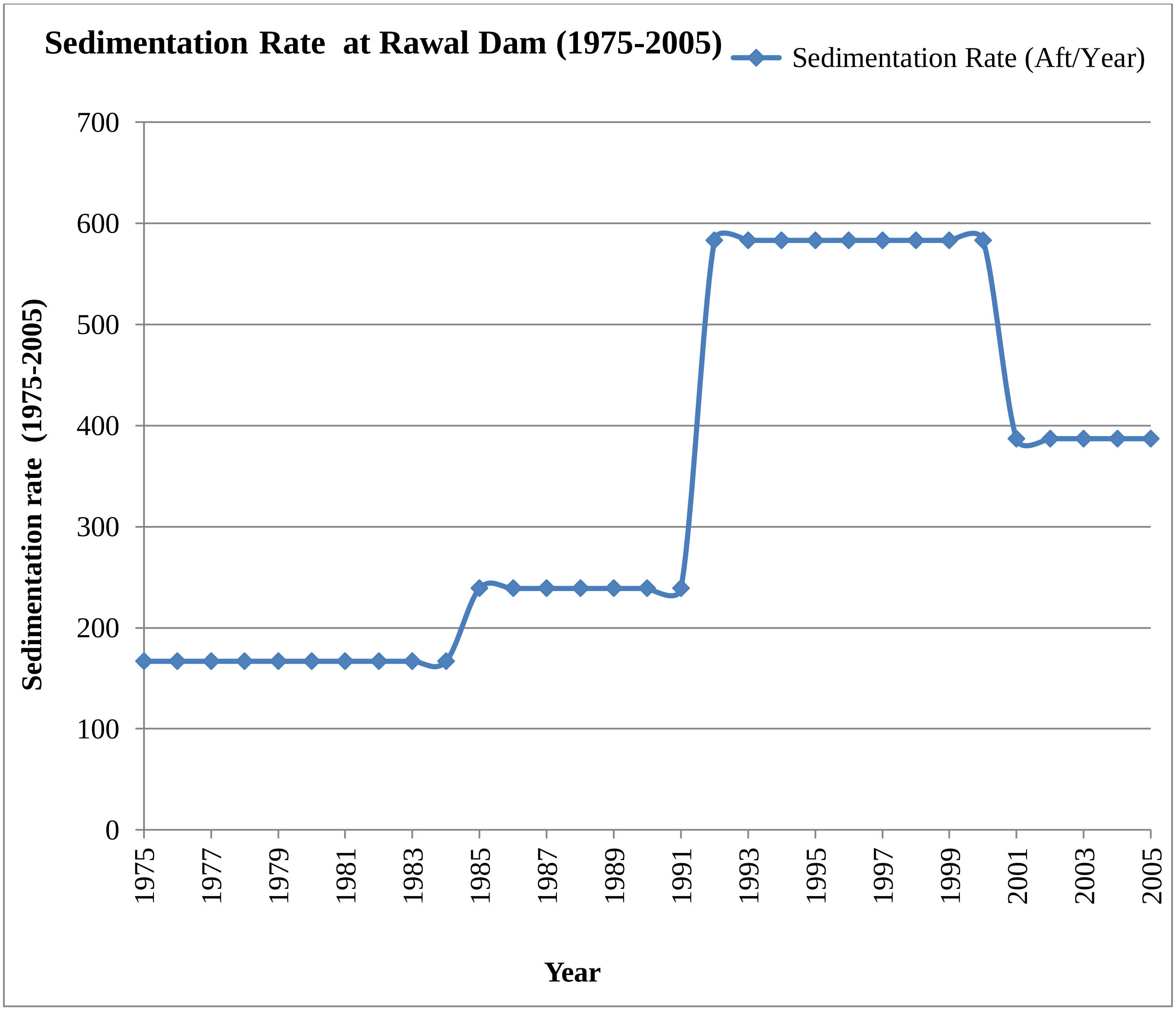

Fig-3.10: Annual Sedimentation rate in Rawal Dam (1975-2005)

Similarly the sedimentation data of Simly Dam for duration of 1983-2005 was collected from Capital Development Authority (CDA) Islamabad. The sedimentation rate at Simly Dam is given in **Figure 3.11** and the details are attached at **Appendix B**.

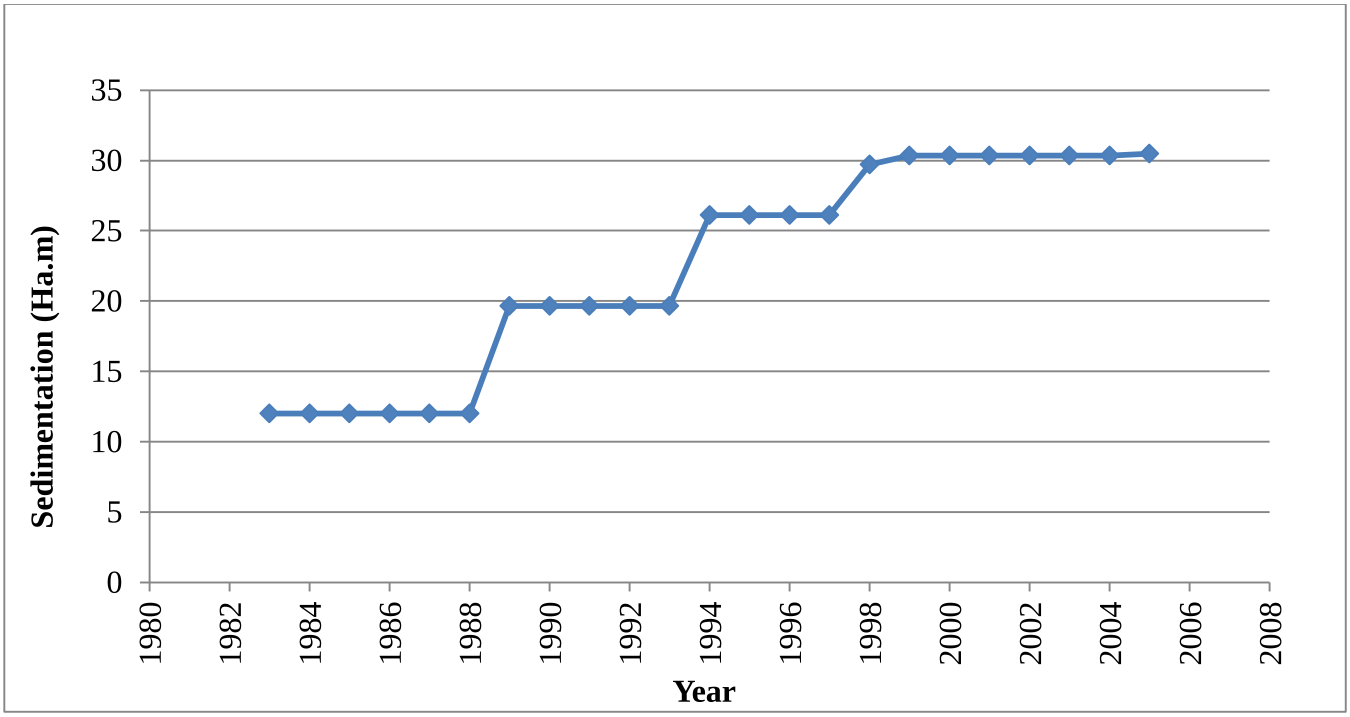

Fig-3.11: Annual Sedimentation rate in Simly Dam (1983-2005)

3.4.2 Remote Sensing Data

The main source for land use study is satellite image because using satellite image land use change can be found in excellent way and also time and money can be saved. There are different data source available for acquisition of satellite images i.e. Ikonos, Quick Bird, Landsat and Geo Eye. These satellites have images of different resolution. Mostly in studies of Land use change detection, evapotranspiration assessment, evaporation assessment, measurement of water use in agriculture, examination of water quality and study of ecosystem issues which impact water quality and quantity Landsat data is used. The Landsat has 35-year old data record and complete global coverage no other satellite imagery has combination of these features at a time. Landsat data is spectrally good and freely available it has relatively high spatial resolution and Landsat images contains layer of data i.e. which type of vegetation present, how a natural disaster has impacted any area this data can be manipulated (USGS LANDSAT SURVEY). That's why it was found appropriate and economical to use Landsat imageries for this study. The satellite images were downloaded from website of USGS GLOVIS for year 1992, 2000, and 2010. The details of the images are given in **Table 3.4**.

Table 3.4 Profile of Satellite Images

Sensors (Instrument)	Satellite Name	Path	Row	Date of Acquisition	Spatial Resolution (m)
Landsat TM	Landsat-5	150	37	9/20/1992	30
Landsat ETM+	Landsat-7	150	37	6/14/2000	30
Landsat ETM+	Landsat-7	150	37	6/18/2010	30

3.4.3 TOPOGRAPHIC SHEETS

Topographic sheet number 43G/1, 43G/2, 43G/5, 43G/6 having scale (1:50,000) were collected from Survey of Pakistan. The catchment area of Rawal and Simly Dam were delineated on these topographic sheets. Using Planimeter the catchment area of Rawal and Simly Dam was calculated. The catchment area of Rawal Dam was 270 km^2 whereas the catchment area of Simly Dam was 150 km^2 which are very close to the actual values.

3.5 Hydrological Data Analysis

Rainfall is a main factor controlling the hydrology of any region. The climate of the region is characterized into two rainy seasons per year monsoon and winter rain. Monsoon occurs from July to September and winter December – February. Murree and Rawal Dam rainfall gauging stations for Rawal watershed and Murree rainfall gauging station for Simly watershed were selected based on their spatial distribution. Details and location of rainfall gauging stations are given in **Table 3.5** and **Figure 3.12** respectively. Annual rainfall and runoff of Rawal watershed and Simly watershed for the period of 1975 to 2012 and 1983-2012 are given in **Figure 3.13** and **Figure 3.14**.

Table 3.5 Location of Meteorological Stations

S.No	Station No.	Station Name	Station Type	Data Type	Latitude "N"	Longitude "E"	Elevation(m)
1	41577	Islamabad Observatory (Z.P)	Manned Automatic	3-hourly observation	33° 42' 0"	73° 4' 48"	543
2	41571	Rawalpindi Airport Observatory (A.P)	Manned	3-hourly observation	33° 37' 12"	73° 5' 60"	507
3	41573	Murree Observatory	Manned	3-hourly observation	33° 55' 12"	73° 22' 48"	2167
4	41RWP	Shamasabad Observatory	Manned	3-hourly observation	33° 38' 60"	73° 4' 48"	517
5	41 Rawal Dam	Rawal Dam Observatory	Manned	3-hourly observation	33° 40' 48"	73° 6' 36"	543.69

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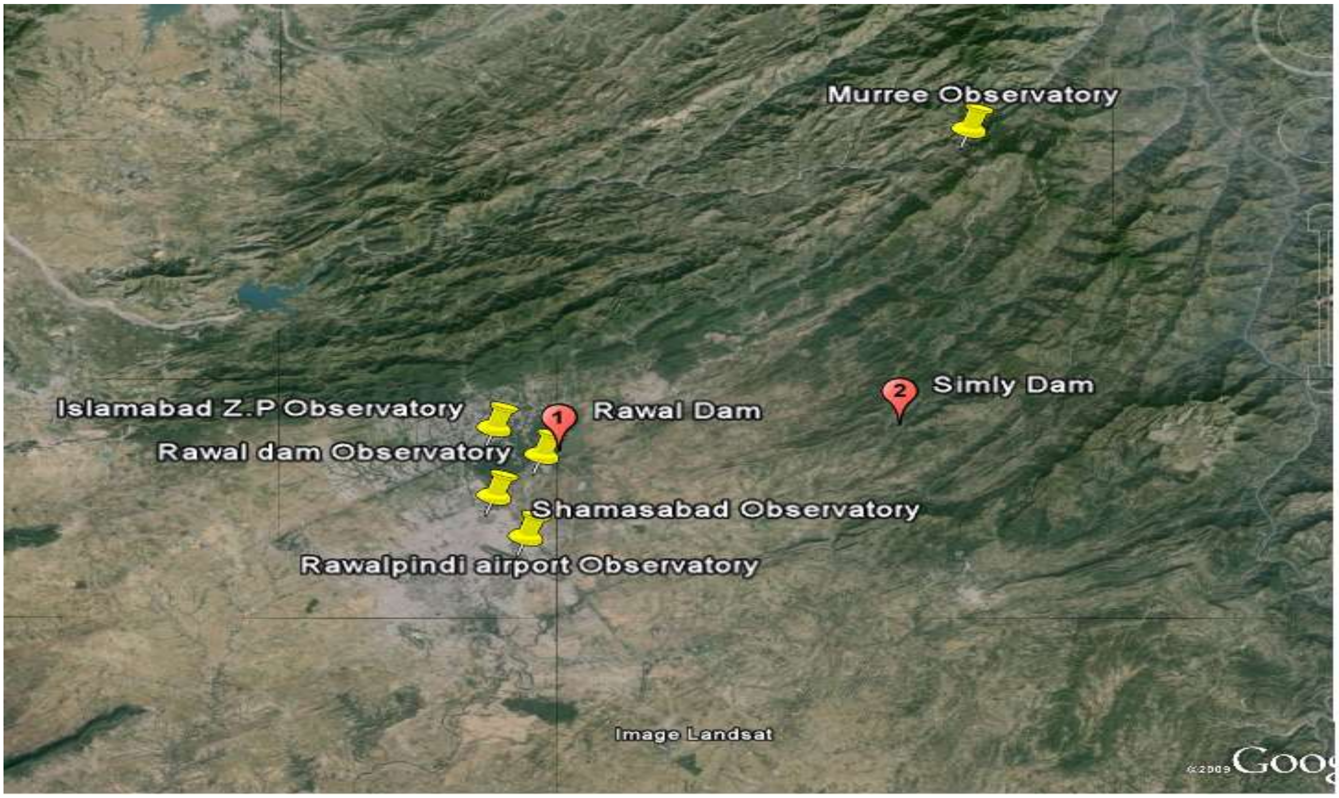

Fig-3.12: Location map of Meteorological Stations (Google Earth)

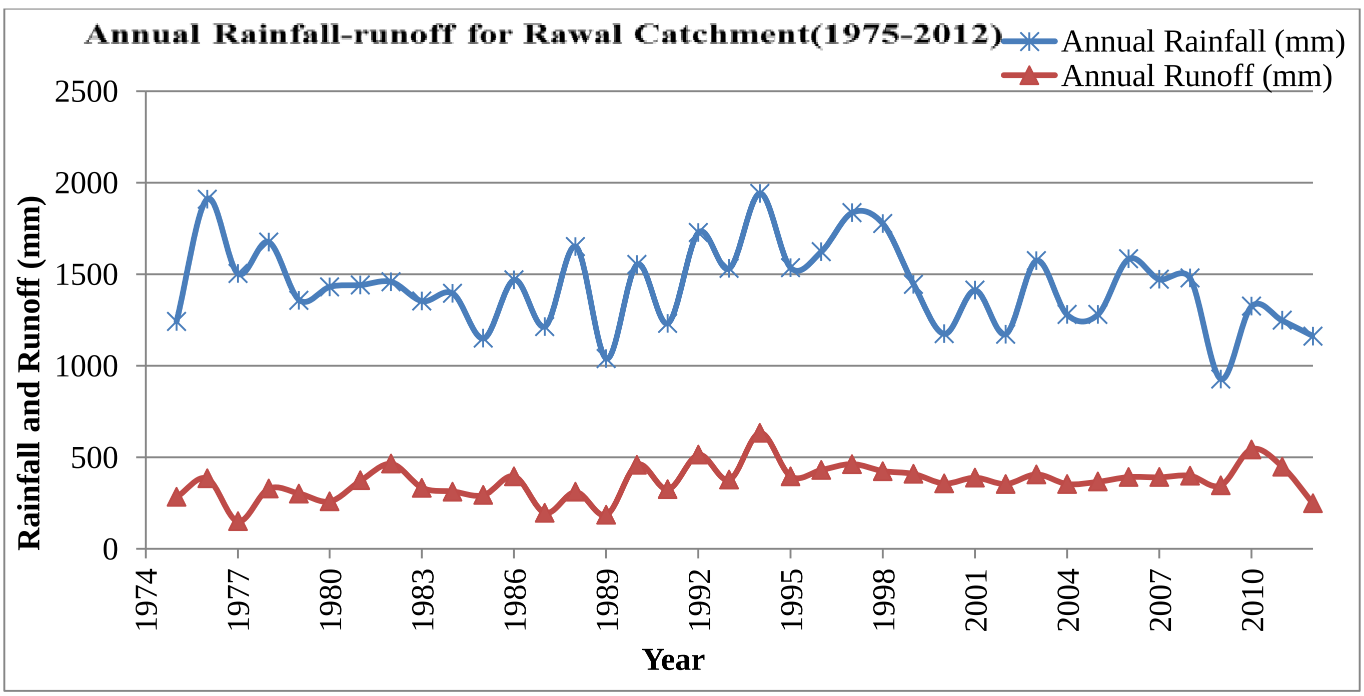

Fig-3.13: Annual Rainfall-runoff for Rawal Catchment (1975-2012)

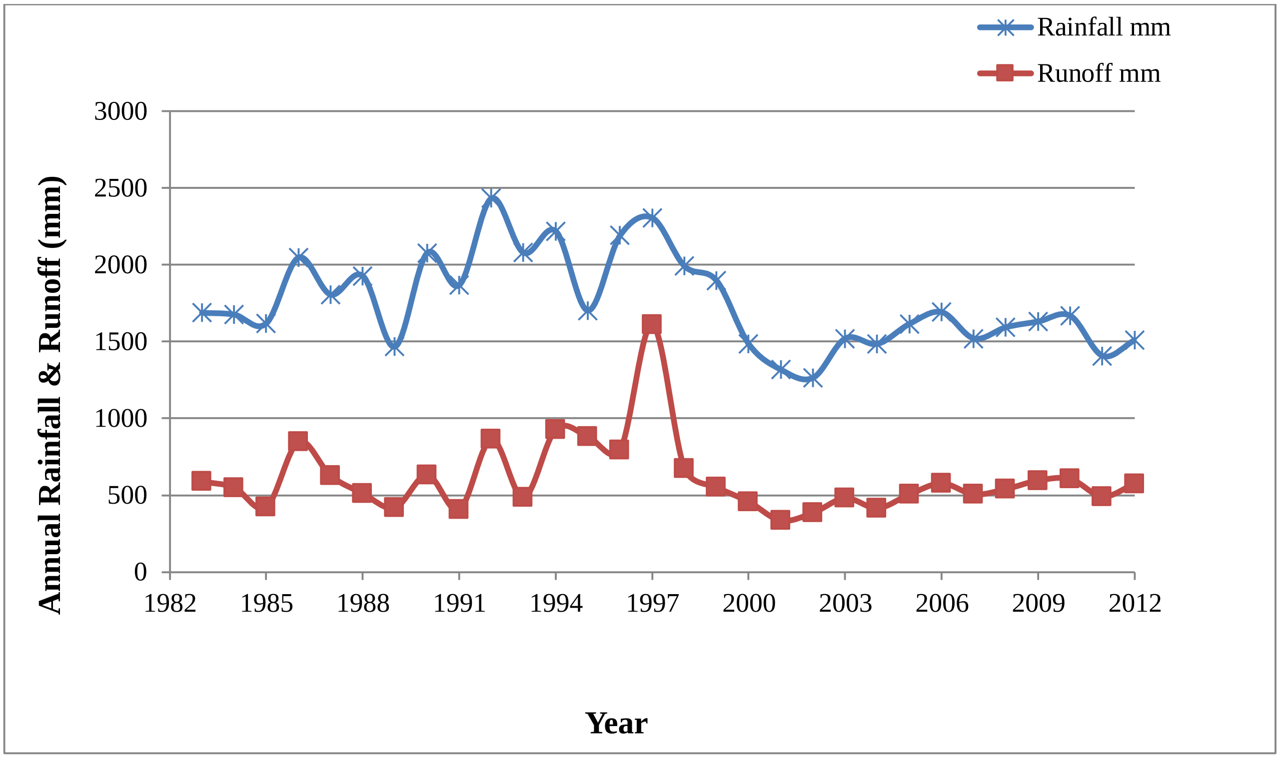

Fig-3.14: Annual Rainfall-runoff for Simly Catchment (1983-2012)

3.5.1 Selection of Suitable Rain Gauge Stations

From the location map of meteorological stations it can be observed, the Murree Observatory lies in upper portion of the catchment area of Rawal Dam, while the Rawal Dam observatory lies in lower portion of the catchment area, Islamabad observatory, Shamasabad observatory and Rawalpindi Airport Observatory are nearby station of the Rawal catchment. For Rawal Dam rainfall data was calculated using Thiessen Polygon method. Using Thiessen polygon method it was concluded that the rainfall data for Rawal Dam catchment will be the average of Rawal Dam and Murree Observatory. The average annual rainfall data for all these stations is given in **Figure 3.15** and the rainfall data for Rawal Dam catchment area is given in **Figure 3.16**.

The catchment area of Simly Dam is ungagged. As it can be observed in **Figure 3.12** most of the Simly catchment lies in Murree and the only record available for rainfall is the data of PMD station Murree observatory so rainfall data of this station was taken. The average annual rainfall data of Simly Dam catchment is given in **Figure 3.17**.

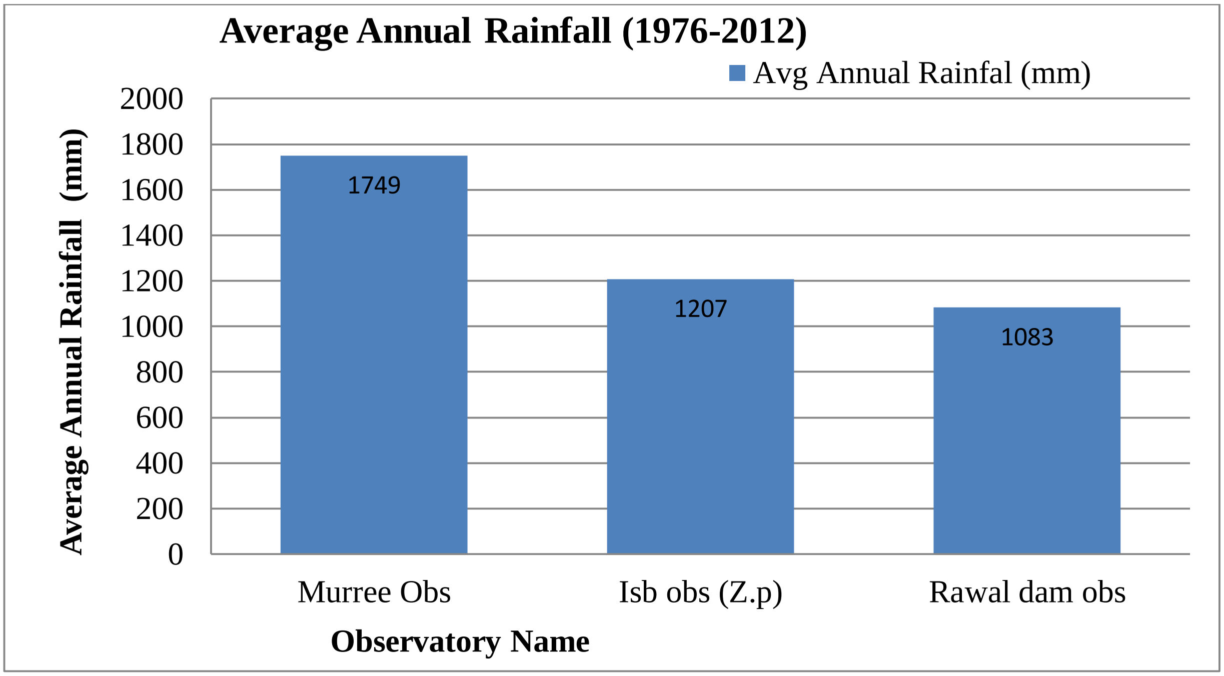

Fig-3.15: Average Annual Rainfall Data of Different Stations (1976-2012)

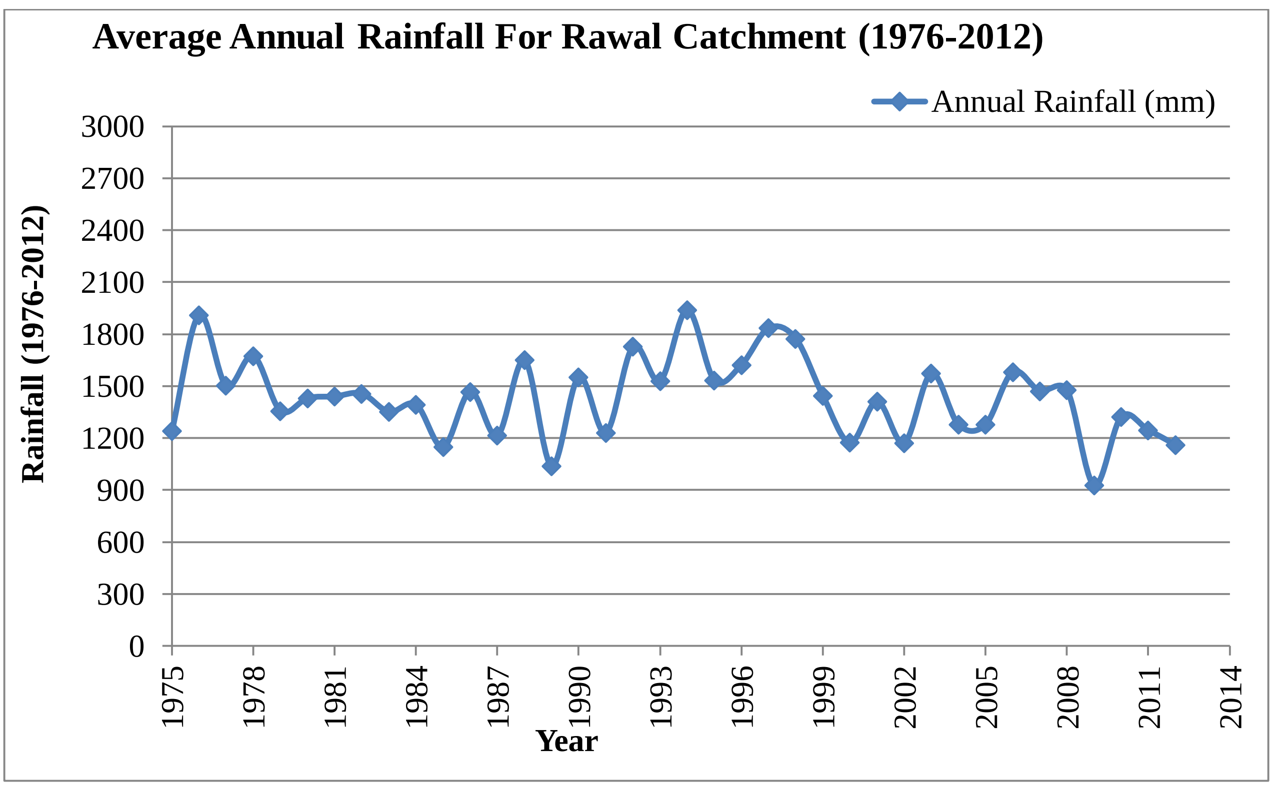

Fig-3.16: Average Annual Rainfall for Rawal Catchment (1976-2012)

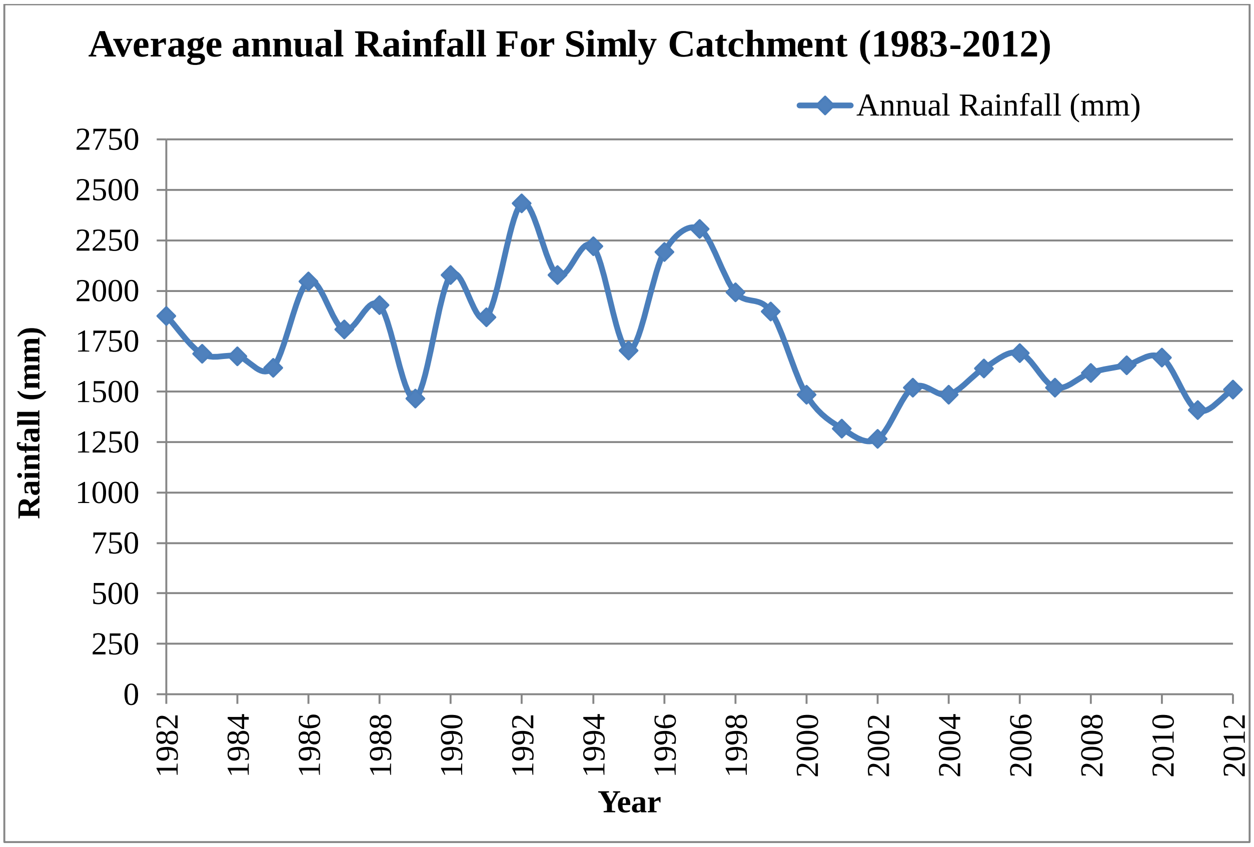

Fig-3.17 Average Annual Rainfall for Simly Catchment (1982-2012)

3.5.2 Double Mass Curve Analysis

To check the consistency of hydrological data over time Double Mass Curve analysis was performed. The change in trends was identified from the change in slope of Double Mass Curves. From Double Mass Curve analysis the history of rainfall, runoff and sediment data can be checked. Double Mass Curve analysis of Rawal Dam catchment and Simly Dam catchment showed the changes in runoff and sedimentation with the time.

The Double Mass Curve analysis was carried out for Both Rawal Dam and Simly Dam by plotting cumulated rainfall data with cumulated runoff for annual basis. To perform Double Mass Curve analysis for monsoon months, the accumulated average monthly rainfall data for monsoon months was plotted with accumulated runoff. The change in proportionality between rainfall and runoff data was reflected from the change in slopes. Similarly the Runoff and sediment data were plotted for both Rawal and Simly catchments and from break in slopes the period were identified in which changes occurred in runoff and sedimentation of Rawal and Simly catchments.

3.6 Remote Sensing Data Analysis

Remote sensing data Analysis was performed. Firstly satellite images were prepared then digital elevation model was prepared for both Rawal and Simly dam. The remote sensing data analysis is explained in the succeeding paragraphs.

3.6.1 Satellite Image Preparation

There are seven to eight bands in a satellite image Landsat 1 to Landsat 5 have 7 bands and land sat 7 have 8 bands. Each band in a satellite image has a particular purpose; some of them have been selected by the instrument designer for vegetation mapping and geological mapping. Bands 1, 2, 3 are used together and it tells us about how the real word appearance. Bands 4, 5, 7 from ETM+ with combination of bands 1, 2, 3 tell us about vegetation condition. Band 6 is used for thermal mapping. The spectral profile in **Figure 3.18** shows the response of each spectral band.

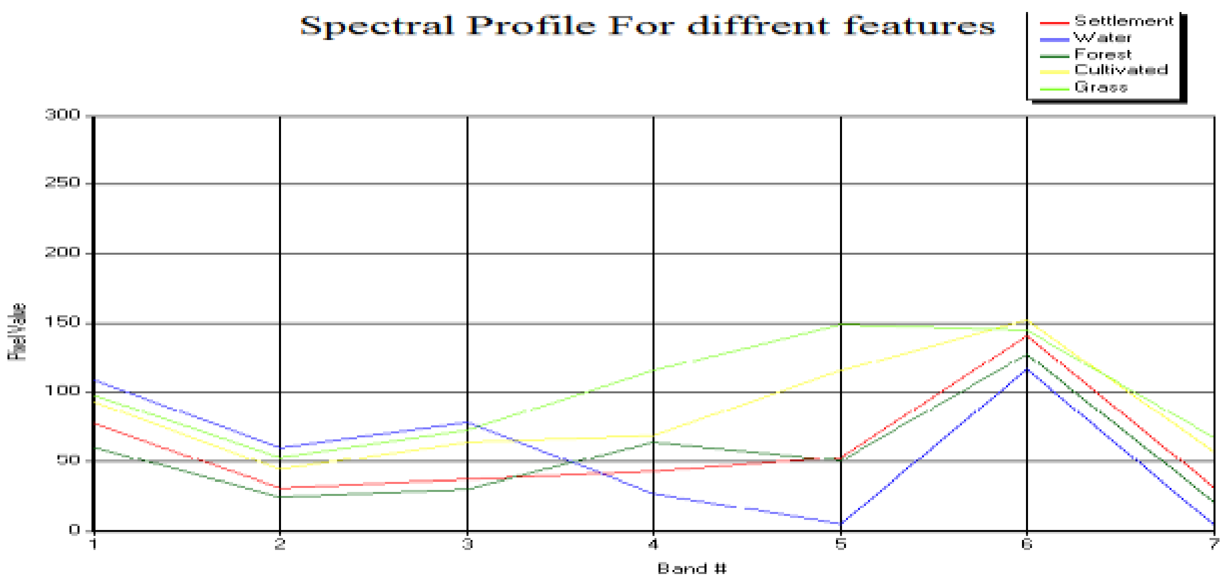

Fig-3.18 Spectral Profile for different Features (Erdas field guide 2009)

The spectral profile tells us about band features this profile enable us to identify the land cover type. Band combination gives us the colorful image the images downloaded from Landsat was black and white. Every band has its importance and tells us about different features. The combination of these bands gives us a composite image. In this research study Landsat images of

1992, 2000 and 2010 were downloaded from USGS GLOVIS. For composite image Spectral band 1, 2,3,4,5 and 7 were used for all three images. The information which was used for band combination of Landsat images is given in **Appendix C** this shows the radiometric characteristic of Landsat5 and Landsat7. In this study three images of the year 1992, 2000 and 2010 were used for classification. The image of 1992 is from Landsat 5 and images of 2000 and 2010 are from Landsat 7. The images obtained from Landsat have scene size of 185m x 185m. After selection of suitable bands the catchment area of both Rawal Dam and Simly Dam was extracted on images of 1992, 2000, and 2010 which was the area of interest. The area of interest in satellite image form for Rawal and Simly Dam is given in **Appendix C**.

3.6.1 Digital Elevation Model (D.E.M)

The Digital Elevation Model (DEM) tells us about topography. It also describes the elevation of any point at specific spatial resolution. It is used to delineate the catchment area, drainage pattern of watershed, width of the channel, slope and stream length calculation. The Digital Elevation Model (DEM) was used to find out the catchment area of Rawal and Simly Dam. Using DEM the fallowing was observed

Catchment area of Rawal Dam = 272.8 km^2

Catchment area of Simly Dam = 153.5 km^2

It can be observed in the **Figure 3.19** that in Rawal catchment high elevation is 2193 meter and low elevation is 503 meter. Similarly **Figure 3.20** is the digital elevation model for Simly catchment it can be observed in **Figure 3.20** that in Simly catchment high elevation is 2274 meter and low elevation is 503 meter.

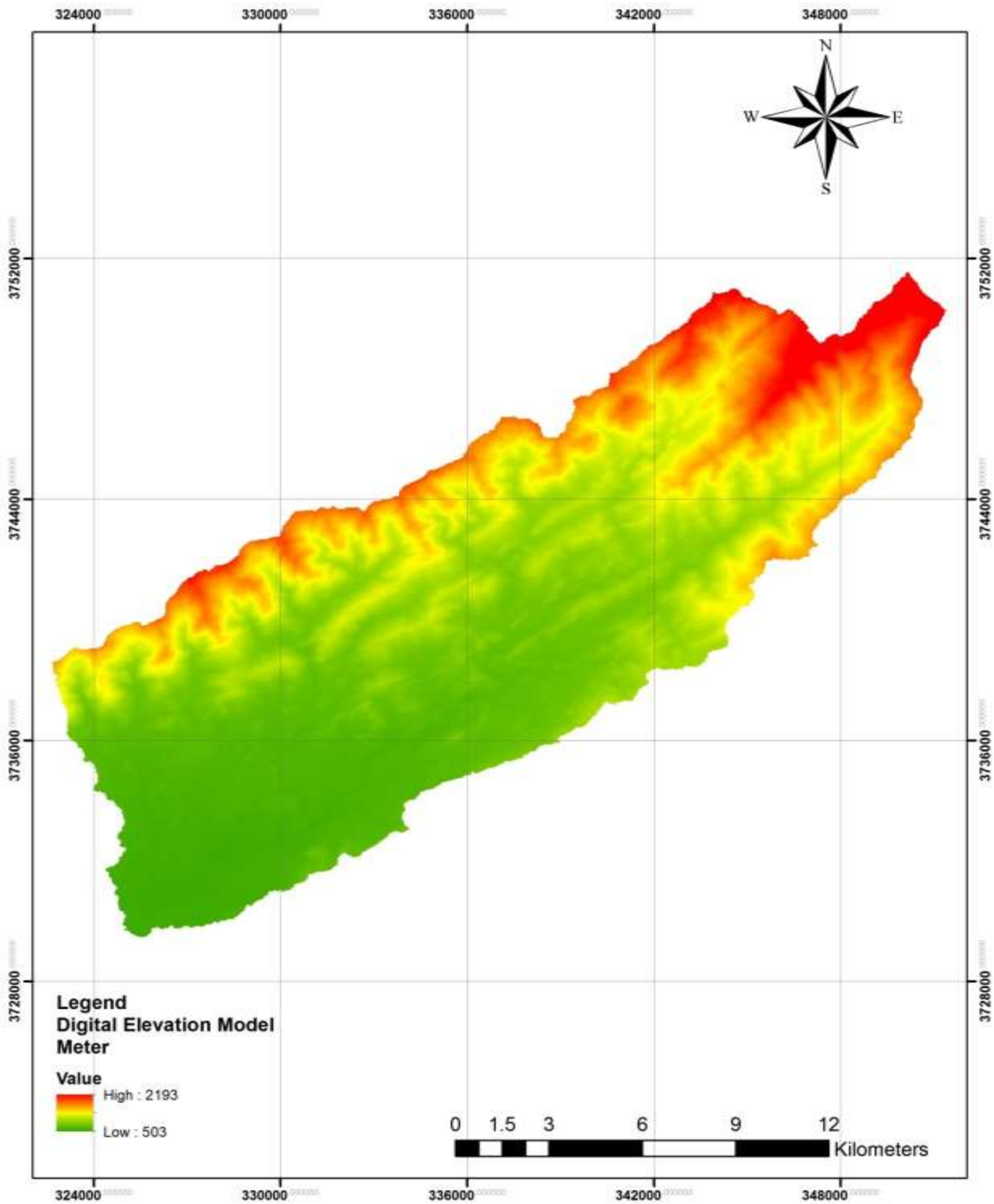

Fig-3.19 Digital Elevation Model for Catchment Area of Rawal Catchment

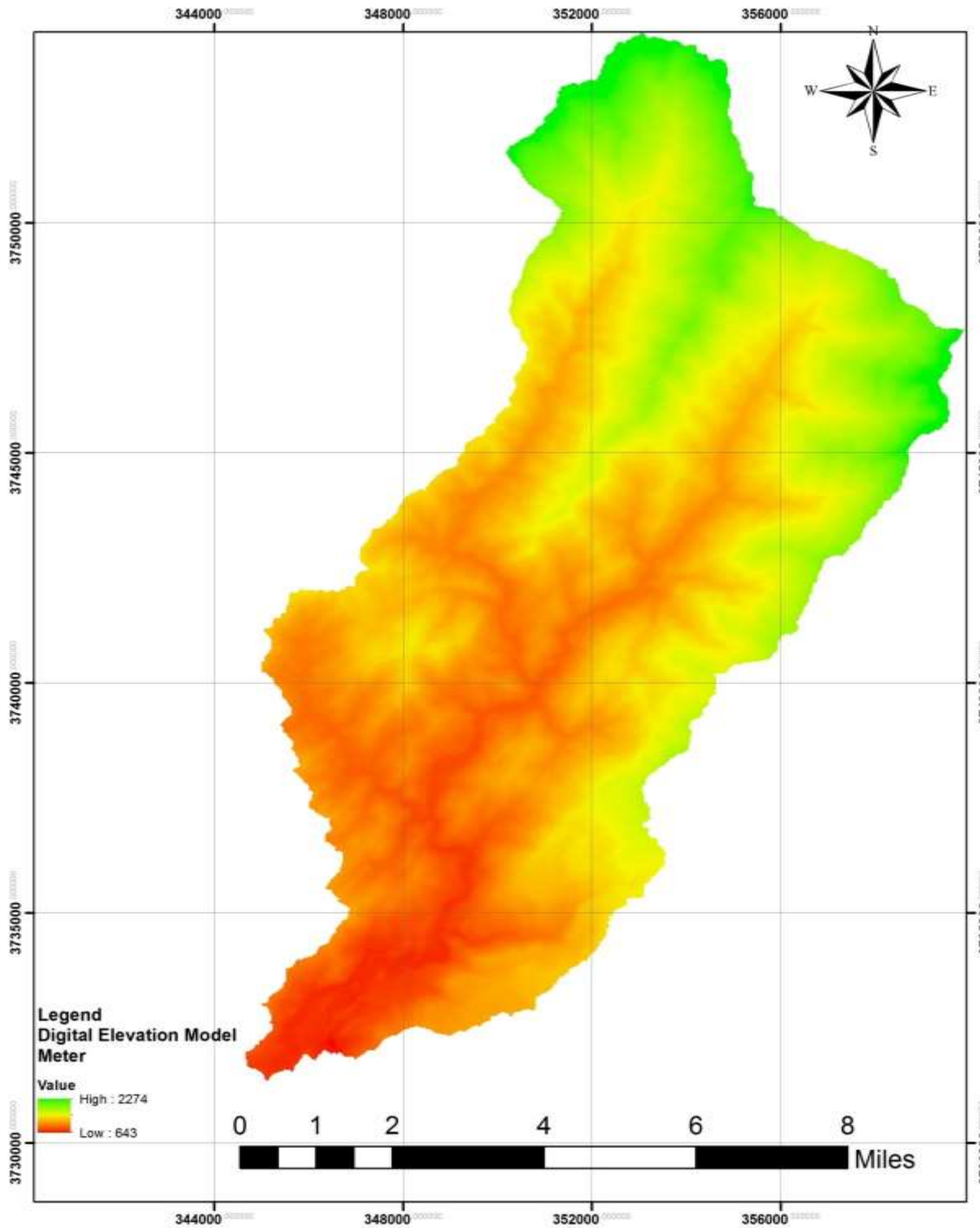

Fig-3.20 Digital Elevation Model for Catchment Area of Simly Catchment

3.7 Methods for Satellite Imageries Classification

There are two stages of image classification. First stage is recognition of categories of real-world objects. These categories include water bodies, wood lands, grass, forests range land and other types depending at the objectives of study. Second category is labeling of entries which are being classified .There are following step for image classification

1. Determine the number and nature of the categories for which land use assessment is required.
2. Assign numerical labels to the pixels using a classification rule.

An image represents two classes which are spectral and information classes. Group of pixels which have uniform spectral characteristic are called spectral classes. The objects that represent actual feathers on ground are called information classes. When performing classification these classes must be distinguished. There are two methods for satellite imageries classification.

1. Supervised classification
2. Unsupervised classification

3.7.1 Supervised Classification

In supervised classification method user classify unknown classes using samples of some known classes. In supervised classification user must have knowledge of the area for which image classification is done and user must provide some input before applying selected algorithm. The input may be derived from air photo analysis, field work surveying the study area, previous reports and study area topographic map. The algorithms used for supervised classification are

1. Parallelepiped
2. Minimum distance to means
3. Maximum likelihood classifiers

Parallelepiped Algorithm

An unknown pixel can be classified according to decision region if it lies outside all regions then the multidimensional analogs of these areas are called Parallelepiped. In Parallelepiped classification for each class maximum and minimum Digital numbers (the each pixel value in data set) are determined and these Digital numbers are used as threshold for image classification. Parallelepiped classification is computationally efficient. The main drawback of Parallelepiped classification is that pixels in gaps between the Parallelepiped and pixel in the region of overlapping Parallelepiped cannot be classified (Lesschen, 2004)

Minimum Distance to Means

In Minimum distance to means classification a centroid for each class is determined from the data by calculating the mean value by band for each class. The distance to each of these centroids is calculated for each pixel image. The closest centroid determines the class.

Maximum Likelihood Classifier

In maximum likelihood classification decision rule is based on probability. The classification procedure is Gaussian i.e. it assumes that data is normally distributed in each band for each class and in a single band data with bi or tri modal histograms is not ideal. Here individual modes represent individual classes which should be trained individually and labeled as individual classes. The probability for a pixel class is calculated and then pixel is assigned to the class whose probability is highest (Kumar, 2000).

3.7.2 Unsupervised Classification

In unsupervised classification method Computer classifies unknown classes. Unsupervised classification involve algorithm in which unknown pixels of an image are examined and aggregated into classes based on natural grouping. In this algorithm values in a cover type should be close in measurement space and data should be separated well in different classes. The result of unsupervised classification is a spectral class because it depends on clusters present in image value.

Initially spectral classes cannot be identified. To identify the spectral class the analyst must compare classification results with maps or large scale images. In supervised classification 1st information category is define and then their spectral separability is checked and in unsupervised classification first spectral classes are defined and then information utility about them. In the supervised classification classifier has to define the class many of these classes may not be apparent to the classifier initially but in unsupervised classification these classes are found automatically which shows advantage of unsupervised classification. The classification algorithms for unsupervised classification are

1. K- means
2. ISODATA

K-Means Algorithm

In K-means algorithm the classifier specify the number of clusters located in the data. The algorithm locates number of cluster centers in the multidimensional measurement space. Pixels are assigned to the cluster for which arbitrary mean vector is closest when all pixels are classified in similar manner then mean vector for each cluster is calculated. Revised means are then used for reclassification of image data. The procedure continues until there is no change in the location of class mean vectors between successive iterations of the algorithm. Then classifiers identify the land use identity of all spectral classes.

Isodata Algorithm

Iterative Self-Organizing Data Analysis Techniques is similar to the K-means algorithm the main difference is that ISODATA algorithm allows any number of clusters as compared to priori for k-means method. The ISODATA algorithm allows number of clusters to change iteration by splitting clusters and each cluster is evaluated. It merges clusters having less number of pixels than threshold also if center for two clusters is close together and it splits big clusters. When required clusters are formed the classifier who has knowledge of the area assigns information class to each cluster for preparation of thematic map (Lesschen, 2004).

3.7.3 Selection of Classification Method

Both methods of classification Supervised and unsupervised can give reliable results. The best classification should have following Properties (Anderson, 1971)

1. The classification should be applicable for extensive area.
2. The classification should be suitable for remote sensing data obtained at various times.
3. Its results comparison with future land use data should be possible.
4. Grouping of categories must be possible.
5. Recognizing of Multiple land use should be possible.

The Supervised classification has variety of algorithms. The major difference between classification algorithms is their way to determine how individual pixel is assigned to a land use category. In supervised classification the analysts defines land use types and then develop spectral classes which may be differ from reality.

In this study classification of images was done using unsupervised classification and Algorithm used for classification was ISODATA algorithm. Unsupervised classification is useful when there is no preexisting field data (detailed aerial photographs) of the study area. In supervise classification method too much computation is required for classifying each pixel also supervise classification require every set should include one more pixel than there are bands. The unsupervised classification has following merits.

1. In Unsupervised classification fast analysis are done and results can be achieved first.
2. Unsupervised classification is easy to use.
3. Unsupervised classification is repeatable.
4. Unsupervised classification is user independent.
5. Unsupervised classification minimizes human error and produces uniform classes.
6. In unsupervised classification algorithm is applied to the entire image quickly and systematically.

7. In unsupervised classification analyst may not be able recognize spectrally different classes, computer assign them pixels.
8. Computer can identify large number of spectrally different classes in unsupervised classification which an analyst can't do.
9. In unsupervised classification, the raw classification techniques employed therein makes it difficult and laborious for an analyst to develop spectral classes for every unique class and subclass.
10. In unsupervised classification Computer creates large number of class's analyst can combine these classes to get final classes.
11. The ISODATA algorithm creates user defined number of classes which helps in accuracy.

3.8 Land Use Classification

Unsupervised classification was performed in this study; unsupervised classification is used to assemble the cluster pixels of a data set into classes based on statistics. The classes are spectral and initially identity of these classes is not known comparison of them with some reference data is required for their identification. In unsupervised classification ISODATA algorithm was used. The number of classes was 200 initially, maximum iteration was 15 and convergence threshold was 0.950.The spectral responses of these 200 classes were checked one by one using spectral profile for identification of all classes and then the classes were grouped into 6 land use categories. The spectral profile is given in **Figure 3.21**

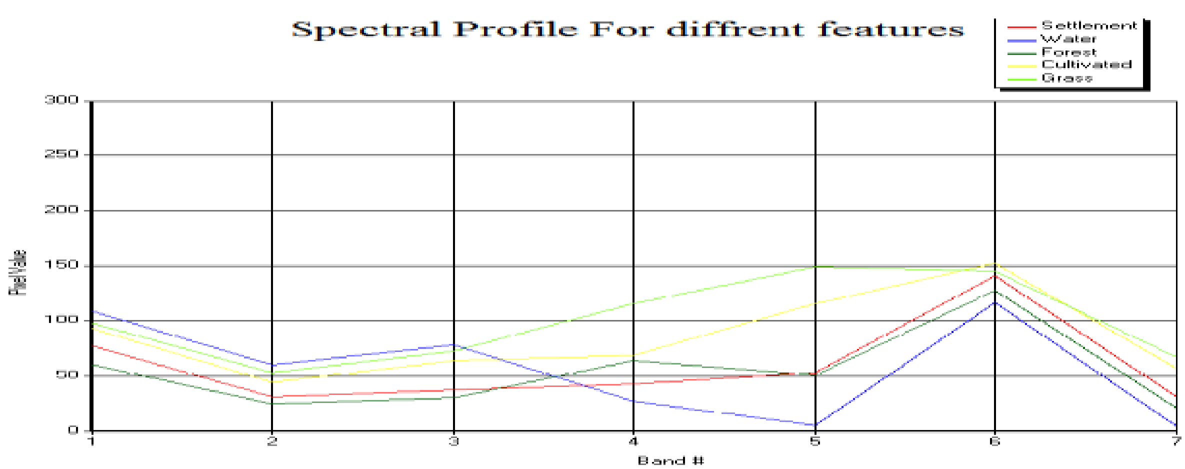

Fig-3.21 Spectral Profile for different Features (Erdas field guide 2009)

After identifying the nature of every class these classes were reduced to 6 major classes. The six land use classes which were considered are forest, vegetation & agriculture, rangeland, built-up area, bare land and Water bodies these classes are explained below.

Forest

Area in which trees density is high it include deciduous forest land and conifer forest.

Vegetation & agriculture

The areas which have green vegetation, shrub and agriculture were classified as vegetation and agriculture.

Rangeland

The areas in the form of grass land and natural landscapes were classified as rangeland.

Built-up area

The areas in which there is permanent buildings construction and man-made structures were named as built-up area.

Bare land

The unproductive land, soil, and rocks were classified as bare land.

Water bodies

The areas which have mostly water throughout the year, in this study water stored areas, reservoirs i.e. Rawal Dam, Simly Dam and their tributaries were taken as water bodies.

The images of 1992, 2000 and 2010 for both Rawal and Simly Dam were classified with unsupervised classification and algorithm was ISODATA algorithm. Firstly 200 classes were made iteration was 15 and convergence threshold was .950 for images of 1992,2000 and 2010 for both Rawal and Simly Dam the 200 classes were then merged into 6 classes which are mentioned above.

3.9 Ground Truthing

The term ground truthing is used in remote sensing. In ground truthing a person on the ground make the measurements of the same thing that the satellite is trying to measure. Ground truthing is essential to validate sensor performance. In ground truthing geographic coordinates of the ground resolution cells are taken using GPS these coordinates are compared with the coordinates of the pixel under study. Ground truthing familiarize the analyst with the materials which exist on the satellite image. Ground truthed data is assumed to be 100 % correct for accuracy assessment. .

Before the classification of satellite imagery ground Truthing was performed using GPS. This survey was performed to obtain locational point data of each class and for generating signature for each class. Six classes were made which were water bodies, forest, vegetation & agriculture, rangeland, built-up area, bare land. 50 points were taken using GPS the detail of ground truthing and the images of different classes which were taken during ground truthing to improve classification are given in **Appendix C.**

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Change of Land Use Pattern for Rawal Catchment

Based on rainfall runoff relationship Land use analysis was performed for Rawal catchment and land use maps were prepared for 1992, 2000 and 2010. The detail of Land use scenario is explained below.

Land Use Change for Rawal Catchment in 1992

The land use map of Rawal Dam catchment for 1992 as shown in Figure **4.2** and its histogram in **Figure 4.1** reveals that 1.9% of the catchment had water bodies' area, 10.8% forest, 54.6% had vegetation & agriculture, 29% rangeland, 2.4% built-up area and 1.2% was bare land.

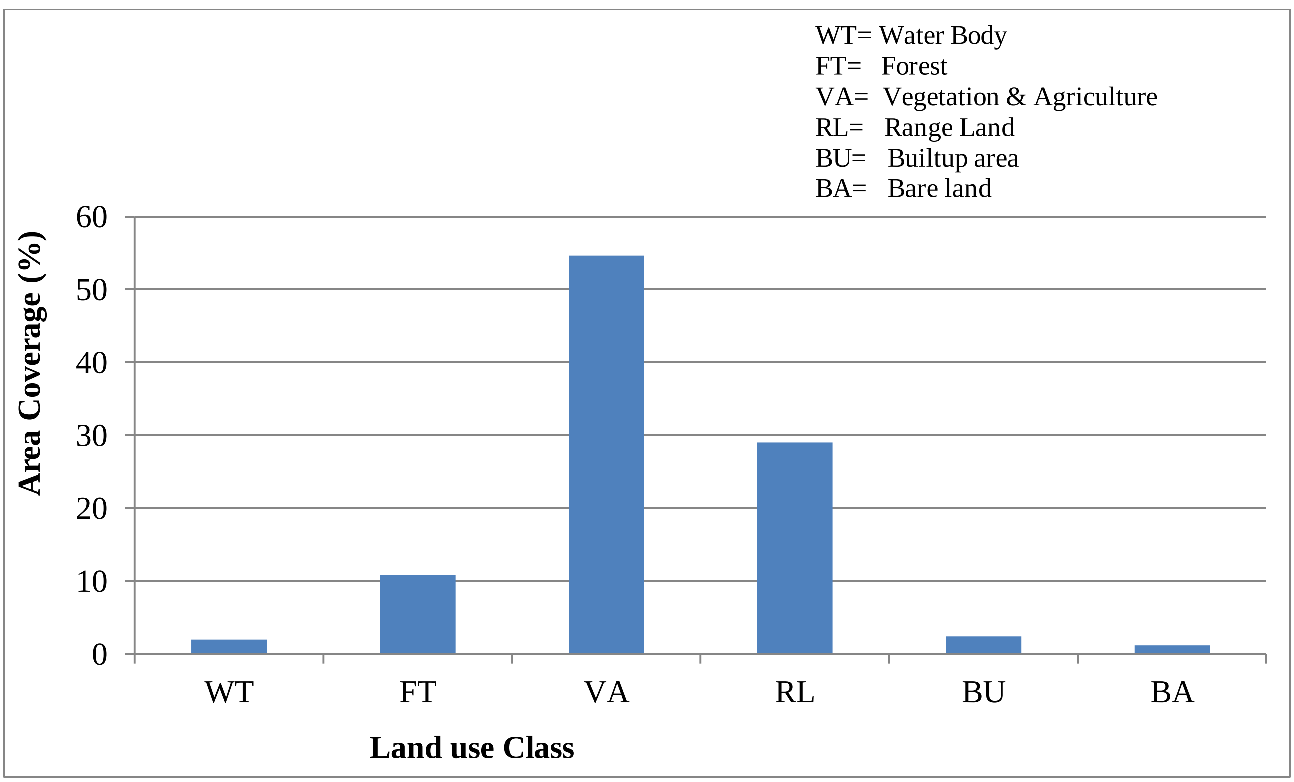

Fig-4.1 Area Coverage of Land Use for Rawal Dam in 1992

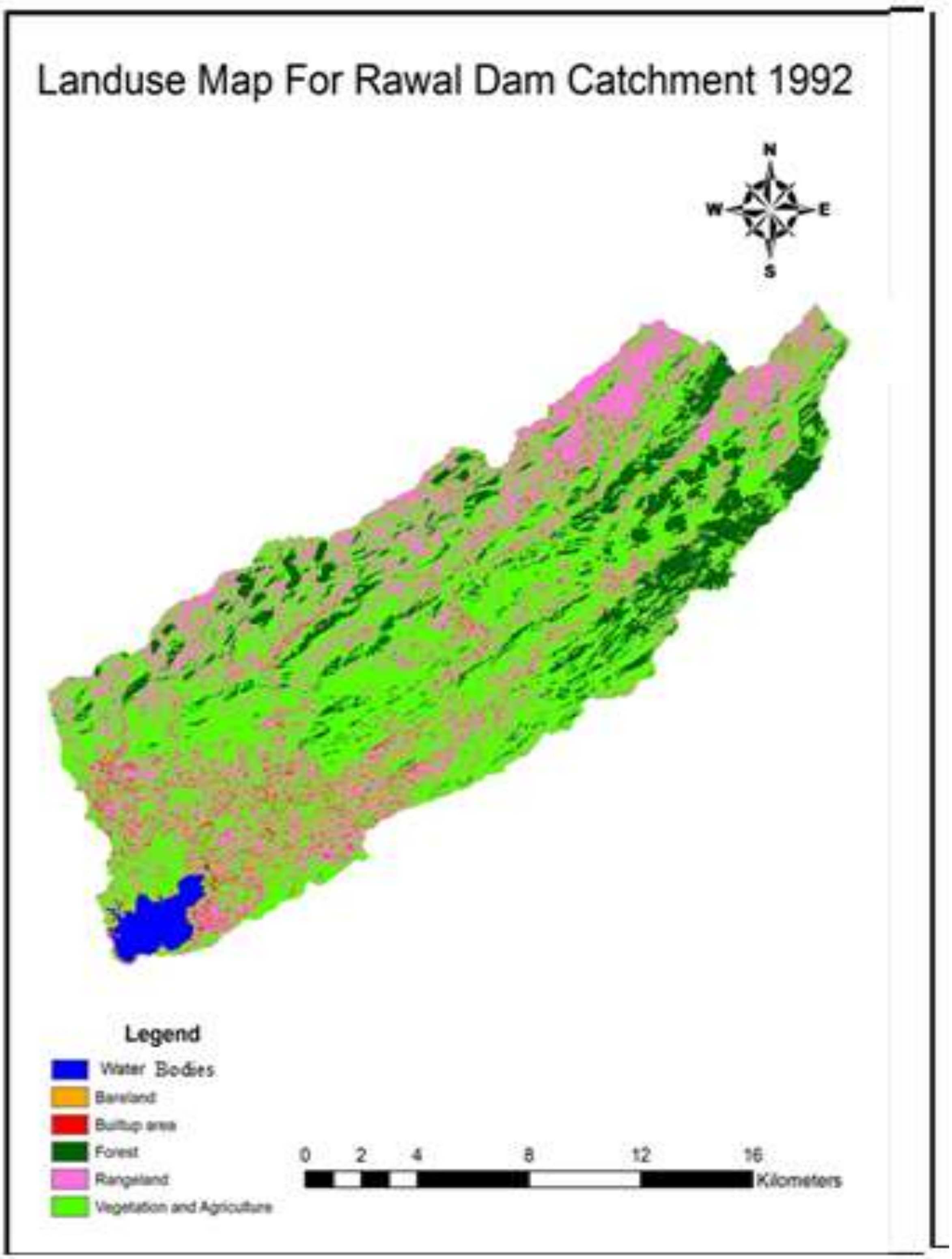

Fig-4.2 Land Use Map for Rawal Dam Catchment in 1992

Land Use Change for Rawal Catchment in 2000

The land use map of Rawal Dam catchment for 2000 is shown in **Figure 4.4** and its histogram is given in given in **Figure 4.3**. The land use map in 2000 shows that, 1.2% of the catchment had water bodies, 9% forest, 49% had vegetation & agriculture, 32.9% rangeland, 5.3% built-up area and 2.6% was bare land.

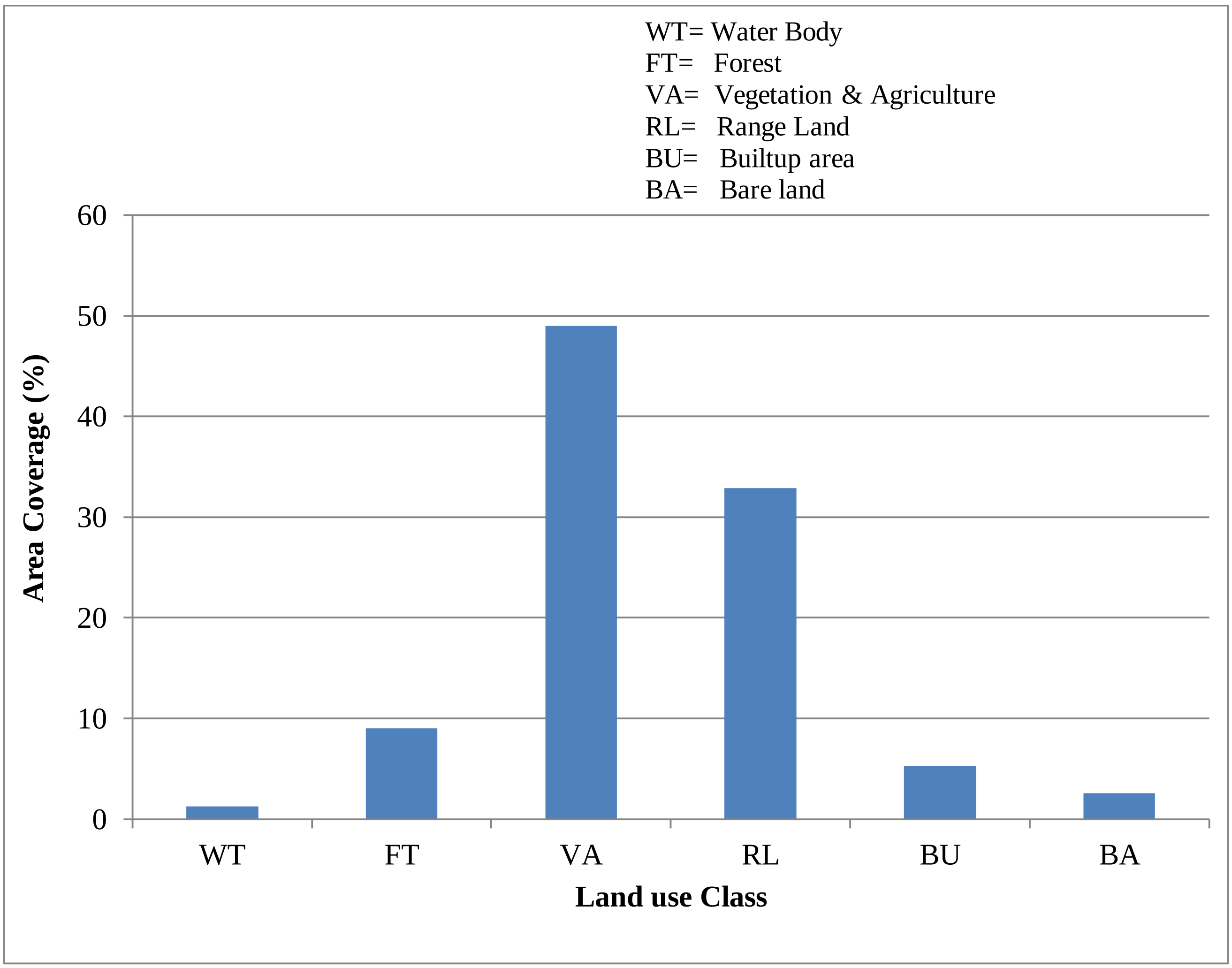

Fig-4.3 Area Coverage of Land Use for Rawal Dam in 2000

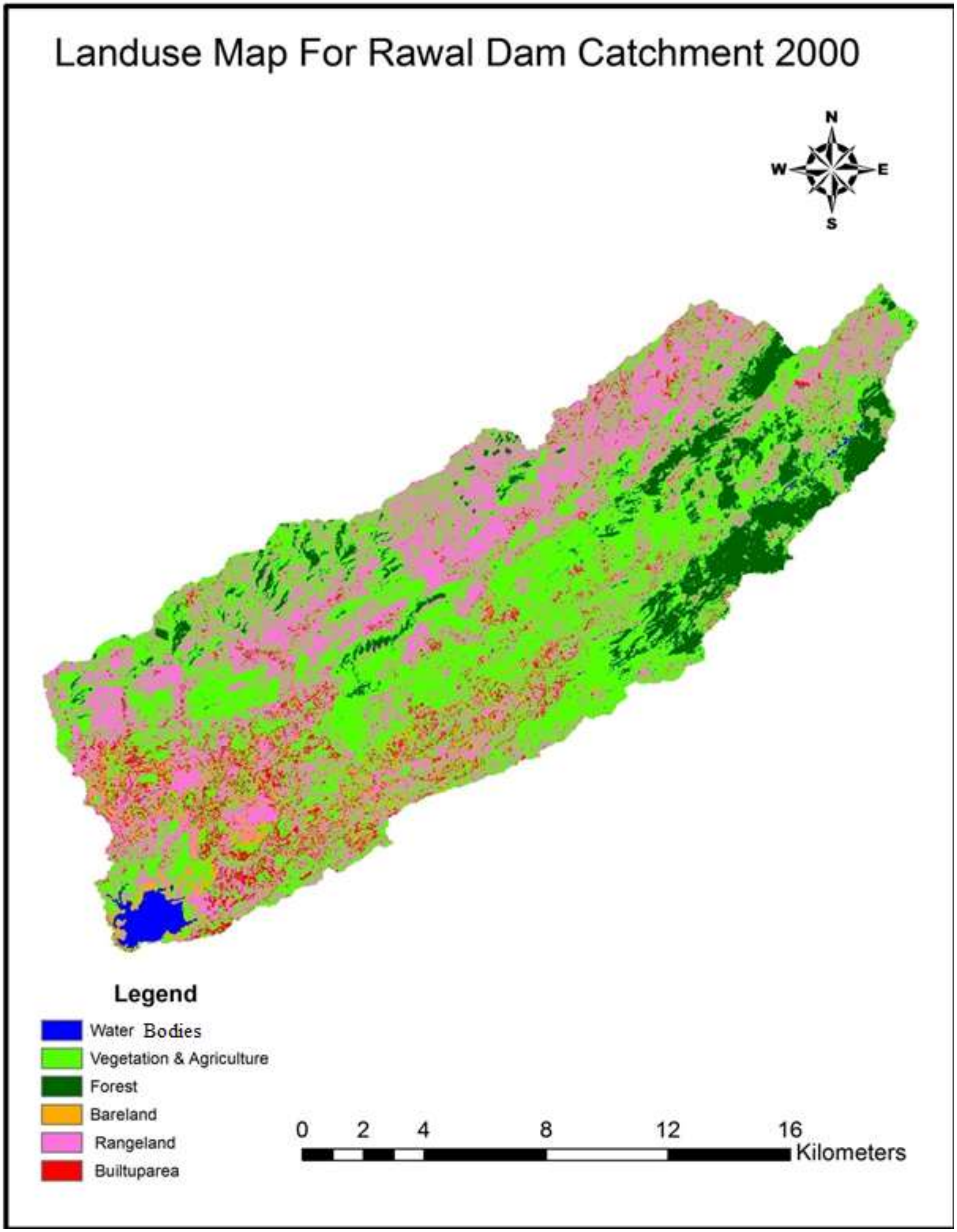

Fig-4.4 Land Use Map for Rawal Dam Catchment in 2000

Land Use Change for Rawal Catchment in 2010

The land use map of Rawal Dam catchment is given in **Figure 4.6**. It illustrates the land use of the catchment area of Rawal Dam in 2010. **Figure 4.5** is the histogram of Land use change in catchment area of Rawal Dam in 2010. Both the figures reveals that in 2010 the catchment area of Rawal Dam had 1.1% water bodies, 5.8% forest, 40.9% vegetation & agriculture, 39.4% rangeland, 8.5% built-up area and 4.3% was bare land.

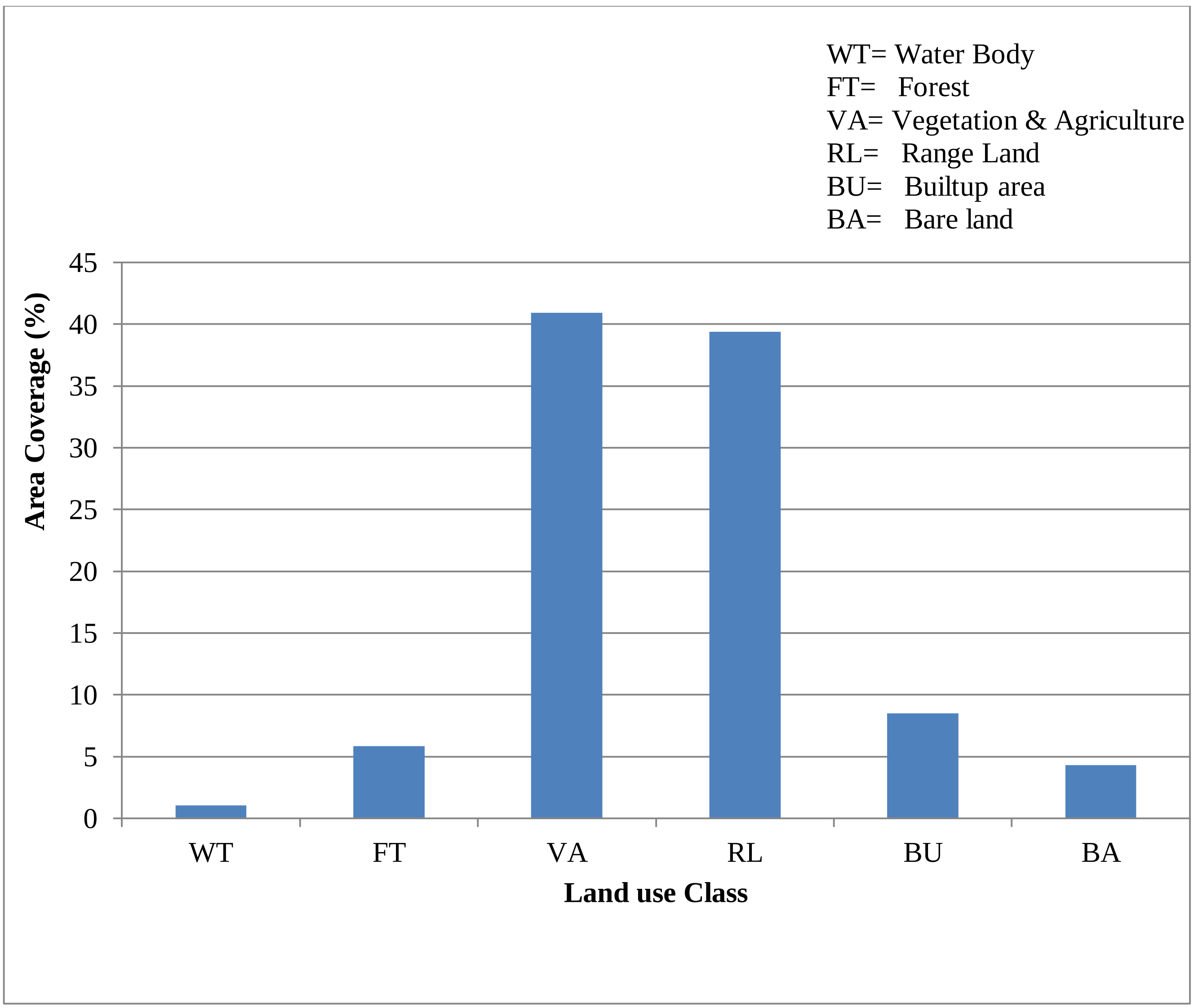

Fig-4.5 Area Coverage of Land Use for Rawal Dam in 2010

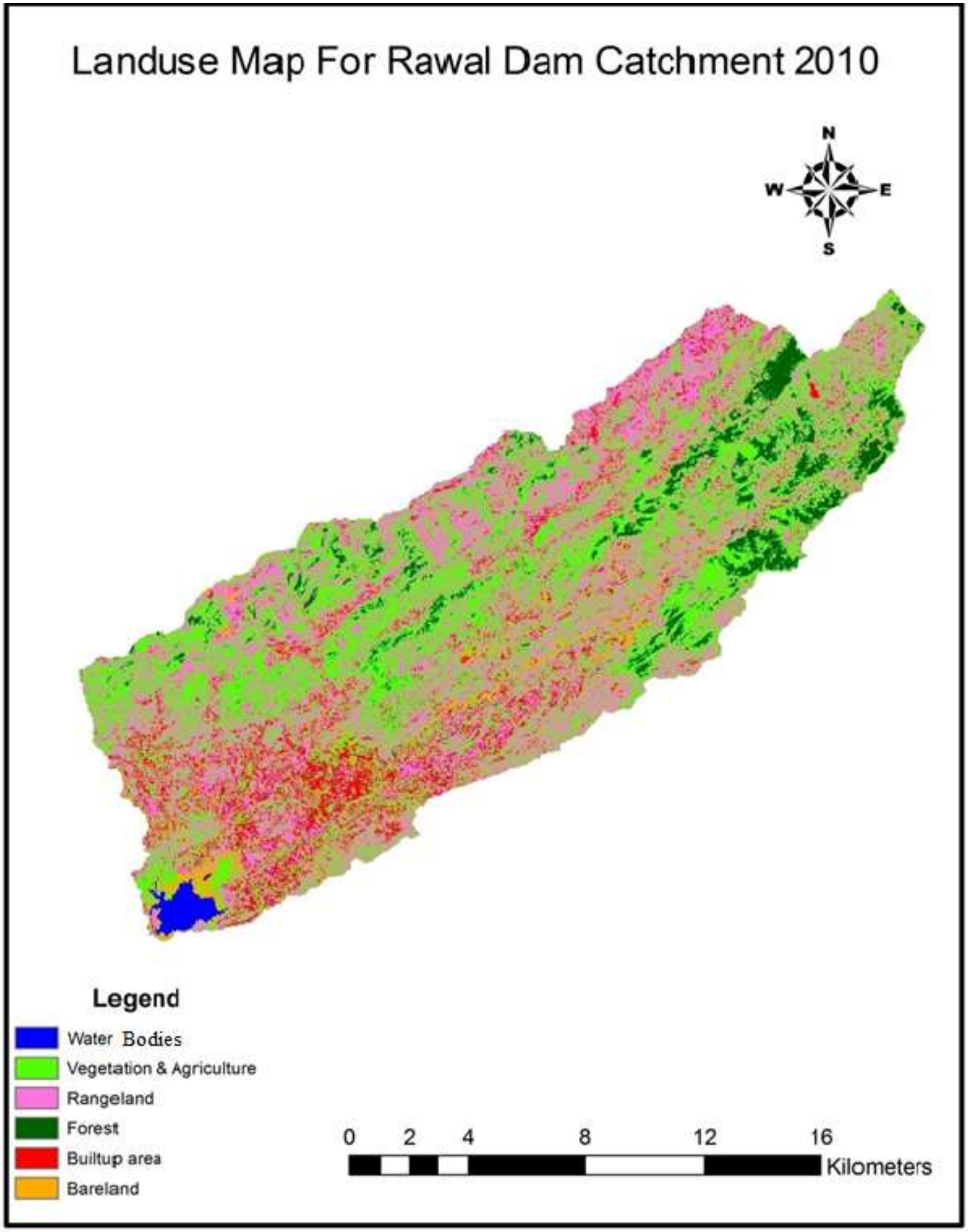

Fig-4.6 Land Use Map for Rawal Dam Catchment in 2010

The results of Land use changes in the catchment area of Rawal Dam for 1992, 2000 and 2010 is given in **Table 4.1**. Future land use changes predicted from extrapolation are shown in **Figure 4.7** and results are tabulated in **Table 4.3.** The equation used for extrapolation was

$$y(x_*) = y_{k-1} + \frac{x_* - x_{k-1}}{x_k - x_{k-1}}(y_k - y_{k-1}).$$

Table 4.1: Results of Land use change For Rawal Dam Catchment in Km ^{2}

Land use	1992		2000		2010		1992-2010	
	Area km^2	Occupied %age	Area km^2	Occupied %age	Area km^2	Occupied %age	Change km^2	Change in %
Forest	29.5	10.8	24.6	9.0	15.9	5.8	-13.6	-46
Vegetation & Agriculture	149	54.6	133.6	49.0	111.6	40.9	-37.4	-25
Rangeland	79.2	29.0	89.7	32.9	107.5	39.4	28.3	36
Built-up area	6.6	2.4	14.4	5.3	23.2	8.5	16.6	252
Barren land	3.2	1.2	7.1	2.6	11.7	4.3	8.5	266
Total	272.8		272.8		272.8			

Table 4.2: Change in Water Bodies area of Rawal Dam Catchment in Km ^{2}

Land use	2000		2010		2000-2010	
	Area km^2	Occupied %age	Area km^2	Occupied %age	Change km^2	Change in %
Water bodies	3.4	1.2	2.9	1.1	0.5	14.7

Table 4.3: Future Land Use Change For Rawal Dam Catchment in %age

Land use	In 2015 (%age)	In 2020 (%age)
Water bodies	1.05	1.00
Forest	4.20	2.60
Vegetation & Agriculture	36.85	32.80
Rangeland	42.65	45.90
Built-up area	10.10	11.70
Barren land	5.15	6.00

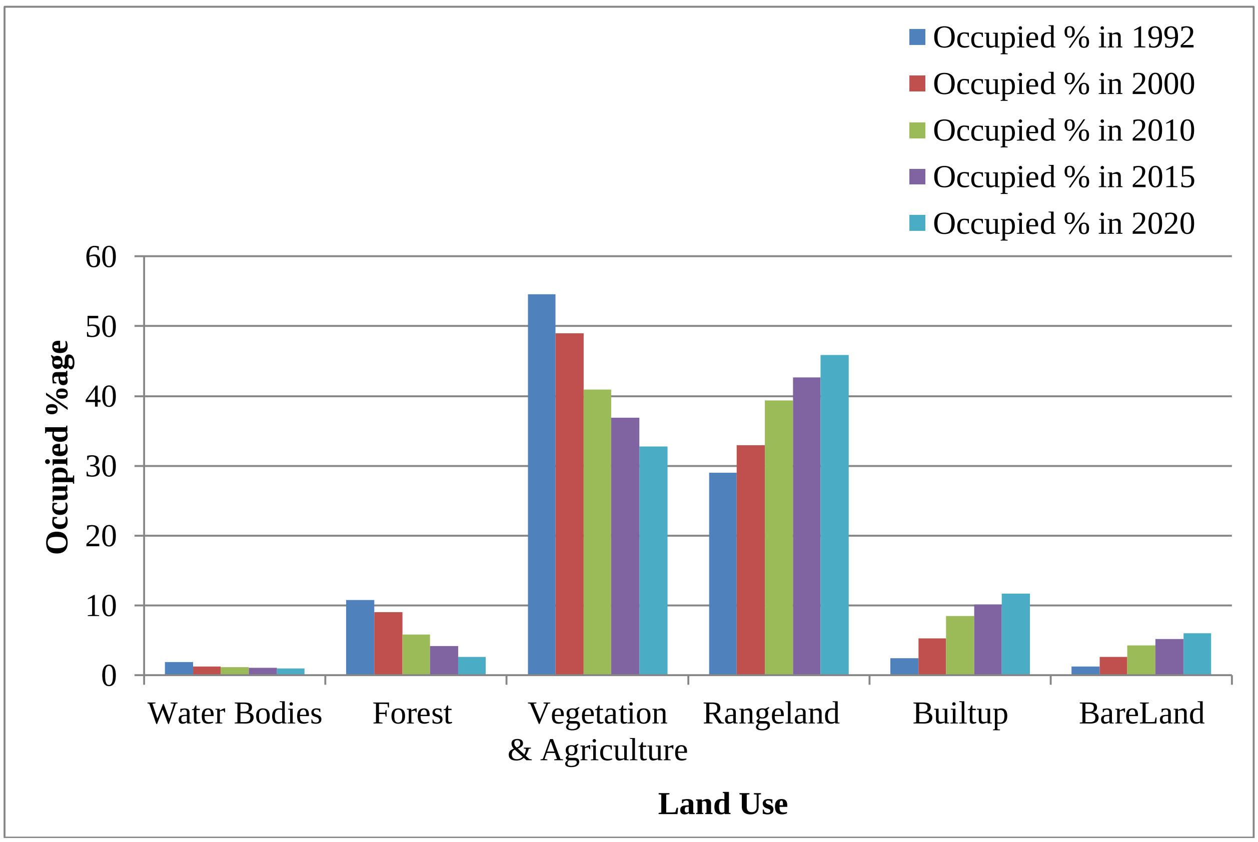

Fig-4.7 Future Land Use Change Pattern for Rawal Catchment

4.2 Effect of Land Use Pattern on Rainfall- Runoff Relationship of Rawal Catchment

The hydrology of a region is controlled by rainfall. To analyze the rainfall and runoff relationship of the Rawal Dam average rainfall and runoff data for the period 1975-2012 was plotted on annual and monthly basis. From **Figure 4.8** it is observed that with the increase of rainfall runoff is also increasing and from 1990 it can be observed that due to land use changes runoff increased according the increase in rainfall. Similarly it can be observed in **Figure 4.9** that rainfall and runoff values were high during monsoon months i.e. July, August and September

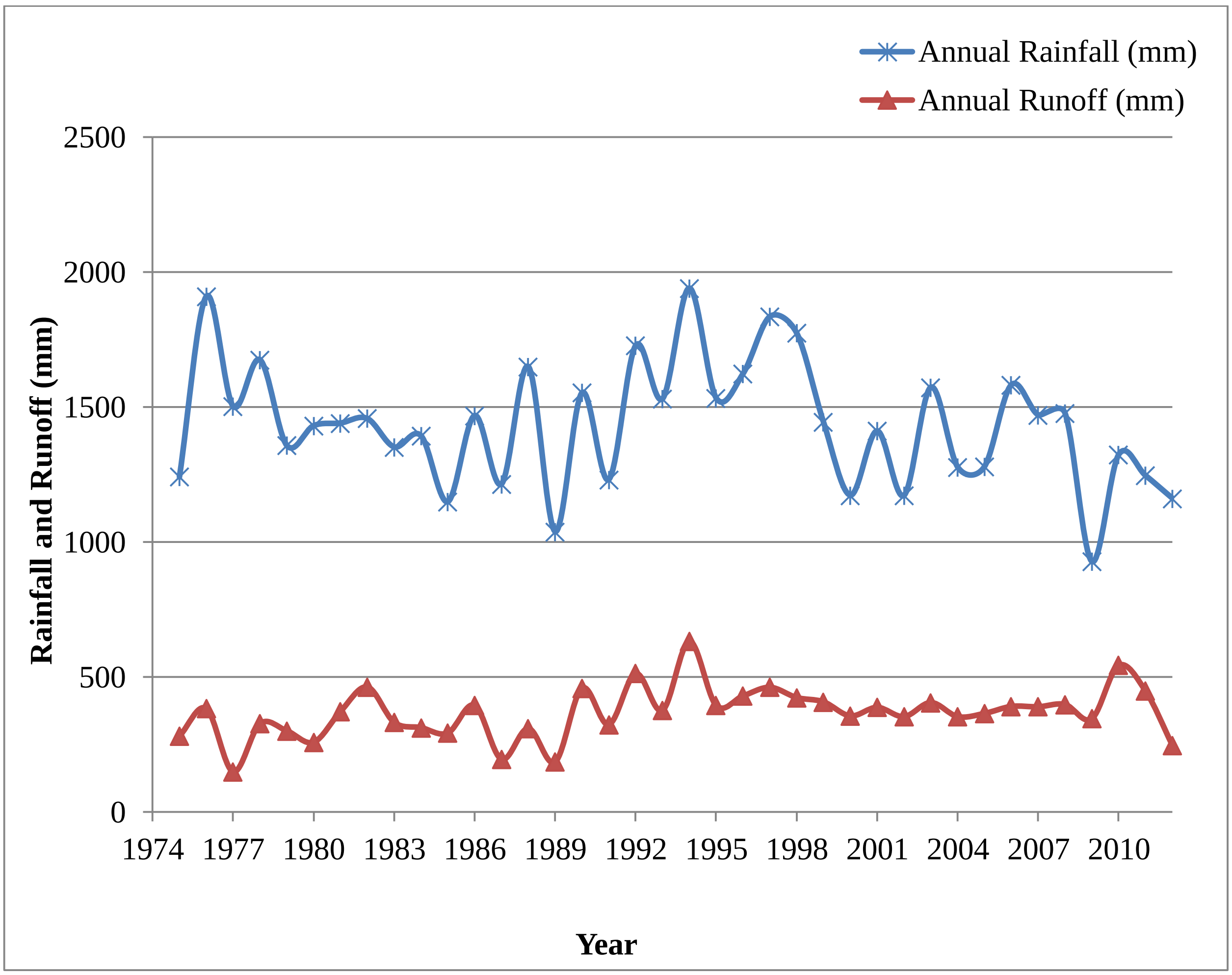

Fig-4.8 Annual Rainfall & Runoff for Rawal Catchment for Period 1975-2012

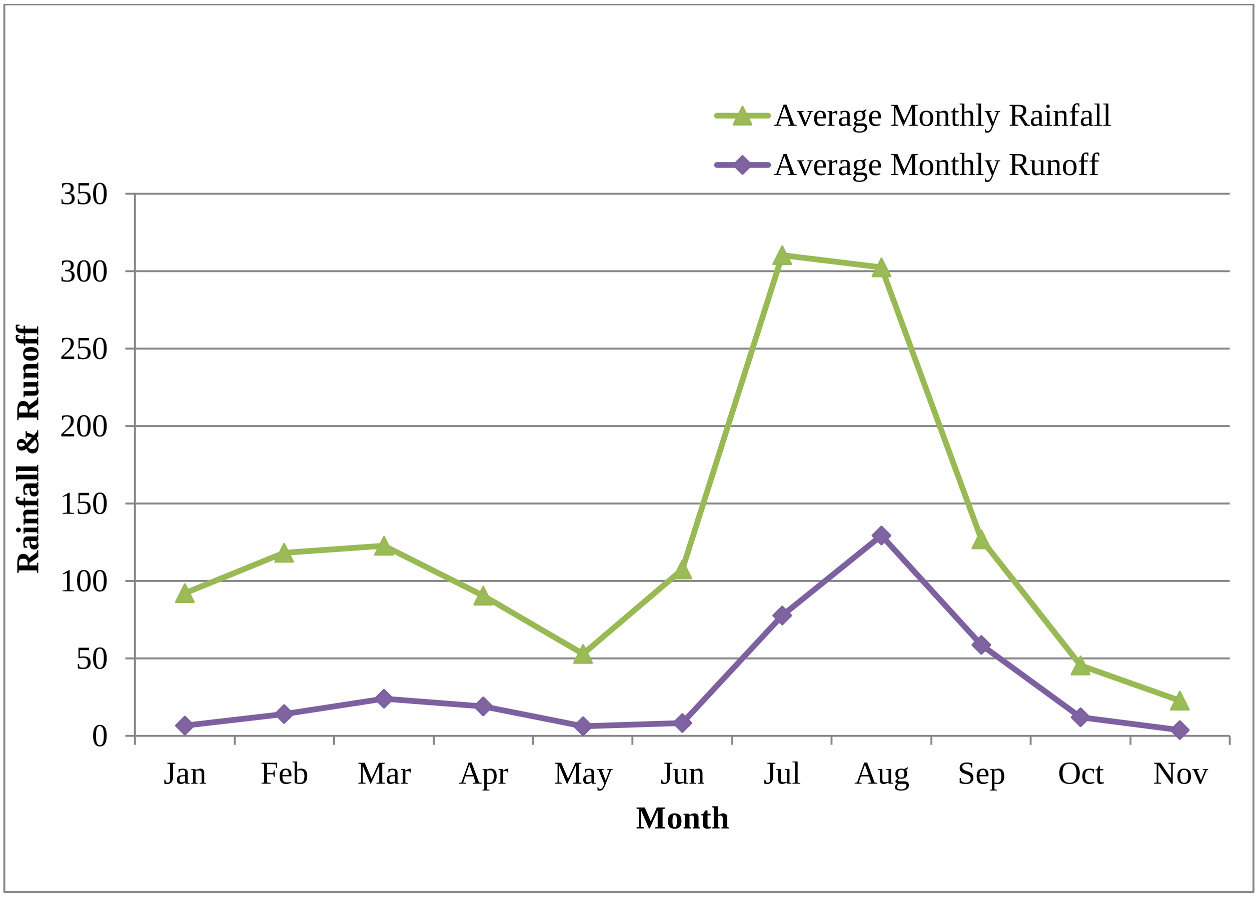

Fig-4.9 Mean Monthly Rainfall & Runoff for Rawal Catchment for Period 1975-2012

The major development activities in the catchment area started from 1998 in which Islamabad Murree dual carriage way was constructed and this project completed in 2008. Nearly 24 km section of the carriageway passes through the catchment area of the Kurang River while about 19 km section runs through the catchment area of Soan River upstream of the Simly reservoir. Similarly over 10 million cubic feet earth/excavated material dumped along Kurang and Soan Rivers is silting up in Rawal and Simly reservoirs. Large scale cutting of trees for the construction of the said highway is also causing environmental impacts and soil loss.

To check the land use change effects double mass curve of rainfall- runoff were plotted for annual and monsoon months, which are shown in **Figure 4.10, 4.11, 4.12, 4.13 and 4.14.** From these figures it can be seen that with the increase in rainfall runoff is also increasing and this trend can be clearly observed in period of 1998-2008 which was the major development period also it can be seen that during 2009-2012 there was increase in trend of runoff.

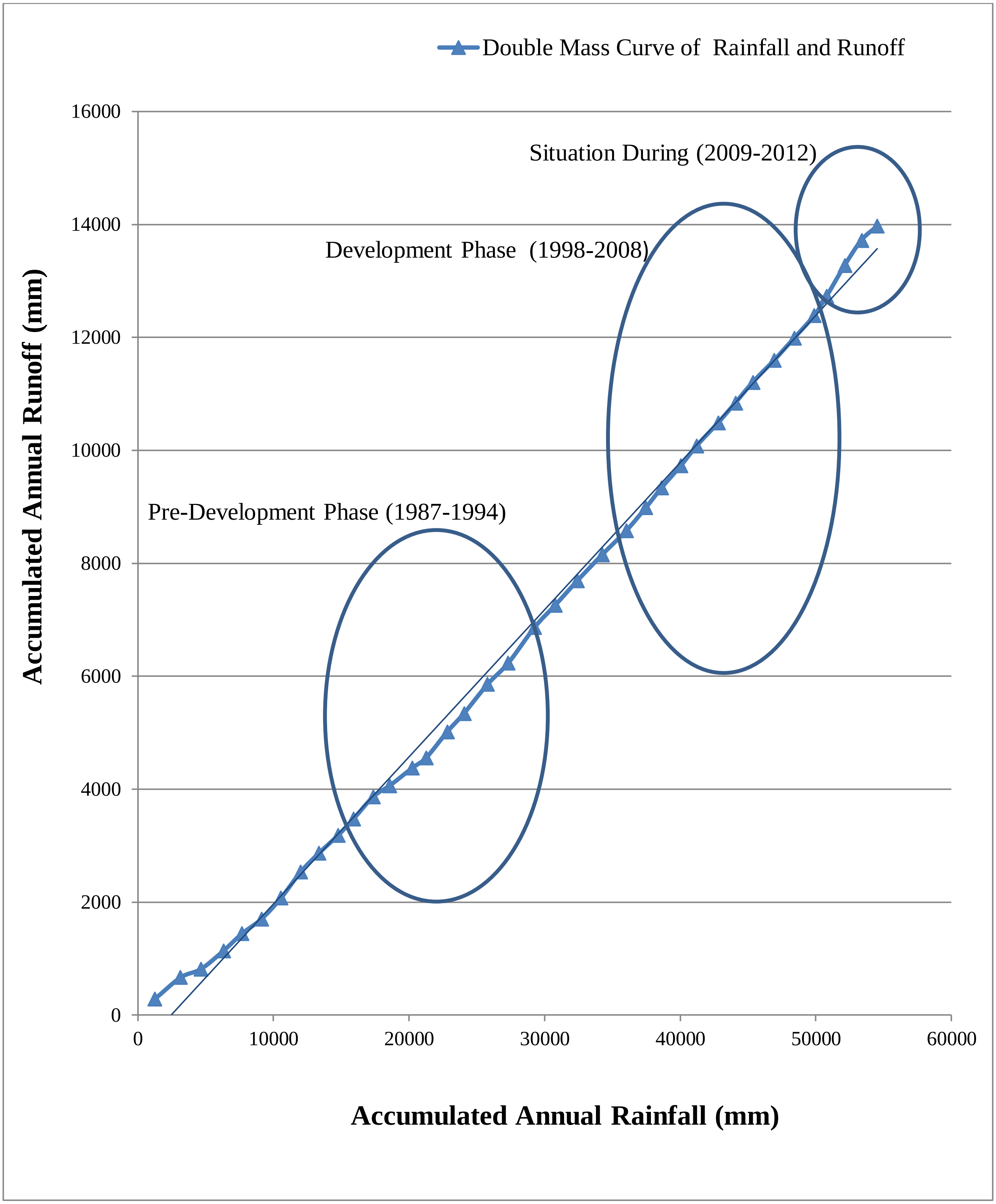

Fig-4.10 Annual Double Mass Curve of Rainfall & Runoff for Rawal Catchment (1975-2012)

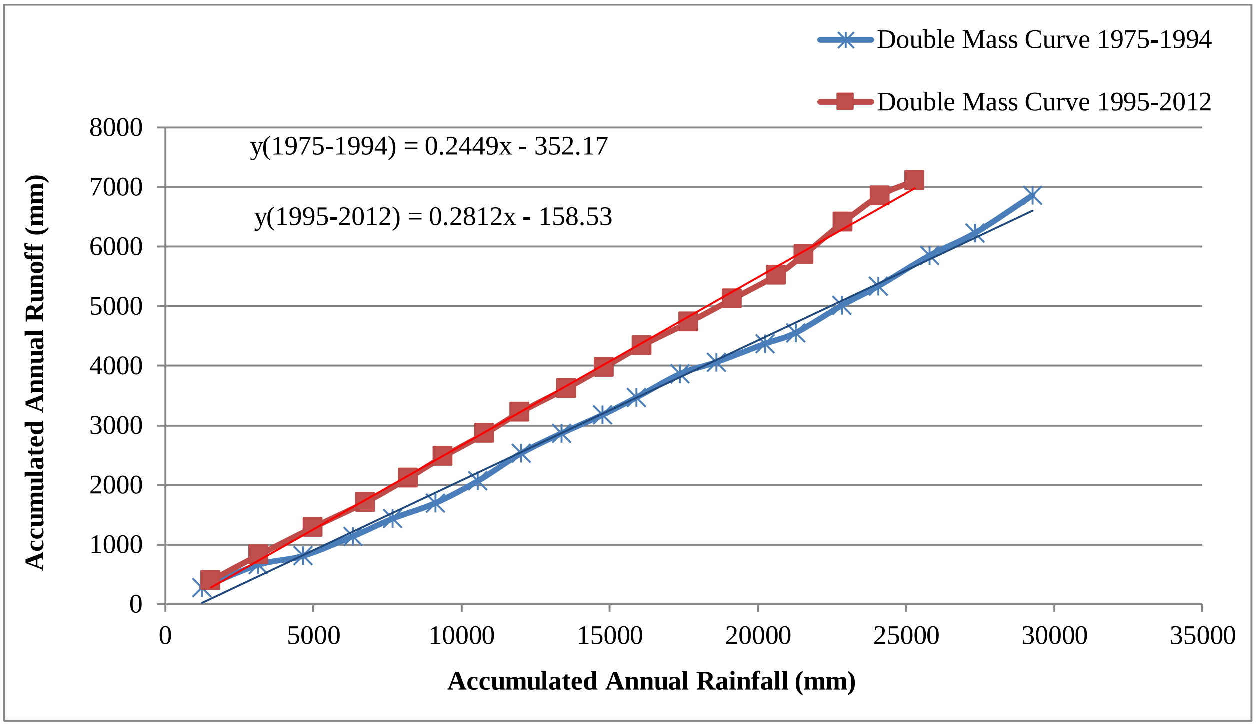

Fig-4.11 Double Mass Curve of Annual Rainfall & Runoff for Rawal Catchment

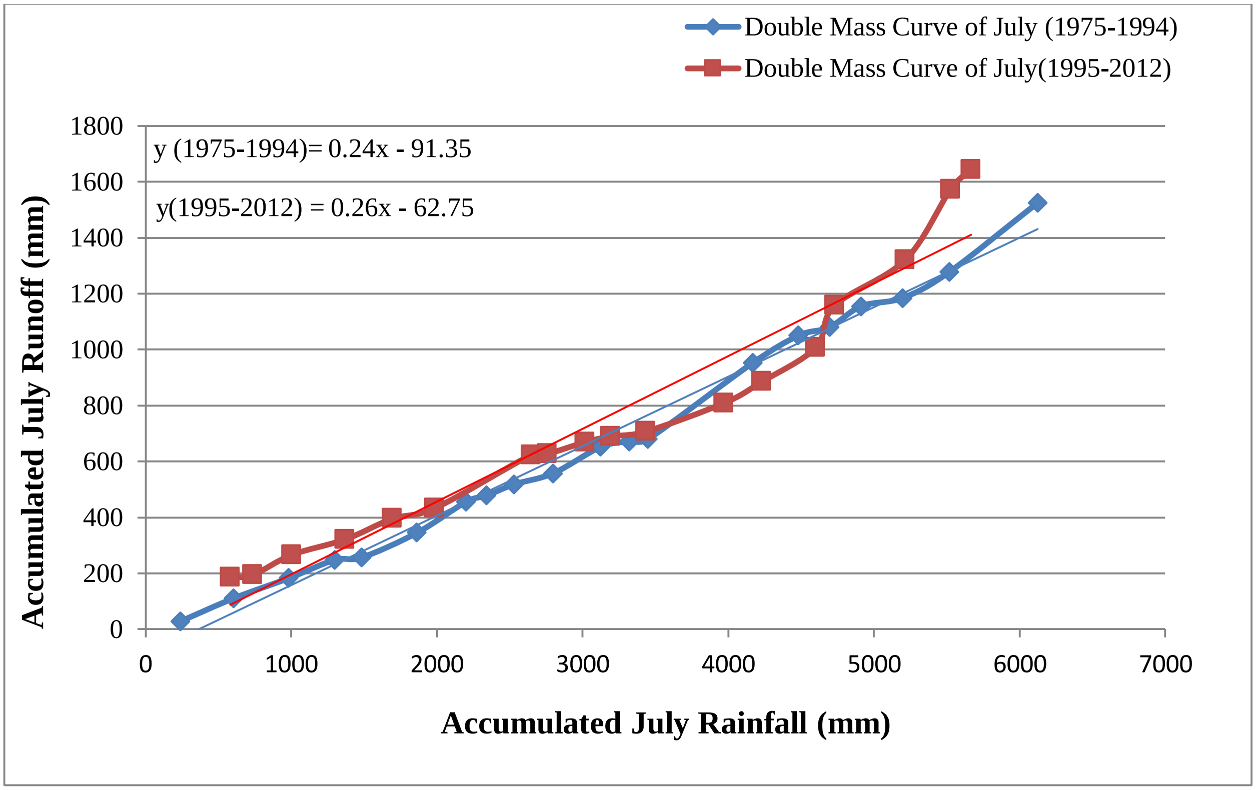

Fig-4.12 Double Mass Curve of July Rainfall & Runoff for Rawal Catchment

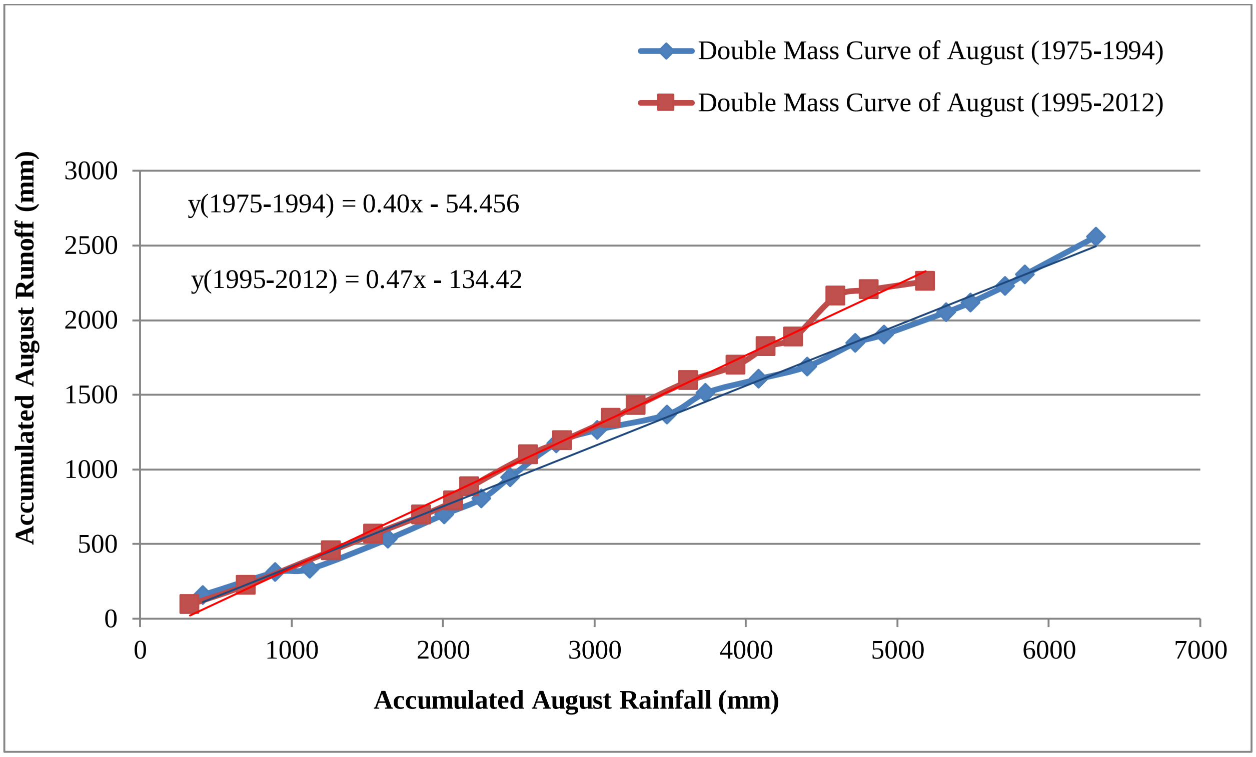

Fig-4.13 Double Mass Curve of Aug Rainfall & Runoff for Rawal Catchment

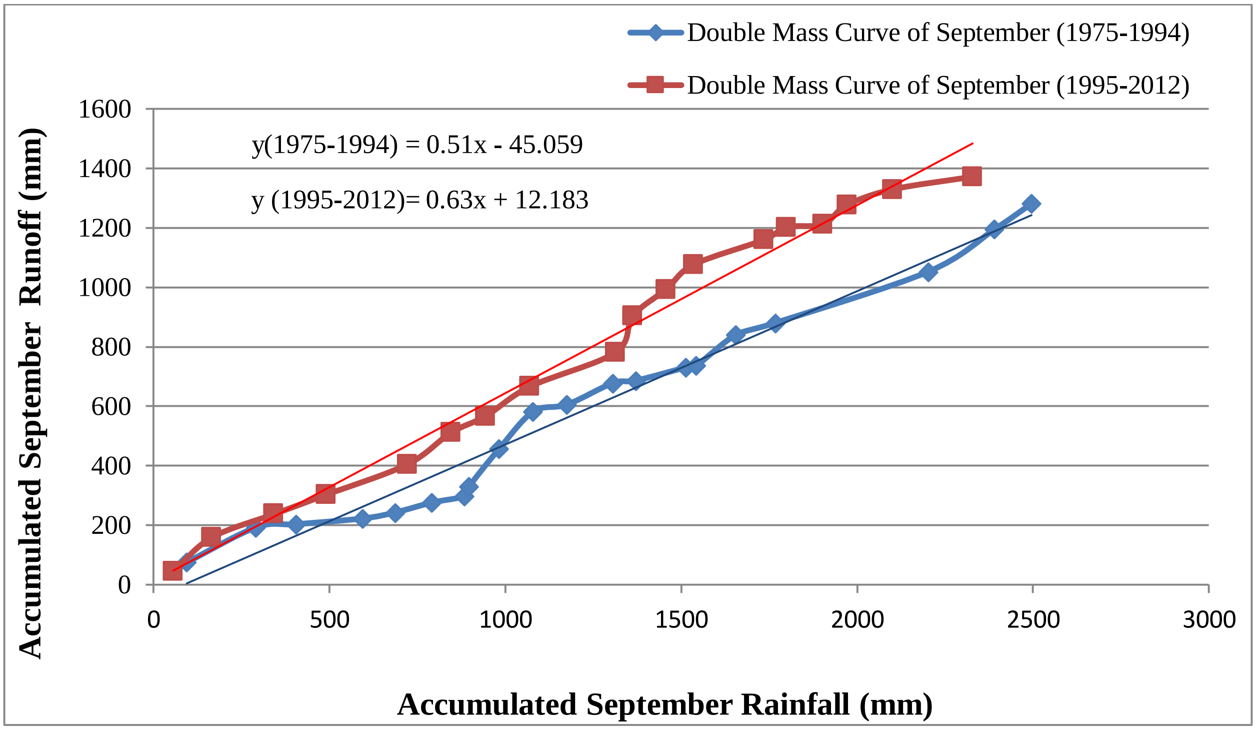

Fig-4.14 Double Mass Curve of Sep Rainfall & Runoff for Rawal Catchment

Annual Runoff-Sedimentation Relationship for Rawal Catchment

As the survey for sediment assessment is carried out after every 5 year by relevant organization, therefore, for yearly assessment of runoff- sedimentation relation the sediment data was calculated using Khosla's method. The earlier designs of reservoirs in India were based on the annual silting rate of 0.036Mm^3 per 100 sq. km of catchment area as suggested by Dr. Khosla, the famous Indian researcher (Sharma, 1992). When sedimentation rate as proposed by Dr. Khosla was applied to the Rawal Dam Watershed the value comes out to be

Silting Rate = 0.036 X 10^6 X 272.8/100 = 98208 m^3/year

= 3468182.7 ft^3/year

= 79.60 Acre-Feet/year

The runoff-sedimentation relationship for Rawal catchment using relevant organization data is given in **Figure 4.15** and **Figure 4.16** its Double Mass Curve is given in **Figure 4.17.** It is shown in the figures that sedimentation is increasing with the increase in runoff and in double mass curve regression coefficients of linear equation shows more value of slope for period 1995-2005. Similarly the runoff-sedimentation relationship for Rawal catchment using Khosla method is given in **Figure 4.18** and its Double Mass Curve is given in **Figure 4.19.** It is shown in the figures that sedimentation is increasing with the increase in runoff and in double mass curve regression coefficients of linear equation shows more value of slope for period 1995-2005.

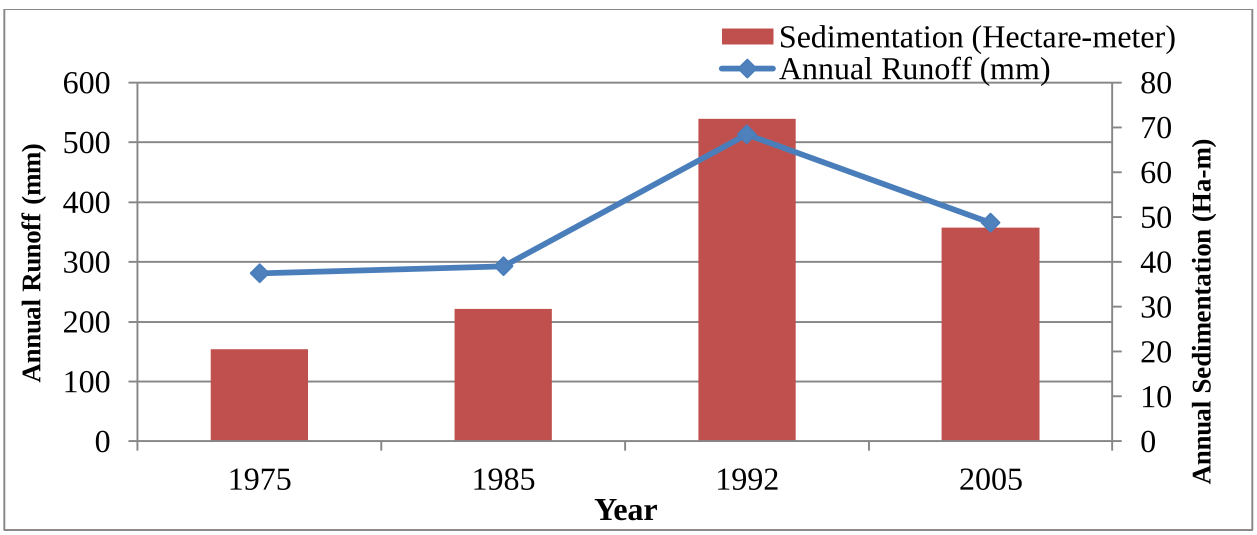

Fig-4.15 Annual Runoff & Sedimentation in Rawal Catchment (1975-2005)

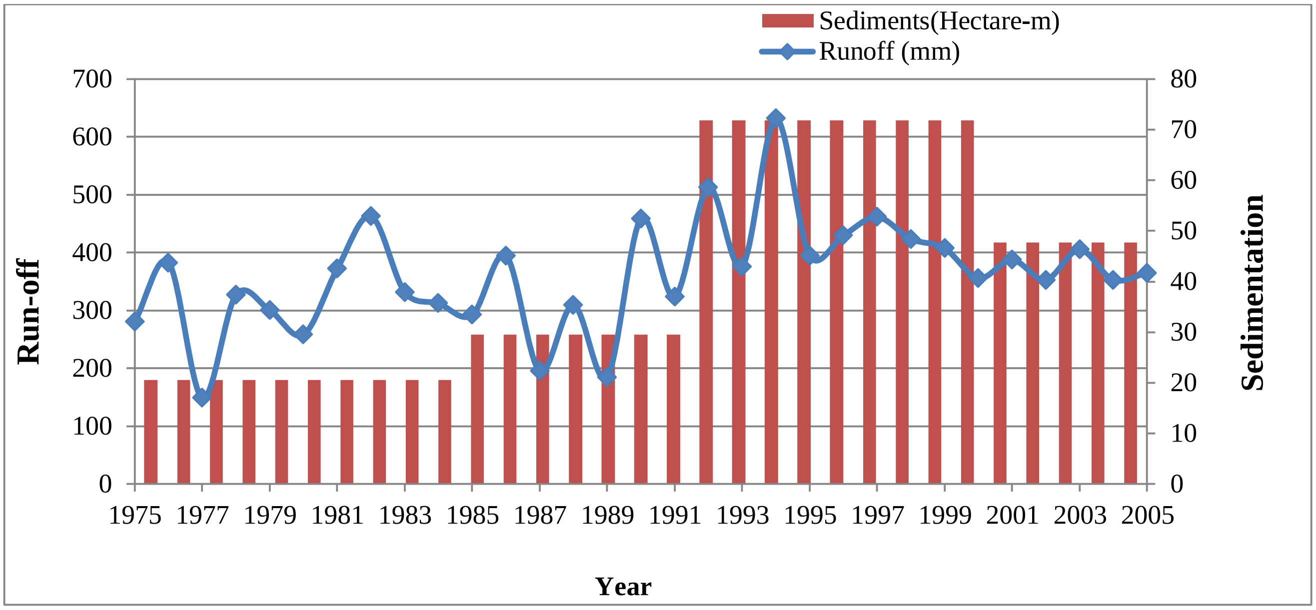

Fig-4.16 Annual Runoff & Sedimentation in Rawal Catchment (1975-2005)

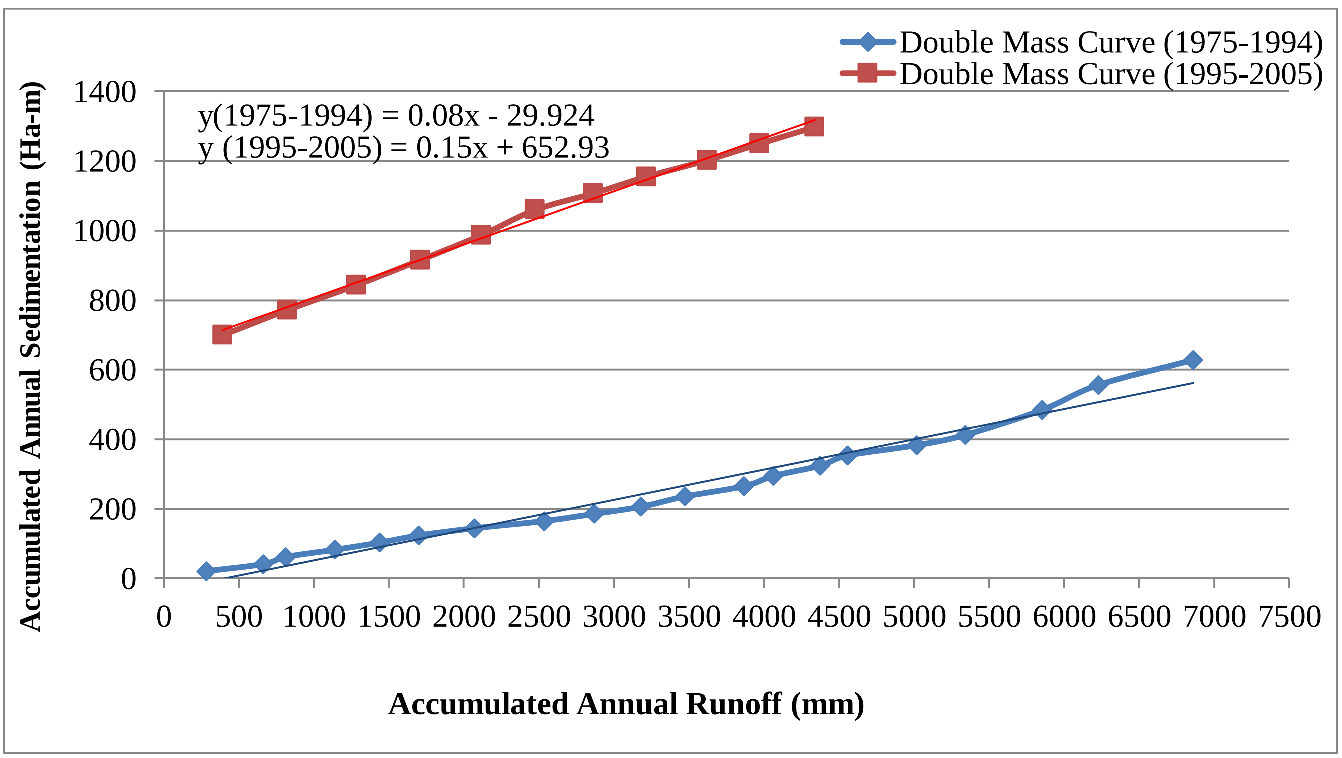

Fig-4.17 Double Mass Curve Annual Runoff & Sedimentation for Rawal Catchment (1975-1994, 1995-2005)

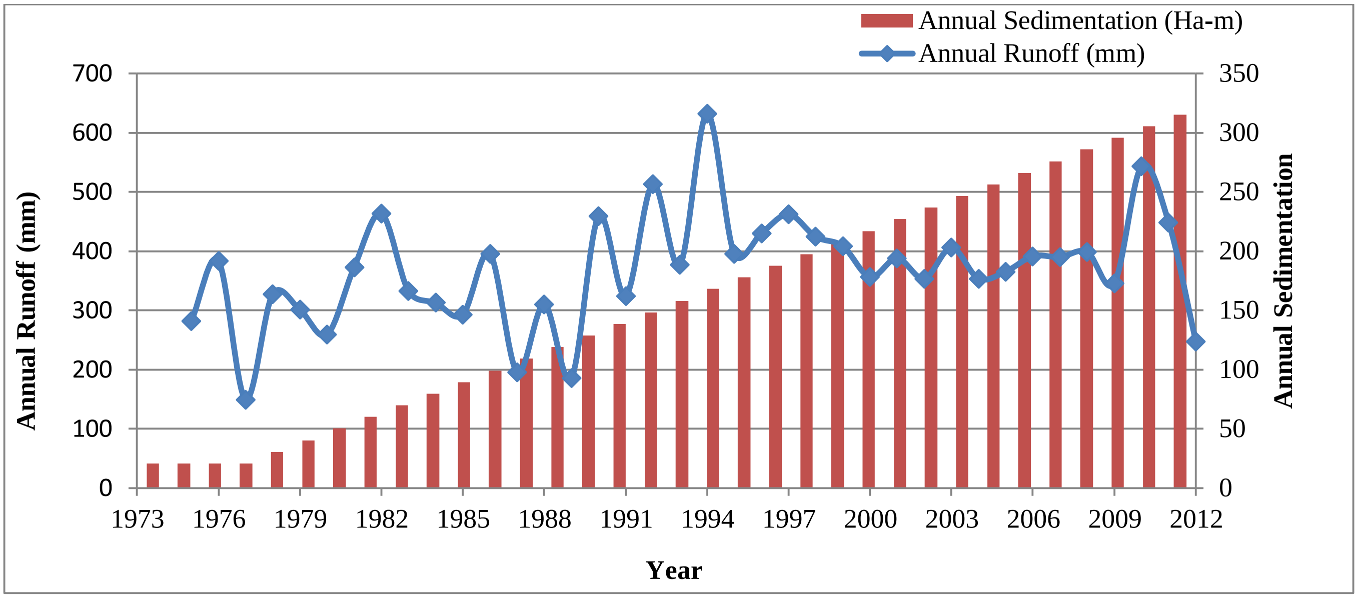

Fig-4.18 Annual Runoff & Sedimentation in Rawal Catchment Khosla Method (1975-2005)

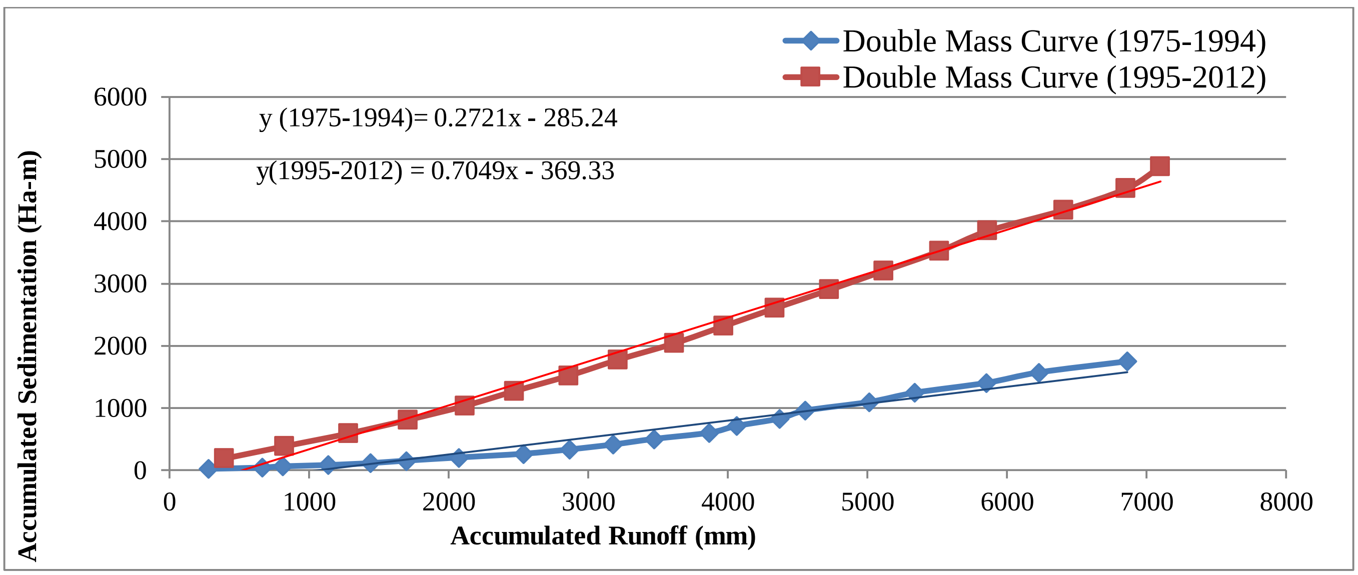

Fig-4.19 Double Mass Curve of Annual Runoff & Sedimentation for Rawal Catchment Khosla Method

4.3 Change of Land Use Pattern for Simly Catchment

Based on rainfall runoff relationship Land use analysis was performed for Simly catchment and land use maps were prepared for 1992, 2000 and 2010. The detail of Land use scenario is explained below.

Land Use Change for Simly Catchment in 1992

The land use map of Simly Dam catchment in 1992 and its histogram is given in **Figures 4.21** and **4.20** respectively. According to this map in 1992 there was 0.8% water bodies, 46.3% forest, 16.9% vegetation & agriculture 29.4% rangeland, 1.6% built-up area and 5.1% bare land in the catchment area of Simly Dam.

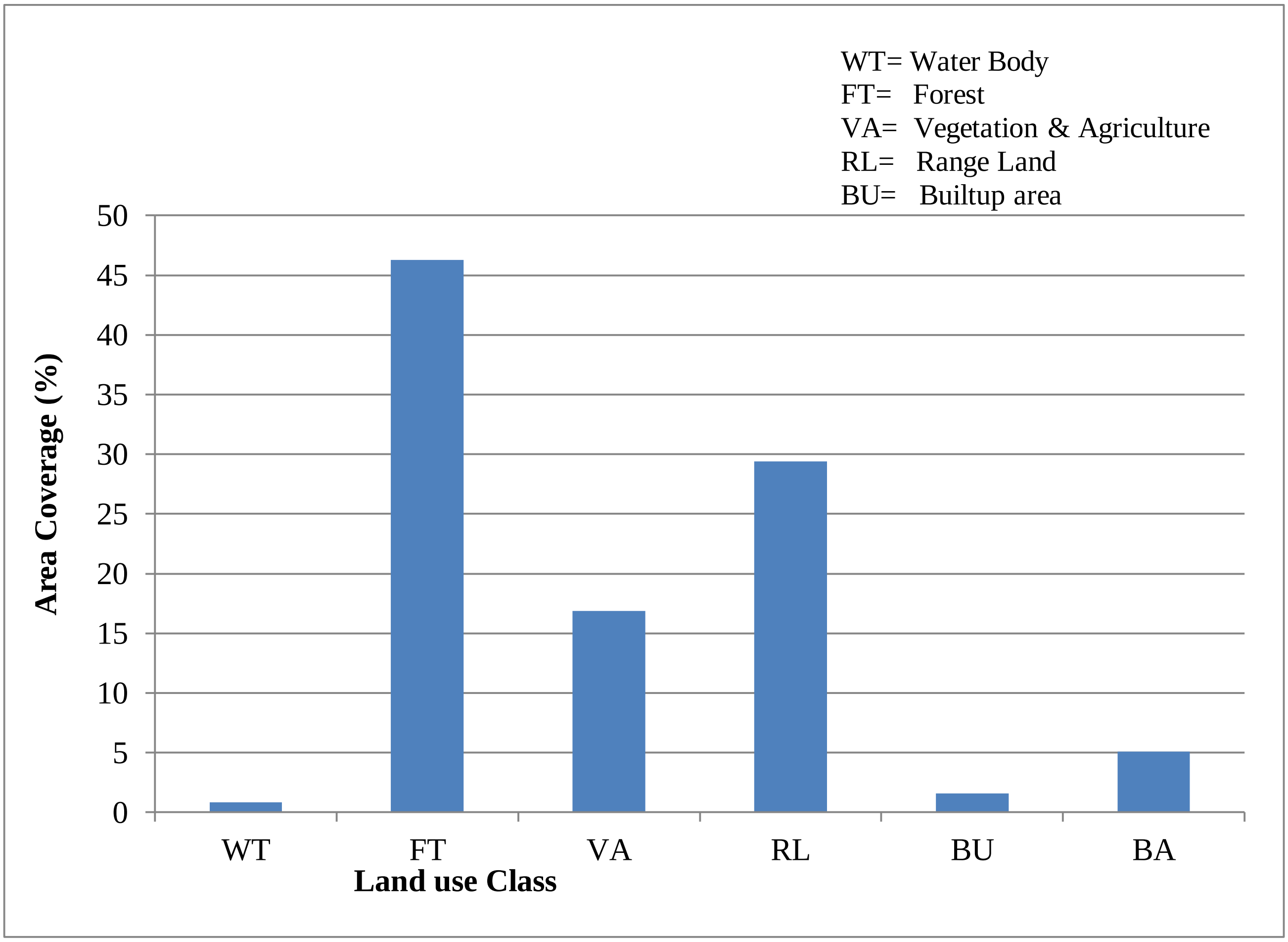

Fig-4.20 Area Coverage of Land Use for Simly Dam in 1992

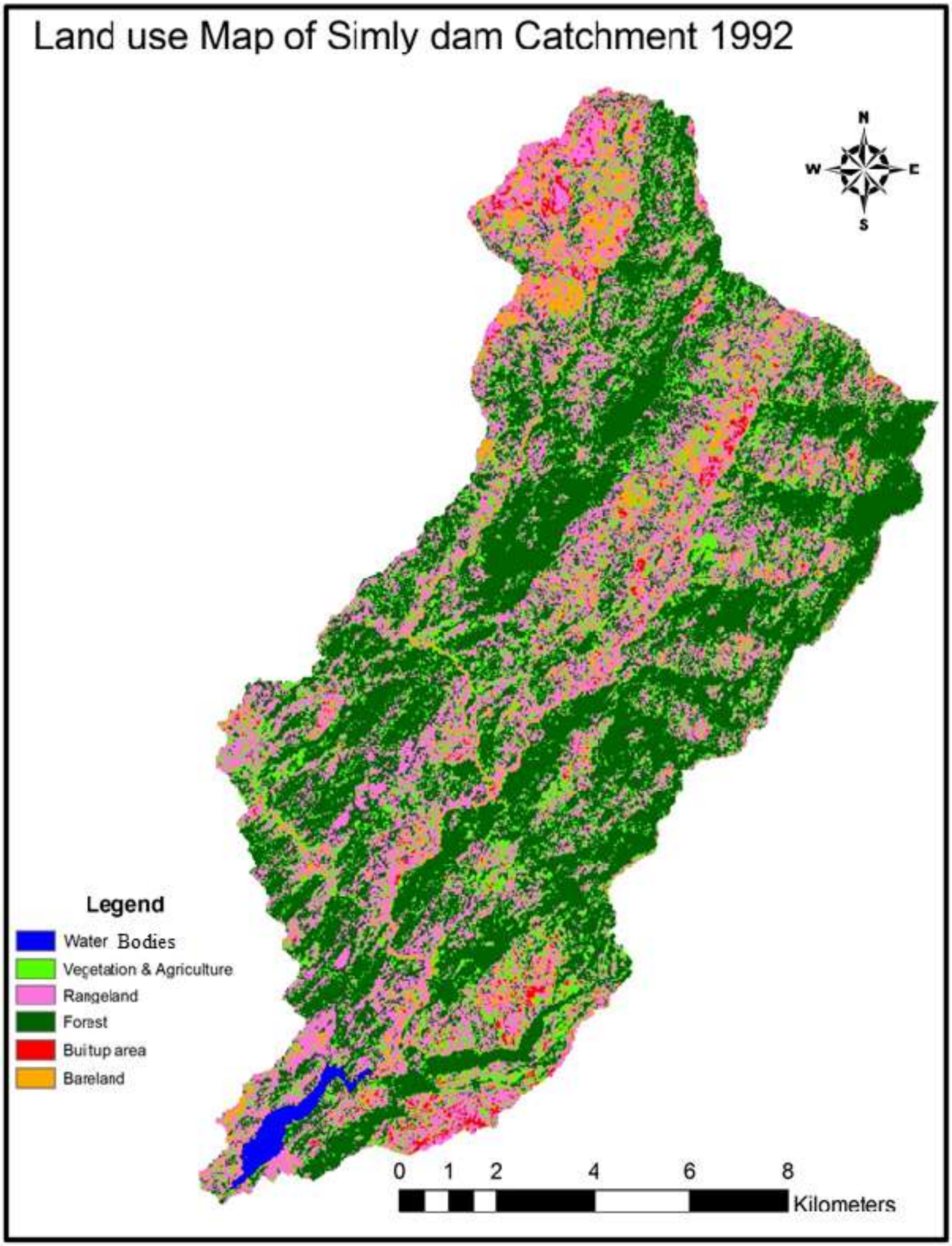

Fig-4.21 Land Use Map for Simly Dam Catchment in 1992

Land Use Change for Simly Catchment in 2000

The land use map of Simly Dam catchment in 2000 and its histogram is given in **Figures 4.23** and **4.22** respectively. According to this map in 2000 there was 0.5% water bodies, 40.3% forest, 15.8% vegetation & agriculture 30.4% rangeland, 4.2% built-up area and 8.7% bare land in the catchment area of Simly Dam.

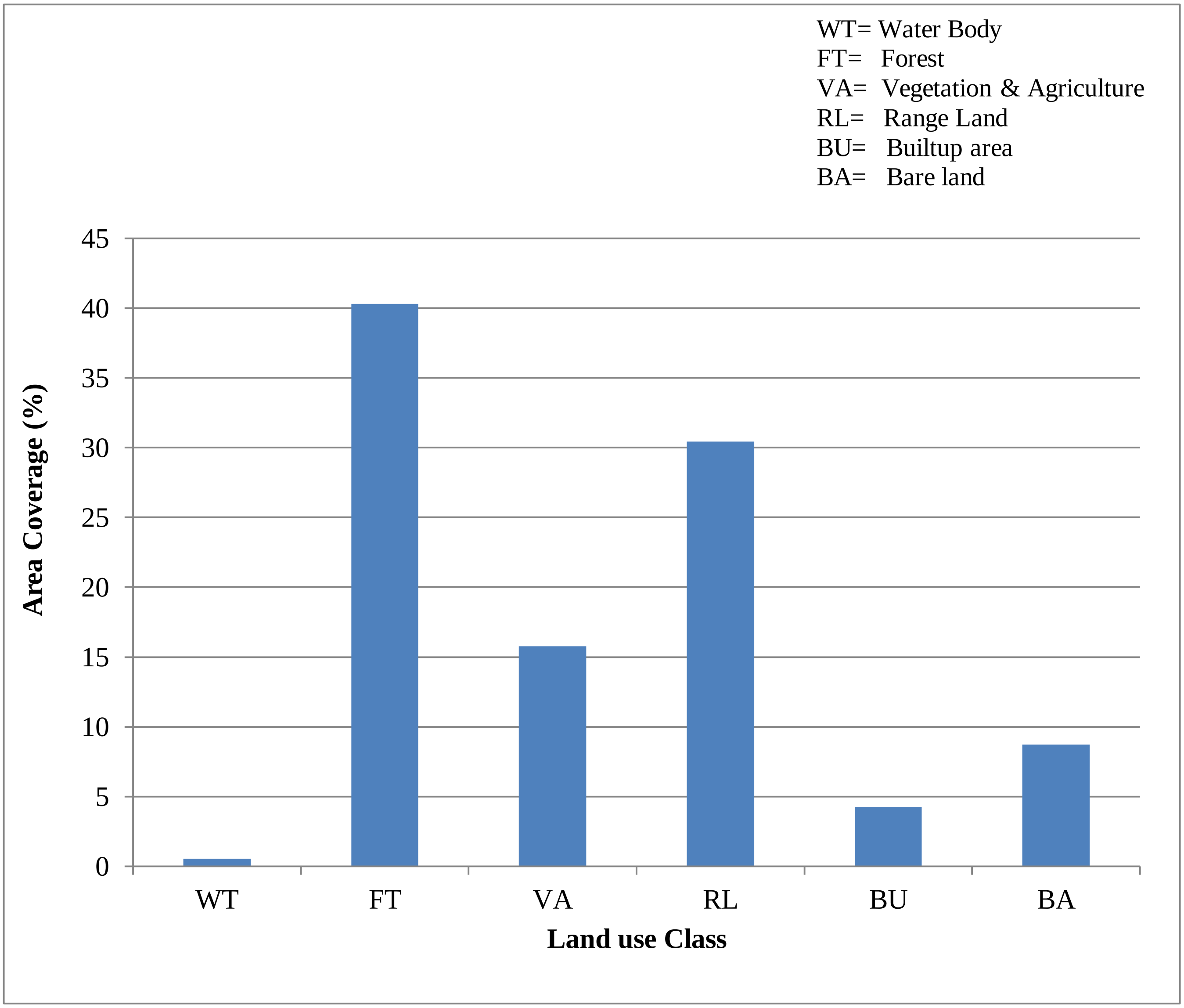

Fig-4.22 Area Coverage of Land Use for Simly Dam in 2000

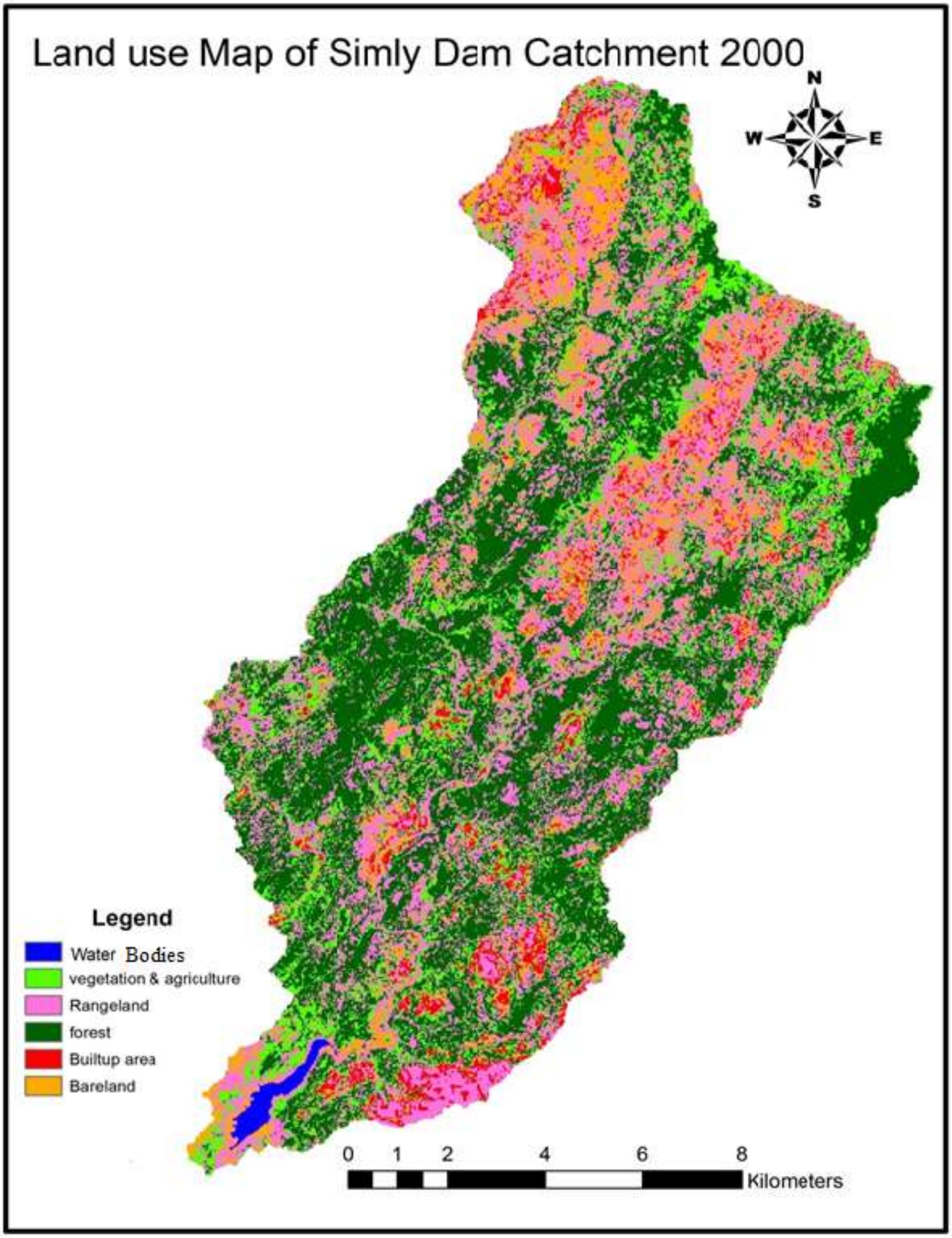

Fig-4.23 Land Use Map for Simly Dam Catchment in 2000

Land Use Change for Simly Catchment in 2010

The land use map of Simly Dam catchment in 2010 and its histogram is given in **Figures 4.25** and **4.24** respectively. According to this map in 2010 there was 0.45 % water bodies, 34.1% forest, 14.2% vegetation & agriculture 33.8% rangeland, 5.8% built-up area and 11.7 % bare land in the catchment area of Simly Dam.

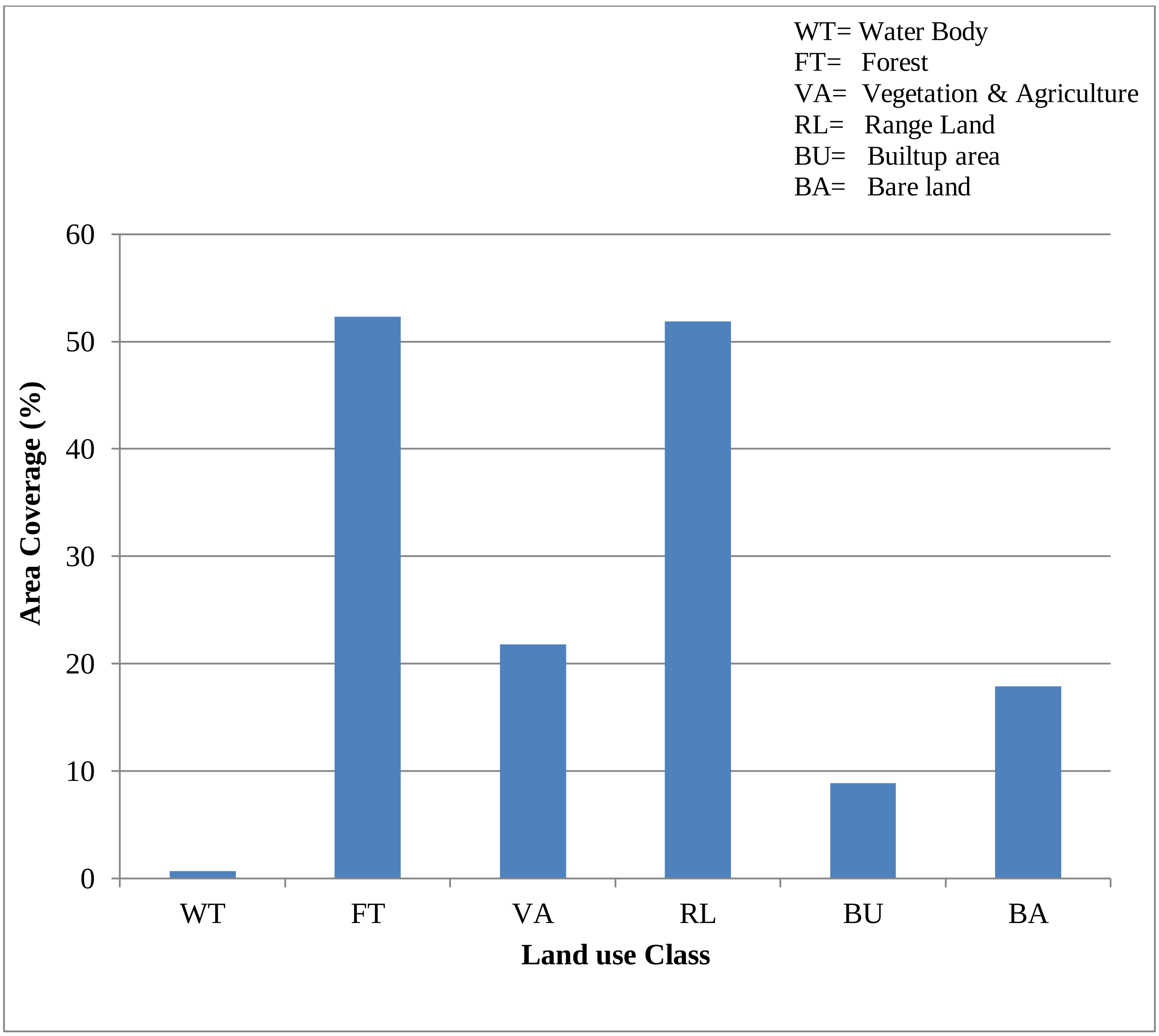

Fig-4.24 Area Coverage of Land Use for Simly Dam in 2010

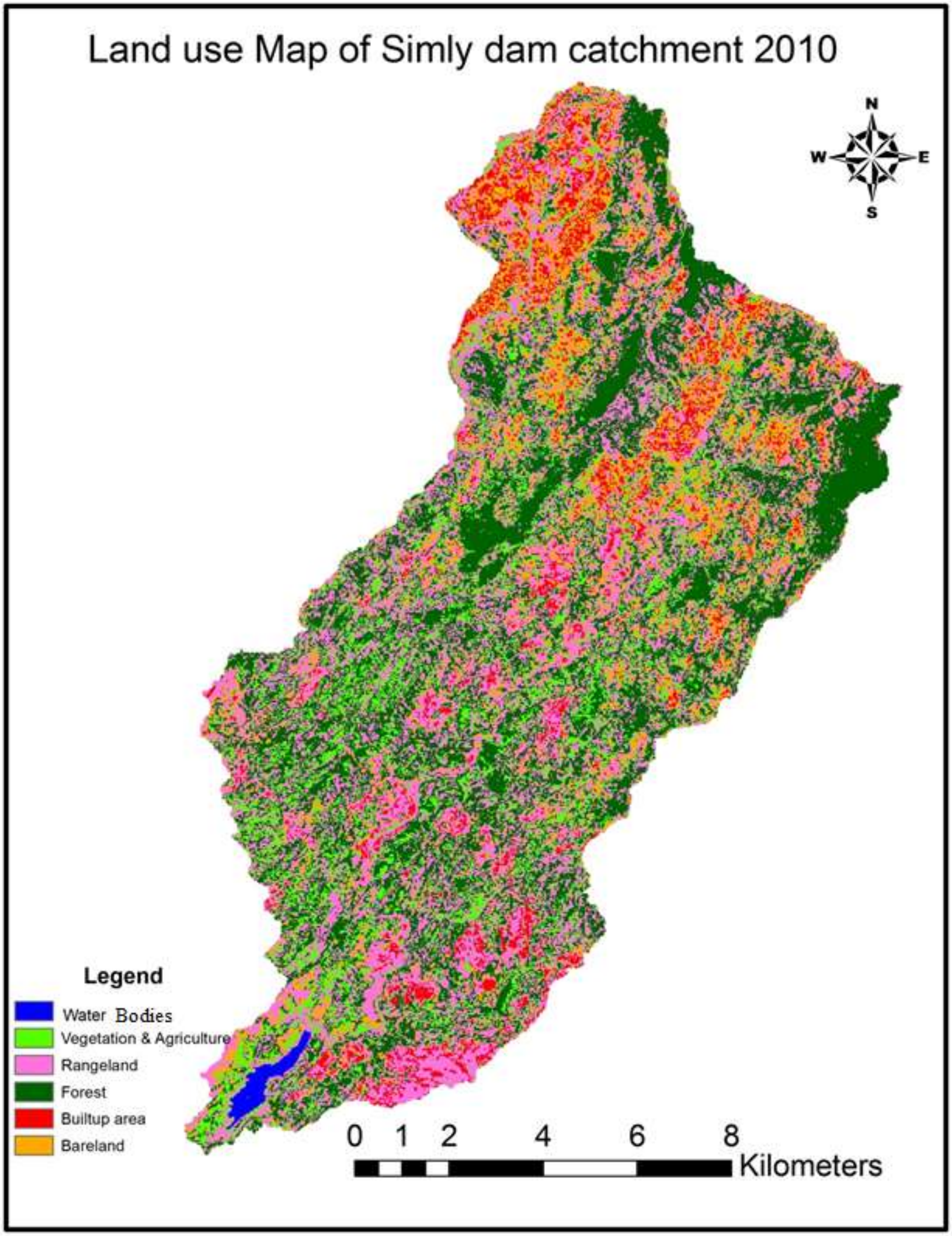

Fig-4.25 Land Use Map for Simly Dam Catchment in 2010

The results of Land use changes in the catchment area of Simly Dam for 1992, 2000 and 2010 is given in **Table 4.4**. Future land use changes predicted from extrapolation are shown in **Figure 4.26** and results are tabulated in **Table 4.6.** The equation used for extrapolation was

$$y(x_*) = y_{k-1} + \frac{x_* - x_{k-1}}{x_k - x_{k-1}}(y_k - y_{k-1}).$$

Table4.4: Results of Land use change For Simly Dam Catchment in Km^2

Land use	1992		2000		2010		1992-2010	
	Area km^2	**Occupied %age**	**Area km^2**	**Occupied %age**	**Area km^2**	**Occupied %age**	**Change km^2**	**Change in %**
Water bodies	1.3	0.8	0.8	0.5	0.7	0.46	-0.6	-46
Forest	71	46.3	61.9	40.3	52.3	34.1	-18.7	-26
Vegetation & Agriculture	25.9	16.9	24.2	15.8	21.8	14.2	-4.1	-16
Rangeland	45.1	29.4	46.7	30.4	51.9	33.8	6.8	15
Built-up area	2.4	1.6	6.5	4.2	8.9	5.8	6.5	271
Barren land	7.8	5.1	13.4	8.7	17.9	11.7	10.1	12 9
Total	153.5		153.5		153.5			

Table 4.5: Change in Water Bodies area of Simly Dam Catchment in Km ^{2}

Land use	2000		2010		2000-2010	
	Area km^2	**Occupied %age**	**Area km^2**	**Occupied %age**	**Change km^2**	**Change in %**
Water bodies	0.8	0.5	0.7	0.46	0.1	12.5

Table 4.6: Future Land use change For Simly Dam Catchment in %age

Land use	In 2015 (% age)	In 2020 (% age)
Water bodies	0.44	0.42
Forest	30.95	27.83
Vegetation & Agriculture	13.40	12.60
Rangeland	35.52	37.19
Built-up area	6.60	7.40
Barren land	13.14	14.62

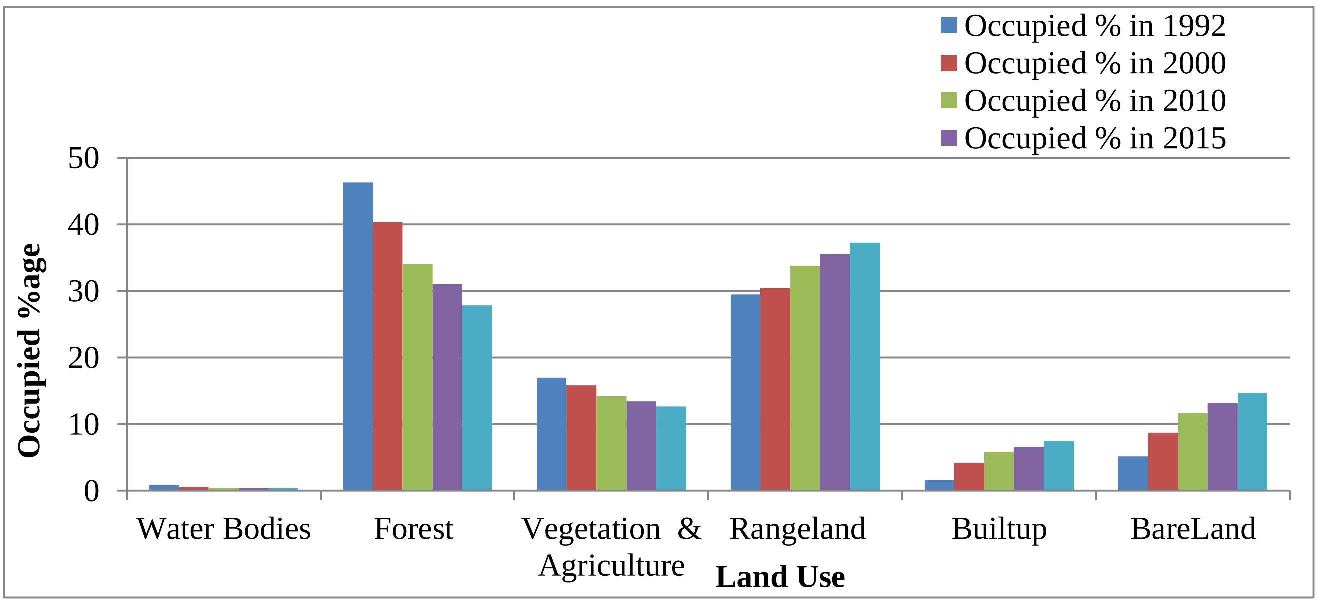

Fig-4.26 Future Land Use Change Prediction for Simly Catchment

4.4 Effect of Land Use Pattern on Rainfall- Runoff Relationship of Simly Catchment

The hydrology of a region is controlled by rainfall. To analyze the rainfall and runoff relationship of the study area average rainfall and runoff data for the period 1983-2012 was plotted on annual and monthly basis. From **Figure 4.27** it is shown that with the increase of rainfall runoff is also increasing and from 1998 it can be observed that due to land use changes runoff increased according the increase in rainfall. Similarly it can be observed in **Figure 4.28** that rainfall and runoff values were high during monsoon months i.e. July, August and September.

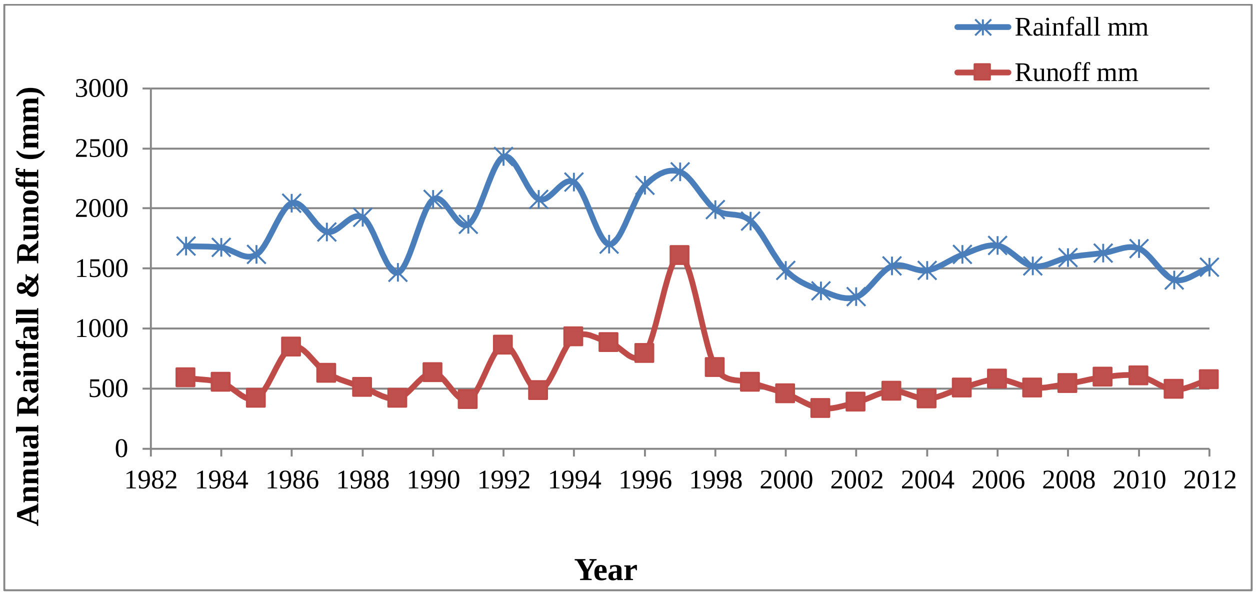

Fig-4.27 Annual Rainfall-Runoff for Simly Catchment (1983-2012)

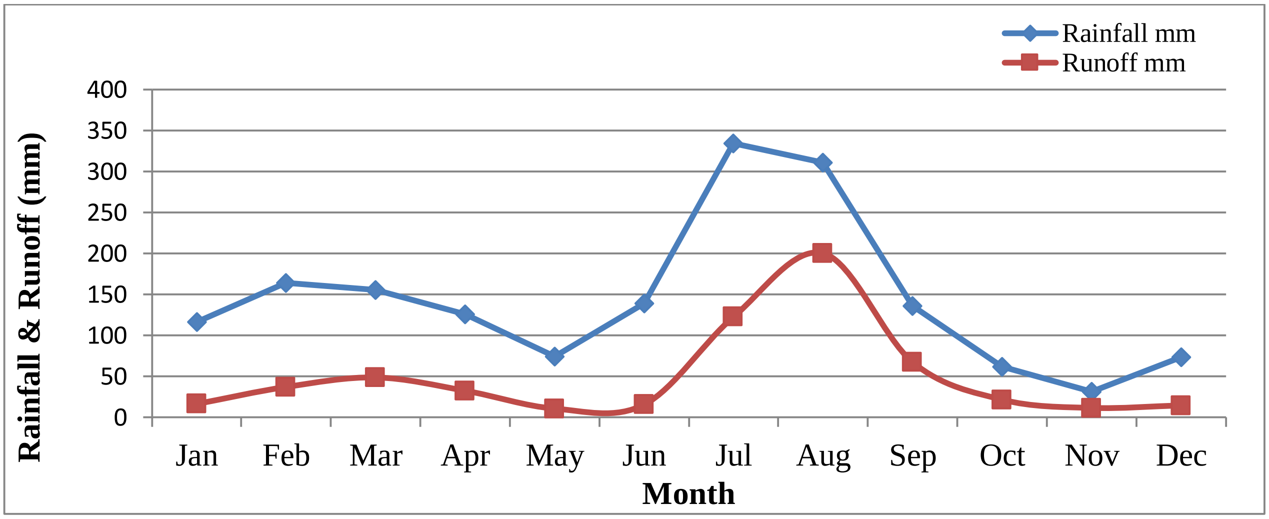

Fig-4.28 Average Monthly Rainfall & Runoff for Simly Catchment (1983-2012)

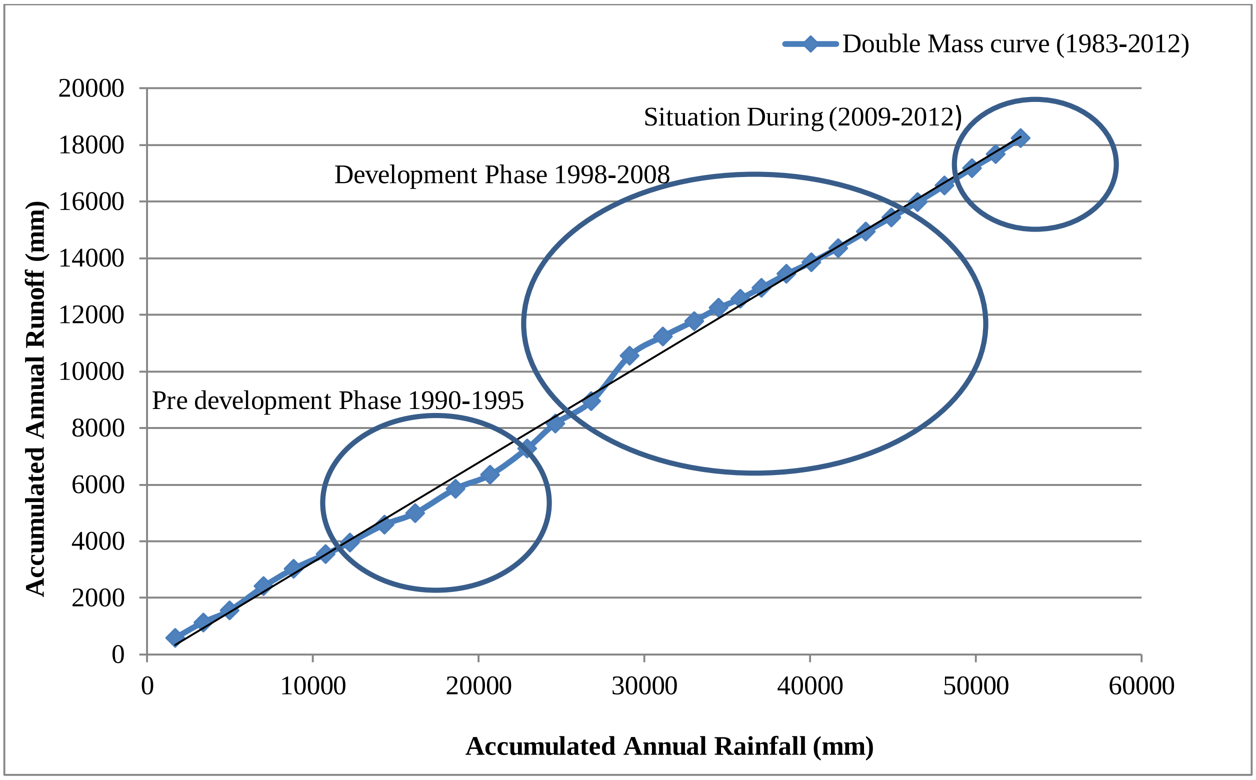

Fig-4.29 Annual Double Mass Curve of Simly Catchment (1983-2012)

The major development activities in the catchment area started from 1998 in which Islamabad Murree carriage way was constructed and this project completed in 2008. Nearly 19 km section runs through the catchment area of Soan River upstream of the Simly reservoir. Similarly over 10 million cubic feet earth/excavated material dumped along Kurang and Soan Rivers is silting up in Rawal and Simly reservoirs. Large scale cutting of trees for the construction of the said highway is also causing environmental impacts and soil loss.

To check the land use change effects double mass curve of rainfall- runoff were plotted for annual and monsoon months, which are shown in **Figure 4.29, 4.30, 4.31, 4.32 and 4.33.** From these figures it can be seen that with the increase in rainfall runoff is also increasing and this trend can be clearly observed in period of 1998-2008 which was the major development period also it can be seen that in during 2009-2012 there was increase in trend of runoff.

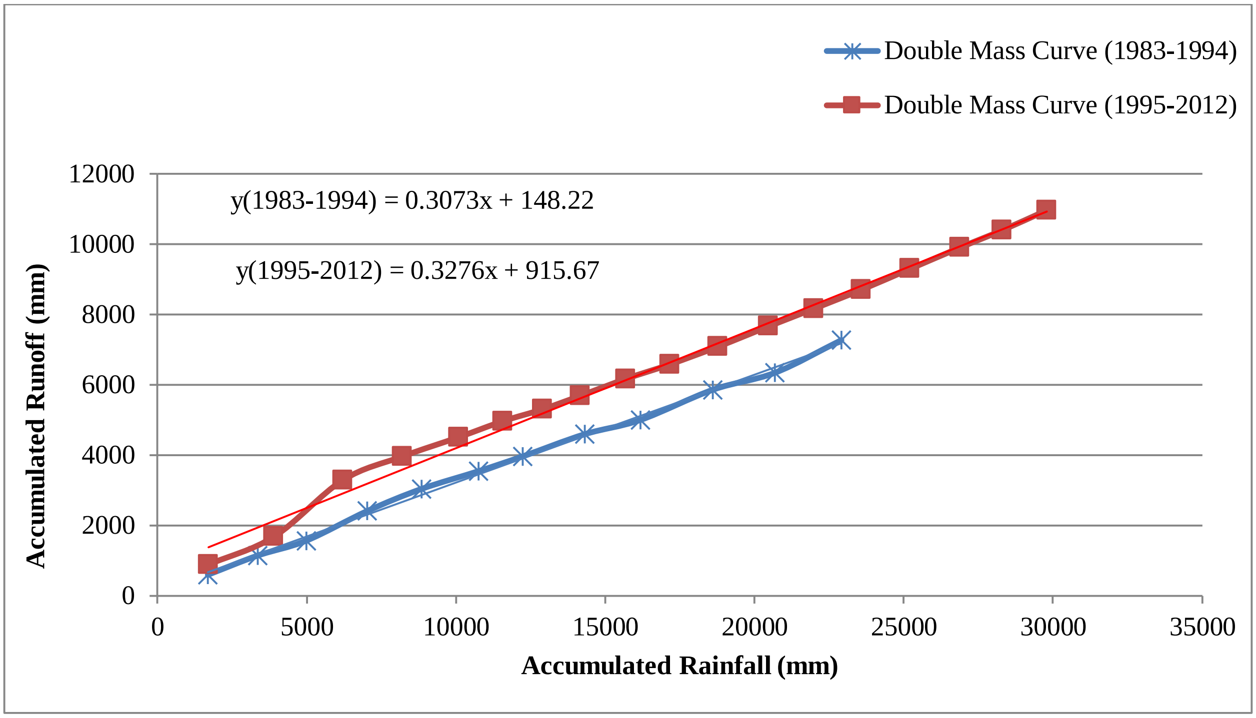

Fig-4.30 Double Mass Curve of Annual Rainfall & Runoff for Simly Catchment 1983-1994 & 1995-2012

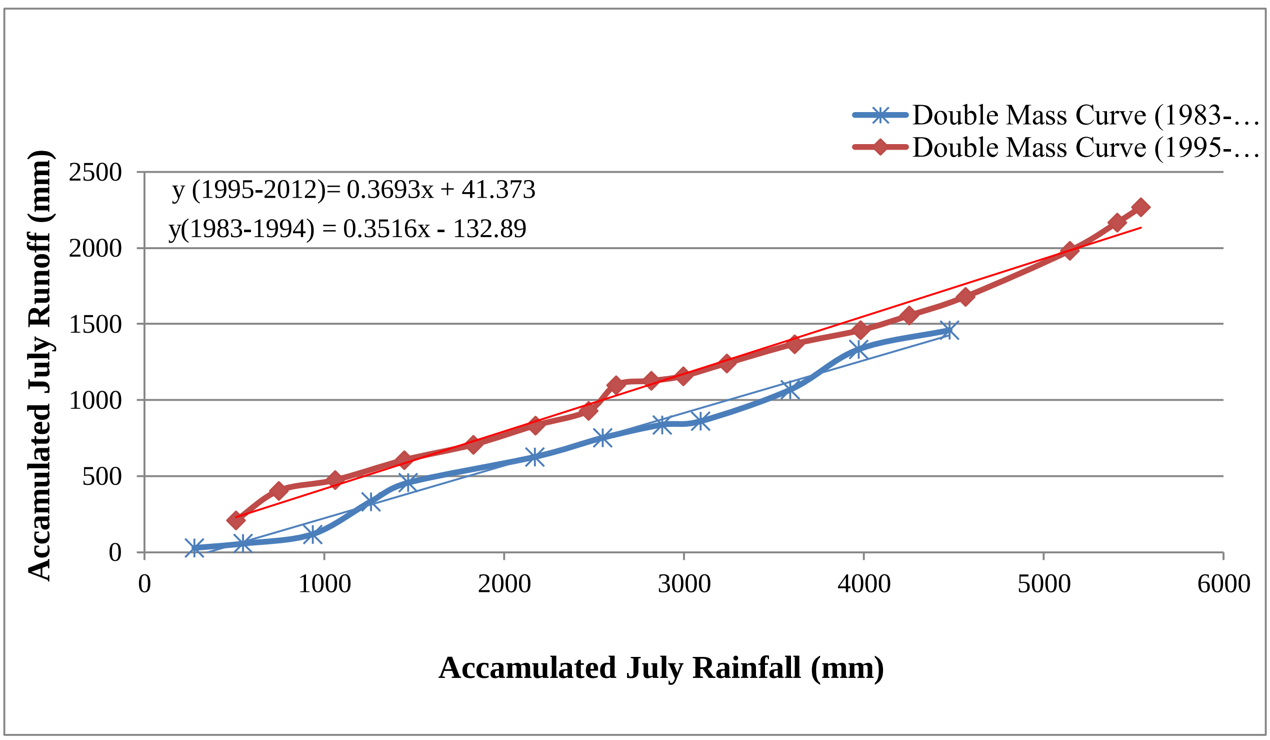

Fig-4.31 Double Mass Curve of July Rainfall & Runoff for Simly Catchment for 1983-1995 & 1996-2012

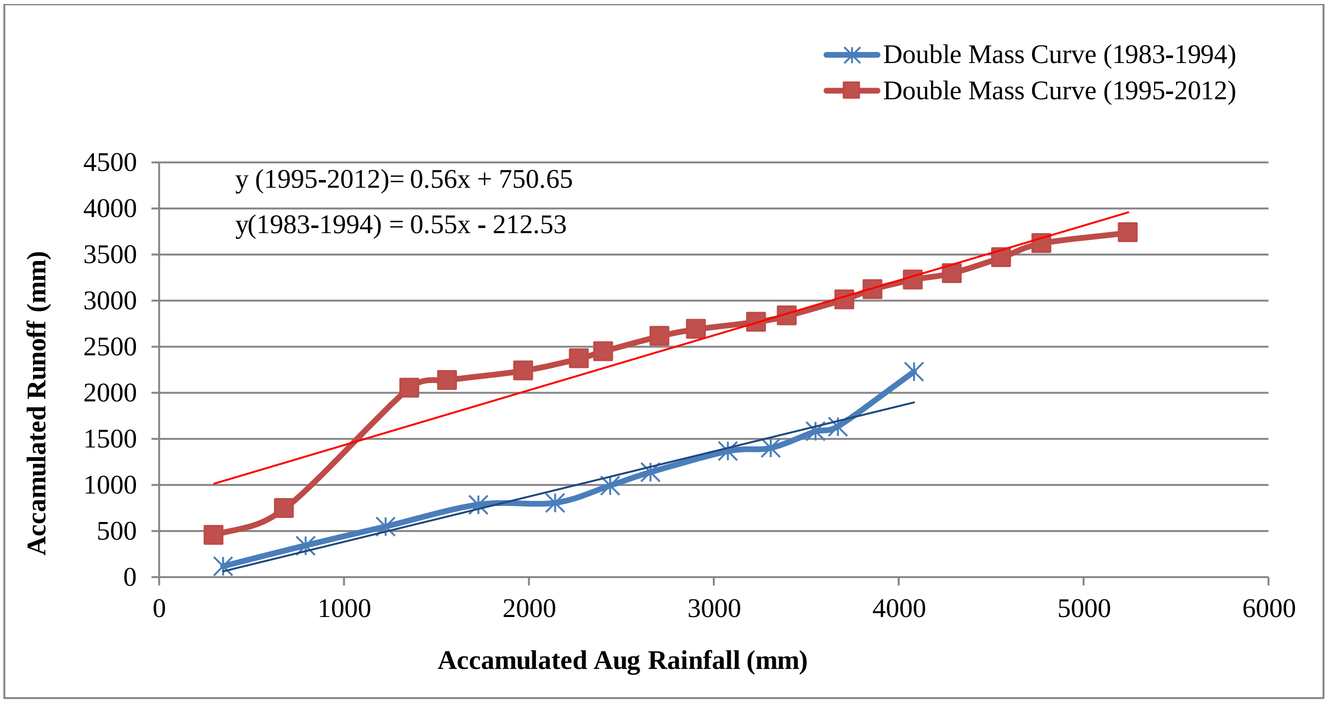

Fig-4.32 Double Mass Curve of Aug Rainfall & Runoff for Simly Catchment for 1983-1995 & 1996-2012

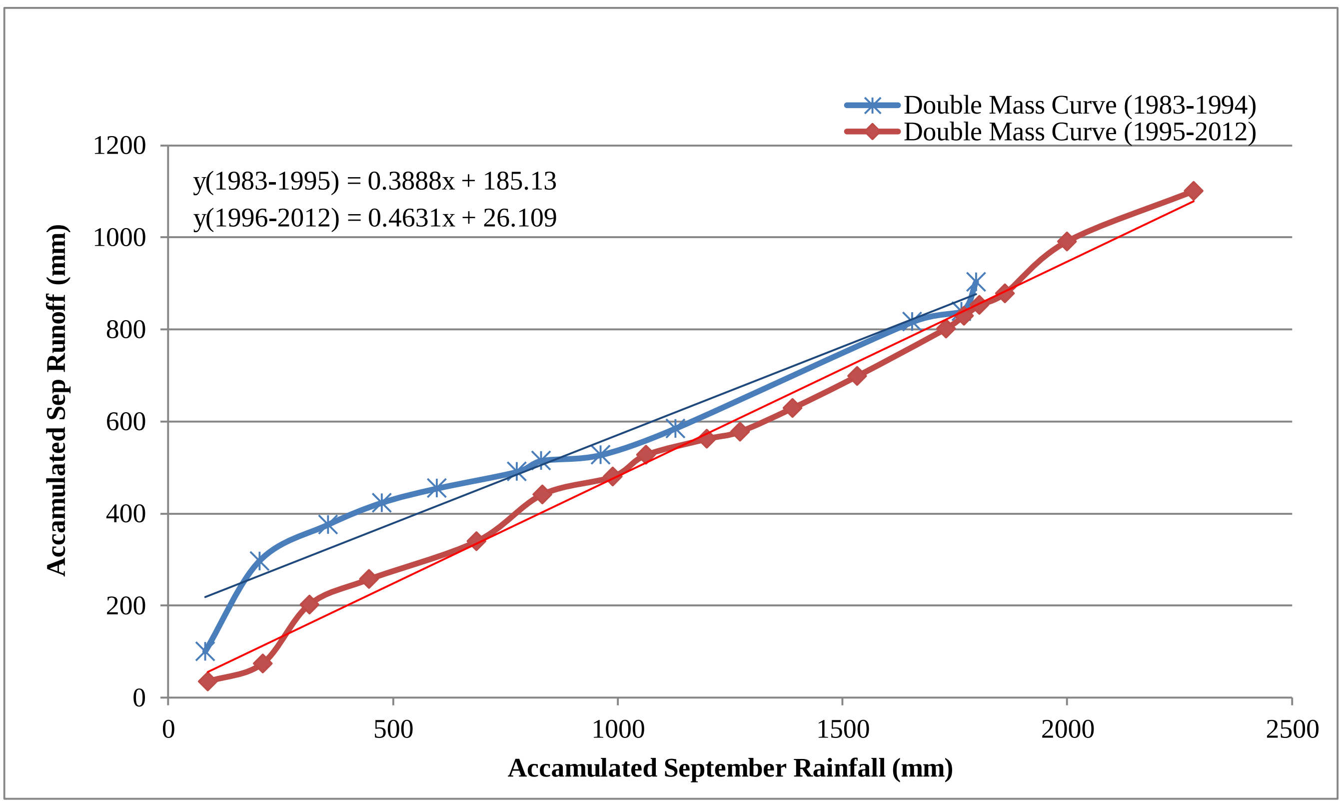

Fig-4.33 Double Mass Curve of Sep Rainfall & Runoff for Simly Catchment for 1983-1995 & 1996-2012

Annual Runoff-Sedimentation Relationship for Simly Catchment

The biggest problem being faced in the Simly basin is the accelerated soil erosion causing sedimentation in the Simly Dam reservoir. As the survey for sediment assessment is carried out after every 5 year by relevant organization, therefore for yearly assessment of runoff-sedimentation relation the sediment data was calculated using Khosla's method. The earlier designs of reservoirs in India were based on the annual silting rate of 0.036Mm^3 per 100 sq. km of catchment area as suggested by Dr. Khosla the famous Indian researcher (Sharma, 1992). When sedimentation rate as proposed by Dr. Khosla was applied to the Simly Dam the value comes out to be

Silting Rate = 0.036 X 10^6 X 152.79/100 = 55006 m^3/year

=1942829 ft$^{3/}$year

= 44.60 Acre-Feet/year

The runoff-sedimentation relationship for Simly catchment using relevant organization data is given in **Figure 4.34** and its Double Mass Curve is given in **Figure 4.35** It can be seen in the figures that sedimentation is increasing with the increase in runoff and in double mass curve regression coefficients of linear equation shows more value of slope for period 1995-2005 . Similarly the runoff-sedimentation relationship for Rawal catchment using Khosla method is given in **Figure 4.36** and its Double Mass Curve is given in **Figure 4.37.** It can be seen in the figures that sedimentation is increasing with the increase in runoff and in double mass curve regression equation coefficients shows more value of slope for period 1995-2005.

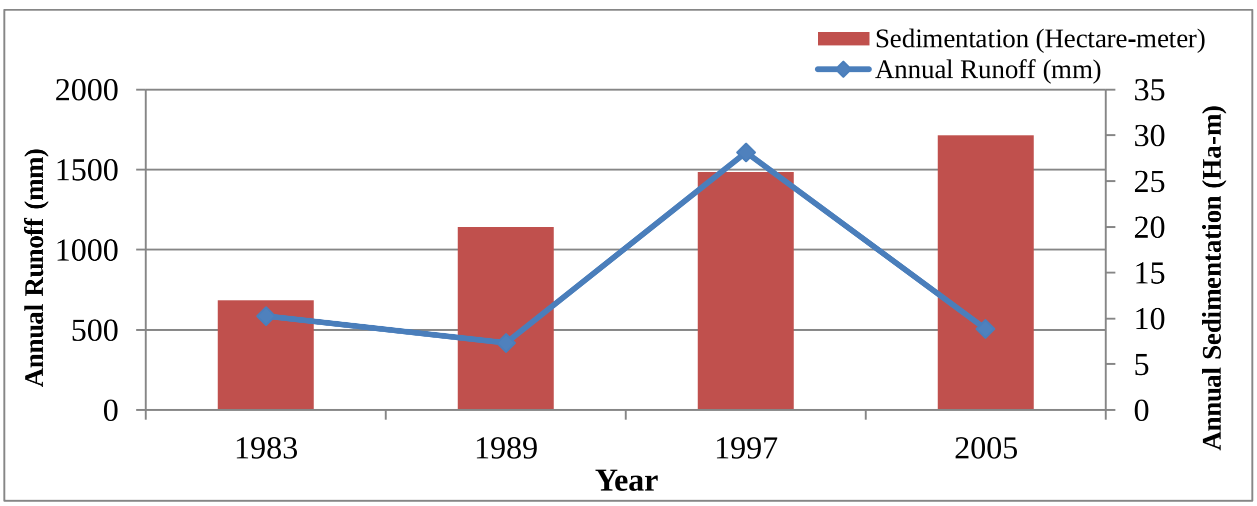

Fig-4.34 Annual Runoff & Sedimentation in Simly Catchment (1983-2008)

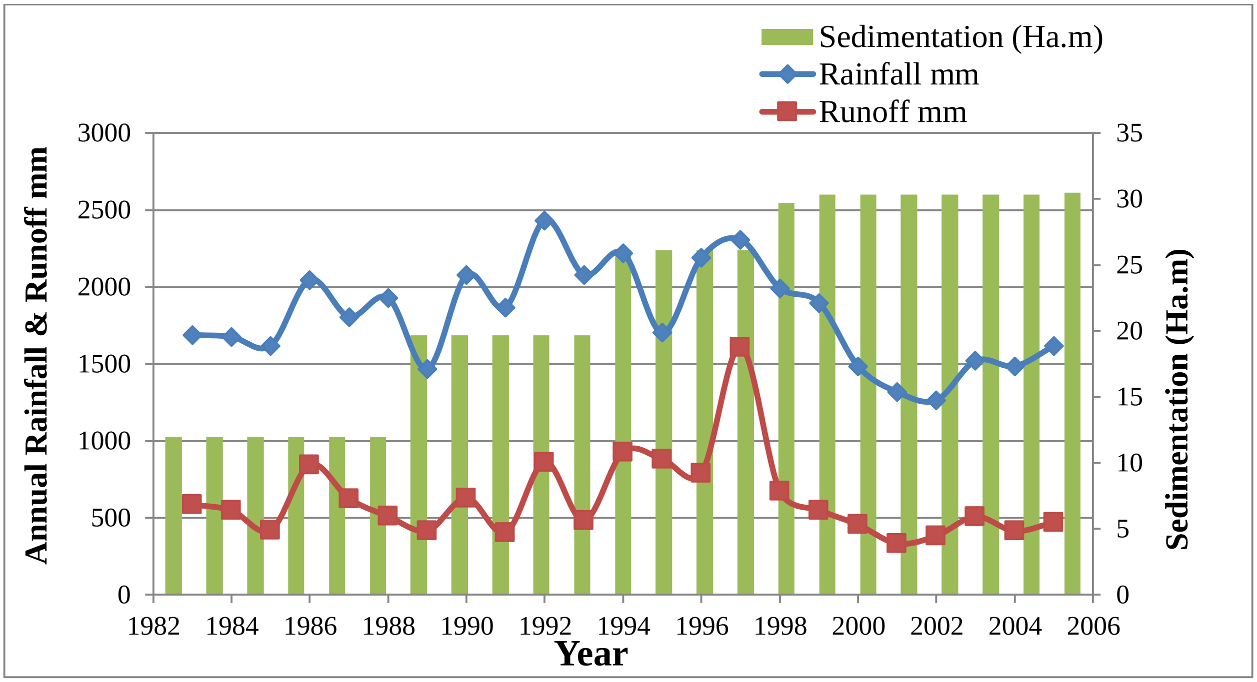

Fig-4.35 Annual Runoff & Sedimentation in Simly Catchment (1983-2008)

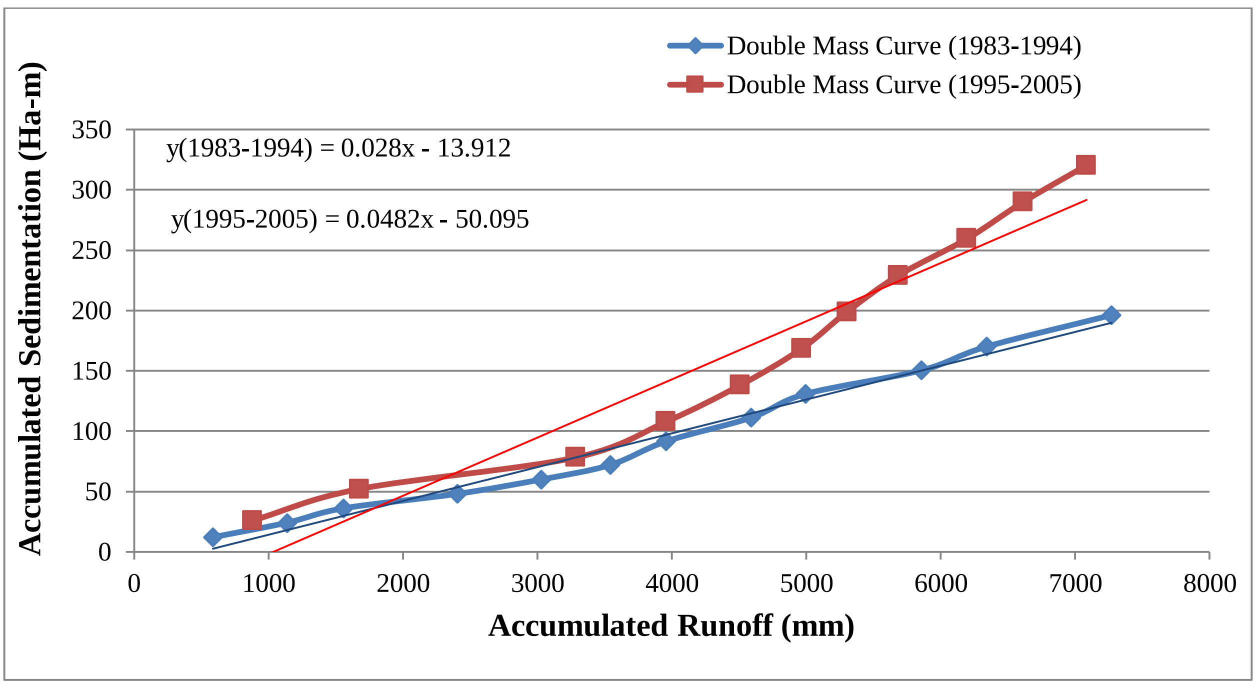

Fig-4.36 Double Mass Curve Annual Runoff & Sedimentation for Simly Catchment (1983-1994, 1995-2005)

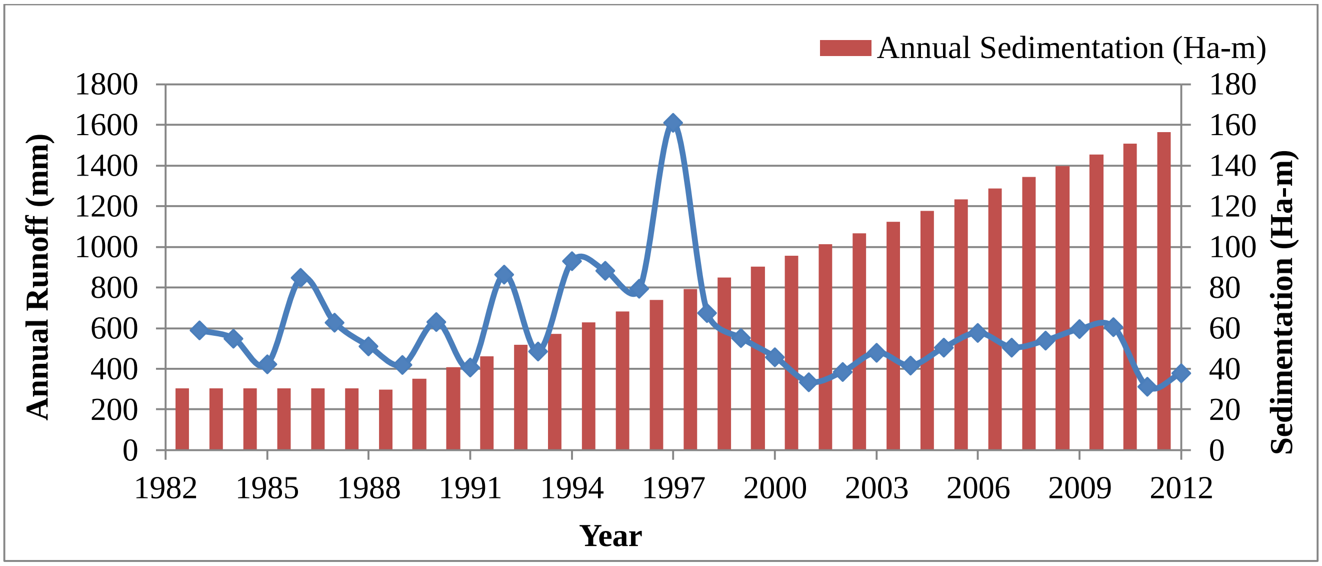

Fig-4.37 Annual Runoff & Sedimentation for Simly Catchment 1983-2012 using Khosla's Method

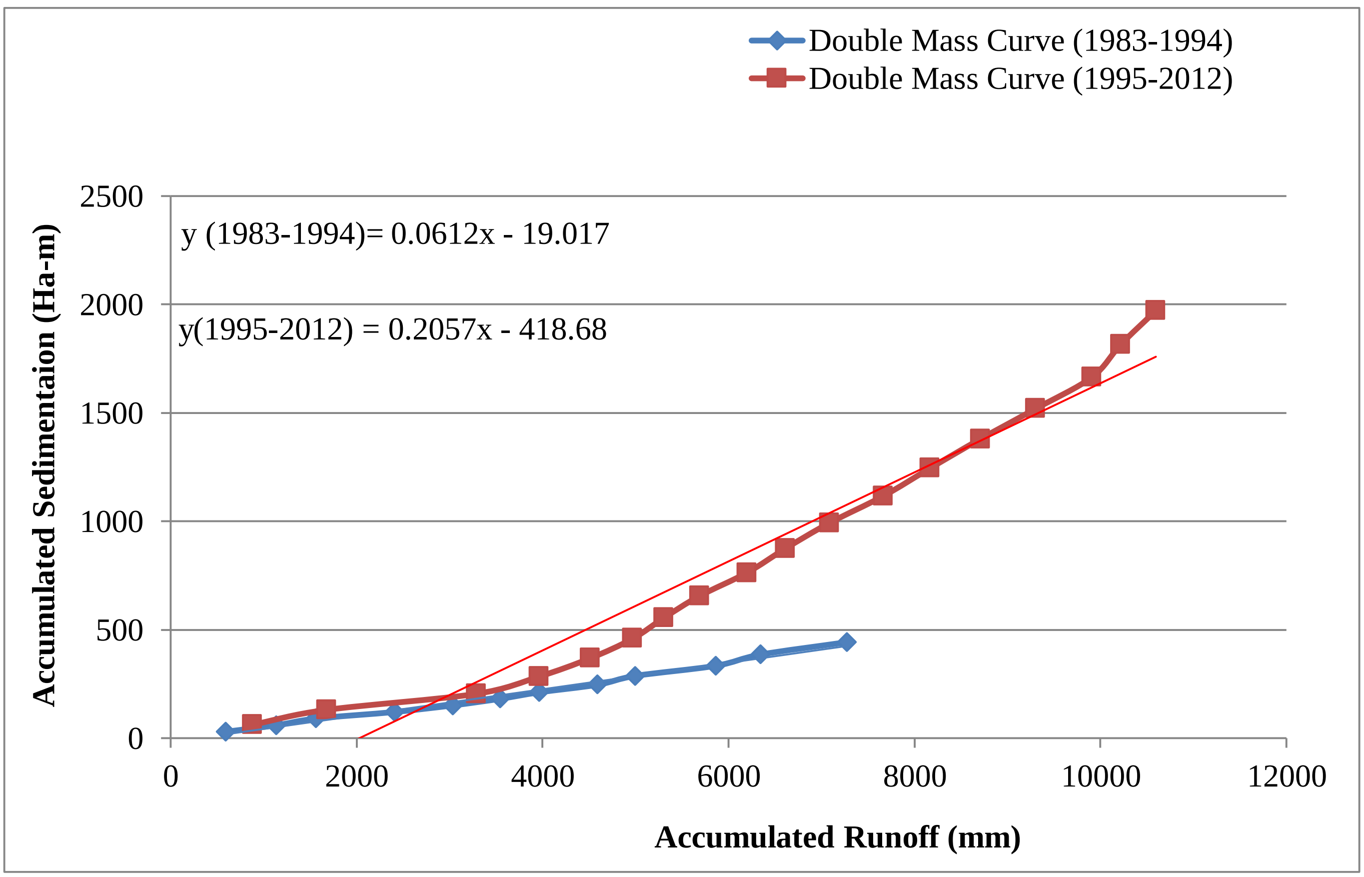

Fig-4.38 Double Mass Curve Annual Runoff & Sedimentation for Simly Catchment (1983-1994, 1995-2012) using Khosla's Method)

CHAPTER 5

CONCLUSIONS & RECOMENDATIONS

5.1 CONCLUSIONS

In this study remote sensing data and GIS were used for evaluation of land use changes in Rawal Dam catchment and Simly Dam catchment. Use of Satellite data and ERDAS & ARCMAP were found very helpful tools for evaluation of land use change. Double Mass Curve and its trend curve was used to evaluate land use pattern effect on Rainfall-Runoff-Relationship and runoff-sedimentation relationship. Following conclusions are drawn from the results obtained.

1. Land use changes turned the rainfall-runoff relationships in both Rawal and Simly Dam catchments. From Double Mass Curve analysis it can be concluded that the slope trend curves of annual and monthly rainfall-runoff mass curves in 1975-1994 are less than those in 1995-2012, which means more runoff occurred in both catchments for the period1995-2012.
2. Land use changes turned runoff-sedimentation relationships in both Rawal and Simly Dam catchments. From Double Mass Curve analysis it can be concluded that the slope trend curves of annual and monthly runoff-sedimentation mass curves in 1975-1994 are less as compared with trend curves in 1995-2012, which shows more sedimentation occurred in both catchments for the period 1995-2012.
3. For satellite imagery classification into 6 land cover classes i.e. forest, vegetation and agriculture, range land, built-up area, barren land and water bodies Isodata algorithm gave good results and ground Truthing with the unsupervised classification makes it possible to explain land use classes.
4. From the remote sensing analysis it has been concluded that from 1992-2010:
    a) 13.6 km^2 forest area decreased in Rawal dam catchment and 18.7 km^2 forest area decreased for Simly dam catchment.
    b) 37.4 km^2 vegetation and agriculture area decreased in Rawal catchment and 4.1 km^2 vegetation and agriculture area decreased for Simly dam catchment.

c) 28.3 km^2 range land area increased in Rawal catchment and 6.8 km^2 range land area increased for Simly dam catchment.

d) 16.6 km^2 built up area increased in Rawal dam catchment and 6.5 km^2 built up area increased for Simly dam catchment.

e) 8.5 km^2 barren land area increased in Rawal catchment and 10.1 km^2 barren land area increased for Simly dam catchment.

f) 2.4 km^2 water bodies' area decreased in Rawal dam catchment and 0.6 km^2 water bodies' area decreased for Simly dam catchment.

5.2 RECOMMENDATIONS

1. The catchment area of Rawal and Simly Dam has mountain ranges with different elevation due to which there is variation in rainfall pattern. The absence of glaciers in the subject catchments makes rainfall/runoff the primary source of recharging the both reservoirs. The installed meteorological stations are insufficient to monitor meteorological conditions therefore it is strongly needed to install more meteorological stations in both catchments.
2. There is no gauging station for flow measurement at Simly reservoir the flow is calculated using empirical relationship therefore it is strongly needed to install gauging station for flow measurement.
3. The yearly sediment data collection should be insured with prime focus on accurate data acquisition.
4. GIS and remote sensing should be used for watershed management.
5. It is recommended that Double Mass curve and remote sensing should be used to evaluate land use changes in similar and adjacent catchments i.e. Khanpur dam, because it is also used for drinking water supply for the twin cities of Rawalpindi and Islamabad.
6. Check Dams should be used to reduce sedimentation in both catchments and funds should be allocated for check Dams.

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APPENDIX A

METEOROLOGICAL DATA

Precipitation Data

Temperature Data

Monthly Precipitation Data in mm

Meteorological Station – Rawal Dam

Period: 1975-2012

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1975	37	65	72	37	33	30	78	380	85	0	0	0	817
1976	100	175	187	63	0	55	325	500	175	13	0	0	1593
1977	60	5	0	65	35	103	237	197	7	0	0	6	715
1978	20	0	70	13	2	115	60	625	90	0	50	0	1045
1979	70	43	250	25	20	25	125	430	40	5	20	15	1068
1980	73	71	98	3	10	125	407	215	60	20	10	0	1092
1981	124	62	147	91	43	6	220	263	73	5	7	0	1041
1982	0	70	210	200	88	15	70	272	8	37	60	8	1038
1983	99	65	103	282	15	12	100	195	90	55	0	0	1016
1984	0	75	50	5	5	140	266	475	73	0	0	22	1111
1985	20	5	10	5	9	15	265	80	40	55	0	175	679
1986	4	166	119	30	23	22	75	195	140	70	20	25	889
1987	0	55	40	28	92	52	42	228	10	75	0	0	622
1988	0	13	123	0	0	10	735	335	105	35	0	15	1371
1989	62	5	53	20	2	3	255	165	5	5	0	35	610
1990	25	87	108	58	0	30	92	403	95	10	3	117	1028
1991	4	42	43	72	14	40	222	86	56	0	0	15	594
1992	85	60	113	28	65	8	73	214	344	2	25	5	1022
1993	19	37	130	23	4	95	262	141	267	0	3	0	981
1994	25	34	19	43	0	92	700	525	178	0	0	45	1661
1995	21	39	83	51	18	13	650	361	23	50	35	20	1364
1996	45	108	125	40	38	95	78	364	98	63	0	0	1054
1997	25	5	49	170	61	28	214	449	250	52	30	30	1363
1998	44	282	103	153	29	54	353	354	162	22	0	0	1556
1999	99	36	70	0	13	42	260	223	223	0	25	0	991
2000	140	78	18	4	20	122	241	124	101	0	0	14	862
2001	0	0	29	6	72	216	1029	77	41	25	6	4	1505
2002	13	30	11	9	2	195	68	470	179	73	0	30	1080
2003	54	240	120	25	20	172	319	254	351	3	19	49	1626
2004	120	6	0	76	20	143	180	318	26	114	27	40	1070
2005	78	236	43	4	5	13	235	158	72	93	5	0	942
2006	46	25	40	25	53	99	700	389	13	13	7	62	1472
2007	0	106	195	24	61	198	149	470	200	0	12	6	1421
2008	128	47	24	99	4	176	468	183	90	48	17	77	1361
2009	62	70	54	110	23	10	56	168	32	10	13	14	622
2010	13	86	26	18	16	14	395	283	80	21	0	27	979
2011	4	95	55	73	12	100	356	230	124	31	5	0	1085
2012	55	59	24	5	5	4	150	269	171	1	4	67	814

Meteorological Station – Murree

Period: 1975-2012

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1974	138	249	22	48	79	228	350	151	68	1	0	192	1526
1975	63	175	113	113	75	151	399	445	101	0	15	17	1665
1976	265	345	176	129	55	55	405	459	221	102	0	14	2226
1977	257	61	16	209	161	201	524	262	222	255	58	66	2290
1978	295	136	170	64	53	219	566	406	286	10	90	10	2305
1979	156	109	227	60	123	84	249	310	147	36	104	44	1647
1980	135	170	212	24	24	319	351	282	146	47	12	47	1769
1981	240	135	310	135	197	96	457	113	113	40	4	0	1840
1982	241	151	280	208	128	84	206	337	19	61	83	78	1876
1983	311	59	180	216	88	62	278	345	82	57	3	9	1688
1984	4	307	96	118	46	184	270	448	121	3	37	43	1676
1985	122	28	65	80	50	56	388	432	152	93	21	134	1619
1986	53	98	214	129	101	157	324	504	120	125	107	119	2048
1987	28	134	183	127	220	123	208	415	123	239	0	8	1807
1988	40	101	249	34	23	141	704	295	178	58	1	103	1928
1989	63	42	220	81	45	81	377	219	54	85	38	160	1467
1990	60	211	299	127	35	80	330	419	132	24	9	353	2077
1991	51	360	196	333	89	87	214	234	167	11	11	117	1869
1992	270	171	343	104	156	42	500	241	526	14	54	14	2434
1993	270	267	386	41	68	325	379	119	110	34	79	1	2079
1994	91	160	120	213	77	92	507	413	32	127	1	388	2220
1995	110	111	28	192	110	80	510	298	88	55	57	63	1703
1996	196	210	321	155	105	218	238	381	122	188	25	34	2192
1997	147	40	150	294	150	249	314	677	104	78	62	44	2307
1998	94	397	220	347	62	87	384	206	134	57	4	0	1993
1999	237	132	221	13	59	67	384	412	239	35	98	0	1897
2000	207	152	67	20	48	177	344	299	146	0	2	22	1484
2001	15	13	79	121	83	342	295	134	157	17	61	2	1317
2002	56	128	120	26	36	315	154	304	74	20	3	29	1264
2003	48	400	178	120	34	100	196	196	135	9	33	70	1521
2004	233	68	6	164	101	105	176	327	74	165	40	28	1485
2005	212	387	193	32	62	98	244	165	116	92	16	0	1616
2006	192	80	53	46	55	139	376	311	144	50	74	172	1692
2007	5	176	236	33	63	243	368	151	198	7	18	23	1521
2008	240	119	30	133	68	218	272	219	40	89	42	124	1594
2009	28	N/A	N/A	N/A	N/A	N/A	312	210	35	80	N/A	N/A	1631
2010	29	255	83	105	112	111	579	269	57	46	2	20	1668
2011	16	197	86	231	33	145	265	216	138	58	21	1	1407
2012	84	123	51	131	42	49	129	469	282	20	9	120	1510

Meteorological Station –Average of Rawal Dam and Murree Station

Period: 1975-2012

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1975	50	120	93	75	54	90	238	412	93	0	8	9	1241
1976	183	260	181	96	28	55	365	480	198	58	0	7	1910
1977	159	33	8	137	98	152	380	230	114	128	29	36	1502
1978	158	68	120	38	27	167	313	515	188	5	70	5	1675
1979	113	76	239	42	71	55	187	370	93	20	62	30	1358
1980	104	121	155	14	17	222	379	249	103	34	11	24	1431
1981	182	99	229	113	120	51	339	188	93	23	5	0	1440
1982	121	110	245	204	108	50	138	305	13	49	71	43	1457
1983	205	62	141	249	51	37	189	270	86	56	2	4	1352
1984	2	191	73	61	26	162	268	462	97	1	18	33	1394
1985	71	17	37	42	29	36	326	256	96	74	10	155	1149
1986	28	132	166	80	62	89	199	349	130	97	63	72	1468
1987	14	94	111	77	156	87	125	321	67	157	0	4	1214
1988	20	57	186	17	12	76	720	315	141	47	0	59	1650
1989	62	24	136	51	24	42	316	192	30	45	19	98	1039
1990	43	149	203	92	18	55	211	411	113	17	6	235	1553
1991	28	201	119	202	52	63	218	160	112	5	5	66	1231
1992	178	115	228	66	111	25	287	228	435	8	40	10	1728
1993	145	152	258	32	36	210	320	130	189	17	41	1	1530
1994	58	97	70	128	38	92	604	469	105	63	1	216	1940
1995	66	75	56	122	64	47	580	329	55	53	46	41	1533
1996	120	159	223	98	72	156	158	373	110	126	13	17	1623
1997	86	22	99	232	106	138	264	563	177	65	46	37	1835
1998	69	340	162	250	46	71	369	280	148	40	2	0	1774
1999	168	84	146	6	36	55	322	317	231	18	62	0	1444
2000	174	115	43	12	34	150	292	211	124	0	1	18	1173
2001	7	6	54	63	77	279	662	105	99	21	33	3	1411
2002	35	79	65	17	19	255	111	387	127	46	2	29	1172
2003	51	320	149	73	27	136	258	225	243	6	26	60	1573
2004	176	37	3	120	61	124	178	322	50	139	34	34	1278
2005	145	312	118	18	34	56	239	161	94	93	10	0	1279
2006	119	53	47	36	54	119	538	350	78	32	40	117	1582
2007	3	141	216	29	62	220	259	311	199	4	15	14	1471
2008	184	83	27	116	36	197	370	201	65	69	30	100	1477
2009	78	84	94	144	27	53	184	189	34	14	14	12	928
2010	21	171	55	62	64	63	487	276	69	34	1	24	1324
2011	10	146	71	152	23	123	311	223	131	45	13	1	1246
2012	70	91	38	68	23	27	140	369	227	11	7	94	1162

Average Maximum Temperature of Islamabad in °C

Period: 1975-2012

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1975	17.1	17.5	23.1	30.5	35.5	38.1	34.2	33.1	32.3	32.7	25.3	20.4	28.3
1976	17.6	17.3	22.0	28.8	-99.9	38.1	34.6	30.7	32.7	-99.9	26.7	20.2	5.8
1977	16.0	21.4	29.1	30.1	33.3	36.7	32.4	33.2	33.9	31.0	26.7	20.7	28.7
1978	16.4	18.9	21.6	31.3	39.8	39.5	32.0	32.1	33.1	30.8	23.2	21.5	28.3
1979	18.5	19.0	21.5	31.5	33.3	39.3	34.6	33.5	33.2	31.7	26.1	20.3	28.5
1980	21.2	1.7	21.3	32.6	38.4	38.5	34.2	34.3	33.9	31.9	26.1	21.2	27.9
1981	16.8	19.3	22.4	31.3	36.2	34.6	34.8	-99.9	34.4	31.0	25.6	21.6	17.3
1982	18.2	16.6	20.2	28.9	32.0	38.4	38.4	33.1	35.0	31.6	25.0	18.7	28.0
1983	17.7	19.2	22.2	25.4	33.4	36.9	35.2	33.3	34.0	30.0	27.3	20.5	27.9
1984	18.9	17.7	27.3	30.3	39.8	39.8	32.7	33.3	32.4	32.1	25.5	19.7	29.1
1985	17.6	22.8	28.4	31.7	37.3	40.7	34.6	34.2	34.6	30.0	25.7	5.6	28.6
1986	18.6	16.9	22.1	29.9	34.0	37.9	34.6	33.3	35.0	30.6	25.8	18.8	28.1
1987	20.4	20.7	23.1	31.2	31.3	38.3	39.2	36.1	36.2	30.9	27.7	22.1	29.8
1988	19.6	21.5	23.2	32.9	38.6	38.6	33.0	33.9	35.3	31.0	27.0	20.4	29.6
1989	17.1	18.7	23.3	29.3	36.5	38.9	35.7	33.4	34.9	32.4	25.5	19.7	28.8
1990	18.8	18.3	22.3	28.7	37.5	39.5	35.1	32.8	33.0	29.6	26.1	18.5	28.3
1991	16.8	18.3	22.9	26.4	33.3	37.9	36.8	33.4	31.7	29.6	25.0	19.3	27.6
1992	16.4	18.1	22.2	28.1	32.9	38.4	34.6	33.3	32.2	-99.9	-99.9	20.3	6.4
1993	15.9	22.4	21.5	30.8	37.1	38.1	34.4	35.4	-99.9	31.7	27.1	22.4	18.1
1994	18.2	17.7	26.0	28.7	35.8	40.1	33.3	32.4	-99.9	29.8	25.8	18.2	17.2
1995	17.5	19.3	23.0	26.5	36.2	40.7	33.1	33.0	34.1	31.1	25.9	18.5	28.2
1996	17.2	20.8	24.3	30.9	-99.9	36.1	35.9	32.6	34.0	29.7	25.5	21.1	17.3
1997	18.3	20.7	23.8	26.7	31.6	36.3	35.0	32.7	33.1	26.9	23.4	17.0	27.1
1998	17.0	18.7	22.4	30.9	35.8	38.7	35.4	33.6	33.8	31.3	27.9	22.0	29.0
1999	16.6	20.6	24.6	34.1	37.9	39.1	36.1	34.2	34.5	31.9	25.2	22.6	29.8
2000	17.6	18.6	25.0	33.7	39.7	39.3	34.8	34.0	33.0	32.9	26.5	22.0	29.7
2001	19.1	23.2	28.4	31.8	39.4	36.3	33.7	34.8	34.9	32.3	27.0	21.9	30.2
2002	19.8	20.4	27.4	33.1	39.1	39.0	39.0	33.6	31.6	31.0	26.3	20.6	30.1
2003	19.6	19.2	24.2	31.5	35.6	39.4	34.9	34.0	32.7	30.5	24.2	19.4	28.8
2004	17.2	21.5	30.1	33.2	36.4	36.7	36.7	33.6	34.5	27.9	25.4	19.7	29.4
2005	15.8	16.0	23.7	30.0	33.6	40.0	34.4	34.5	34.5	31.2	25.5	21.0	28.3
2006	17.7	24.7	25.0	32.6	39.1	37.8	34.5	33.0	33.5	31.3	24.1	18.1	29.3
2007	17.2	20.2	21.2	32.7	37.1	37.6	34.7	34.6	33.5	31.9	27.5	20.1	29.0
2008	15.2	19.5	29.1	28.9	35.5	34.5	33.8	33.2	32.6	31.2	26.4	21.6	28.5
2009	19.3	21.0	25.4	29.4	35.8	37.2	33.8	34.2	34.2	14.6	25.1	21.1	27.6
2010	21.5	20.1	29.0	33.9	36.4	38.2	35.7	32.8	32.5	26.1	27.7	20.9	29.6
2011	17.7	18.6	26.1	29.1	37.7	38.0	34.0	33.5	33.4	30.7	26.6	21.8	28.9
2012	16.8	17.7	25.2	30.8	35.4	41.1	34.9	34.0	26.7	28.2	24.6	19.5	27.9

Average Minimum Temperature of Islamabad in °C

Period: 1975-2012

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1975	3.6	5.0	8.9	15.6	20.4	23.2	23.6	23.9	21.0	14.5	5.6	3.5	14.1
1976	3.8	6.3	9.7	14.7	0.0	23.1	25.1	22.5	20.8	14.1	6.7	2.6	12.4
1977	2.9	4.0	10.8	16.4	19.1	23.4	23.6	23.5	21.0	15.6	9.8	4.5	14.6
1978	2.2	5.8	9.2	16.1	22.3	25.1	24.1	23.4	21.1	14.7	8.7	3.3	14.7
1979	2.9	5.5	8.7	16.9	18.0	22.9	25.3	22.9	19.1	14.8	8.8	4.6	14.2
1980	4.0	6.0	9.6	16.1	21.2	23.7	23.8	22.7	19.7	14.4	7.7	4.0	14.4
1981	3.7	6.6	7.9	15.3	19.6	22.2	23.7	0.0	18.8	12.3	6.5	2.0	11.5
1982	2.9	4.6	8.0	14.4	18.1	21.3	23.9	23.1	19.2	14.3	7.9	4.4	13.5
1983	2.3	4.7	8.3	13.3	18.6	21.9	23.0	24.3	22.4	13.0	6.6	2.7	13.4
1984	0.7	3.3	11.5	14.5	20.7	25.6	23.6	24.1	19.1	11.5	7.0	2.5	13.7
1985	2.8	4.8	11.0	16.0	20.1	24.0	24.3	23.5	21.0	12.9	7.2	19.1	15.5
1986	1.3	4.5	9.3	14.1	17.9	21.7	24.3	23.4	20.5	14.6	9.1	4.2	13.7
1987	2.9	5.4	11.1	14.6	17.6	21.5	24.2	24.3	21.9	15.0	7.4	4.0	14.2
1988	4.8	6.6	10.6	16.7	21.2	23.8	24.4	23.2	21.8	13.8	8.4	4.6	15.0
1989	2.5	3.9	10.2	13.5	19.5	23.7	24.1	23.0	21.1	14.3	8.9	5.4	14.2
1990	5.4	6.5	9.4	14.4	21.8	25.1	24.2	23.5	22.4	14.0	8.4	4.9	15.0
1991	2.9	6.1	10.2	13.9	19.3	22.5	24.7	23.6	21.4	12.7	7.5	5.7	14.2
1992	5.2	5.5	9.9	14.6	18.9	23.4	24.0	24.2	20.5	0.0	0.0	5.5	12.6
1993	3.0	7.4	8.8	15.9	21.5	22.8	24.0	23.7	0.0	13.1	8.5	3.7	12.7
1994	4.4	5.4	11.5	14.0	20.8	24.7	24.5	24.2	0.0	13.6	8.7	5.0	13.1
1995	2.4	5.9	9.5	14.2	19.7	23.6	24.3	24.0	20.9	15.2	7.5	3.7	14.2
1996	2.8	6.6	11.7	15.8	19.2	23.4	24.5	23.4	21.8	13.7	7.3	2.2	14.4
1997	2.0	4.7	10.2	14.3	17.7	23.0	25.5	23.6	22.1	15.1	8.3	5.2	14.3
1998	3.4	6.2	9.8	16.4	20.9	23.4	24.5	23.7	21.9	15.9	8.1	3.1	14.8
1999	4.8	7.8	10.5	16.4	21.2	24.7	24.8	24.0	22.8	15.2	9.7	3.6	15.5
2000	4.0	5.0	10.3	17.2	24.6	25.6	24.7	23.3	21.0	15.9	9.7	4.4	15.5
2001	2.1	5.9	11.3	17.4	23.9	24.9	24.2	24.8	21.0	16.0	8.5	5.1	15.4
2002	3.2	5.7	11.7	18.0	23.1	25.2	25.6	24.8	19.8	15.8	9.3	5.3	15.6
2003	2.0	6.5	11.3	16.8	20.0	24.5	24.4	23.8	22.0	14.1	8.0	5.3	14.9
2004	5.0	6.2	12.8	18.3	20.7	23.6	25.0	23.0	20.6	14.2	8.8	5.5	15.3
2005	2.9	6.2	11.7	14.6	19.2	24.9	24.7	23.5	22.1	15.2	7.7	2.0	14.6
2006	3.8	9.9	11.4	16.2	23.7	23.8	24.9	24.2	21.0	16.6	10.7	5.5	16.0
2007	2.8	7.9	10.6	18.1	21.9	25.1	23.8	23.7	21.3	13.7	8.7	4.1	15.1
2008	1.8	5.4	13.8	16.6	22.6	24.8	24.7	24.2	20.8	16.9	9.0	4.1	15.4
2009	4.8	7.1	10.2	14.0	18.3	21.4	25.1	24.2	21.4	12.6	7.7	4.7	14.3
2010	2.9	7.0	12.6	16.9	20.5	22.5	24.5	24.4	20.7	15.4	8.0	1.7	14.8
2011	1.5	5.8	10.6	14.1	21.1	24.3	23.6	23.9	21.5	14.4	9.7	2.3	14.4
2012	2.9	4.9	10.5	18.2	21.4	25.3	26.8	23.2	21.7	14.7	9.5	6.0	15.4

Average Maximum Temp of Murree in °C

Period: 1975-2012

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1975	6.3	6.1	11.2	17.8	21.6	23.7	20.4	20.4	19.7	20.2	14.6	10.9	16.1
1976	7.7	6.1	20.3	16.5	21.9	23.7	21.7	19.4	19.9	18.5	15.9	9.8	16.8
1977	6.3	6.1	11.2	17.8	21.6	23.7	20.4	20.4	19.9	18.5	0.0	9.6	14.6
1978	0.7	6.6	8.7	18.0	25.7	2.6	20.0	20.8	19.9	19.1	12.6	13.0	14.0
1979	8.6	2.9	9.2	18.9	18.6	24.5	21.5	20.7	19.5	0.0	0.0	9.6	12.9
1980	6.4	7.5	8.8	19.2	24.0	24.0	20.8	21.2	20.3	18.4	14.3	11.5	16.4
1981	6.0	7.9	10.0	18.5	21.9	24.3	21.0	21.4	20.8	17.9	14.4	10.5	16.2
1982	7.4	4.2	7.5	15.4	18.0	23.4	23.3	21.0	21.4	17.7	13.0	8.3	15.1
1983	7.1	6.7	9.1	13.5	18.9	22.6	21.5	21.0	21.2	17.7	16.1	10.1	15.5
1984	7.4	5.8	15.7	17.0	24.8	25.2	20.0	20.5	19.8	19.8	14.0	9.5	16.6
1985	6.6	12.0	15.5	17.4	22.6	26.1	16.8	21.9	21.3	20.5	17.8	14.8	17.8
1986	9.2	7.5	9.7	16.9	19.4	23.7	21.4	20.9	20.2	17.1	14.1	9.0	15.8
1987	6.3	9.1	11.4	17.8	13.1	19.3	24.2	22.4	22.4	17.7	17.3	14.6	16.3
1988	9.3	10.5	11.0	19.6	24.8	24.3	20.6	20.9	20.5	19.2	16.2	11.3	17.4
1989	6.7	5.9	11.0	16.9	23.0	25.7	23.3	21.5	22.5	19.7	14.1	10.4	16.7
1990	10.6	7.8	11.3	17.0	24.5	26.4	23.4	22.2	22.2	19.2	17.1	9.7	17.6
1991	7.5	7.7	12.6	15.5	21.5	26.2	25.6	22.8	21.0	19.8	15.6	0.0	16.3
1992	7.7	8.4	10.6	17.6	20.8	26.0	22.3	18.3	21.6	19.5	16.5	13.3	16.9
1993	6.1	12.8	10.4	19.3	25.4	25.9	22.7	24.1	21.2	21.1	17.4	14.8	18.4
1994	8.5	7.6	15.7	16.6	23.9	28.0	22.5	22.4	23.1	20.0	17.6	9.9	18.0
1995	7.8	9.5	12.6	16.1	24.1	28.9	22.7	22.3	23.0	20.3	17.3	9.2	17.8
1996	7.1	10.2	13.6	19.7	22.0	24.8	23.9	22.6	22.7	19.4	16.8	13.1	18.0
1997	9.9	9.6	12.8	16.2	20.0	23.7	23.4	22.2	22.4	16.1	13.9	9.5	16.6
1998	8.6	8.9	12.1	19.9	24.4	26.6	23.9	23.4	22.6	21.4	19.2	18.0	19.1
1999	8.2	10.5	14.2	22.3	25.2	25.9	23.7	22.3	22.2	20.8	15.4	14.6	18.8
2000	8.8	7.4	13.8	21.8	27.1	25.4	22.4	22.5	21.8	22.9	16.0	13.6	18.6
2001	10.8	12.3	16.1	18.8	25.9	23.4	22.9	23.0	22.9	22.0	16.9	13.0	19.0
2002	10.4	9.4	15.4	20.3	26.2	26.0	25.3	22.1	21.0	20.1	17.2	11.5	18.7
2003	11.3	8.4	13.3	19.5	22.0	27.1	22.8	22.6	21.2	20.1	14.0	11.0	17.8
2004	7.5	11.9	19.4	21.0	23.7	24.2	24.3	22.7	22.8	17.5	16.8	12.7	18.7
2005	6.7	5.2	13.2	18.2	20.8	27.0	22.5	23.3	22.8	20.2	15.4	13.1	17.4
2006	7.9	14.9	13.8	20.2	26.8	25.1	23.7	22.5	22.6	21.4	14.5	10.7	18.7
2007	10.3	9.4	13.1	23.1	24.3	25.6	23.3	24.1	22.3	21.3	19.0	10.6	18.9
2008	4.8	8.7	17.8	17.7	23.5	23.2	22.8	22.7	22.2	20.9	17.4	19.1	18.4
2009	9.3	9.8	14.0	18.0	23.7	25.7	25.0	23.0	23.3	20.4	15.5	11.6	18.3
2010	12.4	8.7	18.1	21.7	22.9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	7.0
2011	9.3	7.8	14.9	17.4	25.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	6.2
2012	7.8	5.4	10.3	21.0	19.4	28.1	29.4	22.3	20.9	23.0	18.3	15.7	18.5

Average Minimum Temperature of Murree in °C

Period: 1975-2012

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1975	-0.79	-0.38	4.27	10.03	13.33	15.13	14.96	15.36	13.96	12.01	6.33	3.44	8.97
1976	1.16	0.29	8.42	9.26	13.49	15.87	16.16	14.65	13.73	10.94	7.83	2.45	9.52
1977	-0.79	-0.38	4.27	10.03	13.33	15.13	14.96	15.36	13.73	10.94	0.00	2.68	8.27
1978	-0.89	-0.14	2.13	10.10	16.23	17.57	15.87	15.71	13.37	11.87	5.57	5.55	9.41
1979	1.65	0.50	2.77	11.50	10.32	17.07	16.00	15.23	12.83	11.26	6.63	2.81	9.05
1980	0.48	0.55	2.81	11.70	15.10	16.13	15.84	15.26	13.60	11.10	6.90	4.71	9.51
1981	-0.06	1.32	3.03	10.50	13.77	16.23	15.82	15.59	13.33	10.06	6.27	2.97	9.07
1982	0.49	-1.91	1.79	8.46	11.45	15.89	16.35	15.43	13.30	10.09	6.41	1.46	8.27
1983	0.41	0.22	2.67	6.52	11.74	14.27	14.41	16.15	14.64	9.73	7.64	2.24	8.39
1984	-0.75	-1.70	5.23	9.11	16.49	17.67	15.43	16.26	11.69	10.99	6.22	1.81	9.04
1985	0.00	3.69	7.25	9.83	13.86	16.80	16.27	16.27	15.69	13.70	10.24	6.86	10.87
1986	0.41	1.14	3.09	8.54	11.35	16.04	15.76	15.81	13.48	10.27	6.92	2.33	8.76
1987	2.15	2.36	5.41	9.43	7.21	13.72	16.40	16.54	15.53	10.35	9.54	6.89	9.63
1988	2.18	3.31	4.49	12.59	16.57	16.29	16.46	15.59	14.11	11.48	8.74	4.51	10.53
1989	-0.21	-0.21	4.14	10.01	14.82	16.28	16.87	15.34	15.10	12.16	7.35	4.15	9.65
1990	3.77	1.78	4.12	9.36	16.34	16.54	16.66	16.85	15.37	11.33	9.15	1.84	10.26
1991	1.34	1.87	5.68	8.40	12.22	16.83	15.37	16.39	14.65	11.64	7.56	0.00	9.33
1992	1.11	0.15	2.22	7.36	11.56	16.71	15.79	16.47	14.49	11.38	3.82	3.39	8.70
1993	-1.90	0.73	1.25	8.59	15.31	16.41	15.35	16.36	14.16	10.71	4.10	-0.61	8.37
1994	-3.28	-3.24	4.72	7.33	12.70	17.20	15.86	16.37	13.89	9.21	7.81	1.58	8.35
1995	-2.10	-1.30	2.54	5.93	13.00	17.94	15.73	15.76	13.81	10.94	6.84	0.45	8.29
1996	-2.12	-1.82	3.55	9.52	12.32	16.03	16.95	16.05	14.35	10.44	4.26	-1.14	8.20
1997	-2.66	-1.55	1.76	5.28	11.04	14.64	17.57	16.00	14.09	7.94	3.89	0.07	7.34
1998	-2.01	-2.24	0.93	8.63	13.85	16.36	17.21	17.01	15.10	12.47	9.16	1.28	8.98
1999	-3.25	-0.84	4.13	12.87	14.39	15.11	15.13	15.35	13.86	10.48	4.87	-1.47	8.39
2000	-5.34	-4.88	0.89	5.73	10.76	8.37	11.83	14.00	12.75	12.48	4.15	-1.96	5.73
2001	-4.68	-3.44	4.04	9.52	15.92	15.33	16.20	16.40	13.64	10.75	3.74	-2.32	7.92
2002	-4.83	-3.49	2.51	7.63	12.95	14.46	15.75	15.36	12.05	9.40	3.30	-3.68	6.79
2003	-4.38	-5.55	-1.96	5.10	8.13	12.54	12.24	12.45	11.01	7.35	1.23	-2.42	4.64
2004	-4.04	-2.10	3.06	6.07	9.24	11.80	12.08	11.41	11.55	6.65	5.72	1.90	6.11
2005	-3.45	-5.08	3.55	6.84	10.05	14.89	13.93	12.91	13.25	7.62	1.03	-2.91	6.05
2006	-3.35	4.52	3.38	7.93	13.85	12.48	14.56	15.27	13.20	10.30	5.77	1.79	8.31
2007	0.71	1.02	5.87	14.06	14.52	16.29	16.46	16.42	13.33	10.50	6.26	-0.55	9.57
2008	-4.21	-0.86	8.19	8.79	13.44	15.58	16.21	15.93	13.88	12.17	8.49	4.06	9.31
2009	2.10	2.89	6.72	9.68	14.55	15.48	16.56	16.35	15.03	11.54	5.86	2.65	9.95
2010	1.75	1.23	9.45	12.38	13.18	N/A	N/A	N/A	N/A	N/A	N/A	N/A	3.17
2011	-1.70	0.70	6.50	8.30	16.10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.49
2012	-3.02	-0.76	2.10	12.40	9.36	19.10	20.00	16.80	16.30	13.30	9.20	4.30	9.92

APPENDIX B

HYDROLOGICAL DATA

Flow Data

Sediment Data

Sediment Data of Rawal Dam

Sediment Data of Simly Dam

SALIENT FEATURES OF RAWAL DAM

SALIENT FEATURES OF SIMLYDAM

Monthly Flow Data

Gauging Station: Rawal Dam

Flow Data in Acre-feet

Period: 1975-2012

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1975	69	322	101	185	655	26	6359	35462	16363	189	2468	13	62211
1976	337	280	1890	718	261	955	18185	33575	26035	1234	1086	190	84746
1977	559	358	0	0	1446	2268	15998	5052	2351	2467	2114	336	32949
1978	528	0	268	1877	447	1463	14346	44387	4224	2396	1877	557	72370
1979	2201	1302	16413	1549	761	354	2010	36254	4537	402	637	95	66515
1980	289	462	2720	396	32	2393	19479	23217	7287	654	106	142	57177
1981	305	4649	8473	5763	872	0	24635	32113	4753	793	0	0	82355
1982	0	1163	8243	15400	10315	634	4786	49950	7209	2415	2197	138	102449
1983	906	1853	1800	8485	1202	959	8873	19895	28071	1455	0	0	73498
1984	0	118	1255	615	67	5978	8684	22688	27729	1875	0	129	69137
1985	95	12	25	85	65	38	20838	32091	5184	5697	65	524	64719
1986	2875	14865	10434	4273	1914	1911	4475	20613	15963	7673	1898	505	87399
1987	1375	3988	1765	1450	7519	1965	1639	18655	1955	2912	0	0	43223
1988	0	90	6771	0	0	35	14489	34413	9731	2688	0	254	68471
1989	1936	0	2710	525	0	12	21675	12780	1302	0	0	0	40940
1990	686	3391	9035	6362	227	2380	6500	33197	23058	5470	899	10276	101480
1991	5332	4350	4892	8665	5666	586	16666	14276	8777	2228	229	0	71668
1992	7648	5568	10345	7418	3178	248	6593	24282	38148	6943	2516	560	113447
1993	234	938	6990	598	131	4678	20653	16912	31510	619	0	0	83263
1994	337	887	657	470	0	1890	54450	56283	19109	2619	856	2259	139817
1995	1669	2019	2398	3490	490	197	40953	21079	10153	2812	1540	567	87367
1996	1938	4277	9454	8629	838	1362	2348	28745	25155	10346	1123	885	95100
1997	731	881	470	1592	2738	1038	15685	51051	17344	9281	1364	0	102175
1998	1669	19508	6781	7808	2027	1079	12275	24745	14355	2256	653	614	93770
1999	1768	2144	1739	5870	2250	1190	20810	27701	22632	2598	980	590	90272
2000	2161	2657	493	8790	1893	5854	8304	21512	23545	2467	780	290	78746
2001	0	2156	580	506	334	6354	42210	20254	12283	261	525	281	85744
2002	0	733	280	690	340	4547	754	47694	22050	508	456	89	78141
2003	659	2485	21073	4325	280	1364	9267	21275	25388	1433	580	1555	89684
2004	2298	1351	2098	1248	298	1166	4592	32811	27346	3550	248	1138	78144
2005	2030	16717	6670	2189	386	1567	3736	18536	19580	6368	1345	1645	80769
2006	1305	315	143	1290	135	643	22591	37188	18387	22	0	4482	86501
2007	36	2493	17723	3267	110	2637	16814	22788	18373	1507	312	152	86212
2008	5865	3519	203.5	2248	360.66	8911	26888	27742.8	9462.8	1274	299.4	1312.4	88086.8
2009	1579	2309	3344	6276	473	9980	33357	13987	2114	1378	390	1290	76477
2010	111.2	3086.2	1012	103.4	735.24	231	36257	60913	14310	2776	238	349.2	120122
2011	217.2	1818.8	1266	938.6	2150	8525	55852	9760	11690	6272	249	459	99196.9
2012	1653	1166.5	1780	454.2	2280	8890	15453	12360.4	9360.8	549.8	390	431.38	54769.2

Flow Data conversion in mm

Gauging Station: Rawal Dam

Period: 1975-2012

Catchment Area of Rawal Dam =67410 Acre

Depth in mm = Flow AFT/catchment area in Acre*304.8

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1975	0	1	0	1	3	0	29	160	74	1	11	0	281
1976	2	1	9	3	1	4	82	152	118	6	5	1	383
1977	3	2	0	0	7	10	72	23	11	11	10	2	149
1978	2	0	1	8	2	7	65	201	19	11	8	3	327
1979	10	6	74	7	3	2	9	164	21	2	3	0	301
1980	1	2	12	2	0	11	88	105	33	3	0	1	259
1981	1	21	38	26	4	0	111	145	21	4	0	0	372
1982	0	5	37	70	47	3	22	226	33	11	10	1	463
1983	4	8	8	38	5	4	40	90	127	7	0	0	332
1984	0	1	6	3	0	27	39	103	125	8	0	1	313
1985	0	0	0	0	0	0	94	145	23	26	0	2	293
1986	13	67	47	19	9	9	20	93	72	35	9	2	395
1987	6	18	8	7	34	9	7	84	9	13	0	0	195
1988	0	0	31	0	0	0	66	156	44	12	0	1	310
1989	9	0	12	2	0	0	98	58	6	0	0	0	185
1990	3	15	41	29	1	11	29	150	104	25	4	46	459
1991	24	20	22	39	26	3	75	65	40	10	1	0	324
1992	35	25	47	34	14	1	30	110	172	31	11	3	513
1993	1	4	32	3	1	21	93	76	142	3	0	0	376
1994	2	4	3	2	0	9	246	254	86	12	4	10	632
1995	8	9	11	16	2	1	185	95	46	13	7	3	395
1996	9	19	43	39	4	6	11	130	114	47	5	4	430
1997	3	4	2	7	12	5	71	231	78	42	6	0	462
1998	8	88	31	35	9	5	56	112	65	10	3	3	424
1999	8	10	8	27	10	5	94	125	102	12	4	3	408
2000	10	12	2	40	9	26	38	97	106	11	4	1	356
2001	0	10	3	2	2	29	191	92	56	1	2	1	388
2002	0	3	1	3	2	21	3	216	100	2	2	0	353
2003	3	11	95	20	1	6	42	96	115	6	3	7	406
2004	10	6	9	6	1	5	21	148	124	16	1	5	353
2005	9	76	30	10	2	7	17	84	89	29	6	7	365
2006	6	1	1	6	1	3	102	168	83	0	0	20	391
2007	0	11	80	15	0	12	76	103	83	7	1	1	390
2008	27	16	1	10	2	40	122	125	43	6	1	6	398
2009	7	10	15	28	2	45	151	63	10	6	2	6	346
2010	1	14	5	0	3	1	164	275	65	13	1	2	543
2011	1	8	6	4	10	39	253	44	53	28	1	2	449
2012	7	5	8	2	10	40	70	56	42	2	2	2	248

Flow Data in Acre-feet

Gauging Station: Simly Dam

Period: 1983-2012

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1983	3316	2231	8075	20452	4378	1121	3487	14612	12498	1759	781	448	73158
1984	750	1430	2134	1617	514	2102	3480	28310	24521	1492	1388	659	68397
1985	674	250	307	1107	67	137	7689	25490	9771	5680	664	580	52416
1986	1375	1247	458	5859	1159	890	26790	29670	5925	7645	13450	10890	105358
1987	1795	5439	11552	5994	8608	689	15403	2340	3884	10890	10670	652	77916
1988	1290	1014	9098	1230	218	540	21089	23289	4493	650	218	430	63559
1989	2128	698	6849	2317	426	186	15618	18161	2971	1688	365	659	52066
1990	944	3941	7560	6580	926	450	10707	28345	1560	4792	609	12071	78485
1991	850	2459	19131	9678	870	936	2854	4506	7238	1085	256	635	50498
1992	980	1230	13327	9342	980	1210	25867	22367	28768	2345	456	520	107392
1993	1297	1521	8624	1611	871	3213	32989	6470	2890	393	274	121	60274
1994	1049	1192	690	1644	571	593	15745	74230	7979	4542	510	6774	115519
1995	2866	3404	6785	3580	1490	2164	25813	56110	4334	1686	1065	541	109838
1996	2392	5726	11786	3457	1230	2684	24356	36226	4899	4253	813	785	98607
1997	664	436	1261	1121	2067	2069	8703	163089	15872	3306	1236	551	200375
1998	2450	15068	16264	9410	2836	1369	16435	10383	6889	1458	980	450	83992
1999	2386	18210	4050	305	2450	1280	12590	12779	10231	2577	1559	260	68677
2000	2797	3961	1468	460	296	1390	15689	16145	12689	1488	208	272	56863
2001	256	4590	2450	1051	270	4729	11927	10024	4804	1057	230	268	41656
2002	936	1890	1373	1034	184	3739	10445	20389	5851	1190	337	510	47878
2003	486	17120	10869	2093	210	2601	11510	9341	4320	1035	210	1113	59795
2004	2465	3098	9124	793	1400	1569	12907	10054	1993	6460	514	1297	51674
2005	3320	19517	7886	2783	1672	698	10563	8098	6287	1476	549	405	62849
2006	12480	861	758	438	325	1367	15809	22212	8653	1018	811	7020	71752
2007	1200	5356	8403	2999	803	2045	11230	13579	12897	2426	811	1099	62848
2008	5460	2396	1029	4356	619	5792	12123	29760	3392	1468	762	1575	67157
2009	2461	3691	2660	7700	1523	5430	15420	18690	12612	2679	510	678	74054
2010	113	5587	1738	5490	1190	6790	27112	21289	3206	1528	570	690	75303
2011	137	15980	11134	4733	664	1900	10180	9170	4023	2299	934	860	61154
2012	1043	19745	7340	1196	122	186	12290	14356	13678	1203	390	734	71549

Flow Data conversion in mm

Gauging Station: Simly Dam

Period: 1983-2012

Catchment Area of Simly Dam =37930.6 Acre
Depth in mm = Flow AFT/catchment area in Acre*304.8

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1983	27	18	65	164	35	9	28	117	100	14	6	4	588
1984	6	11	17	13	4	17	28	227	197	12	11	5	550
1985	5	2	2	9	1	1	62	205	79	46	5	5	421
1986	11	10	4	47	9	7	215	238	48	61	108	88	847
1987	14	44	93	48	69	6	124	19	31	88	86	5	626
1988	10	8	73	10	2	4	169	187	36	5	2	3	511
1989	17	6	55	19	3	1	126	146	24	14	3	5	418
1990	8	32	61	53	7	4	86	228	13	39	5	97	631
1991	7	20	154	78	7	8	23	36	58	9	2	5	406
1992	8	10	107	75	8	10	208	180	231	19	4	4	863
1993	10	12	69	13	7	26	265	52	23	3	2	1	484
1994	8	10	6	13	5	5	127	596	64	36	4	54	928
1995	23	27	55	29	12	17	207	451	35	14	9	4	883
1996	19	46	95	28	10	22	196	291	39	34	7	6	792
1997	5	4	10	9	17	17	70	1311	128	27	10	4	1610
1998	20	121	131	76	23	11	132	83	55	12	8	4	675
1999	19	146	33	2	20	10	101	103	82	21	13	2	552
2000	22	32	12	4	2	11	126	130	102	12	2	2	457
2001	2	37	20	8	2	38	96	81	39	8	2	2	335
2002	8	15	11	8	1	30	84	164	47	10	3	4	385
2003	4	138	87	17	2	21	92	75	35	8	2	9	480
2004	20	25	73	6	11	13	104	81	16	52	4	10	415
2005	27	157	63	22	13	6	85	65	51	12	4	3	505
2006	100	7	6	4	3	11	127	178	70	8	7	56	577
2007	10	43	68	24	6	16	90	109	104	19	7	9	505
2008	44	19	8	35	5	47	97	239	27	12	6	13	540
2009	20	30	21	62	12	44	124	150	101	22	4	5	595
2010	1	45	14	44	10	55	218	171	26	12	5	6	605
2011	1	128	89	38	5	15	82	74	32	18	8	7	491
2012	8	159	59	10	1	1	99	115	110	10	3	6	575

Sediment data of Rawal Dam

Period: 1975-2007

1 acre foot = 0.123348184 hectares meter

Year	Sedimentation Rate (Acre-Ft/Year)	Sediments (Hectare-m)
1975	167	20.6
1976	167	20.6
1977	167	20.6
1978	167	20.6
1979	167	20.6
1980	167	20.6
1981	167	20.6
1982	167	20.6
1983	167	20.6
1984	167	20.6
1985	239	29.5
1986	239	29.5
1987	239	29.5
1988	239	29.5
1989	239	29.5
1990	239	29.5
1991	239	29.5
1992	583	71.9
1993	583	71.9
1994	583	71.9
1995	583	71.9
1996	583	71.9
1997	583	71.9
1998	583	71.9
1999	583	71.9
2000	583	71.9
2001	387	47.7
2002	387	47.7
2003	387	47.7
2004	387	47.7
2005	387	47.7

Sediment data of Simly Dam

Period: 1983-2007

1 acre foot = 0.123348184 hectares meter

Year	Sedimentation Rate (Aft/year)	Sedimentation Hectare-m
1983	97	12
1984	97	12
1985	97	12
1986	97	12
1987	97	12
1988	97	12
1989	159	20
1990	159	20
1991	159	20
1992	159	20
1993	159	20
1994	212	26
1995	212	26
1996	212	26
1997	212	26
1998	241	30
1999	246	30
2000	246	30
2001	246	30
2002	246	30
2003	246	30
2004	246	30
2005	247	30

SALIENT FEATURES OF RAWAL DAM

DATA SOURCE: Small Dam Organization Punjab

1	**Catchment area**	106 Sq. miles and its shape is elongated
2	**Type of Dam**	Gravity Dam, partly arched in plan with a radius of 300 feet. Built in stone masonry with cement mortar (1:4) and having coarse rubble stone facing
3	**Length of Dam**	700 feet which comprises left bank RD 0 to 215 Spillway RD 215 to 483, Right flank RD 483 to 700
4	**Deepest River bed level**	R.L.1650
5	**Sill level of Sluices**	R.L.1708
6	**Spillway crest level**	R.L.1742
7	**Full reservoir level (Top of Radial gates)**	R.L.1752
8	**Top of road way on Dam**	R.L.1763.50
9	**Maximum height of non-overflow portion of Dam**	133.5 feet
10	**Height of over flow portion of Dam**	102 feet
11	**Clear width of Dam at top**	12 feet
12	**Over fall width of spillway and bucket and apron**	240 feet
13	**Type of Spillway**	Ogee type with a curved crest operating under a maximum head of 19 feet fitted with 8 No's gates
14	**Type of gates**	Radial gates 30 feet wide 10 feet-21/2 height of structural steel curved in plan to suit the shape of the Dam operated electrically as well as manually
15	**D/S slope of Spillway**	0.675 h : 1.0 v

16	**Spillway discharge capacity**	82000 cusecs (maximum)
18	**Designed live storage capacity**	43000 Aft
19	**Present storage capacity**	37500 Aft
19	**Dead storage capacity**	4500 Aft
20	**Type of saddle embankment**	Rolled earthen embankment with a maximum height Of 24 feet. with U/S and D/S slopes 2 1/2 horizontal to 1 vertical with stone revetment on U/S slopes and turfing on d/s slope and graded gravel filled longitudinal and transverse drains
21	**Length of earthen embankment (Saddle portion)**	6991 feet
22	**Water supply to WASA/RDA**	21-23 MG/day
23	**Cultivable command area under the left bank canal**	550 Acres

SALIENT FEATURES OF SIMLY DAM

Data Source: WAPDA

Salient features of Simly Dam are given below

1	**Location of Dam**	35km North-East of Islamabad on Soan river
2	**Construction**	Its construction started in 1972 and completed in 1982
3	**Purpose**	Water supply for Islamabad
4	**Catchment area**	150 sq.km
5	**Area**	468 acre
6	**Reservoir length**	6 km
7	**Dead storage capacity**	5407 Aft
8	**Embankment type**	Earth & Rock fill
9	**Crest level**	1010 feet
10	**Crest width**	30 feet
11	**Crest elevation**	2330 feet
12	**Maximum height at deepest foundation**	263 feet
13	**No of gates**	3 gates 32 x 25 feet
14	**Discharge Capacity**	35,800 cusecs
15	**OUTLET WORKS Diameter**	6 feet
16	**Water supply tunnel length**	590 feet
17	**Drainage gallery size**	5 x 7.5 feet
18	**Drainage gallery length**	432 feet
19	**Project cost**	Rs.643.443 (M)
20	**Water supply to CDA**	Up to 42 MGD

APPENDIX C

Remote Sensing Data

Radiometric Characteristics of Landsat

Land-Sat Images of Area of Interest

Ground Truthing Details

Ground Truthing Images

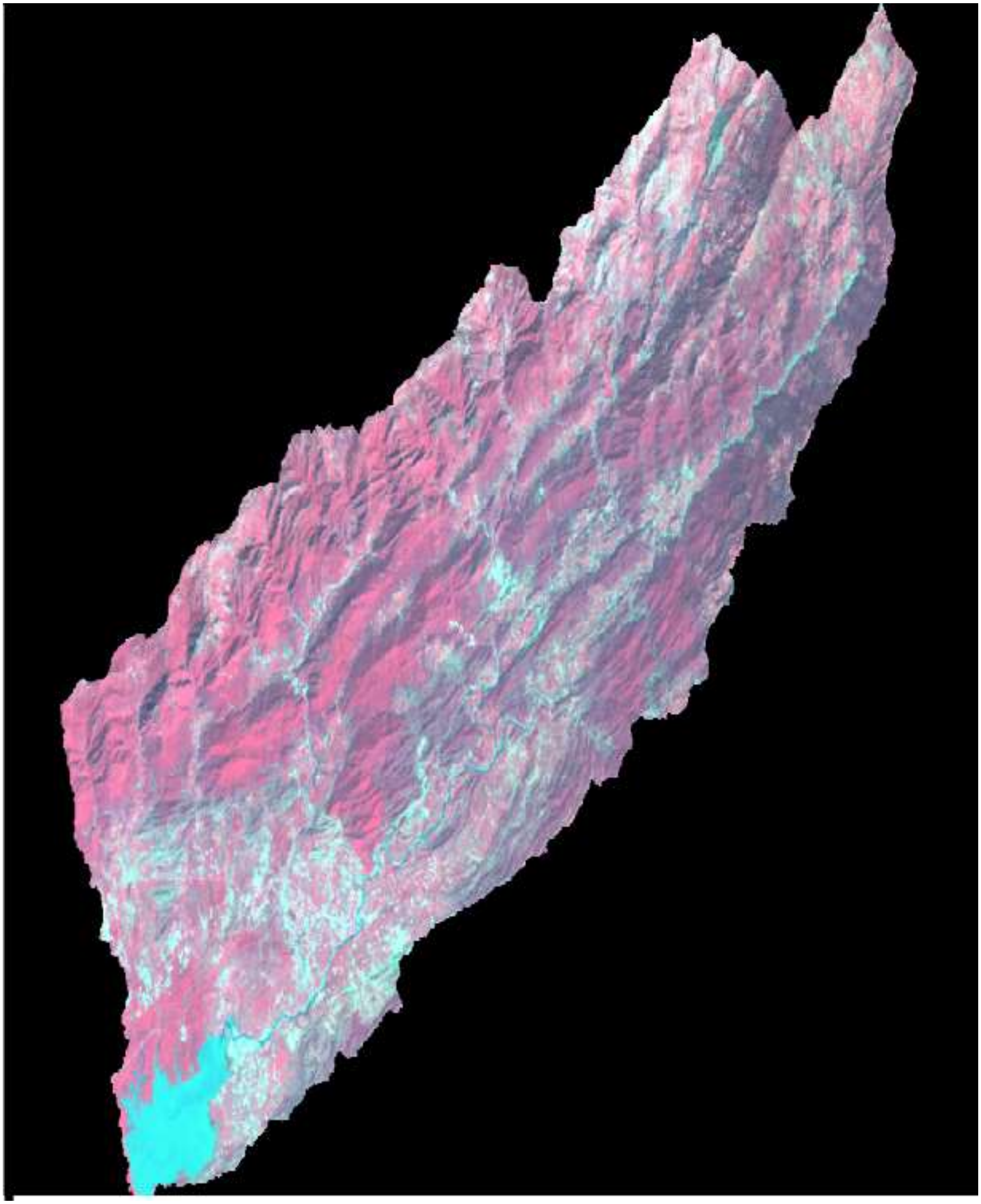
Radiometric Characteristics of Landsat-5 (GLFC)

Band N.O	Band Name	Spectral Resolution (µm)	Spatial Resolution (m)	Applications
1	Blue	0.45 – 0.52	30	Soil/vegetation discrimination, Forest type mapping, Identifying man-made features.
2	Green	0.52 – 0.60	30	Vegetation mapping, Identifying man-made features.
3	Red	0.63 – 0.69	30	Soil and urban features' identification.
4	Near Infrared	0.76 – 0.90	30	Mapping shorelines and biomass content; Detecting and analyzing vegetation.
5	Shortwave IR-1	1.55 – 1.75	30	Moisture content identification in soil and vegetation, Snow and cloud identification.
6	Thermal IR	10.4 – 12.5	120	Useful to identify temperature and its effects.
7	Shortwave IR-2	2.08 – 2.35	30	Cloud penetration, Moisture content identification in soil.

Radiometric Characteristics of Landsat-7 (GLFC)

Band N.O	Band Name	Spectral Resolution (µm)	Spatial Resolution (m)	Applications
1	Blue	0.45 – 0.52	30	Soil/vegetation discrimination, Forest type mapping, Identifying man-made features.
2	Green	0.52 – 0.60	30	Vegetation mapping, Identifying man-made features.
3	Red	0.63 – 0.69	30	Soil and urban features' identification.
4	Near Infrared	0.76 – 0.90	30	Mapping shorelines and biomass content; Detecting and analyzing vegetation.
5	Shortwave IR-1	1.55 – 1.75	30	Moisture content identification in soil and vegetation, Snow and cloud identification.
6	Thermal IR	10.4 – 12.5	120	Useful to identify temperature and its effects.
7	Shortwave IR-2	2.08 – 2.35	30	Cloud penetration, Moisture content identification in soil.
8	Panchromatic	0.52 – 0.92	15	It is used to sharpen images.

Area of interest Landsat image of Rawal Dam 1992



Area of interest Landsat image of Simly Dam in 1992

Ground Truthing in Catchment area using GPS

Sr No	Latitude (N)	Longitude (E)	Land use type
1	33.716	73.114	Vegetation & Agriculture
2	33.718	73.133	Vegetation & Agriculture
3	33.711	73.131	Built up area
4	33.713	73.13	Vegetation& Agriculture
5	33.732	73.144	Built up area
6	33.734	73.158	Built up area
7	33.729	73.161	Vegetation & Agriculture
8	33.726	73.163	Built up area
9	33.721	73.171	Built up area
10	33.722	73.182	Forest
11	33.724	73.195	Forest
12	33.727	73.2	Forest
13	33.73	73.21	Vegetation & Agriculture
14	33.737	73.26	Vegetation & Agriculture
15	33.72	73.24	Range land
16	33.719	73.25	Range land
17	33.7	73.26	Range land
18	33.698	73.28	Vegetation & Agriculture
19	33.691	73.32	Built up area
20	33.7	73.12	Water
21	33.714	73.19	Built up area
22	33.742	73.201	Built up area
23	33.742	73.201	Built up area
24	33.742	73.204	Built up area
25	33.745	73.22	Built up area
26	33.748	73.216	Vegetation & Agriculture
27	33.739	73.179	Built up area
28	33.736	73.173	Built up area
29	33.745	73.132	Built up area
30	33.745	73.127	Vegetation & Agriculture
31	33.744	73.117	Range land
32	33.744	73.112	Range land
33	33.734	73.108	Range land
34	33.73	73.111	Built up area
35	33.723	73.106	Bare land
36	33.715	73.103	Vegetation & Agriculture
37	33.785	73.274	Built up area
38	33.782	73.229	Built up area
39	33.745	73.107	Built up area
40	33.731	73.113	Built up area
41	33.746	73.119	Built up area
42	33.712	73.111	Built up area
43	33.748	73.137	Built up area
44	33.733	73.138	Water bodies
45	33.751	73.149	Water bodies
46	33.772	73.139	Built up area
47	33.713	73.126	Built up area
48	33.733	73.168	Built up area
49	33.732	73.142	Built up area
50	33.726	73.141	Built up area

GROUND TRUTHING RESULTS

(1) LOCATION OF SITE Latitude 33.72 N
PHULGRAN Longitude 73.24 E

(2) LOCATION OF SITE Latitude 33.7 N
SHAH PUR Longitude 73.26

(3) LOCATION OF SITE Latitude 33.7 N
KOT HATYAL Longitude 73.26

1, 2, 3 were selected as Range land.

(4) LOCATION OF SITE Latitude 33.73 N

PHULGRAN Longitude 73.21 E

(5) LOCATION OF SITE Latitude 33.74 N

NUR PUR SHAHAN Longitude 73.26 E

(6) LOCATION OF SITE Latitude 33.75 N
MALPUR Longitude 73.22 E

4, 5, 6 were selected as vegetation & agriculture.

(7) LOCATION OF SITE Latitude 33.72 N
PHULGARAN Longitude 73.19 E

(8) LOCATION OF SITE Latitude 33.722 N
NANYAH Longitude 73.182 E

(9) LOCATION OF SITE Latitude 33.727 N

BASSANDH Longitude 73.2E

7, 8, 9 were selected as forest

(10) LOCATION OF SITE Latitude 33.711 N
NUR PUR SHAHAN Longitude 73.31E

(11)LOCATION OF SITE Latitude 33.726 N
BHARA KAHU Longitude 73.163E

(12) LOCATION OF SITE Latitude 33.745 N

BANNI GALA Longitude 73.22E

10, 11, 12 were selected as Built up area.

(13) LOCATION OF SITE Latitude 33.7 N

KORANG NALLAH Longitude 73.12E

(14) LOCATION OF SITE Latitude 33.75 N

Simly DAM Longitude 73.14 E

(15) LOCATION OF SITE Latitude 33.73 N

RAWAL DAM Longitude 73.13E

13, 14, 15 WERE selected as water bodies.