OPTIMAL ECOLOGICAL MANAGEMENT PRACTICES FOR CONTROLLING SEDIMENT AND WATER YIELD FROM A HILLY URBAN SYSTEM WITHIN SUSTAINABLE LIMIT

Submitted in Partial Fulfillment of the Requirement for the Degree of
DOCTOR OF PHILOSOPHY

By

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Dedicated to My Parents

Statement of Originality

The work in the thesis entitled ***"Optimal Ecological Management Practices for Controlling Sediment and Water Yield from a Hilly Urban System Within Sustainable Limit"*** has been carried out by me under the supervision of Prof. A.K. Sarma of Civil Engineering Department , IIT Guwahati and Prof. C. Mahanta of Civil Engineering Department , IIT Guwahati. This work has not been submitted elsewhere for the award of any degree.

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Certificate

It is to certify that the work in the thesis entitled ***"Optimal Ecological Management Practices for Controlling Sediment and Water Yield from a Hilly Urban System Within Sustainable Limit"*** **by** Banasri Sarma, Roll Number 07615203, a student of Centre for the Environment, Indian Institute of Technology Guwahati for the award of the degree of Doctor of Philosophy has been carried out under our supervision and that this work has not been submitted elsewhere for a degree.

(Chandan Mahanta) (Arup Kumar Sarma)

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Abstract

Urbanization is increasing at a rapid rate and in many places expanding into the hilly areas, thereby inducing significant alteration in the hydrological response of watershed. In the developing world, the process of urbanization is more often unplanned and disorganized, which results in higher yield of sediment and surface runoff, which manifest itself in the form of hazards like flash flood and landslide. Washing off of pollutants from the urbanized impermeable upper catchment is also causing downstream water quality declination. Therefore, urban developments in hilly watersheds require application of efficient management practices that can handle adverse consequences of urban developments in an ecologically sound and sustainable manner. Such ecofriendly sustainable management practices can be termed as Ecological Management Practices (EMPs). However, the cost, efficiencies and applicability of EMPs vary widely from place to place depending upon the site condition. Therefore, it is necessary to determine the optimal combination of EMPs that satisfies all requirements at minimum cost. In this study, allocation of EMPs for managing sediment and water yield from hilly urban watershed has been done through an optimization model.

Due emphasis was given towards prioritization of EMP application projects based on severity of watershed degradation and their impacts on surroundings. A GIS based River Water Quality Information System (RWQIS) was developed with a primary objective of identifying most degraded watersheds by considering river water quality as an index of catchment degradation. To demonstrate applicability of the RWQIS, it was applied to Northeastern Region of India and two rivers of Guwahati City- Bharalu and Basistha were identified as most urban impacted rivers of the region. A systematic procedure for studying pattern of urban expansion by

using geoinformatics was developed and applied to the Guwahati City along with a socio-economic survey to help development planning associating hydrological aspects.

Two adjacent watersheds were developed as disturbed and undisturbed watershed for studying hydrological response of residential development in terms of sediment and water yield and also for conducting experimentation on performance of some competitive EMPs. The study revealed that sediment yield and water yield per unit area increases by 2 - 21% and 3 - 54% respectively in the disturbed watershed as compared to the undisturbed watershed. Experimentation on erosion control efficiency of EMPs proved Grass (*Paspalum conjugatum*) and Golden glory (*Tradescantia zebrina*) to be highly efficient; Grass has efficiency of 75-100% and Golden glory has efficiency of 36-97% as compared to bare land.

Analysis of chemical composition of rainwater and runoff samples showed significant ionic contribution from soil to the runoff water. Leaching study of soil revealed that leaching behavior of soil differs from site to site. Based on this study, a conceptual model was developed for determining limiting value of sediment yield from a watershed from the water quality perspective.

Three optimization models, namely, OPTEMP-LS (**OPT**imal **EMP** model with **L**inear programming for **S**ingle ownership), OPTEMP-LM (**OPTi**mal **EMP** **m**odel with **Li**near programming for **M**ultiple ownership) and OPTEMP-LDM (**OPT**imal **EMP** model with **L**inear and **D**ynamic programming for **M**ultiple ownership) were developed for determining optimal EMP combination for two different situations: 1) plots with single ownership and 2) plots with multiple ownerships. In the multiple ownership situations, the watershed was considered to be consisting of several plots in sequence from upstream to downstream under different ownership.

These models were applied to a micro watershed of Guwahati, Assam, India with three EMPs, namely: Grass, Garden and Detention pond. A sensitivity analysis carried out for the different model parameters used in OPTEMP-LS showed rainfall intensity to be highly sensitive; whereas rainfall erodibility factor, soil erodibility factor, slope length factor and runoff coefficient of garden were found to be moderately sensitive. In case of multiple plots, OPTEMP-LM was found to give better result from financial point of view compared to OPTEMP-LDM. However, OPTEMP-LM may become computationally expensive, as number of decision variables increases in multiple of number of plots. On the other hand, in OPTEMP-LDM model, number of variables is independent of number of plot and stages of DP only increase with increase in number of plots.

An idea for enhancing sustainability of EMP project by utilizing carbon sequestration potential of vegetative EMPs was explored by developing two optimization models OPTEMP-CSL (**OPT**imal **EMP** model for maximizing **C**arbon **S**equestration with **L**inear programming) and OPTEMP-CSMO(**OPT**imal **EMP** model for maximizing **C**arbon **S**equestration with **M**ulti-**O**bjective programming). In the OPTEMP-CSL, minimization of net cost (Net cost=Total cost – benefits obtained from carbon sequestration) was considered as objective function subjected to other constraints. The OPTEMP-CSMO model was built as a multi-objective model, which considers maximization of carbon sequestration and minimization of total cost of EMPs as objectives subject to other associated constraints. The application of these models to the micro watershed of Guwahati showed that benefits of carbon sequestration can be derived to help sustainability of such EMP based urban development projects.

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$(a_{max})_i$	= Maximum area kept for i^{th} EMP in the plot according to owner's choice (m^2)
$(a_{max})_{ki}$	= Maximum area kept for i^{th} EMP in the plot according to owner's choice in the k^{th} plot(m^2)
$(a_{min})_{ki}$	= Minimum area required for i^{th} EMP in the k^{th} plot (m^2)
$(a_{min})_i$	= Minimum area required for i^{th} EMP(m^2)
$(as)_{ki}$	= Suitable area available for i^{th} EMP in the k^{th} plot (m^2)
$(as)_i$	= Suitable area available for i^{th} EMP in the plot (m^2)
$(Cc)k_i$	= Capital cost of the i^{th} EMP in the k^{th} plot (₹)
$(Cm)k_i$	= Maintenance cost of the i^{th} EMP in the k^{th} plot (₹)
$(LS)_k$	= LS factor of the k^{th} plot (dimensionless)
A	= Area of the plot (m^2)
Ac	= Coverage area of the plot (m^2)
Ac_k	= Coverage area of the plot in the k^{th} plot (m^2)
a_i	= Area of the i^{th} EMP in the plot (m^2)
A_j	= Area of the j^{th} land cover in the plot(m^2)
$A_{j k}$	= Area of the j^{th} land cover in the k^{th} plot (m^2)
A_k	= Area of the k^{th} plot in the watershed (m^2)
a_{ki}	= Area of the i^{th} EMP in the k^{th} plot (m^2)
AL_k	= Available EMP area in the k^{th} plot (m^2)
C1	= Cover factor of Grass (dimensionless)
C2	= Cover factor of Garden (dimensionless)
Cc_i	= Capital cost of the i^{th} EMP (₹)
Ci	= Cover factor for the ith EMP in the plotc (dimensionless)
$C_{i k}$	= Cover factor for the i^{th} EMP in the k^{th} plot (dimensionless)
$C_{j k}$	= Cover factor for the j^{th} land cover in the k^{th} plot (dimensionless)
C_j	= Cover factor for the j^{th} land cover in the plot (dimensionless)
C_{kmax}	= Maximum coverage allowed in the k^{th} plot (%)
Cm_i	= Maintenance cost of the i^{th} EMP (₹)

C_{max} = Maximum coverage allowed in the plot (%)

CS_i = Amount of carbon sequestration from the ith EMP in the plot having an area of a_i (tonnes/yr)

D = Duration of rainfall (hr)

i = Number of EMPs

I = Maximum intensity of rainfall for a duration equal to the time of concentration of the plot (mm/hr)

I_k = Maximum intensity of rainfall for the time of concentration of the selected design storm for the kth plot

j = Number of landcover present except the coverage area and EMPs

K = Soil erodibility factor (dimensionless)

K_k = Soil erodibility factor of the kth plot (dimensionless)

LS = Slope length factor (dimensionless)

m = Number of different landcover in the plot except the EMPs and coverage area

n = Number of possible EMPs that can be applied

NN = Slope steepness factor, ranging from 0.2–0.5.

Qk_{max} = Maximum allowable peak rate of runoff from the kth plot (cumec)

Qk_{min} = Minimum allowable peak rate of runoff at downstream from the kth plot, (cumec)

Q_{max} = Allowable peak discharge from the plot

Q_{min} = Minimum peak discharge requirement at downstream from the plot

R = Rainfall erodibility factor

Rc = Runoff coefficient of the coverage area

RC1 = Runoff coefficient of Grass

RC2 = Runoff coefficient of Garden

RC_i = Runoff coefficient for the ith EMP in the plot

RC_j = Runoff coefficient for the jth landcover in the plot

Rc_k = Runoff coefficient of the coverage area in the kth plot (dimensionless)

RC_{ki} = Runoff coefficient for the ith EMP in the kth plot (dimensionless)

RC_{kj} = Runoff coefficient for the jth landcover in the kth plot (dimensionless)

R_k = Rainfall and runoff erosivity index of the k^{th} plot (100 ft·tonf·in/acre/hr/yr)

Slope = Slope steepness (%),

Slope length = Length of slope (ft),

S_{max} = Maximum sediment yield allowed from the plot (tonnes/yr)

S_{min} = Minimum sediment yield required from the plot (tonnes/yr)

S_p = State variable representing amount of sediment yield from the p^{th} stage

St_{max} = Maximum sediment yield allowed from the watershed (tonnes/yr)

St_{min} = Minimum sediment yield required from the watershed (tonnes/yr)

X_p = Trial discrete sediment yield from the current plot in p^{th} stage

Abbreviations

EMP	Ecological Management Practices
GIS	Geographical Information System
RWQIS	River Water Quality Information System
D	Disturbed watershed
UD	Undisturbed watershed
EC	Electrical Conductivity
TDS	Total Dissolved Solid
LPP	Linear Programming Problem
DP	Dynamic Programming Problem
OPTEMP-LS	OPTimal EMP model with Linear programming for Single ownership,
OPTEMP-LM	OPTimal EMP model with Linear programming for Multiple ownership
OPTEMP-LDM	OPTimal EMP model with Linear and Dynamic programming for Multiple ownership
OPTEMP-CSL	OPTimal EMP model for maximizing Carbon Sequestration with Linear programming
OPTEMP-CSMO	OPTimal EMP model for maximizing Carbon Sequestration with Multi-Objective programming

Chapter 1
INTRODUCTION

1.1. PURPOSE OF STUDY

Urbanization is increasing at an alarming rate all over the world. According to an estimate of Department of Economic and Social Affairs of the United Nations Secretariat (2011), the total urban population of the world has increased by 5 folds during the last sixty years (1950 to 2010). The process of urbanization is faster in the developing world (Chen, 2007) and as estimated by Angel et al. (2011), urban land cover in developing countries will increase from 300,000 km^2 in 2000 to 770,000 km^2 in 2030 and to 1,200,000 km^2 in 2050. India is not an exception. While total population of India has doubled during the last 50 years, urban population has grown nearly five times (Taubenböck et al., 2009).

Urbanization induces significant alteration in the local hydrological cycle by increasing impervious areas and simultaneously decreasing natural vegetative cover (Brun and Band, 2000; Kondoh and Nishiyama, 2000; Biggs et al., 2010). Increase in imperviousness not only increases surface runoff but also reduces time of concentration, and thus intensifying the problem of flash floods (Viessman and Lewis, 2008). Removal of vegetative cover exposes the soil surface resulting in higher surface erosion, particularly in a region of high rainfall. The problem of flash flood in urban watershed is more pronounced with higher sediment yield, as sediment deposition raises bed level of drainage channels and reduces their flow carrying capacity. Also, water quality declines due to washing off of accumulated pollutants by runoff from impervious surfaces to local waterways (EPA, 2004). Besides, reduction in vegetative cover reduces carbon sequestration capacity of an area, which is a major concern with the increasing need of alleviating impact of climate change.

Therefore, the developments in urban watersheds especially require application of efficient management practices that can handle adverse consequences of urban developments in an ecologically sound and sustainable way. Such ecofriendly sustainable management practices, used for maintaining and enhancing landuses in a natural way, are termed as Ecological Management Practices (EMPs). Some of the EMPs like contour terracing, mulching, grass, shrubs, detention/retention pond, buffer zone with vegetation and tree, sediment trap, rainwater harvesting systems and vegetated waterways can go a long way in controlling sediment yield, non point source pollution and runoff volume from land surface. Besides, some of them being vegetative in nature can also help to increase the carbon sequestration in the area. However, efficiency, applicability and implementation cost of EMPs vary widely from place to place depending upon site conditions. Several alternative EMP combinations can be adopted to restrict sediment and water yield from a hilly urban watershed within permissible limit. However, for developing countries like India, achieving these objectives at the minimum possible cost and that too with logical sharing of total expenditure among the land-users is a challenging task. Before suggesting an urban renovation plan for a developing country, one must consider the fact that in countries like India, people from lower economic group, coming in search of job, generally form a large section of the total urban population who start residing in hilly or low lying areas, as land in plain area become expensive for them.

In this study, an optimization model has been developed to allocate EMPs in such a way that the undesirable hydrological consequences of urban development can be alleviated in a sustainable manner at minimum possible cost while addressing various other constraints imposed by topography and owner's choice. Assessing degree of degradation of urban watersheds is essential for prioritizing implementation of watershed management projects. A systematic approach of assessing degree of degradation of watersheds through a GIS based river water quality monitoring system has also been developed in this research work. Experimental studies have been carried out to have better understanding about efficiency of some competitive EMPs in controlling sediment yield. The influence of sediment on stream water quality has also been studied to set logical permissible limits of sediment yield for the optimization model.

1.2. OBJECTIVES

The broad objective of this research work is to develop an optimization model for limiting sediment and water yield from a degraded urban watershed within permissible bound at a minimum cost and to develop a decision support system to assist prioritization of degraded watershed for EMP application on the basis of severity of degradation and its impact on the surroundings.

This has been attempted by addressing the following specific objectives:

(i) To develop a procedure for prioritizing degraded urban watershed through application of Geographical Information System (GIS) and Remote Sensing.

(ii) To conduct a geoinformatic study for analyzing the rate of urban expansion in the identified degraded urban watershed.

(iii) To assess the sediment yield behavior of different land covers through an experimental study.

(iv) To assess the possible influence of sediment on stream water quality through laboratory experimentation.

(v) To develop an optimization model for allocating the best EMP combination that restricts sediment and water yield within permissible limit, maximizes carbon sequestration and minimizes the total EMP cost.

1.3. METHOD OF INVESTIGATION

To achieve the objectives of this research work, the study was organized in different phases and presented in the chapters as summarized below:

To have state of the art knowledge on various topics relevant to this study, a detail review of previous works done on the different components of this research work was first carried out in a systematic way and has been presented in chapter 2.

Chapter 3 presents a GIS based decision support system for prioritizing degraded urban watersheds based upon of river water quality monitoring. To demonstrate the utility of this system, it has been applied to Northeastern region of India and one of the most degraded urban watersheds was identified for applying the optimization model as a case study.

Different land cover types and conditions have different hydrological responses. Their efficiency to control sediment and water yield too varies widely. To explore the sediment control efficiency of different feasible EMPs suitable in hilly urban watersheds, an experimental study has been carried out in an experimental watershed located at the IIT Guwahati campus. Also, the chemical enrichment of runoff by the soil surface has been presented in this study. The details of the experimental study along with results obtained are presented in chapter 4.

Sediment is recognized as an important non point source pollutant. However, soil particles are also an important source of nutrients and metals and therefore they influence the chemical composition of water coming in contact with them. Attempt was made to determine the desired limit of sediment yield from a watershed, so that sediment itself does not become a nuisance to the water body. A soil leaching study was carried out for the purpose and is presented in chapter 5.

Scope of using optimization technique in landuse planning for achieving sustainable solutions to wide range of environmental problems has drawn attention of researchers in recent years (Seppelt and Voinov,2002; Gabriel et al. ,2006; Holzkamper and Seppelt,2007, Riveira et al. 2008; Lin et al. 2009). Optimization models developed for optimal, allocation of EMPs for managing sediment and water yield from hilly urban watershed are presented in chapter 6. With an objective to ensure sustainability of such EMP projects, scope of including carbon sequestration benefit of vegetative EMPs in the optimization model was also analyses. Performance of all these proposed models has been tested by applying them in a micro watershed in Guwahati , a premier city of Northeastern region of India.

Chapter 7 deals with comprehensive conclusions and general discussion on the outcome and future scope of this research work.

Chapter 2
LITERATURE REVIEW

2.1. INTRODUCTION

A brief review of previous works done on different aspects related to this research work is presented in this chapter. Past literatures that have been reviewed can be categorized as:

(i) Hydrological models and their application to landuse planning

(ii) Application of GIS and remote sensing in natural resource management and landuse planning

(iii) Application of landuse based approaches for controlling sediment and other non point source pollution

(iv) Impact of sediment on stream water quality

(v) Use of optimization technique in landuse planning

2.2. HYDROLOGICAL MODELS AND THEIR APPLICATION TO LANDUSE PLANNING

The hydrological behavior of a catchment depends on storm characteristics (Intensity, duration and spatiotemporal distribution) as well as static catchment characteristics such as area, slope, shape, landuse and soil type. Many hydrological models are available for modeling rainfall runoff and soil erosion characteristics of a watershed.

2.2.1. RAINFALL RUNOFF MODELS

The most well known models for rainfall runoff modeling are the Rational method, the Unit hydrograph method and the SCS-CN method.

Rational method for estimating the peak discharge from small urban and rural watershed was introduced in US by Emil Kuichling in 1889 (Viessman and Lewis, 2008). This method is traditionally used to size storm sewer, channel and other drainage structures. Rational method assumes that rainfall duration equals to the time of concentration those results in the greatest peak runoff.

The rational method has wide applicability due to its simplicity (Zoppou 2001; Hayes and Young, 2006). Rational method assumes a factor to consider all the losses while calculating runoff (infiltration, evaporation, transpiration, initial abstraction and depression storage). This factor is called runoff coefficient (C) and the value of C is determined through observation and experience.

The rational formula is:

$$Q = \frac{CiA}{3600000} \quad (2.1)$$

Where, Q = Peak rate of runoff (Cumec)

C = Runoff coefficient

i = Maximum intensity of runoff for the time of concentration of the selected design storm. (mm/hr)

A = Area (m^2)

The major disadvantage of the Rational method is that it provides only a peak discharge from a watershed, not a complete hydrograph, and therefore it cannot be used for routing multiple flows toward a single outlet. However, for design of drainage system, most important information required is the peak discharge. So the rational method remains the simplest way to obtain estimates of peak discharge and average runoff rates for the design of drainage system.

The concept of Unit Hydrograph was first introduced by Sherman in 1932 (Viessman and Lewis, 2008). A unit hydrograph is the hydrograph of direct runoff (excluding the base flow) for any storm that produces exactly 1 unit of net rainfall (the total runoff after abstractions).

The unit hydrograph method has the advantage of providing a complete storm hydrograph for describing the rainfall runoff relationship (Cavallini, 1993). While dealing with complex watersheds, the storm hydrograph for each sub watershed can be computed independently by the unit hydrograph method for subsequent routing down the main channel. However, the chief weakness of this method is involving the determination of infiltration loss.

The unit hydrograph method is more suitable than rational method for large watersheds. Various other methods that are based on the concept of Unit Hydrograph are also developed by different investigators to study rainfall runoff behavior. Agirre et al. (2005) proposed the Geomorphological Unit Hydrograph of Reservoirs (GUHR) and compared the model with Nash's Instantaneous Unit Hydrograph (Nash's IUH) while applying it to Aixola watershed of Northern Spain. Both the models showed similar behavior, however GUHR was more preferred for considering the watershed morphology.

The SCS-CN model for small watersheds has been used extensively. The SCS-CN (or curve number method) was developed by the USDA Natural Resources Conservation Service (SCS, 1956). This is an empirical method and widely for determining the approximate amount of direct runoff from a rainfall event in a particular area. The runoff curve number is based on the area's hydrologic soil group, land use, treatment and hydrologic condition.

The popular form of SCS-CN method is

$$Q = \frac{(P - Ia)^2}{P - Ia + S} \tag{2.2}$$

where

Q is runoff ([L]; in)

P is rainfall ([L]; in)

S is the potential maximum soil moisture retention after runoff begins ([L]; in)

Ia is the initial abstraction ([L]; in), or the amount of water before runoff, such as infiltration, or rainfall interception by vegetation; and it is generally assumed that $I_a = 0.2S$

The runoff curve number method, S and CN, is related as

$$S = \frac{1000}{CN} - 10 \tag{2.3}$$

CN has a range from 30 to 100; lower numbers indicate low runoff potential while larger numbers are for increasing runoff potential. The lower curve number indicates more permeable soil condition.

Mack (1995) developed an interactive computer model called HER (Hydrological Evaluation of Runoff) with the SCS-CN method. Patil et al. (2008), while indicating the natural resources conservation services curve number (NRCS-CN) method as one of the most widely used methods for quick and accurate estimation of surface runoff from ungauged watersheds, developed an ArcGIS interface to estimate the surface runoff by adopting the NRCS-CN technique and its three modifications. The developed interface was validated using the recorded data for the periods from 1993 to 2001 of a gauged watershed, Banha, in the Upper Damodar Valley, Jharkhand, India and concluded that the application of the modified CN I method in the ungauged watersheds that are hydrologically similar to the Banha watershed would result in an accurate surface runoff estimation. Shi et al. (2009a) determined the initial abstraction ratio (Ia) in an experimental watershed in the Three Gorges Area of China, by analyzing measured rainfall-runoff events and compared the performance of the traditional and modified ratio of initial abstraction (Ia) to maximum potential retention (S) with observed rainfall-runoff data. This Ia/S-adjusted SCS-CN method appears to be better for runoff prediction in the Three Gorges Area of China.

However, the curve number does not provide the flexibility that the rational method C value gives in evaluating site characteristics, since the SCS model was designed for rural and agricultural areas. In addition, the SCS-CN model cannot use intensity-duration-frequency data of precipitation, which, if available, improves the accuracy of the rational methods.

2.2.2. SEDIMENT YIELD MODELS

The Universal Soil Loss Equation, USLE (USDA Agricultural Handbook 282) is widely used for estimating annual sediment yield from a watershed area. The USLE was developed by W. Wischmeier and D. Smith. An updated version was published in 1978 in Agricultural Handbook 537. The Revised Universal Soil Loss Equation (RUSLE) which is a improved version of USLE with improvements in many factor estimation was initially released for public use in 1992. CREAMS, ANSWERS, SPUR, SWRRB, AGNPS are few such models based on USLE. Sarma et al. (2005) used RUSLE model to a small watershed of Guwahati City and found very good agreement with the field estimation.

The RUSLE (Renard et al., 1997) is a method for estimating soil loss from most undisturbed lands experiencing overland flow, lands undergoing disturbance and from newly established reclaimed lands. A variety of human and natural activities disturb the land surface of the earth causing soil erosion. RUSLE estimates soil loss from a hill slope caused by raindrop impact and overland flow, collectively referred to as sheet erosion. It does not estimate gully or stream-channel erosion.

Effective control of soil erosion requires a conceptual and empirical model capable of predicting the amount of soil loss quantitatively. While newer methods are now becoming available, most of them are still founded upon the principles introduced by USLE. RUSLE states that the field soil loss in ton per acre, A, is the product of six factors.

$$A = RKLSCP \tag{2.4}$$

Where,

A = Soil loss, tons/ acre/year

R = Rainfall and runoff erosivity index, in 100 ft $*$ ton/acre $*$ in/hr.

K = Soil-erodibility factor, ton/acre per unit of R

LS = Slope Length and Steepness factor, dimensionless

C = Vegetative cover factor, dimensionless

P = Erosion control practice factor, dimensionless

Tyagi et al. (2008) developed a SCS-CN based sediment yield model to estimate the temporal rates of sediment yield from rainfall events on natural watersheds. The model utilizes the infiltration model for computation of rainfall-excess rate and the SCS-CN-inspired proportionality concept for computation of sediment-excess. The computed rates of sediment yield were in good agreement with the observed rates for most of the events of the study watersheds.

Singh et al. (2008) proposed new conceptual sediment graph model based on Nash model based instantaneous unit sediment graph (IUSG), soil conservation service curve number (SCS-CN) method, and Power law. The model was reported to have substantial potential for computing sediment graphs (temporal sediment flow rate distribution) as well as total sediment yield. The study also reported that the exponent of the power law is the most sensitive parameter of the model.

Shaw et al. (2008) tested a stochastic model of sediment transport by rainfall-runoff by conducting a laboratory scale experiment, using simulated rainfall to imitate ‘‘wash-off’’ of sediment (0.225 mm silica sand) from an impervious surface. Fitting two parameters (ejection and deposition rates) to minimize least squares error resulted in good agreement between stochastic model and measurements.

Aytek and Kisi (2008) proposed genetic programming (GP) as a new approach for the explicit formulation of daily suspended sediment–discharge relationship. Empirical relations such as sediment rating curves were applied to determine the average relationship between discharge and suspended sediment load.

Some recent experimental study has added the knowledge of sediment yield behavior. Cao et al. (2009) conducted hydraulic flume experiments with the flow discharges ranging from 1 to 5 l/s and the slope gradients ranging from 8.8% to 46.6% to simulate the soil detachment process on a road surface and to develop tools in order to calculate detachment rates occurring on that road surfaces. The results illustrated that the soil detachment rate is closely related to flow depth, slope gradient and other hydraulic parameters such as shear stress, stream power and unit stream power.

2.2.3. HYDROLOGICAL MODELS FOR STUDYING IMPACT OF SEDIMENT AND OTHER NON POINT SOURCES POLLUTANT ON WATER BODIES

Hydrological behavior and pollutant generation process of a watershed is strongly governed by the landuse and landcover of an area. Therefore, the hydrological models have wide applicability non point source pollution studies. Sediment, being an important non point source pollutant, many computational and experimental studies has been carried out related to sediment yield from a catchment.

The relationship between landuse land cover and non point sources are reported in many studies (Fisher et al., 2000; Kelsey et al., 2004; Ahearn et al., 2005). Tong and Chen (2002) while using the BASIN model to investigate the relationship of landuse and water quality in the East Fork Little Miami River Basin, found a significant relationship between land use and in-stream water quality, especially for nitrogen, phosphorus and fecal coliform. The study reported that agricultural and impervious urban lands release high level of nitrogen and phosphorus.

Many researchers used AGNPS (agricultural non point source pollution) model in non point pollution study. He (2003) integrated GIS and AGNPS to analyze the effect of land use change on non point source pollution in Dowagiac River, a major tributary of the St Joseph River in southwestern Michigan that flows into Lake Michigan, USA. An interface between ArcView GIS and AGNPS called AVNPSM was developed to study the watershed to simulate the impact of land use change on runoff, sediment, and nutrient yields based on a 25-year, 24-h period of single storm event of 114 mm. The simulation results showed that urban land expansion likely to lead to an increase in surface runoff, peak flow, and soil erosion.

Polyakov et al. (2007) evaluated the performance of AnnAGNPS (Annualized Non-Point Source Pollution Model), in simulating runoff and soil erosion in a watershed located on the Island of Kauai, Hawaii. The study concluded that this model can be used as a management tool on tropical watersheds to estimate sediment loads. Monthly runoff volumes predicted by AnnAGNPS compared well with the measured data; however, up to 60% difference between the actual and simulated runoff were observed during the driest months (May and July). According to the study, prediction of daily runoff was less accurate and the predicted and observed sediment yield on a daily basis was poorly correlated. For the events of small magnitude, the model generally overestimated sediment yield, while underestimated for larger events. Also ground residue cover and canopy cover were found as the most sensitive input parameter of the model.

AnnAGNPS was also used by Sarangi et al. (2007) to predict runoff and sediment losses from a forested and an agricultural watershed of St. Lucia Island in the Caribbean. This study revealed that the AnnAGNPS can be successfully applied for assessment of runoff and sediment losses and subsequent land use planning to conserve the natural resources in the watersheds of St. Lucia.

Jianchang et al. (2008) evaluated AGNPS model for the Wuchuan catchment, of Fujian Province. The results indicated correlation coefficients of 0.98 for runoff, 0.95 for the peak runoff rate, and 0.76 of for sediment yield. In the study SCN-CN and rainfall quantity were found as the most sensitive parameters of the model.

Tong and Naramngam (2007) used the Soil Water Assessment Tool (SWAT) to evaluate the individual and combined impacts of various farming practices on flow, sediment, ammonia, and total phosphorus loads in the Little Miami River basin of southwestern Ohio. For those tested farming scenarios, the study reveals that the no-tillage (NT) offered more environmental benefits than moldboard plowing (MP).

Parajuli et al. (2008) used SWAT model in the Upper Wakarusa watershed (950 km^2) in northeast Kansas to determine the effectiveness of vegetative buffer strips (VBS) and sediment yield. Priority areas for the targeted approach were selected based on model-predicted sediment yield and Fecal Coliform Bacteria (FCB) concentration. A targeted watershed modeling approach-using SWAT was found to be effective at reducing sediment yield load both overland and at the watershed outlet, but this approach was effective at reducing FCB only from overland flow. This study also used SWAT to evaluate effectiveness of various VFS lengths in removing FCB concentration and sediment yield from the agricultural watershed. The model determined that applying VFS using a target approach can be more cost-effective than a random approach and concluded that the 15-m VFS reasonably reduced fecal bacteria concentration in the watershed. Also, Parajuli et al. (2009) used SWAT microbial sub-model 2005 to evaluate source-specific fecal bacteria. The SWAT model was calibrated at the Rock Creek sub watershed, validated at the Deer Creek sub-watershed, and verified at the Auburn sub-watershed and then at the entire Upper Wakarusa watershed for predicting daily flow, sediment, nutrients, total fecal bacteria, and source-specific fecal bacteria. Model results indicated both coefficient of determination (R^2) and Nash-Sutcliffe Efficiency Index (E) parameters ranging from 0.52 to 0.84 for daily flow and 0.50–0.87 for sediment (good to very good agreement); 0.14–0.85 for total phosphorus (poor to very good agreement); 3.55 to 0.79 for total nitrogen (unsatisfactory to very good agreement) and 2.2 to 0.52 for total fecal bacteria (unsatisfactory to good agreement).

WEPP (Water Erosion Prediction Project) model is one of the most common models which predict the amount of sediment yield. The model determines where and when the sediment production occurs and also locates possible deposition places. Yuksel et al. (2007) used a geo-spatial interface for WEPP (Water Erosion Prediction Project), called GeoWEEP model to estimate total sediment prediction from a dam watershed from Kahramanmaras region (Turkey). This study indicated that GeoWEPP could provide quick estimation of sediment yield from large watersheds in high accuracy. Pandey et al. (2008) used WEPP watershed model in the upper Damodar Valley, India. The model was calibrated using data from the 1996 monsoon season and subsequently its performance was evaluated by estimating the daily runoff and sediment yield using the monsoon season data of different years. It was concluded that the WEPP model can be successfully used for estimating sediment yield in this watershed. The sensitivity analysis of the model showed that the sediment yield was found highly sensitive to interrill erodibility and effective hydraulic conductivity, whereas, runoff was observed to be more sensitive to effective hydraulic conductivity.

Cho and Mostaghimia (2009) proposed the dynamic agricultural non-point source assessment tool (DANSAT), which is a distributed-parameter, physically-based, and continuous-simulation model for simulating the spatial and temporal impacts of agricultural best management practices(BMPs) on hydrology and water quality in small agricultural watersheds. Hydrology, sediment, and dynamic variable are the components of DANSAT .The dynamic variable component includes interactive soil, plant growth, and residue decomposition subcomponents which predicts temporal changes in hydrology- and detachment-related soil parameters, crop variables, and the decomposition of three types of residues, respectively. The hydrology components include interception, evapotranspiration, infiltration, percolation, overland flow, channel flow, interflow and base flow components. Sediment components simulate interrill detachment, rill detachment, channel detachment, transport capacity, overland routing, and channel routing.

2.3. APPLICATION OF GIS AND REMOTE SENSING IN NATURAL RESOURCE MANAGEMENT AND LANDUSE PLANNING

Scope of using GIS for natural resource management and hazard mitigation studies have been highlighted by many researchers worldwide (Nath et al. ,2000; Zhan et al., 2008; Elbir,2004; Harley et al., 2010). GIS is an useful tool for watershed based study, watershed modeling and management, documentation of the fluvial geomorphology, water quality modeling, development of water quality management plan, modeling of point and non point pollution in rivers.

Dai et al. (2001) describes a GIS based geoenvironmental evaluation of urban landuse with large databases of topography, geology, water and related hazards for northwestern China. Coulibaly et al. (2004) presented a multimedia model that was developed using publicly available GIS data, chemical release information and local monitoring networks to assess the fate of trichloroethene (TCE) within the Passaic River watershed. A multimedia environmental model was shown to make use of the extensive environmental data from NJDEP, TRI and New Jersey ambient monitoring network and was used to assess a watershed-wide contamination of a toxic contaminant. This study was further built on existing multimedia models to better characterize the spatial and temporal distribution of contamination. The results of this simulation provided a detailed assessment of the contaminant distribution. A brief description of databases and GIS resources available through NJDEP and other public agencies were provided. The Linking of multimedia modeling to GIS was done and this was represented as an important first step in making use of the very comprehensive landscape and contaminant-release data available from the different agencies.

Gangalakunta et al. (2004) carried out a GIS based approach using remotely sensed data to study the drainage morphometry and its influence on landform processes, soil physical and land erosion characteristics in Vena river basin of basaltic terrain (Deccan traps), Nagpur district, Maharashtra. Morphometric analysis was carried out at sub basin level using Spatial Analysis System (SPANS ver. 7.0) GIS system to analyze the influence of drainage morphometry on landforms, soil depth, drainage, available water holding capacity and land erosion characteristics. The study showed that systematic analysis of morphometric parameters through integrated remotely sensed data and GIS. The developed system can be used effectively in land resources evaluation, understanding the spatial distribution of soil characteristics and status of land erosion for judicious resources planning and management at river basin level.

Wang et al. (2005) presented a study that links ArcIMS, web-based GIS software to ROUT, a national and regional scale river model which evolved from the US Environmental Protection Agency's Water Use Improvement and Impairment Model, to create a GIS-based river simulation model called GIS-ROUT. GIS-ROUT is used to predict chemical concentrations in perennially flowing rivers throughout the continental United States that receive discharges from more than 10,000 publicly owned wastewater treatment plants (WWTPs).Each WWTP, containing data on treatment type and influent and effluent flows, was spatially associated with a specific receiving river segment. Based on user defined treatment-type removal rates for a particular chemical, an effluent concentration for each WWTP is calculated and used as input to the river model. The integration of spatial data, GIS and modeling in GIS-ROUT makes it possible to organize and analyze data spatially, and view results on interactive maps as well as tables and distribution charts. The GIS-ROUT allowed scientists and managers in different locations to coordinate and share their estimations for environmental exposure and risk assessments.

GIS also has applicability in non point pollution modelling for watershed management and restoration. Smart et al. (2001) used GIS (ARCINFO) to assemble existing spatial data sets on catchment characteristics to predict stream water quality using simple empirical models. The study was based on the river Dee catchment in NE Scotland, found that geological maps and associated geochemical information provided a suitable framework for predicting chemical parameters associated with acidification sensitivity including alkalinity and base cation concentrations.

Tong and Naramngam also (2007) examined the general association of land use and flow and water quality in the East Fork Little Miami River Basin (Ohio). In the study, both GIS and statistical analysis tools were used to aggregate, synthesize and analyze large databases, and to identify spatial relationships to locate the watersheds that are enriched with contaminants.

Melesse and Shih (2002) conducted a GIS and remote sensing based study on the sub-basin of the Kissimmee River basin in south Florida to determine spatially distributed runoff curve numbers and runoff depth for the watershed for different land use. The study presented determination of spatially distributed runoff curve numbers from LANDSAT images using GIS and image processing software. In the study, GIS and remote sensing were used to provide quantitative measurements of drainage basin morphology for input into runoff models so as to estimate runoff response.

Sivertun and Prange (2003) carried out a GIS based non-point source critical area analysis study in the Gisselo watershed of southeast Sweden. In the study, GIS USLE model was used to estimate the load of both pollutants and sediments, which is able to show the areas that are critical for the water quality at the outlet of the water basin.

Woli et al. (2004) carried out a GIS based study to evaluate the impact of land use on quality of river water in the drainage basins of Shibetsu River (Shibetsu area) and Bekkanbeushi River (Akkeshi area) in eastern Hokkaido, Japan by using the Arcview GIS and statistical information. The study concluded that the land use pattern in a drainage basin affected the quality of river water, and the increase in proportions of upland in drainage basins increased NO –N concentration. The study results also indicated that the analysis of land use patterns and estimation of N budgets were very effective in predicting NO –N concentration in river water.

Kelsey et al. (2004) used GIS and regression modeling techniques to evaluate relationships between land use and fecal pollution in Murrells Inlet, , SC. The study used GIS to identify and calculate land use and spatial variables to be used in a regression model. The results of the regression analyses indicated that areas with septic tanks and runoff from urbanized areas are the main source of fecal coliform in the estuary.

Greiner et al. (2005) used a multi-criteria based tool for assessing the relative impact of diffuse-source pollution to the Great Barrier Reef (Australia) to provide a framework for reducing discharge of sediment, nutrient and other diffuse-source loads and for prioritizing management actions for that between and within river basins. The multi-criteria approach assessed river basins against four criteria, namely ecological impact (of diffuse-source pollution), social impact (of land-use change for pollution control), economic impact (on marine industries from diffuse-source pollutants), and future development pressure.

Maillard and Santos (2008) carried out a GIS based and statistical study to establish the relationship between water quality, land use and the distance from the stream in the Velhas river watershed of Brazil and reported a strong relationship between landuse/land cover and turbidity, nitrogen and fecal coliform.

2.4. REVIEW ON LANDUSE BASED APPROACHES FOR CONTROLLING SEDIMENT AND OTHER NON POINT SOURCES OF POLLUTION

Non point source pollution is a major issue for water resources and has become an increasing concern all over the world. Surface water quality degradation due to non point sources has been reported in different studies (Gnecco et al., 2005; Faram et al.; 2007; Zaimes et al., 2008). With growing concern towards environmental conservation, issues of non point pollution are also receiving more attention from the scientific community during the last decade.

Surface runoff is a major source of non-point pollution (Tong et al., 2002). As reported by Santhi et al. (2006), sediment and nutrients are the major non point pollutants in West Fork Watershed of Trinity River Basin in Texas, USA. According to Jung et al. (2008) one of the main reasons for not achieving the target of water quality management besides the effective effort through point source control in the Han River Basin, Korea, was pointed out as to taking sufficient measures toward diffuse pollution, particularly in the control of storm water discharge. This has become a great concern for India as well. According to Jain (2007), non-point source run-off is one of the significant contributors to the nutrient loading in the Ganga River of India.

In recent years, more emphasis has been given to the application of landuse based management practices in controlling non point source pollution. Efficiencies and applicability of various landuse management practices for controlling yield of sediment and other non point pollutants are found in many studies (Robb, 1992; Smith, 2001; Anbumozhi et al.,2005; Shiono, 2007; Boving et al., 2007; Moreno et al., 2007; Parajuli et al., 2008; Maillard et al., 2008; Hatt et al., 2009).

According to Robb (1992) wetlands have an important role in the landscape through their ability to improve water quality by filtering, transforming, and accumulating pollutants and thereby protecting adjacent rivers, lakes, and streams; and thus wetlands is an useful components of NPS pollution control strategies. Similarly, sumps can also be utilized to capture pollutants to a significant level in controlling non point source pollution (Smith, 2001).

According to Wenger (1999), grass and forest have good sediment control and their efficiency also depend on width and extent and also vary widely from place to place. Collins (2003) predicted grass buffer strip with a mean annual decrease of 20% sediment yield in the Waiarohia catchment relative to that under bare soil. According to Maillard and Santos (2008) also reported that the riparian forests serve as a buffer zone and filter between the higher watershed and the aquatic ecosystem. Thus riparian forest help in (i) absorbing nutrients and other chemicals from surface runoff, and (ii) reducing and filtering the sediment load of surface runoff.

Taebi and Droste (2004) examined the efficiency of two controlling systems- advanced treatment of sanitary wastewater and urban runoff quality control systems like detention ponds for pollution discharges into receiving waters in the city of Isfahan (Iran) having 10 topographical urban catchments. The result showed that in low precipitation urban area, advanced treatment is a more suitable option, but for high precipitation urban areas, urban surface runoff quality control installations were more effective for suspended solids and oxygen-demanding matter control, and that advanced treatment is the more effective option for nutrient control.

Anbumozhi et al. (2005) summarized the results of a field monitoring study done in Tokachikawa watershed in Hokkaido watershed (Japan); Cisadane watershed, Cianten watershed and Citamyang watershed (Indonesia) and Cauvery watershed (India) to quantify the impact of riparian buffer zones on changes in stream water quality. The results demonstrate the positive impact of forest buffer zones in reducing the influence of agricultural nutrients and chemicals on surface stream waters.

In a study conducted by Wang et al., (2006) in Zhangcunhe Creek watershed in China, for the prevention of eutrophication and algae bloom from nutrients, constructed wetlands and riparian aquatic plants were suggested to form buffer zones.

Moreno et al. (2007) evaluated the effectiveness of constructed and natural wetlands in removing nutrients from agricultural wastewater at Monegros region located in the central part of the Ebro River basin (NE Spain). In this study experimental wetlands showed a remarkable Nitrogen removal efficiency (24–43% of the inflowing N concentration), in spite of the fact that they were at the initial stages of their development (two years). For phosphorus, the experimental wetlands showed removal of 80% of the phosphorus input.

Boving and Neary (2007) conducted an experimental study to remove the dissolved PAH for storm water runoff through the application of wood filters. The wood filters are found to be effective to remove on an average between 18.5% and 35.6% (up to 66.5%) of the dissolved PAH contaminants.

Holvoet et al. (2007) evaluated the impact of implementation of different BMPs on pesticide fluxes entering the surface water using SWAT modeling approach in the Nil catchment of Belgium. The results reveal that the strip cropping seems to be more efficient than cover crops than buffer strips than a 25% reduction of point looses and plough management respectively.

Vegetative filter strips (VFS) are control measures for controlling sediment yield. Shiono et al. (2007) investigated the performance of a centipede grass (Eremochloa ophiuroides (Munro) Hack.) strip for reducing sediment runoff from an upland field in Okinawa, focusing on strip length and sediment aggregate size as factors affecting performance. According to the study the sediment removal efficiencies were 24% for the 0.5-m strip, 36 to 54% for the 1.5-m strip and 73% for the 3.0-m strip. The study also concluded that strips trapped well the sediment aggregates larger than 0.02 mm in diameter, regardless of strip length. Also it is found that longer strip trapped more aggregates of the 0.002-0.02-mm size class but aggregates smaller than 0.002 mm strips were trapped poorly. Gharabaghi et al. (2006) studied the effect of vegetation type, width of the filter strip, runoff flow rate and inflow sediment characteristics on effectiveness of the VFS and found that sediment removal efficiency increased from 50 to 98% as the width of the filter increased from 2.5 to 20 m. In addition to the width of the filter strip, grass type and flow rate were also significant factors. Parajuli et al. (2008) used SWAT model in the Upper Wakarusa watershed (950 km^2) in northeast Kansas to test the effectiveness of vegetative filter strip (VFS) (lengths 0, 10, 15 and 20 m) for removing sediment and fecal bacteria concentration and rank sub-watersheds after determining sediment and fecal bacteria contribution of each sub-watershed using targeted and random approaches to select 10, 25 and 50% of the sub-watersheds. The study indicated that the 15-m VFS can reasonably reduces fecal bacteria concentration in the watershed. The observed difference between the target and random approaches to fecal bacteria reduction was at 50% VFS adoption; the target approach removed about 60% of fecal bacteria, and the random approach removed about 42%. For sediment yield, the greatest reduction was at 25% VFS adoption; the target approach removed about 63% of sediment yield, and the random approach removed about 33%. The study thus indicated that a targeted watershed modeling approach using SWAT was effective at reducing both fecal bacteria concentration and sediment yield.

Besides the traditional practices, some new practices in controlling non point pollution were emerged in recent years. The biofilters are typically configured as vegetated filtration trenches or basins with an underlying collection pipe. Vegetated biofilters aim to replicate the physical, chemical and biological processes that occurs within the natural environment i.e. settling of particulates as vegetation decreases the flow velocity, mechanical straining of particulates and sorption of dissolved pollutant as water filtrates through the filter media, transformation and uptake of pollutant by microorganisms and plants (Hatt et al., 2009).

2.5. PREVIOUS WORKS ON SEDIMENT LEACHING AND THEIR IMPACT ON WATER QUALITY

Various experimental studies have been carried out to understand the leaching behavior of metals and nutrients from soil. Haidouti (1995) carried out an experimental study to investigate the effects of fluoride pollution on the mobilization and leaching of aluminum in soils. The study was done with a laboratory set up designed with a flow rate equivalent to rainfall event of 2 mm/h and then by percolating homogeneous soil samples with distilled water, Potasium Chloride and Sodium Chloride solutions. The study concluded that for all soil samples Fluoride-containing solutions induce substantial losses of Aluminium than Chloride. Also, the leaching losses from the contaminated soil were higher than those from the uncontaminated soils.

Bohan et al. (1997) studied the leaching behavior of two forest soils of Guiyang and Nanchang in southern China to see the effect of acid deposition through a column leaching study. It was found that in the top layer of soil, exchangeable Aluminum, increased particularly when leached with the most acid solutions, while exchangeable calcium decreased for these solutions.

Hansen and Dijurhuu (1997) studied the effects of tillage and growth of a catch crop on nitrate leaching into soil porewater with variable soil type, climatic and vegetation growth condition through a field based experimental study. It was concluded that the growth of catch crop reduced leaching.

Reemtsma et al. (1997) conducted a column leaching test to investigate the hydrophobic organic contaminants leaching from soil. The study found that the leachability of Poly Aeromatic Hydrocarbon (PAH) was related to their molecular weight and hydrophobicity with desorption percentages ranging from 1 - 10% for acenaphthene to below 0.02 % for pyrene and higher PAHs. Kim et al (2003) conducted a batch leaching study to evaluate the factors affecting leachability of Hydrophobic Organic Pollutants (HOPs) with PAH and found that the shaking time, temperature, and dissolved humic matter (DHM, as coexisting matter) increased, leachability; whereas ionic strength reduced leachability, whereas the liquid-to-solid ratio and pH level had no effect on leaching concentration of HOPs.

Barcan (2002) conducted a laboratory based experiment with lysimeter to estimate the velocity of leaching Nickel and Copper from the forest litter contaminated by the metallurgical dust. The study concluded that complete removal of these two heavy metals from the metallurgical dusts contaminated podzolic soils takes 160 to 270 years for Nickel and 100 to 200 years for Copper, and also dependent on the type of metallurgical dust. Also, increased pH in the irrigation water can increase the amount of metals leached from the soil.

Chen et al. (2006) carried out a laboratory column leaching experiments to evaluate P leaching from sandy soil amended with DPR fertilizers, as compared with water-soluble P fertilize and found that use of N-Viro-based DPR fertilizers can reduce P leaching from sandy soils. Schipper et al. (2008) stated that agriculture sources are important for the total loads to surface water for Cadmium, Lead and Zinc.

Qin et al. (2010) while developing an index to assess the environmental risk of P loss potential in vegetable soils with chronic difference of plantation in the suburbs of Changsha, Hunan Province, China. The study concluded that the Phosphorus leaching potential was high in Changsha and the phosphorus leaching loss was related to chronic length of vegetable cropping.

Sediment after being transported to water bodies also plays an important role in water chemistry. Many researchers have investigated sediment behavior in water column. Jain and Ram (1997) studied the adsorption characteristics of the bed sediments collected from the River Kali in western Uttar Pradesh, India, for the uptake of Lead and Zinc ions. The study revealed that adsorption of metal ions increases with increasing initial metal ion concentration and decreases with adsorbent particle size, also extent of adsorption observed to be increased with the increase of pH of the solution.

Lau and Chu. (1999) conducted a study on Gei wai, tidal shrimp ponds (coastal wetlands) of Hong Kong to investigate the level of contamination of underlying sediments. The study concluded that sediment in Gei wai was contaminated with nutrients and heavy metals, of which Nitrogen and Phosphorus tend to bind to coarser particles, while Copper, Nickel and Zinc to finer ones (silts and clays). Mobility of Nitrogen and Phosphorus from the sediment was observed to increase with increasing levels of salinity and temperature of the overlying water.

Mayer et al. (1999) studied the sediment chemistry and chemistry of interstitial water the Lower Great Lakes, Point Pelee National Park, Ontario, Canada to determine the role of benthic sediments in nutrient dynamics. The results indicated high concentrations of dissolved nutrients (about 4 mg/l of Phosphorous and over 20 mg/l of Nitrogen) in sediment porewater.

Crabil et al. (1999) observed two sediment sites in Oak creek, Arizona with high fecal coliform counts, averaging 2200 times the fecal coliform counts of the water column.

Jamieson et al. (2005) in studying the processes which control the fate and transport of enteric bacteria in alluvial streams stated that the majority of enteric bacteria in aquatic systems are associated with sediments and that these associations influence their survival and transport characteristics.

Bai and Lung (2005) found that fecal bacteria kinetics in sediment bed is more complicated than in the water column. In this study, to investigate the impact of sediment on the transport of fecal bacteria, a modeling framework based on the Environmental Fluid Dynamics Code (EFDC) model was proposed. Using this model, the contributions of fecal bacteria from sediment bed and from the watershed can be modeled separately and explicitly. The case study showed that the model performed correctly to simulate the settling and resuspension of fecal bacteria associated with sediments transport under various conditions.

Jiang et al. (2008) studied the effects of biological activity, light, temperature and oxygen on the Phosphorus release processes at the sediment and water interface of a shallow lake, Taihu Lake, China. The results showed that organisms at the sediment and water interface can stimulate Phosphorous release from sediments, and their metabolism can alter the surrounding micro environmental conditions. The extent of Phosphorous release and its effects on P concentration in the overlying water were affected by factors such as light, temperature and dissolved oxygen.

Stutter and Lumsdon (2008) investigated benthic sediment Phosprous sorption in relation to river soluble reactive phosphorus (SRP) concentrations during high- to low-flow changes in a major mixed land use river system in NE Scotland. The study showed that pollution- impacted tributaries (32–69% catchment agricultural land cover) had increased SRP concentrations (0.19–2.62 micro mol P/L) and maintained (Equilibrium Phosphorous Concentration) EPC0 < SRP values during changing flow conditions. Moorland-dominated tributaries and main stem sites had small SRP concentrations (0.03–0.19 micro mol P/L) but showed EPC0 > SRP values during summer baseflow so that sediments were indicated as P sources.

Butler (2009) while studying the streambed sediments of Acid Mine Drainage (AMD) impacted North Fork Clear Creek (NFCC), Colorado, stated that the changes in water chemistry may cause the existing contaminated bed sediments to become a source of metals to the stream water. The study revealed that greater concentrations of metals were released from the smaller sized sediments compared with the larger, with the exception of Copper. The results suggested that the expected changes in water chemistry following removal/treatment of the AMD sources would result in a release of metals from the existing sediments, with a greater effect on the release of Copper and Iron, than on the release of Cadmium, Manganese, and Zinc.

2.6. USE OF OPTIMIZATION TECHNIQUE ON LANDUSE PLANNING

Optimization techniques have wide applicability in solving different types of engineering and environmental problems. The choice of an optimization technique depends on the availability of data, objective function of the problems and constraints. Generally, either simulation model or optimization techniques like linear programming (LP), non linear programming (NLP) Dynamic Programming (DP) and heuristic methods like genetic algorithm (GA), Ant Colony Optimization (AC) are used for deriving optimal solutions.

Linear programming is a valuable tool in optimization. Linear programming deals with the optimization (maximization or minimization) of a function of decision variable known as objective function, subjected to a set of linear equations known as restrictions or constraints. The objective may be profit, cost, production capacity or any measures of effectiveness, which is to be obtained in the best possible or optimal manner. The restriction may be imposed by different sources such as market demand, production process and equipment, storage capacity, raw material availability etc. The model thus obtained will be referred to as linear programming model if the objective function and constraints are linear mathematical expression.

Linear programming problems can be solved by graphical solution, whoever graphical solution is not possible when the decision variables are more than two. In such situation, analytical methods like Simplex method, Dual Simplex method, Revised Simplex method Big M method are used for solving linear programming problem. In 1947, Gorge Dantzing and his associates found a technique called Simplex method, for solving military planning problems while they were working on a project for US air force. This technique consists of representing the various essential activities of an organization as a linear programming model and arriving at the optimal program by minimizing a linear objective function.

Dynamic programming (DP) a method first introduced by Bellman (1957) is an optimization procedure for solving a multistage decision process. DP has a wide variety of applications in engineering and economic decision problem (Yakowitz, 1982). The popularity and success of the technique can be attributed to the fact that the non linear and the stochastic features, which characterize a large number of water resource systems, can be translated into a DP formulation. In addition, it has the advantage of effectively decomposing highly complex problems with large number of variables into a series of sub problems, which are solved recursively. The computational requirement for DP increases exponentially with increase in state dimension.

Optimization techniques are widely used in variety of landuse planning problems. Lost (1979) attempted to solve is the joint optimization of a land-use plan and of a transportation plan with a Discrete-Convex Programming approach. Guldmann (1986) presented a structural framework for analyzing landuse/environmental interactions and formulating planning models accounting for these interactions. The purpose of the study was to conceptually lay out the structure of a comprehensive planning model encompassing land-use, economic, and environmental interactions in a region viewed essentially as a closed one, at least environmentally. The basic problem considered was the allocation of different land uses to potential sites in the region, including the selection of the locations and capacities of transportation links, and the determination of an environmental pollution control plan that will optimize some regional welfare function subject to several technological, mass balances, locational and environmental standards constraints. The model had five basic components: a landuse subsystem, the residuals generation subsystem, the centralized treatment subsystem, the environmental subsystem and the externality reception subsystem.

Matthews et al. (1999) developed a spatial decision support system (DSS) for rural land use planning at the management unit level with two software platforms: Gensym's G2 knowledge based system (KBS) development environment and Smallworld GIS. The DSS is based on five components: GIS, land use modules; impact assessment modules, a graphical user interface; and land use planning tools. These components are implemented across the use of genetic algorithms, to find optimum land use plans using the integrated functionality of both KBS and GIS.

Wang et al. (2004) used a watershed optimization model in Lake Erhai basin, China, incorporating into a GIS-based spatial allocation model to provide specific location recommendations based on existing land use, slope, distance to surface water and conversion preference. The study an inexact-fuzzy multi-objective linear programming (IFMOP) model of a multi-objective decision-making problem and the results were found also useful for generating detailed design for a number of environment-related activities. According to the author, in China land use is controlled by various local governments. To coordinate different and sometimes competing needs for land, the IFMOP model were found suitable to formulate the planning process as a set of objectives and constraints, which are transparent to and can be modified by planners and decision makers. The GIS allocation model further specifies where the land use change may occur to maintain the compatibility of land uses and the feasibility of physical conditions. The IFMOP is a significant contribution based on single objective inexact programming.

Ittersum et al. (2004), presented the SysNet, a systems research network in South and South-east Asia, established to develop and evaluate methodologies for enhancing formulation of strategic landuse policies. SysNet adopted theory and concepts from both natural and social science approaches. Multiple goal linear programming was used to integrate information on a broad range of alternative landuse systems, resource availability and policy objectives, to reveal possibilities and limitations of agricultural resource use and tradeoffs between policy objectives. Jiangqian (2007) proposed a basic framework for the sensitivity analysis and continuous optimization of integrated land use and transportation model.

Hsieh and Yang (2007) used optimization method and an annual average reservoir water quality model to develop optimal Best Management Practice (BMP) strategy for controlling non point pollution in the Fei-Tsui Reservoir watershed. The study suggested installation of several detention ponds in the watershed to attain oligotrophic conditions in the reservoir.

Riveira et al. (2008) used simulated annealing (SA) for allocation of land units to a set of possible uses on, the basis of their suitability for those uses, and the compactness of the total areas allotted to the same use or kind of use. The study concluded that SA is superior to hierarchical optimization, ideal point analysis, and MOLA, offering solutions that have better suitability but are more fragmented than those achieved by the other methods.

Lin et al. (2009) demonstrated the utility of optimal spatial models for modeling specific spatial patterns to facilitate rational land-use planning of a watershed in northern Taiwan. In the study, optimization was implemented using SA in a spatial pattern optimization model (OLPSIM), and developments predicted by the drivers of past land-use changes were modeled with the CLUE-s model. The landscapes simulated by the models were used with HEC-HMS to assess the impact of land-use patterns on runoff in the watershed and sub-watershed scales.

Gabriel et al. (2006) developed a multiobjective optimization model to land development considering the conflicting interests of the various stakeholders involved in land development decisions: the government planner, the environmentalist, the conservationist, and the land developer. The resulting model was applied for a GIS-based data set for Montgomery County, Maryland. This model suggested by Gabriel et al., consist of linear and quadratic objective functions subject to linear and binary constraints. Using the weighting method for determining Pareto optimal points resulted in Quadratic Mixed Integer Programming (QMIPs) to solve for each choice of positive weights applied to the stakeholder objective functions. Sadeghi et al. (2009) formulated a multiobjectives linear optimization problem for the Brimvandwatershed, Iran, to find out the most suitable land allocation to different land uses, viz. orchard, irrigated farming, dry farming and rangeland targeting soil erosion minimization and benefit maximization. The simplex method with the help of ADBASE software package was used and the results of the study revealed that the amount of soil erosion and benefit could, respectively reduce and increase to the tune of 7.9 and 18.6%, in case of implementing optimal allocation of the study land uses. The results of sensitivity analysis also showed that the objective functions were strongly susceptible to the constraint of maximum summation of irrigated farming and orchard areas. Riveira et al. (2008) described a multiobjective linear programming for the optimization of land-use areas, where the objectives include economic, social, and environmental aspects using three techniques: hierarchical optimization, ideal point analysis, and simulated annealing. The model was applied in Terra Cha (NW Spain), and pointed out the possibility to develop alternative land-use plans for the region according to different stakeholders' perspectives.

2.7. CONCLUSIONS

Wide applicability of remote sensing and GIS thus have become advantageous in modeling, analyzing and retrieving large spatio-temporal data required for management of natural resources especially land and water. Considering this, development of a GIS and remote sensing based River Water Quality Information System (RWQIS) is taken up as a part of this study, which can assist in identification of degraded watersheds that need different levels of restoration and management.

The rational method and the RUSLE method were found to have wide applicability in studying the runoff and sediment yield behavior from different types of landuse. Based on these two models, various software based advanced hydrological models like SWAT, AGNPS, DANSAT, WEEP were developed for modeling the runoff, sediment yield and other non point source pollution. Different researchers have found suitable application of these models in their study areas. For this current research work, first considering the focus of the optimal EMP model and secondly considering the simplicity of data requirement by rational method and RUSLE, these two models were found to be suitable.

Landuse based management practices like grass, forest, vegetative strips and ponds are scientifically recognized as efficient sediment and non point source pollution control measures. The efficiency of such practices highly depends on soil, topographic and climatic conditions and therefore varies from place to place. Thus, it is important to study the site specific suitability and efficiency of the landuse management practices in controlling sediment or other non point source pollution so as to achieve a cost effective and sustainable management plan for a particular area. In the Guwahati City of NE India, no such particular study has been carried out. Thus, to have a quantitative idea regarding efficiencies of different management practices of this kind, a field based experimental study is necessary for this region. Therefore, development of an experimental watershed and to carry out a detail experimental study has been considered as an essential component of this research work. Again, as cost and efficiency of different management practices vary from place to place, determination of a site specific optimal combination of management practices is another challenging task under the constraint of economical, social and ecological sustainability. Such management practices are stated in this study as Ecological Management Practices (EMP).

Literature review on the leaching of nutrients and heavy metals from soils and sediments has revealed that the process of leaching contributes significantly to water quality. The leaching behavior varies with ionic species, level of contamination, land cover condition and the properties of the prevailing liquid medium. However, contribution by leaching from the natural vegetated soil surface into surface runoff has not yet been explored and thus comparative study on rainfall-runoff water chemistry has been carried out to see how much ionic strength is added to the surface runoff by the process of leaching. A batch leaching study is carried out for soils with different landcover conditions to investigate the total amount of leachable ionic species present in different soil types. This study will help in determining permissible limit of sediment yield from a watershed from water quality perspective.

Optimization techniques are widely used in optimal allocation of different landuses to maximize the benefits and for solving conflicting objectives. Besides the use of traditional optimization models like linear programming, non linear programming, quadratic programming, convex programming for solving single objective and multiobjectives problems, recent studies have also highlighted the use of modern techniques like Genetic Algorithm(GA) and simulated annealing (SA). For problems requiring input of spatial data some researchers in recent study have coupled GIS with optimization models. The focus of this study being determination of most optimal combination of ecologically sustainable management practices for development of urban watershed, formulation of an optimization problem for allocating optimal EMP combination at minimum possible cost subjected to restriction of sediment yield and runoff volume within the permissible limit has been attempted in this study by utilizing topographic and landuse/landcover data derived from GIS.

Chapter 3
PRIORITIZATION OF DEGRADED WATERSHEDS

3.1. INTRODUCTION

Application of EMPs for urban watershed requires detailed planning considering various socio-economic aspects and can become cost intensive, particularly in respect of capital cost. Because of unplanned urbanization, most of the hilly urban watersheds of India have degraded extensively and need immediate restoration measures. However, economy of developing country like India may not permit execution of management practices in all such degraded watersheds at a time because of financial constraints. On the other hand, demand for implementing watershed management projects with EMPs will come from different degraded urban watersheds, and everyone will claim their watershed to be the one that requires urgent attention. Therefore, it is necessary to have a decision support system which will help in prioritizing the watershed in a most logical way according to their degree of degradation and impacts on the surroundings. Application of GIS and Remote Sensing can be of great help in developing such system, particularly for an area like Northeast India, where some areas are not easily accessible. Since continuous monitoring and analysis over a large watershed including their documentation and dissemination, is often challenging, integrating such data into a GIS based information system can be rewarding from many aspects. . With the increasing pace of urbanization and industrialization, river water quality is deteriorating at an alarming rate all over the world (Sire and Balamurugan, 1991; Al-Kharabsheh and Taanyw., 2003; Gürlük, 2009; Schaffner et al., 2009). While field verification of degradation status of a watershed is difficult in some areas, river water quality can be conventionally used as an index of catchment degradation. Regular spatio-temporal monitoring of river water quality is also important for relatively pristine regions like the Northeastern region of India, where a large section of both rural and urban population depends on river water.

A comprehensive river water quality information system has been developed and presented in this chapter. This system was also used for evaluating river water quality of the Northeastern region of India, leading to the identification of the seriously degraded watershed. In addition, a systematic procedure is suggested to study the rate and pattern of urban expansion of degraded urban watershed and presented in this chapter.

3.2. NEED AND SCOPE OF USING REMOTE SENSING AND GIS

Management of natural resources requires analysis and handling of large number of spatial and non spatial data. In many cases, topographical data necessary for such purposes requires extensive physical survey, which appears to be very time consuming and expensive. However collection of topographic data has now become easy and affordable with the advances in remote sensing technology. Necessary topographic data like geomorphology, geology, geography, lands cover, elevation, slope, aspects etc now can be easily extracted from various remote sensing products and thus remote sensing is now becoming an unavoidable part of natural resource management.

River water quality management requires maintaining and regular updating of large amount of water quality data at their different spatial and temporal dimensions. GIS has enormous advantage in handling and managing such large datasets and also provide various tools for analysing the data along with other relational databases. Scope of using GIS for natural resource management and hazard mitigation studies have been highlighted by many researchers worldwide. Use of GIS was found to be advantageous in aquaculture development (Nath et al., 2000), urban landuse studies (Dai et al., 2001), air pollution inventory (Elbir, 2004; Zhan et al., 2008) as well as for specific uses like cave management (Harley et al., 2010).

Considering the established advantages, a GIS based River Water Quality Information System (RWQIS) was developed to classify degraded watershed based upon river water quality for various purposes. The efficiency of the developed RWQIS was tested by integrating a river water quality database for the entire Brahmaputra Barak system of India.

3.3. STRUCTURE OF THE RIVER WATER QUALITY INFORMATION SYSTEM (RWQIS)

The major components of the RWQIS were the river network database and the river water quality database. Additional databases like watershed database and discharge database were also included in this river information system. These databases were made relational with a common field ("River Name"), which provides linking of the rivers with their respective water quality data at the geographical location of the sampling sites. In the structure of the GIS database (Figure 3.1), the various primary data generated and secondary data collected have been incorporated in different layers. All these layers are linked with the digital river network layer. Eventually linking of the rivers with their respective water quality was done (Figure 3.2) for evaluation of the respective watersheds.

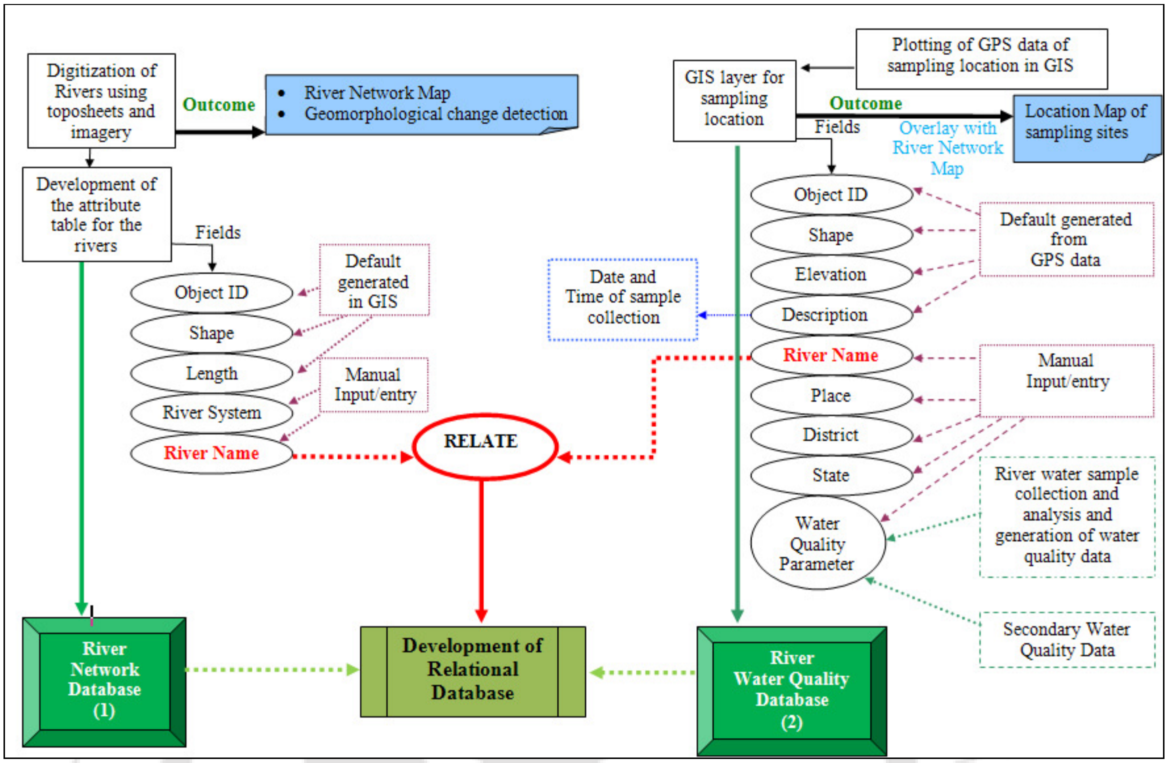


Figure 3.1: Schematic diagram of the RWQIS

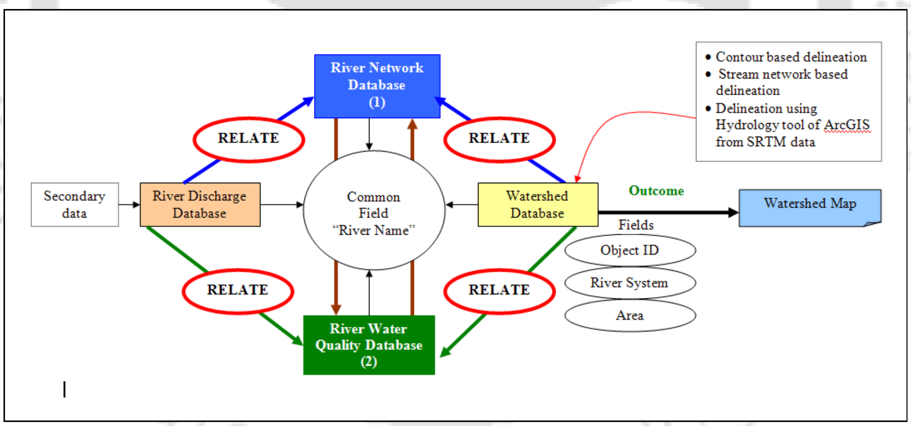


Figure 3.2: Linking of different databases in the RWQIS

3.4. APPLICATION OF RWQIS FOR NORTHEASTERN REGION OF INDIA

3.4.1. STUDY AREA

The study area covered a major part of the Brahmaputra Basin within India, which is a region with an intricate network of streams and rivers. These rivers are with great water resource potential and also are sites for rich aquatic biodiversity. Lately, rapid industrialization and urbanization are taking place in the region and there is a serious threat to the watersheds due to deteriorating water quality. A GIS database of the rivers incorporating all relevant information related to water quality has become essential to assess the existing status of the watersheds to plan mitigation measures.

Geographically, the study area in the Northeastern region of India extends from latitude 22^{o}N to 29^{o}N and longitude $87^{o}55^{/}$E to 98^{o}E and comprises of eight states: Assam, Arunachal Pradesh, Meghalaya, Mizoram, Manipur, Nagaland, Tripura and Sikkim (Figure 3.3).

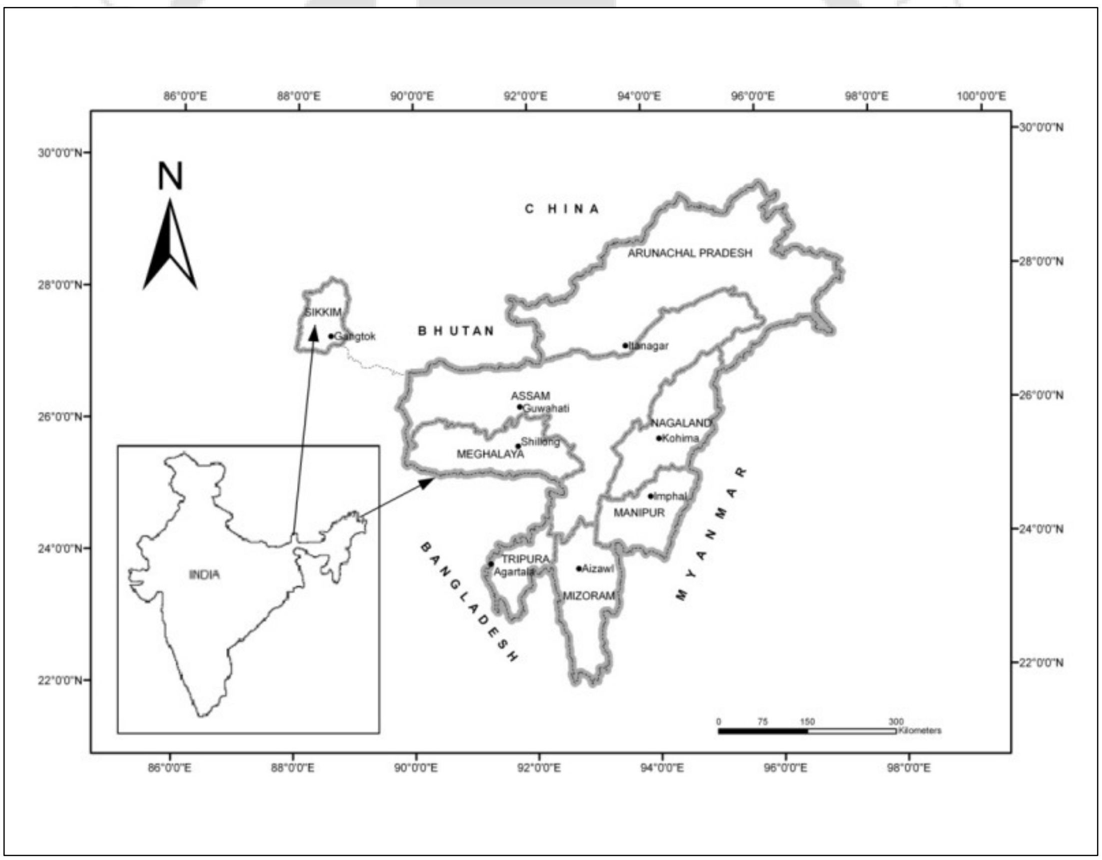


Figure 3.3: Map of the study area showing major administrative boundaries and state capital

3.4.2. MATERIALS AND METHODS

Remotely sensed data and GIS based approach have wide applicability in detecting spatio-temporal changes. With the increase of spatiotemporal resolution, satellite data are now becoming quite useful for investigating the changes in landform characteristics and river morphology. The database described in this study has been developed in the ArcGIS 9.1 environment. At first, the digital river network map of the region was prepared from toposheets and imageries (Table 3.1) by following the projection system adopted in SoI toposheets i.e. Polyconic Everest. Rivers were digitized by line features (polyline), representing the centre line of the river.

Table 3.1: Details of the maps and imageries used in developing RWQIS for Northeastern Region of India

Sl. No	Toposheets/Imageries	Source
1	1: 2500000 scale toposheets covering the region	University of Berkely website
2	1:50000 scale toposheets covering the region (1972 edited)	Survey of India
3	IRS AWiFS imagery (multispectral) of the region Resolution:59mx59m	NRSA
4	Recent IRS LISS III imagery (multispectral) Resolution:23.5mx23.5m	NRSA

The river water quality database was prepared incorporating both primary and secondary data. A GARMIN GPS (model: 76 CSx) was used for recording the sampling locations of the primary water quality data. Feature classes for these sampling locations were created and the water quality data in these locations were incorporated in respective attribute tables of the feature classes. The secondary water quality data collected from different sources (CIFRI, 2003; Mahanta and Subramanian., 2004; Trisal and Manihar, 2004; Hussain et al., 2006 ; CPCB,2008;Girija, et al., 2007) were too incorporated in the database.

The water quality database was finally linked with the river network database by using inbuilt 'relate' tool of ArcGIS. This enables the relational analysis of these information covering both spatial and non spatial aspects (Sarma et al., 2010)

The application of the RWQIS to the Northeastern region of India identified the Guwahati City as the city with two most degraded watersheds. As such the trend and pattern of urban expansion of Guwahati City was studied with SoI toposhhets and satellite imageries as given in Table 3.2. The thematic maps of built up area of Guwahati within the GMDA boundary were then prepared in ArcGIS 9.1. These map layers prepared for different time period were superimposed to investigate the status of urban expansion in Guwahati city. The vector layers of built up area of Guwahati for different time period were done as ArcGIS feature class and the total built up area was thus obtained from the attribute table of the feature class.

Table 3.2: Details of the maps and imageries used in study of urban expansion of Guwahati City

Sl. No	Toposheets/Imageries	Source
2	1:50000 scale toposheets of Guwahati (1972-73 edited)	Survey of India
4	IRS LISS III imagery (multispectral) Resolution:23.5mx23.5m	NRSA
5	IRS LISS IV imagery (multispectral) Resolution:5.5mx5.5m	NRSA
6	CARTOSAT 2A Resolution:1m x 1m	NRSA

3.4.3. THE RIVER NETWORK DATABASE

Recording exact location and present status of a river is essential to carry out systematic analysis of spatio-temporal physical and chemical changes of the watersheds. Both morphological characteristics and water quality status undergo significant changes over time. Considering this, digital maps of present locations of all the rivers and streams of Northeast India were prepared.

The attribute tables of the rivers were developed along with the river network map in GIS. The table contains following attributes for each river:

(i) A feature ID: This gets generated by default in ArcGIS for every feature at the time of digitization. This ID is unique for each and every river.

(ii) Shape length: Length of the river.

(iii) River name: Corresponds to the local name of the river.

(iv) River system: Name of the major tributary of which the stream is a part.

The digital stream network map of the Northeastern region gives the geographical locations and morphological status of the rivers (Figure 3.4). Stream network data thus developed revealed that the rivers were generally of meandering nature and sometimes of braiding type at the foothill areas and they have undergone various morphological changes since the past. Morphological changes are more prominent in rivers carrying high sediment load and therefore can become an additional indicator of human activities in the upper catchments. Of course, evidence of high sediment yield from the upper catchments due to natural weathering process and landslides are also common. An idea of the geomorphological changes of the rivers of Northeast India can be obtained from the digital stream network map (Figure 3.5).

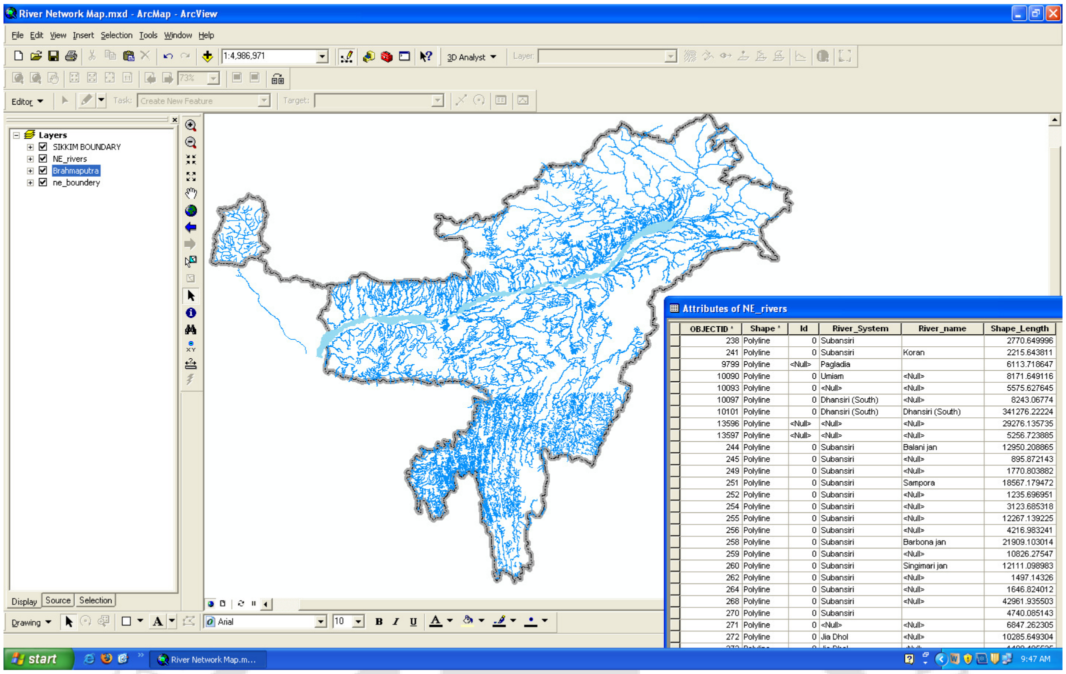


Figure 3.4: A view of the river network database in GIS

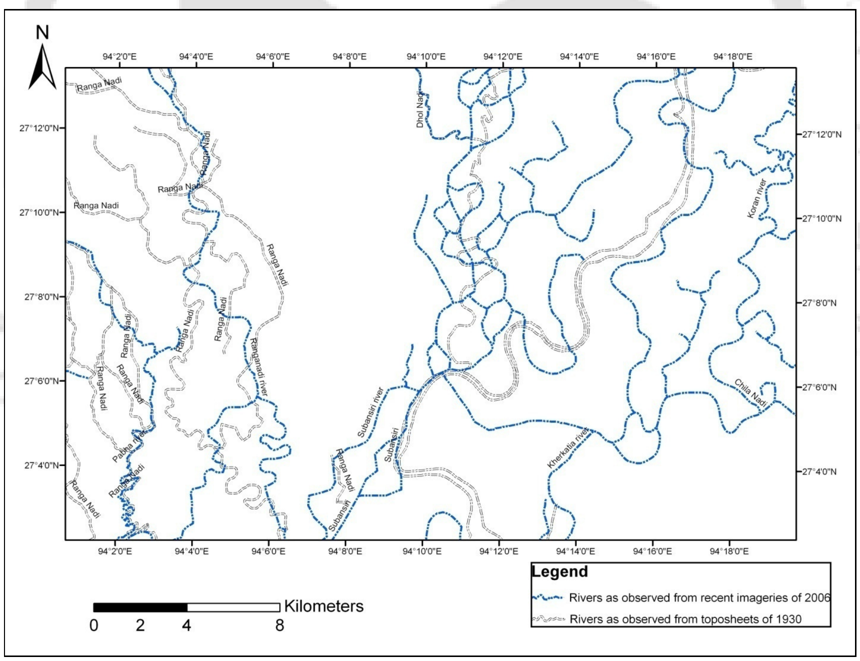


Figure 3.5: An example of geomorphological changes of rivers between 1930 and 2006

3.4.4. THE WATER QUALITY DATABASE

In the water quality database, river water quality information with reference to the geographical location of each sampling point was incorporated (Figure 3.6). The database provides scope of observing temporal changes in water quality of the rivers. All these information were linked with the river network database (Figure 3.10). The database provides scope of getting information on as many as 24 key water quality parameters and location details of all sampling sites (119 sites) covered under the study. The attribute table of this water quality database contains the following information:

(i) The source of the data

(ii) A unique feature ID

(iii) Latitude and longitude of the point

(iv) River name

(v) Place name of the sampling point

(vi) Date and time of sampling

(vii) State where the sampling point is located

(viii) District where the sampling point is located

(ix) Water quality parameters analyzed for the locations

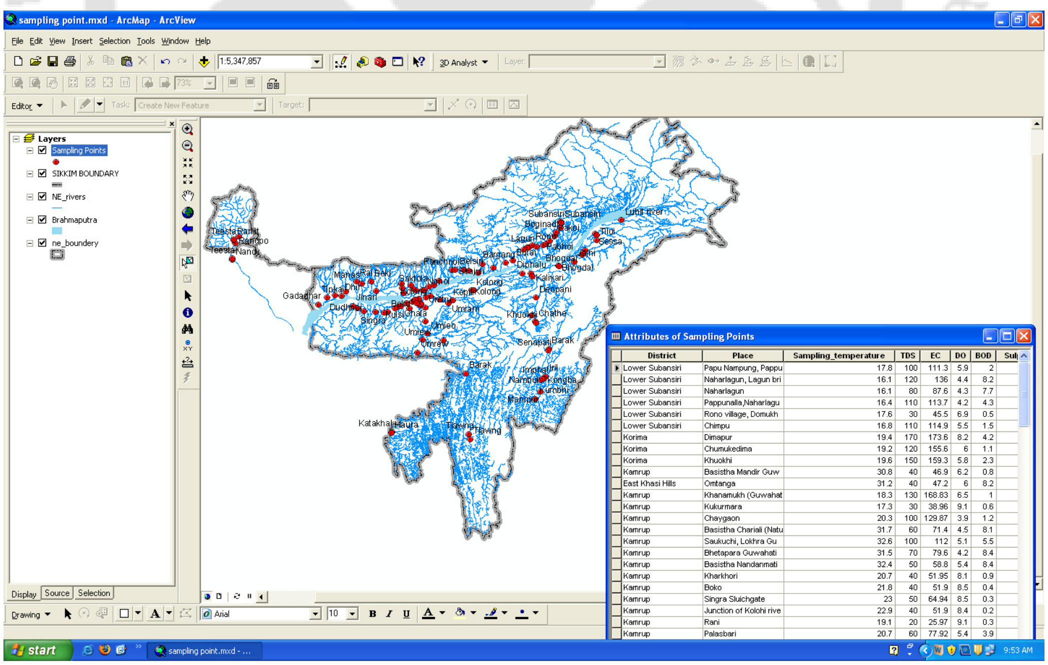


Figure 3.6: A view of the river water quality database of Northeastern region of India in GIS

3.4.5. SOME ADDITIONAL DATABASES OF THE RIVER INFORMATION SYSTEM

3.4.5.1. Watershed database

To have an idea about watershed degradation by referring river water quality information of a particular river, it is necessary to have a watershed database. The watershed database contains the following information:

(i) An unique feature ID of the watershed

(ii) Name of the watershed (as per the name of the river system)

(iii) Area covered by the watershed

A view of this database in GIS platform is shown in the Figure 3.7

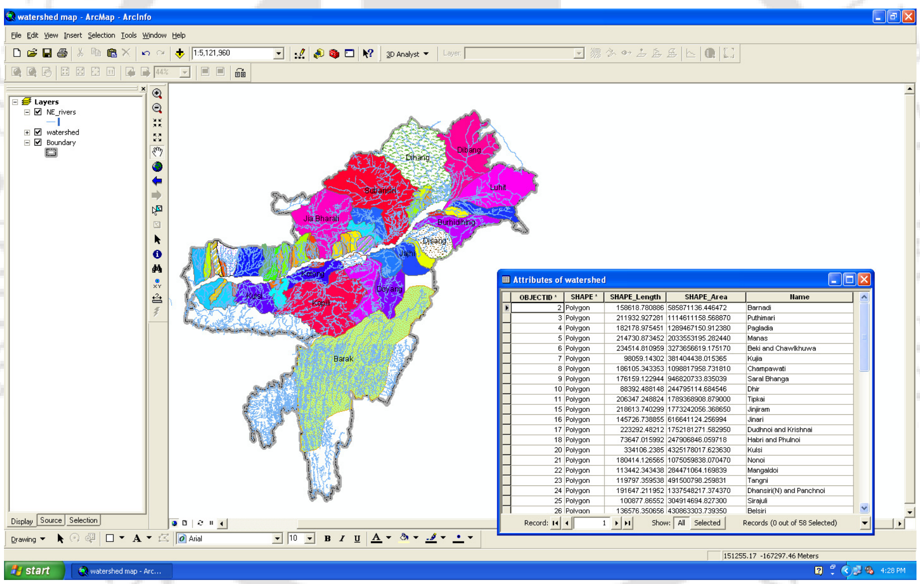


Figure 3.7: A view of the watershed database in GIS

3.4.5.2. River width and discharge database

Average widths of rivers can be measured using the measuring tool of ArcGIS from toposheets and imageries and likewise, river width database can also be created. Width of some major rivers in the plain area was measured in equally spaced points along the river and average of these widths was taken as the average width of the river. In GIS, a table was created with these data and linked with the GIS database of the rivers (Figure 3.8). Discharge data of some major tributaries of the region were collected from Brahmaputra Board, Guwahati, Assam and incorporated in a geodatabase table (Figure 3.9). Width and discharge of a river reach give an idea about the extent of watershed with respect to the observation points. In absence of finer watershed delineation data and extensive river water quality observation stations, width and average discharge of a river reach can be used as an indicator of influencing catchments based on the experience of regional hydro-morphological setup and can be used as guideline for further investigation of watershed degradation.

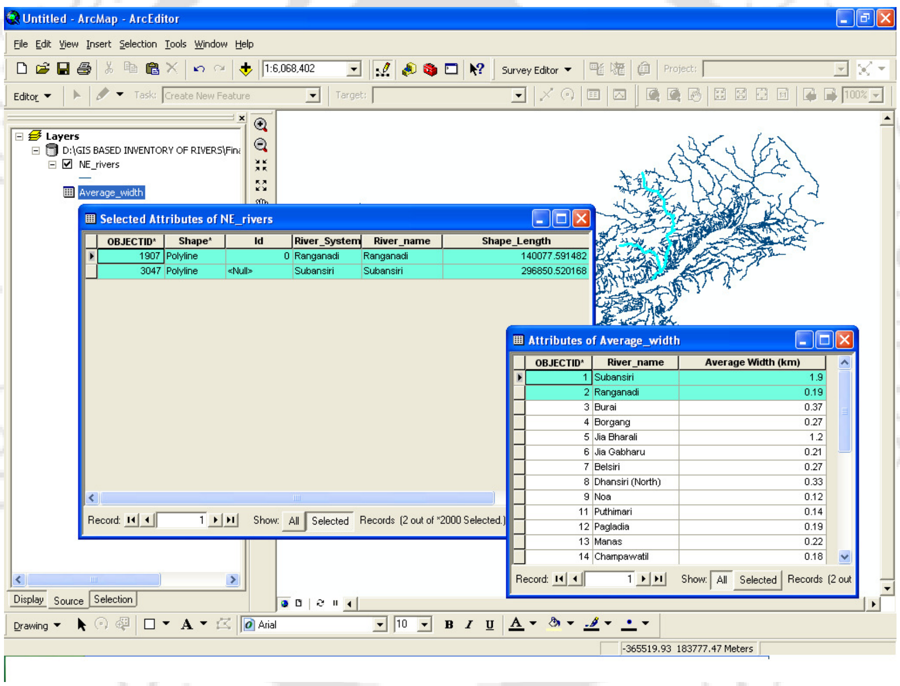


Figure 3.8: The width database with the river network layer in GIS

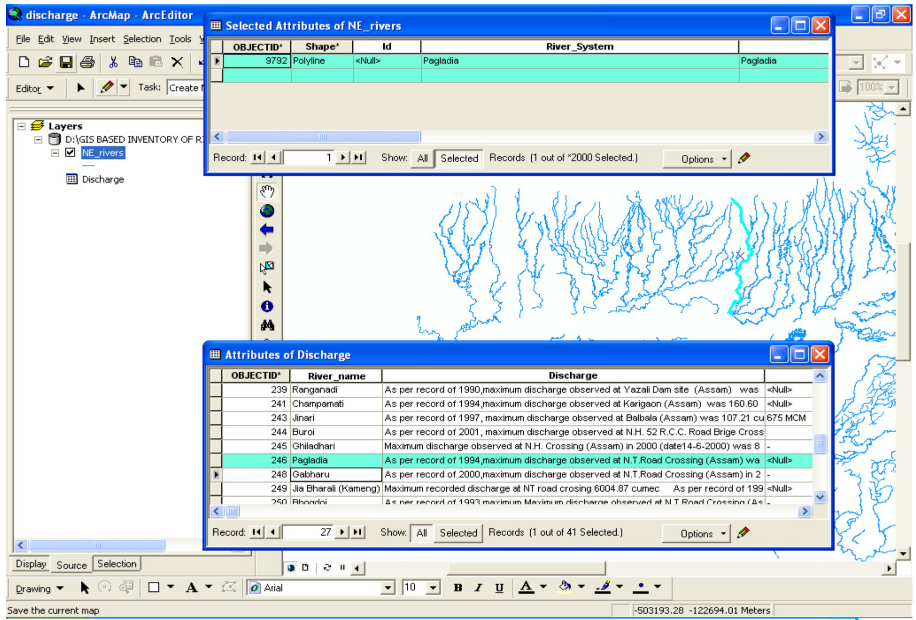


Figure 3.9: The discharge database with the river network layer in GIS

3.4.6. LINKING OF DIFFERENT DATABASES IN THE GIS

The various primary data generated and secondary data collected were incorporated in different layers in GIS. All these layers were linked with the digital river network layer. This linking provision, using the 'relate' tool of ArcGIS, enables the information of different databases to superimpose with each other. This helps in relational analysis of geomorphological and biochemical features of the river system (Figure 3.10).

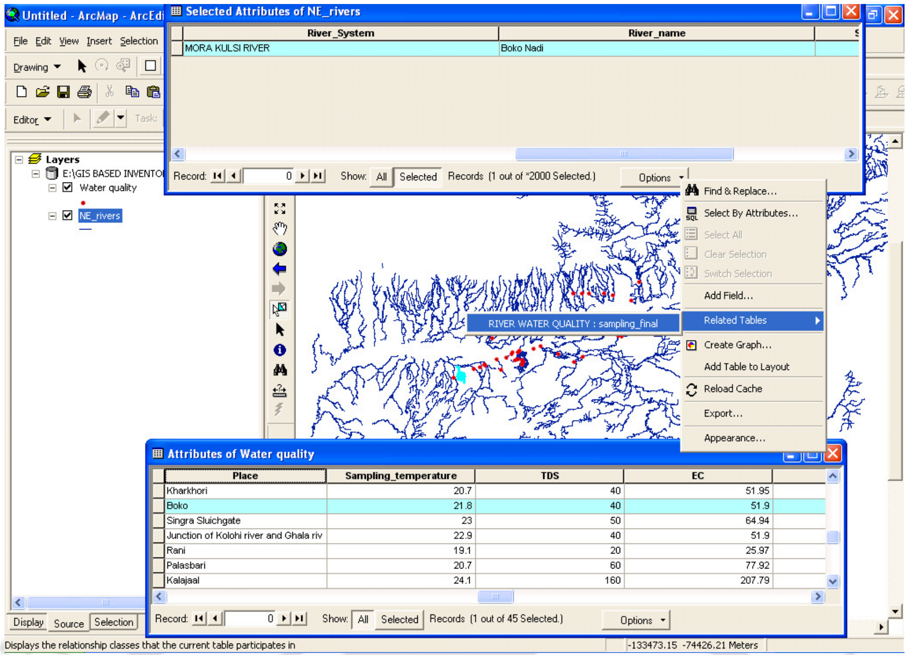


Figure 3.10: A view of the linking of water quality layer and river network layer created for the rivers of Northeastern Region of India

Further, GIS provides various query tools with which one can also retrieve other information like number of streams, their names, lengths or other related information like width, discharge and water quality contained by a particular watershed. With this system developed for the rivers of Northeastern Region of India, one can have the water quality information of a river at any sampled location. This water quality layer can be overlayed with other information like industrial locations layer of the region and this can then help to observe the effect of industries on river water quality status at a particular location. The information system can help to identify the locations where water quality monitoring and management practices need to be carried out on priority basis.

3.4.7. APPLICATION OF THE RWQIS IN PRIORITIZING DEGRADED WATERSHED OF NORTHEASTERN REGION OF INDIA,

The developed RWQIS was primarily applied to the rivers of Northeastern region of India to evaluate and identify the degraded watersheds and following are some of the major findings:

- Proposed RWQIS has diverse applications. Identification of degraded watershed is one of its prime applications, which is performed by making relational query involving three datasets: *river network*, *river water quality* and *river watershed.*
- The rivers of the region are generally having higher sediment load leading to high turbidity values (Table 3.3). Any disturbances including urbanization, if occur in the catchment area, increase sediment load in the draining rivers. The different turbidity values at their sampling location are shown in Figure 3.11.
- Water samples from 95 rivers were analyzed and DO, BOD, fecal coliform (FC) and turbidity have been found to be violating parameters (according to BIS guideline) for most of the urban rivers (Table 3.4).
- Therefore, these four parameters can be considered as important parameters for assessing the status of urban catchments. Based on these parameters, urban watersheds needing catchment treatment with EMPs were identified and prioritized according to the turbidity value of the river draining these cities. Table 3.5 shows a prioritized list of 12 townships needing urgent attention.

The Bharalu and Basistha Rivers of Guwahati city showed high turbidity values greater than 100 NTU, which reflects higher sediment yield from its hilly catchment. Also, these two rivers were observed to be the most urban impacted, as DO, BOD and FC values were also found to be violating in several locations of these two rivers (Figure 3.15). The Bharalu River is an important tributary of the Brahmaputra River flowing through the heart of the Guwahati City. The Bharalu basin, situated centrally in the Guwahati Municipal area, has to its east the Silsako Bil, to the south the Meghalaya hills, to the west the Dipar basin and to the north the fore shore basin of high land and hill ranges from Uzanbazar-Kharghuli hill, Nabagraha hill and Chunsali hills near Guwahati Refinery which divides the Brahmaputra, and the Bharalu basin in the east-west direction. It has a catchment area of 60 km^2 in hills where it is known as Bahini and 40 km^2 in the plains. River Bharalu is the master drainage channel of the highly commercialized and industrialized Guwahati Municipality area and outfalls into the Brahmaputra at Bharalumukh. The Basistha River is also one of the major streams of Guwahati City, urbanization is comparatively new in its watershed area. The river is originated from the Meghalaya hills and after transversing through the Guwahati city; it ultimately joins to Deepor Beel. In recent years, rapid growth of residential, commercial and small scale industries is observed in the Basistha watershed.

Table 3.3: Turbidity values of the river of Assam

River name	Latitude and longitude	Place	Turbidity (NTU)
Dikrang	N27 06.752 E93 49.701	Bandardewa, Parbatipur	100
Ghiladhari	N26 44.464 E93 04.046	Ghiladhari	103
Jinari	N26 04.190 E90 35.891	Bolbola	109
Pabhoi	N27 08.256 E93 57.135	Baromile	110
Basistha	N26 06.542 E91 47.842	Basistha Chariali,Guwahati	114
Bargang	N26 50.017 E93 16.900	Bargang	115
Jajhi	N26 50.844 E94 29.563	Jajhi	119
Beki	N26 29.689 E90 54.941	Bandarkhuwa	126
Burhi Dihing	N27 18.665 E94 53.065	Lepang	134
Barak	N24 52.504 E92 35.025	Panchgram	161
Bharalu	N26 06.662 E91 47.822	Bharalumukh, Guwahati	200
Saktola	N26 24.528 E91 56.287	Saktola	212
Belsiri	N26 42.425 E92 32.513	Brlsiri	262
Panchnoi	N26 42.013 E92 20.142	Orang	272
Kolong	N26 14.658 E91 57.513	Kazalimukh (Gobordhan)	284
Dhansiri (South)	N26 37.858 E93 43.774	Numalighar	301
Subansiri	N27 26.857 E94 15.241	Chawldhuwa ghat	327
Dikhou	N26 58.608 E94 37.858	Amolabari	349
Subansiri	N27 32.081 E94 15.567	Garukamukh	360
Jia Gabharu	N26 41.290 E92 37.551	Ghabharu	427
Jia Bharali	N26 48.600 E92 52.393	Taubhanga	761
Sirajuli	N26 41.895 E92 23.928	Sirajuli	763
Disang	N27 03.173 E94 40.716	Betbari	849
Tangni	N26 30.508 E92 06.986	Nij Kharupetia	914

Table 3.4: Rivers and the watersheds facing major quality threats

River name	Assessment based on	Nearest city/town
Bharalu River	DO, BOD, Fe, FC, Turbidity	Guwahati, Assam
Basistha River	DO,BOD, Turbidity, FC	Guwahati, Assam
Kolong River	DO (Marginally low), Turbidity, FC	Nagaon, Assam
Bhogdoi River	Turbidity, FC	Jorhat, Assam
Burhi Dihing River	Turbidity	Dibrugarh and Margherita, Assam
Pagladiya River	Turbidity	Nalbari, Assam
Disang River	Turbidity	Namrup, Assam
Barak River	Turbidity, FC	Silchar, Assam
Boko River	Turbidity	Boko, South Kamrup, Assam
Kalbhog River	pH, DO, Turbidity	Palashbari, South Kamrup, Assam
Lagun River	DO, Turbidity, FC	Itanagar, Arunachal Pradesh
Borapani River	DO, Turbidity, FC	Itanagar, Arunachal Pradesh
Haora River	BOD, Turbidity, FC	Agartala, Tripura
Imphal River	BOD, Turbidity	Imphal, Manipur
Senapati River	BOD, Turbidity, FC	Senapati, Manipur
Dhansiri River	BOD, FC	Dimapur, Nagaland

*** The limiting values of the parameters according to BIS norms:*
DO: >5 mg/L
BOD: <3 mg/L
FC: <100 colony/100 ml
Turbidity: <10 NTU

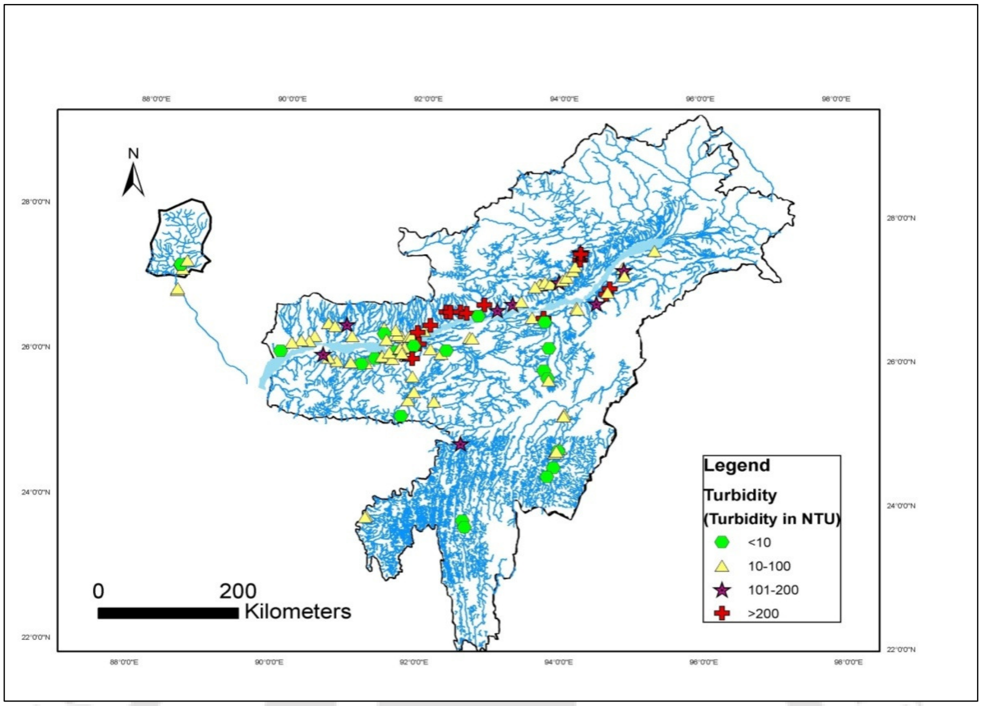


Figure 3.11: Turbidity of the sampling sites

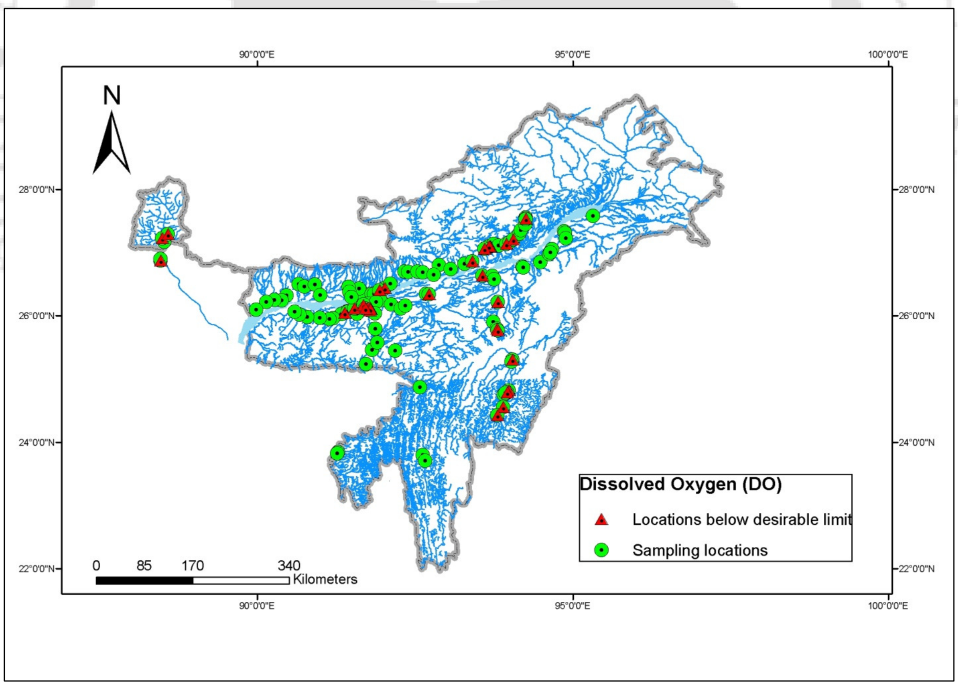


Figure 3.12: Locations with DO below desirable limit

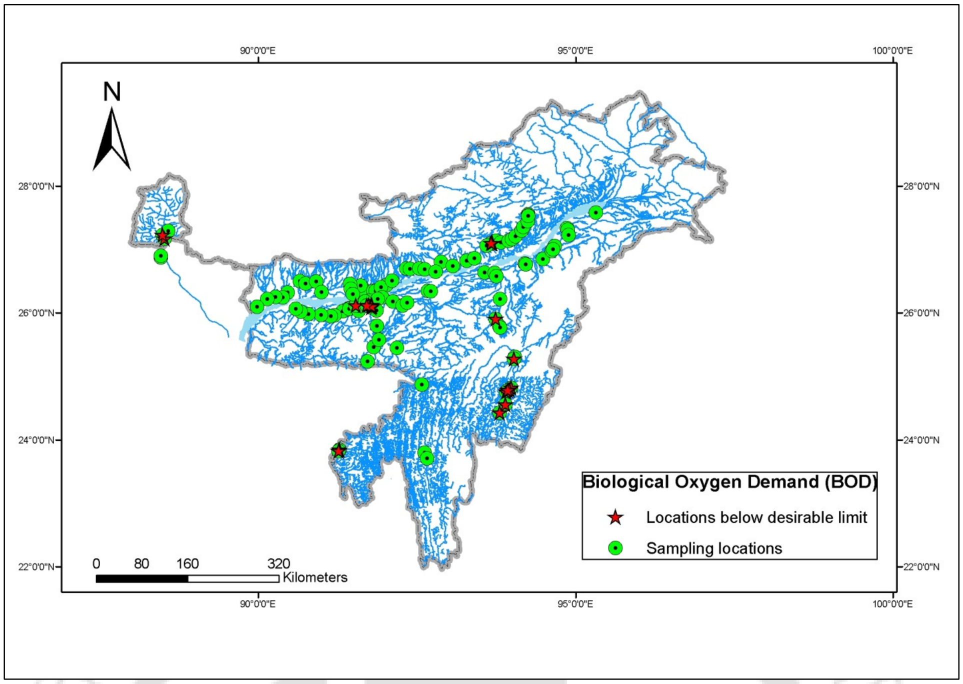


Figure 3.13: Locations with BOD below desirable limits

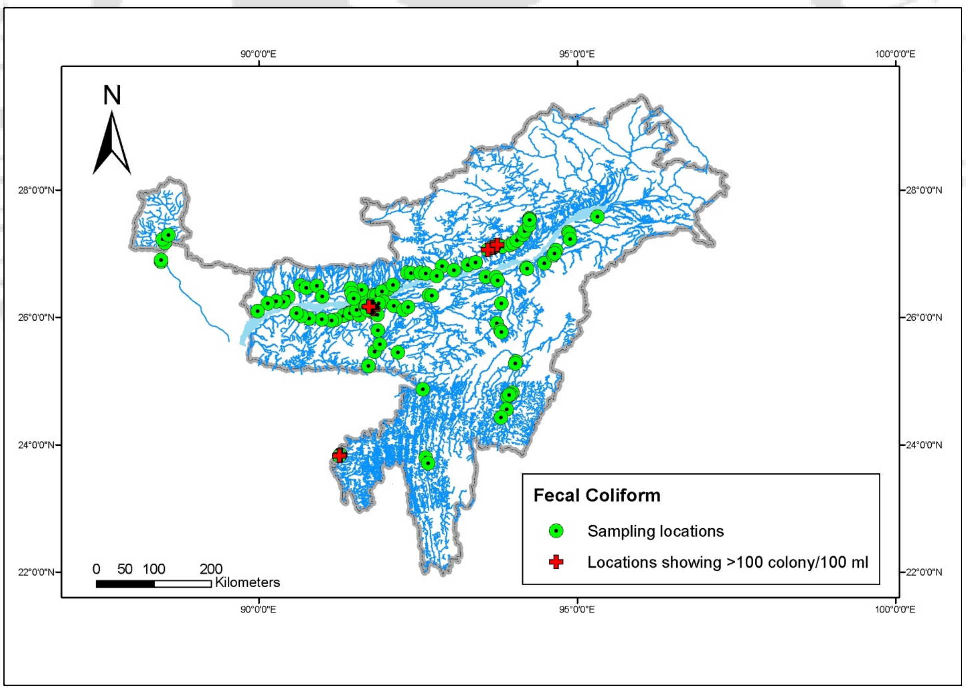


Figure 3.14: Locations with FC more than 100 colony/100 ml

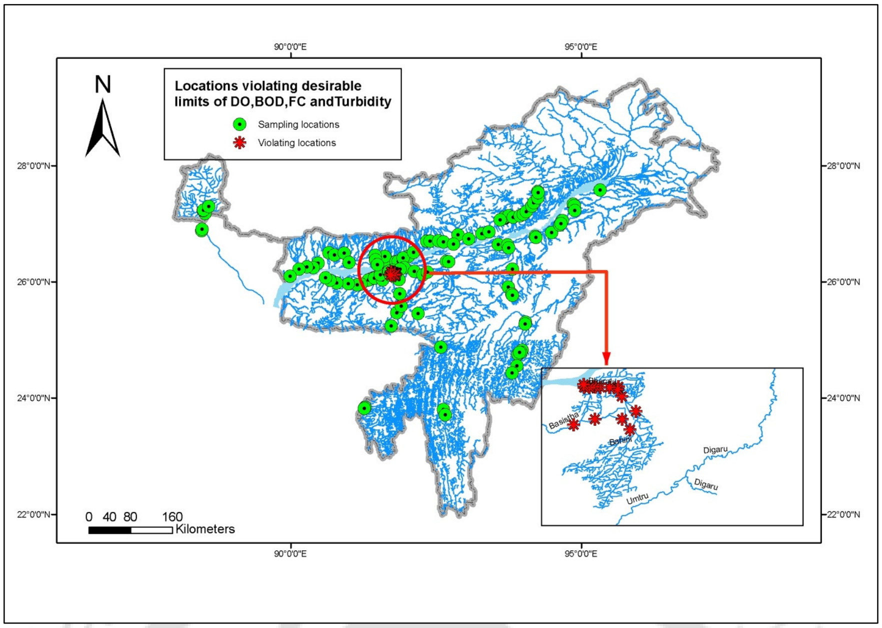


Figure 3.15: Locations violating DO, BOD, Turbidity and FC limits
(The Basistha River and Bharalu River of Guwahati)

Table 3.5: Prioritization of township needing catchment treatment

Sl No	River name	City/Town
1	Bharalu River	Guwahati, Assam
2	Basistha River	Guwahati, Assam
3	Haura	Agartala, Tripura
4	Kalbhog	Guwahati west, Assam
5	Lagun	Itanagar, Arunachal Pradesh
6	Borapani	Itanagar, Arunachal Pradesh
7	Pappunalla	Itanagar, Arunachal Pradesh
8	Katakhal	Agartala, Tripura
9	Nambul	Imphal, Manipur
10	Imphal	Imphal, Manipur
11	Senapati	Imphal, Manipur
12	Dhansiri (South)	Kohima, Nagaland

From the application of RWQIS to Northeastern region of India, it is observed that while several cities were found to be responsible for poor water quality of the draining rivers, the two major rivers of Guwahati city, the Bharalu River and the Basistha River are the most urban impacted rivers of the region needing immediate attention for restoration of its catchment area. Therefore it is important to see the trend of urban expansion of the city so as to develop sustainable restoration and management policies.

3.5. GEOINFORMATIC STUDY FOR ANALYZING SPATIOTEMPORAL GROWTH OF GUWAHATI CITY

Analyzing spatiotemporal growth of an urban area is essential to understand pattern of urban expansion. From the rate of growth of urbanization, one can also get an idea about possibility of urban expansion towards unfavorable landscape in near future. Urbanization in unfavorable landscape of hills and plains may make the habitat area susceptible to hazard like flood and landslide. Such information is helpful for making a strategic plan for sustainable urban development with the application of EMPs. Therefore a GIS and remote sensing based systematic procedure is developed to analyze the rate and pattern of urban expansion. The steps are as follows:

(i) Development of Digital Elevation Model (DEM) or Triangulated Irregular Network (TIN) for the area from the available elevation contours. In absence of contour map SRTM / ASTER DEM can be used.

(ii) Preparation of slope and aspects map for the area from the DEM.

(iii) Preparation of georeferenced landuse map using high resolution imageries.

(iv) Demarcation of hilly area based on elevation, slope and landcover.

(v) Preparation of georeferenced map of settlements/ built-up-area for different time periods using toposheets and high resolution imageries.

(vi) Overlaying of these maps to generate necessary topographic parameters for hydrological application.

3.5.1. TIN MODEL, SLOPE MAP AND ASPECTS MAP OF GUWAHATI

The TIN model of Guwahati (Figure 3.16) is developed from the contours of Survey of India (SoI) toposheets by using 3D analyst tool of ArcGIS 9.3. From the TIN model, the slope map (Figure 3.17) and aspect map (Figure 3.18) of the city is also prepared by using the 3D analyst tool of ArcGIS 9.3. These maps were superimposed and the hilly and plain areas of the city are demarcated.

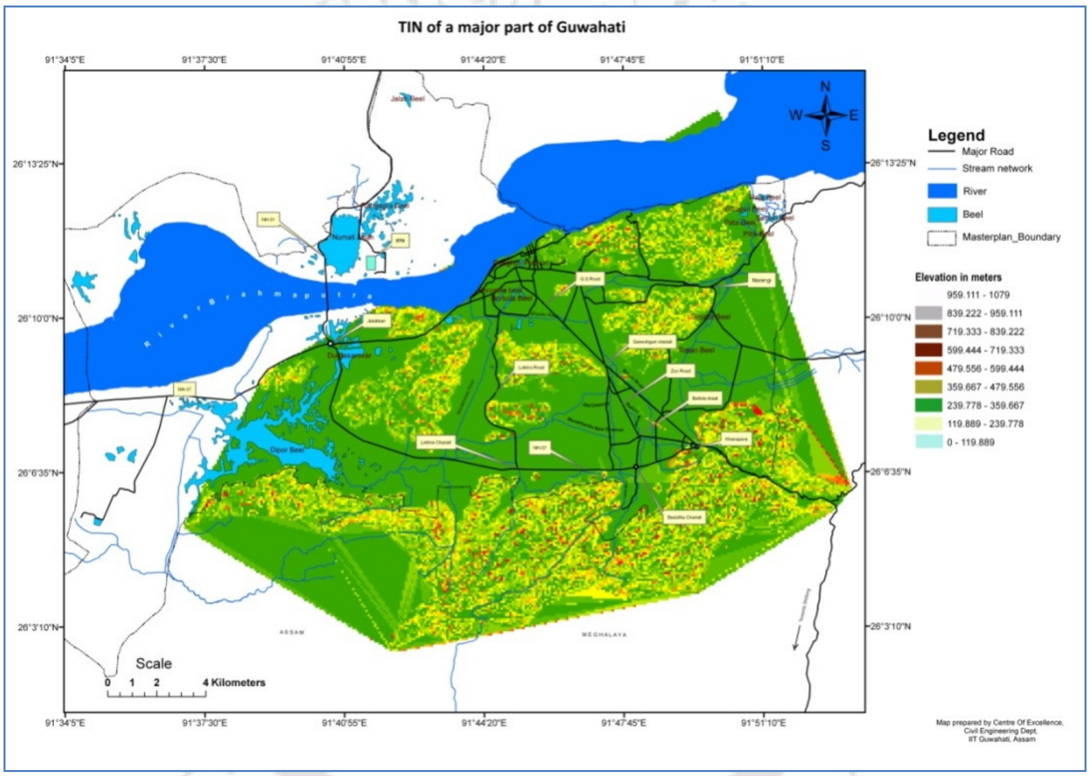


Figure 3.16: TIN model of Guwahati City

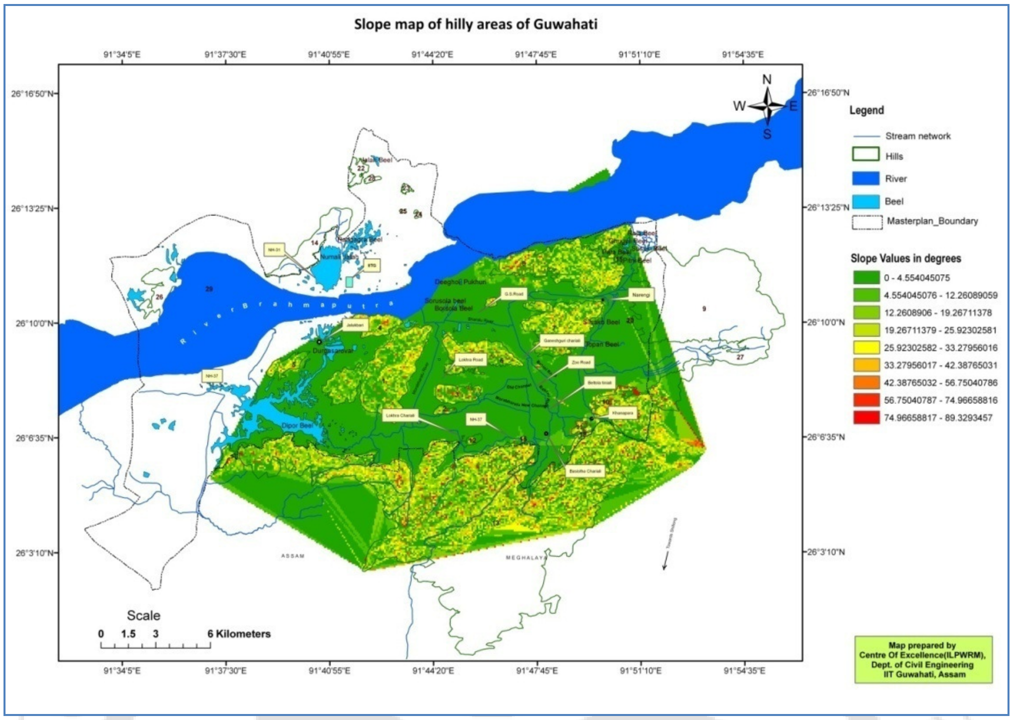


Figure 3.17: Slope map of Guwahati City

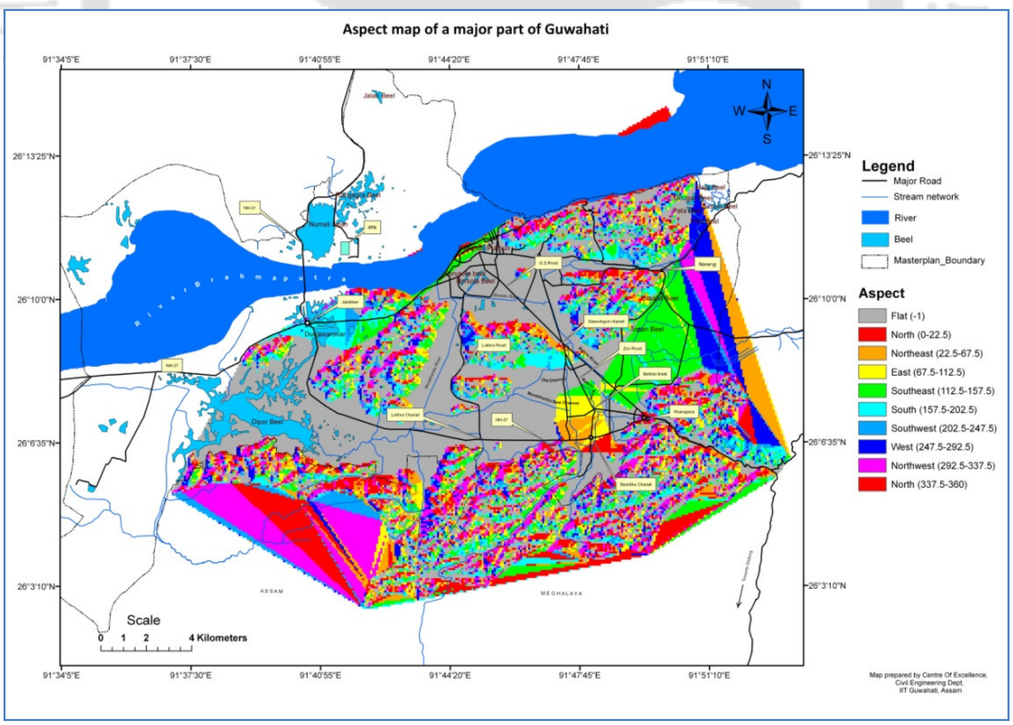


Figure3.18: Aspects map of Guwahati City

3.5.2. URBAN EXPANSION IN GUWAHATI CITY AND ITS IMPLICATION TO THE CATCHMENT AREAS

The Guwahati City is composed of plains and hills. The city extends from $91^{o}32^{/}$ E to $91^{o}52^{/}$ E latitude and $26^{o}2^{/}$ N to $26^{o}16^{/}$ N longitude covering an area of 383 km^2 as per the Masterplan boundary of Guwahati Metropolitan Development Authority (GMDA). It has been observed that the majority of the built up areas are concentrated in the plain areas of the city, but in recent years, the built up areas are also observed to be expanding in the hilly areas of the city. In this study, settlement areas in the hills and plain areas of the city in 1972 and 2000 was estimated and is presented in Table 3.6. In Figure 3.19 and Figure 3.20, the total settlement areas of the city in 1972 and 2000 are presented, where about 3 times increase in built up areas was observed. In Figure 3.21 and Figure 3.22, the expansion of settlement areas in the hills of the city has been presented, where approximately 10 times increase in built up areas in hills was observed.

Table 3.5: Built up area in hills and plains of Guwahati City

Year	1972	2000
Built up area in plains (km^2)	38.7	126
Built up area in Hills (km^2)	4.8	40

The main reason of such rapid expansion in the hills can be attributed to the people coming in search of work, who generally reside in the hills, as they cannot afford the high cost of land in plain area of the city.

In order to assess the present scenario of urbanization in hilly areas of Guwahati City, a random sample survey was also conducted from November, 2009 to February 2011 with a questionnaire designed to gather information on major hazards and their causes, type of housing, availability of basic infrastructure, socio economic conditions and environmental aspects.

During the field survey of hilly areas it was observed that faster rate of urban expansion has led to deforestation of the hilly area and has resulted in increased surface erosion from the upper catchments. Plain areas of the city now experience severe flood havoc even during a moderate storm event, as deposition of eroded sediment in the natural and manmade drainage network has reduced their water carrying capacity significantly. Such unplanned settlement in hilly area has also resulted in slope instability in the hills and has increased risk of landslide hazards. Some of the localities in hilly area contain infrastructures like primary schools, community halls and religious places. However the overall growth is unplanned with least concern about environment.

Out of the 572 no of households surveyed, following data (Table 3.7) are compiled.

Table 3.7: Field survey results carried out in hilly areas of Guwahati City

Monthly Income (% of Household)	Less than Rs 2000	12%
	Rs 3000-Rs10000	68%
	Rs10000-Rs 20000	18 %
	Above Rs 20000	6%
% of Kutcha house		34%
% of Household without sanitary toilet		27%
% of Household without pipe water supply		79%
% of Household without access road		5%
Landslide prone zones		Total : 93 nos Very steep slope : 14 nos Steep slope : 14 nos Gentle slope : 29 nos

As observed, people residing in the hills of Guwahati are mostly lower to middle income group people. Therefore, the economic selection of management practices is a need considering the socio economic conditions of the people residing in the hills.

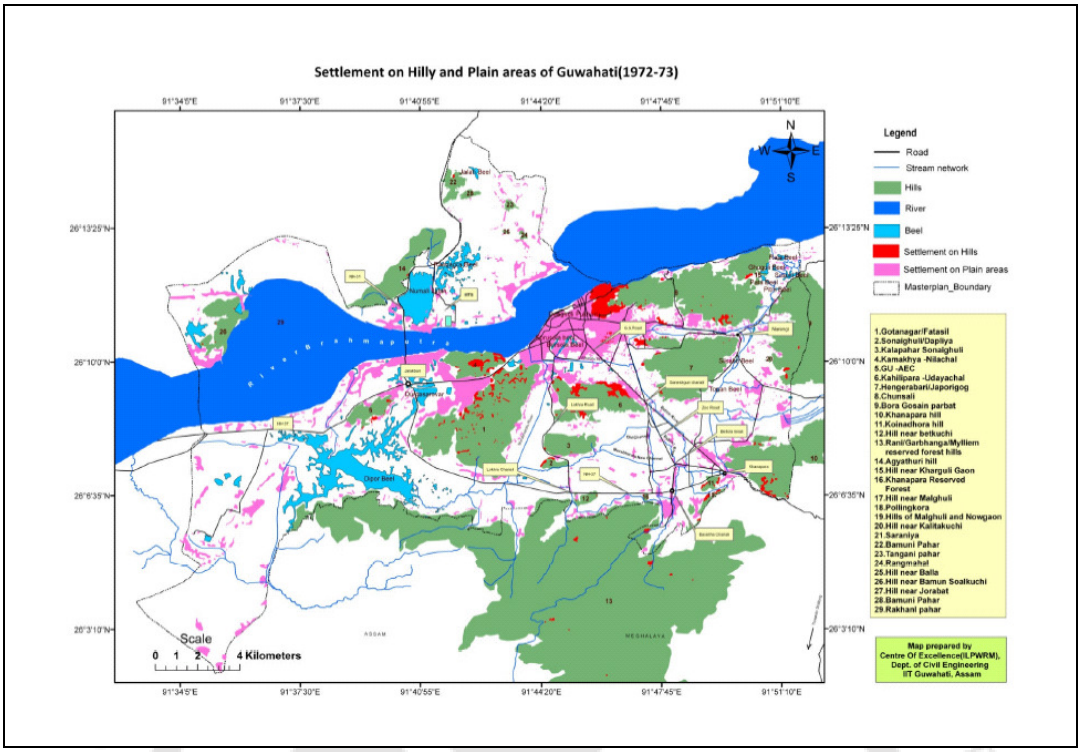


Figure 3.19: Settlements and hilly and plain areas of Guwahati City in 1972-73

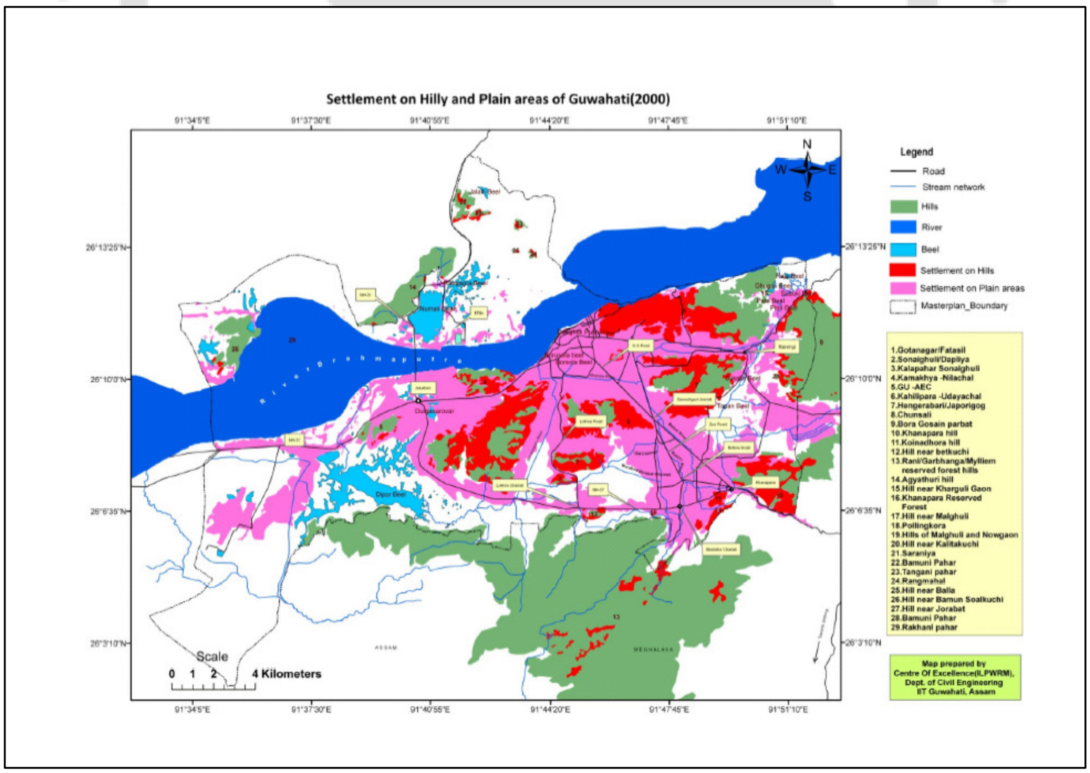


Figure 3.20: Settlements and hilly and plain areas of Guwahati City in 2000

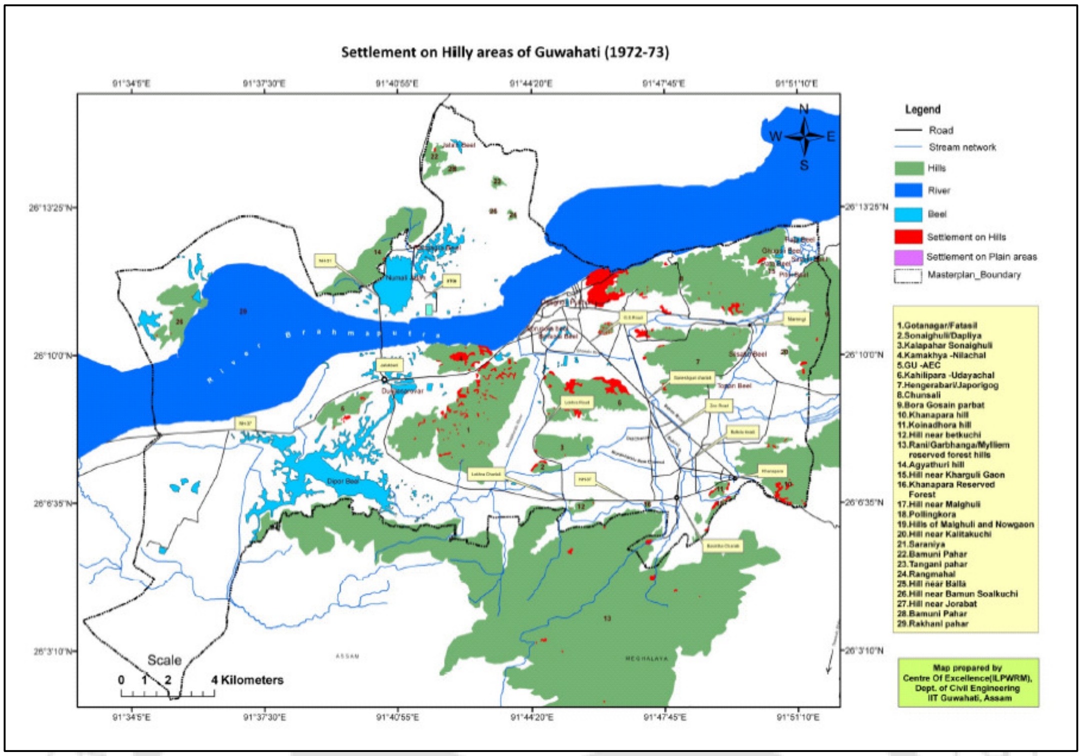


Figure 3.21: Settlements in hilly areas of Guwahati City in 1972

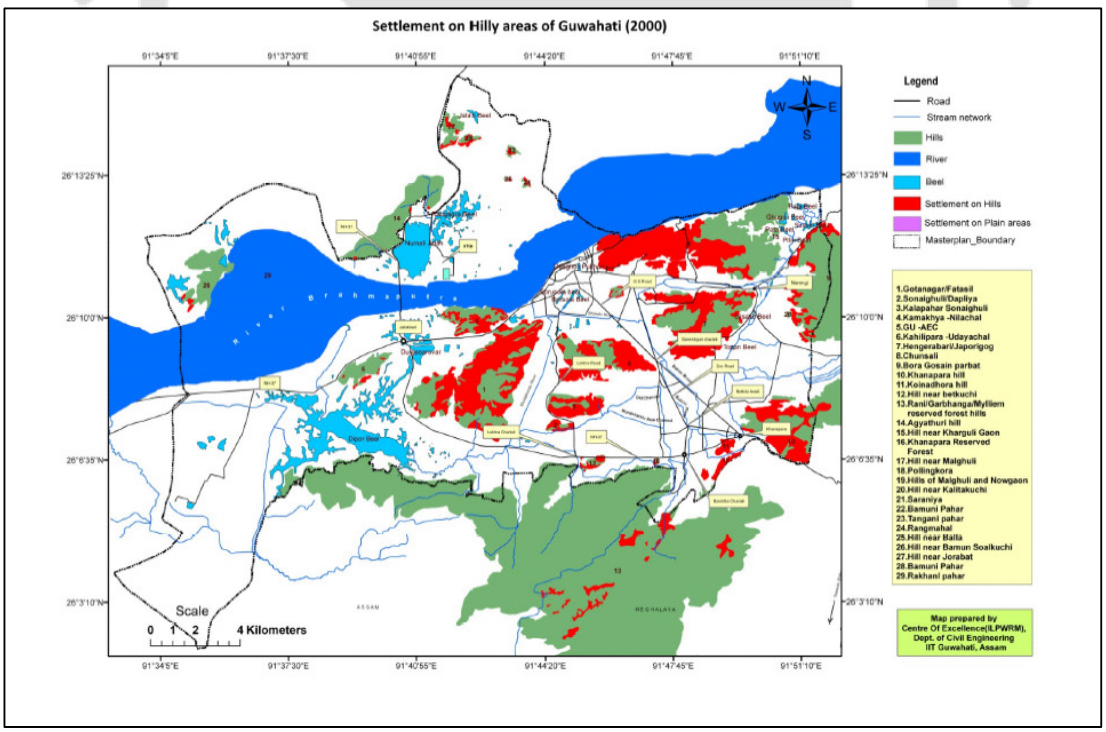


Figure 3.22: Settlements in hilly areas of Guwahati City in 2000

3.6. CONCLUSIONS

The application of the RWQIS to Northeatern region of India revealed that the system can be conventionally used for prioritizing the degraded urban watersheds. The Basistha River watershed and Bharalu River watershed of Guwahati city were observed as the most urban impacted catchments needing immediate attention considering the present rate and pattern of urban development in the Guwahati city. The city is presently expanding towards the hills at a faster rate. Most of the developmental activities that are occurring in the hills are unplanned and disorganized. During field observation it was observed that one of the main reasons of flooding in the plain area is the reduction of flow carrying capacity of drains because of sediment deposition. Denudation of hills has also increased the risk from slope instability in many localities. The socio economic condition of the people implies that attention should be given for selecting efficient management practices at least possible cost. Any landuse management plan for the city thus has to accounts for the upper catchments of the stream and river systems of the city and necessary components have to be integrated into the mitigative measures. Attempt has been made to include all such possible aspects rationally in the proposed EMP model.

Chapter 4
EXPERIMENTAL WATERSHED

4.1. INTRODUCTION

Understanding hydrological response of residential development in hilly watershed is attempted through experimental observation in an experimental watershed developed in IIT Guwahati campus and is presented in this chapter. As alteration of sediment and water yield directly affect the day to day life of people residing in the downstream of the watershed, more emphasis is given in assessing impact of residential development on these two characteristics. In addition, the influence of soil erosion in runoff water quality is investigated. The determination of efficiencies of some competitive EMPs in respect of soil conservation capabilities are also presented in this chapter.

4.2. SCOPE OF THE EXPERIMENTAL STUDY

Different landcovers exhibit different hydrological behaviors in terms of sediment and water yield during a storm event (Viessman and Lewis, 2008; Poff et al., 2006; Thanapakpawin et al., 2006). Assessing the impacts of converting forest or other natural landcovers into a residential area is essential to know the adverse consequences / impacts of unplanned residential development on the hydrological processes. An experimental study in a prototype scale can help in getting insight into these processes, which in turn helps in taking judicious measures for alleviating undesired impacts of unplanned residential development in hilly terrain. An experimental facility also helps in analyzing performance of different EMPs in respect of their soil and water conservation efficiencies. EMPs that are vegetative in nature can broadly be grouped into grass, creeper, forest, bushes and other herbs. However, different varieties, having varied soil conservation potential, are available within these groups (Shino et al., 2007; Millard and Santos, 2008; Parajuli et al., 2008). Before selecting a particular species for using as an EMP, one needs to know its implementation convenience, maintenance cost and conservation efficiency. To analyze these, an experimental watershed was developed within the campus of IIT Guwahati. The basic objectives of developing the experimental watershed were (i) to investigate the hydrological response of residential development in terms of sediment and water yield, (ii) to create a facility for studying performance of some competitive EMPs in respect of soil conservation capabilities and ease of maintenance, and iii) to conduct experimentation on some selected competitive EMPs.

4.3. DESCRIPTION OF THE EXPERIMENTAL WATERSHED

Two adjacent watersheds in IITG campus were selected to conduct the experimental study. Both the watersheds (WS1 and WS2) are located near the administrative building of IIT Guwahati (Figure 4.1).The geographic location of the two watersheds falls in $26^{0}11.439^{/}$N and $91^{0}41.452^{/}$E. For conducting experimentation on hydrological behavior of disturbed and undisturbed watersheds, model houses were constructed in WS2 (Figure 4.2) to simulate the topographic conditions of a disturbed watershed. The watershed WS1 was kept undisturbed. The disturbed watershed in true sense can be called as a partially disturbed watershed, as about 20% of the watershed area located in the lower part was only disturbed by constructing model houses mentioned above. Experimental observations included recording of sediment yield and surface runoff from WS1 (representing undisturbed virgin hilly watershed) and WS2 (resembling disturbed watershed in a hilly area with developmental activities). The areas of the disturbed watershed and the undisturbed watershed were 3948 m^2 and 2884 m^2 respectively.

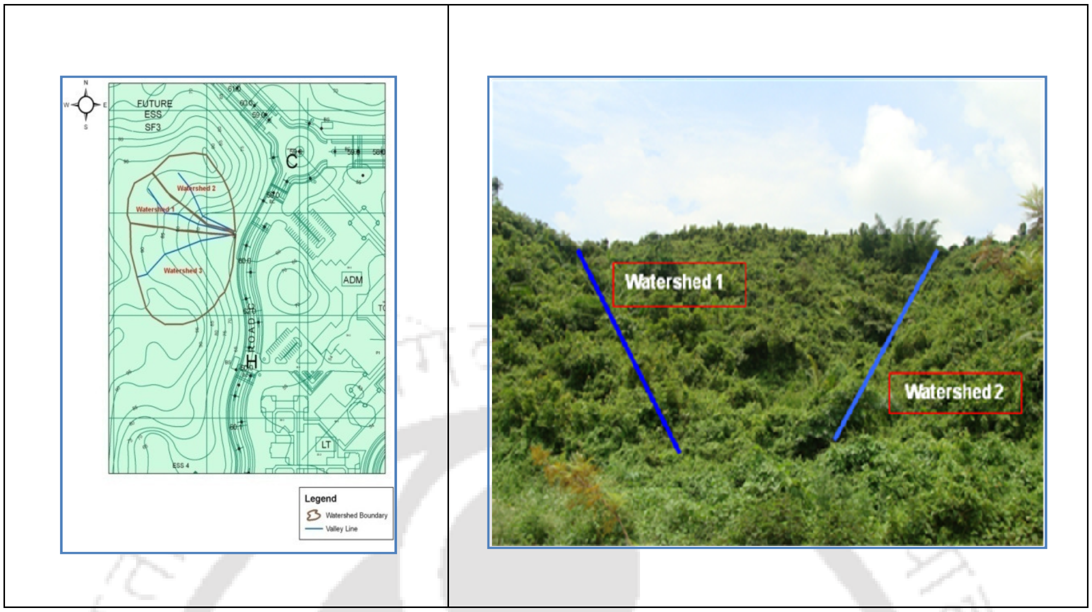


Figure 4.1: Location map and photograph of experimental watersheds
(Watershed 1: Undisturbed watershed, Watershed 2: Converted to disturbed watershed)

Figure 4.2: Model houses in the disturbed watershed

4.3.1. TOPOGRAPHIC MAPS OF THE EXPERIMENTAL WATERSHEDS

To understand the existing topographic characteristics of the experimental watersheds, a TIN (Triangulated Irregular Network) model was developed using the available contours of the area. The 3D Analyst tool of ArcGIS 9.3 was used to develop the TIN model (Figure 4.3). As observed from the TIN, the elevation values ranged from 65 to

95 m for both the watersheds. The slope and aspect maps for the experimental watersheds were developed using the TIN (Figure 4.4 and Figure 4.5). The slope values of the experimental watersheds were found to vary in the range of 0^o to 85^0.

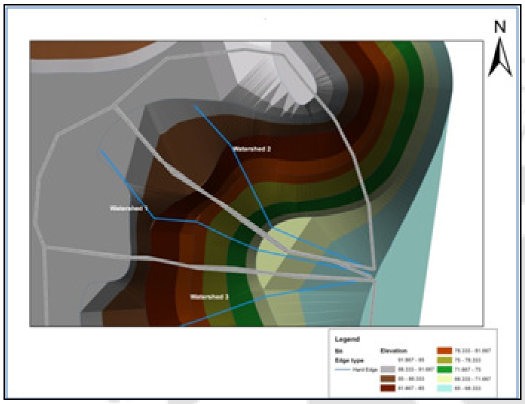


Figure 4.3 : TIN model of experimental watersheds

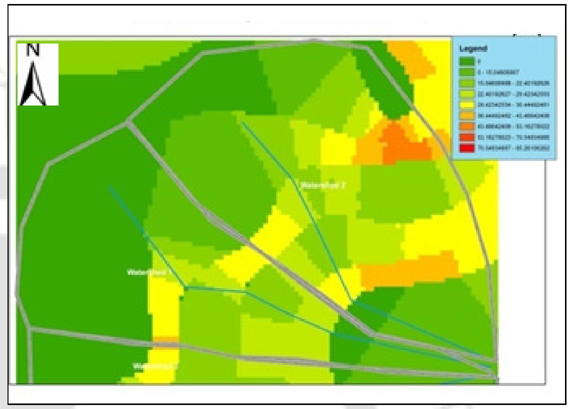


Figure 4.4: Slope map of experimental watersheds

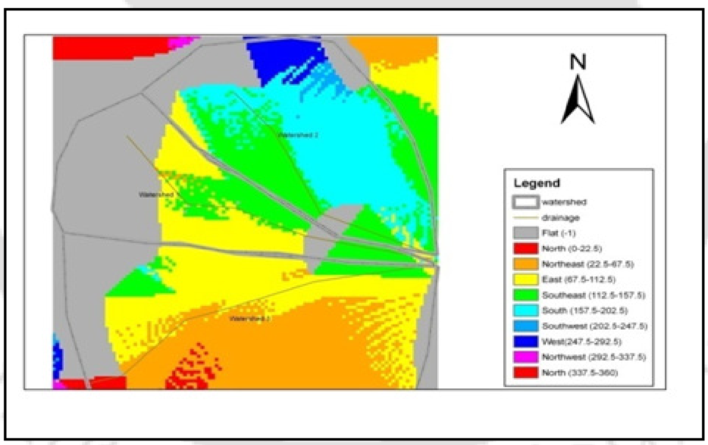


Figure 4.5: Aspect map of experimental watersheds

4.4. METHODOLOGY

Developments in hilly watersheds causes increased yield of sediment and water. To understand runoff and sediment yield characteristics of a disturbed and an undisturbed watershed, the discharge characteristics and the sediment yield characteristic of the watersheds were monitored for two rainy seasons during 2010 and 2011 as described below.

4.4.1. DISCHARGE CHARACTERISTICS OF THE DISTURBED AND UNDISTURBED WATERSHEDS

Discharges at outlets of both the watersheds were measured by installing two H-flumes at the outlet points along with two automatic stage recorders. As the watersheds are located in a region of high rainfall, experimental observations were made as and when natural rainfall events occurred. The discharge characteristics of both the watersheds for different rainfall events were then compared.

4.4.2. RECORD OF RAINFALL DATA

An automatic raingauge station (tipping bucket type) was installed near the experimental watersheds to have record of the rainfall characteristics for the study period. The raingauge was set at a log rate of 10 min so that small duration rainfall could also be recorded and this had also enabled recording maximum 30 min rainfall intensity of a storm, which is an important parameter for computing sediment yield by applying RUSLE model.

4.4.3. STUDY OF SEDIMENT YIELD OF THE DISTURBED AND UNDISTURBED WATERSHED

Two Coshocton type runoff samplers were installed in the experimental watersheds (Figure 4.6). The Coshocton type runoff sampler contains a small redial opening in a circular plate mounted over a nearly vertical axis. The circular plate of the sampler rotates freely as water flows and small predefined fraction of the flow was sampled by the slot, which is conveyed to a water tight container (tank). The sediment concentration in the runoff was determined as per the guideline of ASTM (D 3977-97, method B). A known volume of sample is then filtered through a glass fiber filter paper of 0.45 μm poresize. The filter paper was then dried and weighted, and then the sediment concentration is calculated as below:

$$S = \frac{Fw - Iw}{V} \quad (4.1)$$

Where,

S=sediment concentration (mg/ml)

Iw=Weight of the filter paper before filtration (mg)

Fw=Weight of the filter paper after filtration (mg)

V=Volume of sample taken (ml)

Figure 4.6: The sediment and runoff sampler located at the experimental watershed

4.4.4. IONIC CONTRIBUTION OF SOIL INTO RUNOFF WATER

4.4.4.1. Collection and Analysis of Rainwater Samples

The rainwater samples were collected in the period June 2010- August 2011 once in every month. The pH, Electrical Conductivity (EC) and Total Dissolved Solid (TDS) of the samples were immediately tested after collection by using the standard portable pH, EC and TDS meter of Wagtech Potakit. The anions , Nitrate (NO_3), Sulphate (SO_4) Phosphate (PO_4) , Chloride (Cl) and Fluoride(F) were tested in Ion Chromaograph (Model: Basic IC 792- Metrohm, Switzerland). The cations, Sodium (Na), Potassium(K) and Calcium(Ca) were tested in Flame Photometer (Make: Systronics). Presence of trace metals, Iron (Fe), Manganese (Mn), Lead (Pb) Cromium (Cr), Nickel (Ni) and Cadmium (Co) were tested in Atomic Absorption Spectrophotometer (AAS-Model: AA240 - Varian Inc).

4.4.4.2. Collection and Analysis of Runoff Samples

The runoff samples were collected in the period September 2010-August 2011 from the experimental watershed of IITG campus by using a standard runoff collector designed by ICAR, Borapani (Figure 4.6). Runoff samples of two watershed areas, one representing an undisturbed natural/forested watershed (presented as UNDISTURBED WATERSHED) and another with a higher sediment yield in order of 2 to 21 times the UNDISTURBED WATERSHED (presented as DISTURBED WATERSHED) were collected. The pH, EC and TDS of the samples were immediately analysed after collection by standard portable pH, EC and TDS meter of Wagtech Portable kits. The anions (NO_3, SO_4, PO_4, Cl and F) were analyzed using Ion Chromaograph and cations (Na, K and Ca) were analysed in a Flame Photometer. Concentration of trace metals (Fe, Mn, Pb, Zn, Cr, Ni, and Cd) were examined in AAS.

4.4.4.3. Determination of Bicarbonate (HCO_3^-)

The phenolphthalein alkalinity and total alkalinity of the water samples were determined by the titration method (APHA, WEF, AWWA, 1998)). 50 ml of sample was taken and two drops of phenolphthalein indicator was added to the sample. Appearance of slight pink colour indicates the presence of phenolphthalein alkalinity. The sample is then titrated against 0.02 N H_2SO_4 until the sample become colourless and the end point is determined. The phenolphthalein alkalinity (in mg/L as $CaCO_3$) is calculated as below

$$\text{Phenolphthallein} = \frac{P \times 1000}{S} \qquad (4.2)$$

Where P=Titrant used (ml), S= Sample volume (ml)

In the same sample, two drops of methyl orange indicator was added and titrated against the same titrant until the colour of the sample changed from methyl orange to pink. The end point was noted and the total alkalinity (in mg/L as $CaCO_3$) was calculated as below:

$$TA = \frac{T \times 1000}{S} \tag{4.3}$$

Where T=Titrant used (ml), S= Sample volume (ml)

Then the Bicarbonate alkalinity is calculated as given by Peavy et al. (1985).

If the volume of acid needed to reach the 8.3 endpoint (Phenolphthalein alkalinity) is known , the species of alkalinity can also be determined. Because all of the hydroxide and one half of the carbonate has been neutralized at pH 8.3, the acid required to lower the pH from 8.3 to 4.5 must measure the other half of the carbonate , plus all of the original bicarbonate. If P is the amount of acid required to reach pH 8.3 and M is the total quantity of acid required to reach 4.5 (methyl orange), the following generalizations concerning the forms of alkalinity can be made:

If P= M, all alkalinity is OH^-

P=M/2, all alkalinity is CO32-

P= 0, (i.e. initial pH is below 8.3, all alkalinity is HCO^-_3

P< M/2, predominant species are $CO_3{}^{2-}$ and HCO^-_3

P> M/2, predominant species are CO_3^{2-} and OH^-

The CO_3^{2-} would be then measured by 2P and the HCO_3^- would be measured by the reminder (M-2P)

Here 1 ml of 0.02 N H_2SO_4 neutralizes 1 mg alkalinity as $CaCO_3$

$$HCO_3^- = \frac{M - 2P}{V} \times 1000 \quad (4.4)$$

Where, V= Volume of sample taken (ml)

Bicarbonate Alkalinity as HCO_3^- (mg/L) = 1.22 × Bicarbonate Alkalinity as CaCO3 (mg/L)

4.4.4.4. Determination of Hardness

The EDTA hardness of the water samples were determined by the titration method (APHA, WEF, AWWA, 1998). The hardness of the samples was determined as below:

$$\text{Hardness}(CaCO_3) = \frac{A \times B \times 1000}{S} \quad (\text{mg/L}) \quad (4.5)$$

Where

A= ml titrant for sample

B=mg of $CaCO_3$ equivalent to 1 ml of EDTA titrant (=1)

S= Sample volume (ml)

4.5 ASSESSMENT OF SEDIMENT CONTROL CAPACITY OF SOME SELECTED COMPETITIVE EMPs

Grass and forest have good sediment control capability and their efficiency depends also on width and extent, and varies widely from place to place (Wenger, 1999). Collins (2003), applying GLEAMS model in the Waiarohia catchment, predicted that grass buffer strip can reduce mean annual sediment yield by 20% that of the bare soil. In the GLEAMS model, they represented the grass landcovers with a high hydraulic roughness coefficient value (Mannings coefficient n), which cannot be considered as a complete representation of grass characteristics. Also, roughness characteristics will vary with type of the grass species. Thus, this simulation study gave a qualitative estimation regarding efficiency of grass in controlling sediment yield.

Parajuli et al. (2008) applied the SWAT model to see the effectiveness of vegetative filter strips (VFS) (lengths 10, 15 and 20 m) in removing sediment and fecal bacteria in the Upper Wakarusa watershed (950 km^2) in northeast Kansas. The following equation was used for finding the effectiveness of VFS in SWAT model:

$$trap_{ef} = 0.367 \times (width_{filtstrip})^{0.2967} \tag{4.6}$$

where $trap_{ef}$ is the fraction of the constituent loading trapped by the filter strip, and $width_{filtstrip}$ is the width of the filter strip (m). Based on this, it was estimated that about 73% of sediment yield can be reduced with a 10-m, 82% by a 15-m and 89% by a 20-m VFS. Here also, the equation used is a generalized form and for accurate estimation, the coefficient and exponent of the equations may vary with type of vegetation and topographic and soil condition.

Knowing the effectiveness of vegetative measures in controlling non point source pollution, various field based studies were conducted on VFS by many investigators to see their efficiencies in controlling sediment yield. Gharabaghi et al. (2006) conducted a detailed field based study with six different filter strips having combination of different species and tested their efficiency in terms of type & width of strip, and runoff flow rate and inflow sediment characteristics with artificial water supply. The study concluded that sediment removal efficiency increased from 50 to 98% as the width of the filter increased from 2.5 to 20 m. In addition, grass type and flow rate were found to be significant factors. Another field based study was conducted by Shiono et al. (2007) in Okinawa, Japan for centipede grass (Eremochloa ophiuroides) for different strip lengths (0.5,1.5 and 3.0 m) with a 4.0-m by 31.5-m bare source area under natural conditions. The study has reported that the sediment removal efficiencies of 24% for the 0.5-m strip, 36 to 54% for the 1.5-m strip and 73% for the 3.0-m strip. The study also found that strips trapped well the sediment aggregates larger than 0.02 mm in diameter, regardless of strip length. Also, the longer strip trapped more aggregates of the 0.002–0.02-mm size class, which were dominant in the eroded sediment runoff from the plots. The strips poorly trapped aggregates smaller than 0.002 mm. These field based experiments were conducted basically to find out the efficiency of vegetative strips in terms of sediment trapping form sediment laden water. However, the study did not investigate the capability of vegetation in minimizing sediment erosion from the area itself, which in fact is an important aspect of study.

To have an idea about erosion control efficiency of different EMPs, an experimental set up having facility of studying performance of 3 EMPs at a time was constructed in the study watershed (Figure 4.7). Three strips, each of length 4 m along the slope and of width 2 m across the slope were constructed for installing different EMPs. Varieties of grass species and other type of herbs, apparently having similar erosion control capacities, were identified. Based on convenience one indigenous common grass locally called bon in Assamese language and buffalo grass in English (Scientific name: *Paspalum conjugatum* (Poaceae)) was selected for the study(Figure 4.8). The other selected species is a herb called Golden Glory or Wandering jew, (Scientific name: *Tradescantia zebrina* (Commelinaceae) was considered for the comparative study (Figure 4.9). The reason of selecting this grass is that it is widely available and also grows easily even in undulated hilly terrain. The Golden glory is an ornamental herb having aesthetic view and thus this type of herb may be preferred for urban areas by some people. Another advantage of this species is that once grown, it requires minimal effort for maintenance and gives a good coverage within a short period.

Figure 4.7: Experimental setup for performance analysis of EMPs

Figure 4.8: A close view of the grass used as EMP in the study

Figure 4.9: A close view of Golden glory used as EMP in the study

Erosion control capabilities of these two vegetative measures were compared with that of bare land. All the strips were of equal area and similar slope condition were maintained in all the strips. Sediment traps were constructed at immediate downstream of each of these three strips. The three sediment traps were basically constructed by dividing a large chamber into three sub chambers, so that the sediment coming from these three strips can be collected separately in the three chambers and the relative efficiencies of these strips can be compared by weighing the amount of sediment that was collected in each of these three chambers. Each chamber was of 0.5 m depth, 2 m in length and 0.8 m in width.

4.6. RESULTS AND DISCUSSION

4.6.1. DISCHARGE AND SEDIMENT YIELD CHARACTERISTICS OF DISTURBED AND UNDISTURBED WATERSHEDS

A comparative study of the sediment and water yield at outlets of the disturbed and undisturbed watershed has revealed that these two characteristics changes significantly when a natural watershed gets disturbed. The differences in sediment concentration observed in the surface runoff collected from these two watersheds (Figure 4.10) showed significant increase in sediment concentration in the runoff samples of the disturbed watershed compared to that of the undisturbed watershed. On an average, the sediment concentration in the water samples of the disturbed watershed was found to be 7 times that of the undisturbed watershed. For some severe storm events, sediment concentration in the disturbed watershed becomes as high as 20 to 30 times that of the undisturbed one.

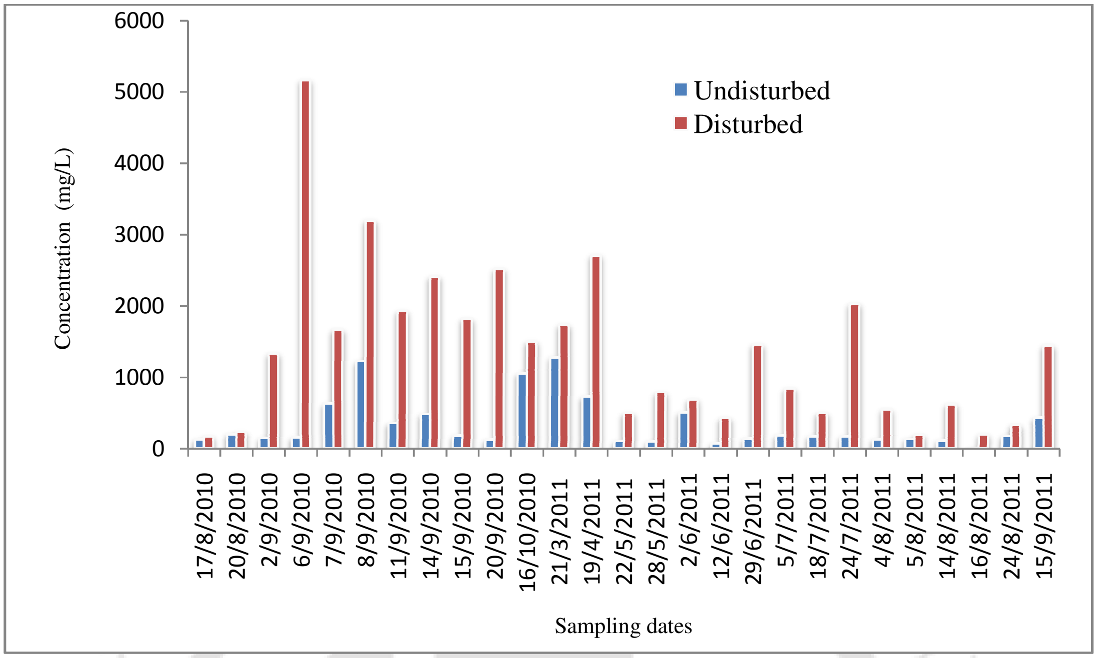


Figure 4.10: Sediment concentrations in the disturbed and undisturbed watersheds for some rainfall events

Some of the rainfall events were not large enough to produce sufficient runoff to make it detectable by the stage recorder installed at outlet of these watersheds. Five events during the study period were found to have detectable stage for measuring total runoff and total sediment yield from the watersheds. The differences in water and sediment yield from the two watersheds for these storm events (Table 4.1) demonstrated that the sediment and water yield characteristics of the undisturbed and disturbed watershed were significantly different. Sediment and water yield from the disturbed watershed was observed to be much higher as compared to that of the undisturbed watershed. While sediment yield depends primarily on the rainfall intensity (Romkens et al., 2002; Dijk et al., 2005), water yield depends on both intensity and duration of the storm (Reddy, 2008; Viessman and Lewis, 2008). Increase in runoff volume and sediment yield due to disturbance depends on various other factors such as rainfall intensity and duration, sediment yield during previous storm event and antecedent moisture content (Vahabi and Nikkami, 2008; Viessman and Lewis., 2008). Removal of vegetation and construction of inclined corrugated roofing modify the size of raindrop. Weggel and Rustom (1992) observed that raindrop size also influences soil erosion process. Depending on various such conditions during a storm event, 3 to 54 percent increase in total runoff volume and 2 to 21 percent increase in total sediment yield due to disturbance was observed in the experimental watersheds. The Figure 4.11 and Figure 4.12 present differences in runoff volume and sediment yield of the disturbed and undisturbed watersheds. This experimental study has given a firsthand quantitative idea regarding sediment and water yield due to impact of urbanization in the climatic set up of Northeastern region of India. The results obtained are comparable to some of the mathematical model studies (Corbett et al.,1997; Nelson and Booth. ,2002; Poff et al. ,2006) that were conducted to simulate sediment and water yield from urban watersheds in different parts of the world.

Significant difference in runoff and sediment yield characteristics of different landcovers were reported in simulation study by Corbett et al. (1997). The study compared the hydrological behavior of a forested watershed and an urban watershed on the South Carolina coast using AGNPS with 10 simulated rainfall events and the simulation results indicated runoff volume was on average 5.5 X (±2.7) and sediment yield 5.5 X (±2.3) times greater in the urban watershed than from the forested watershed. The study also found that the ratio of rainfall volume to runoff volume was on average 14.5% higher in the urban watershed compared to the forested watershed. In another model study, Nelson and Booth (2002) evaluated a watershed-scale sediment budget to determine the relative effects of land-use practices on sediment supply and delivery in Issaquah Creek watershed, Western Washington and found that urban development caused an increase of nearly 50% in the annual sediment yield. Poff et al. (2006) studied hydrologic alteration using 10 ecologically-relevant hydrologic metrics that describe magnitude, frequency, and duration of flow for 158 watersheds within the Southeast (SE), Central (CE), Pacific Northwest

(NW), and Southwest (SW) hydrologic regions of the United States. In response to increasing urban land cover, peak flows increased (SE and CE), minimum flows increased (CE) or decreased (NW), duration of near-bankfull flows declined (SE, NW) and flow variability increased (SE, CE, and NW).

All these studies are based on mathematical modeling. However, it is difficult to represent all physical processes of watershed degradation in a mathematical model and to include all influencing parameters in a model study. Studies containing field based observation regarding impact of urbanization on sediment and water yield are limited. Increase in sediment and water yield due to urbanization, though has been established through model study, field based observations are necessary to have better understanding about extent of such increased yield due to degradation of watershed induced by unplanned urbanization.

In the two watersheds of IIT Guwahati, though the disturbed watershed was having a little impervious area and disturbances were made only in terms of clearing up of vegetation, cutting of slope and constructing small houses, a clear difference in the hydrograph characteristics of the disturbed watershed and undisturbed watershed was found. The peak discharge was quicker and about two times higher in the disturbed watershed than the undisturbed watershed (Figure 4.13).

Table 4.1: Runoff volume and total sediment yield in the watersheds for different rainfall events

Storm events	30 min maximum intensity (mm/hr)	Duration (min)	Runoff volume (Disturbed) (L)	Runoff volume (Undisturbed) (L)	Total sediment yield (kg) (Disturbed)	Total sediment yield(kg) (Undisturbed)	Percentage difference in runoff volume per unit area between Disturbed and Undisturbed	Percentage difference in sediment yield per unit area between Disturbed and Undisturbed
2-9-2010	76.2	300	123066	63539	159	9	41	12
6-9-2010	83.8	160	124656	78684	398	94	15	2
11-9-2010	45.7	160	53007	29715	99	10	30	3
16-10-2010	57.4	190	112426	53039	240	8	54	21
28-5-2011	36.1	120	10317	7265	0.81	0.07	3	7

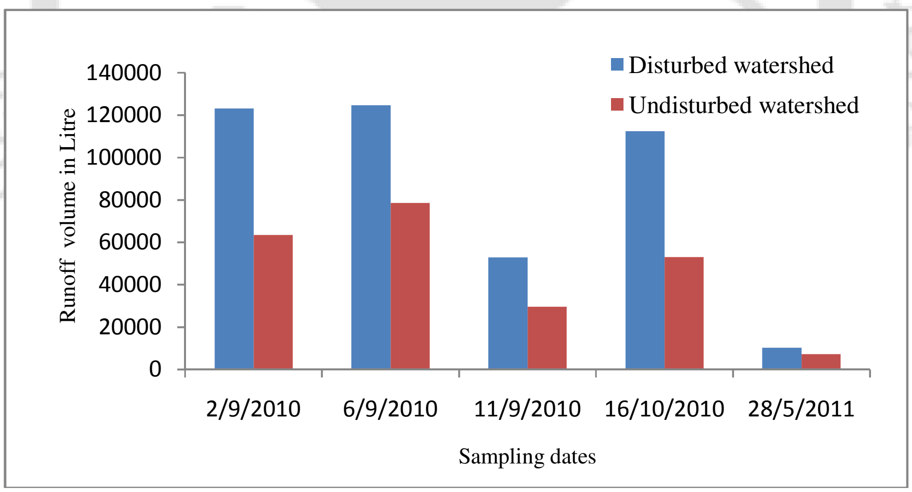


Figure 4.11: Runoff volume in the disturbed and undisturbed watersheds for some rainfall events

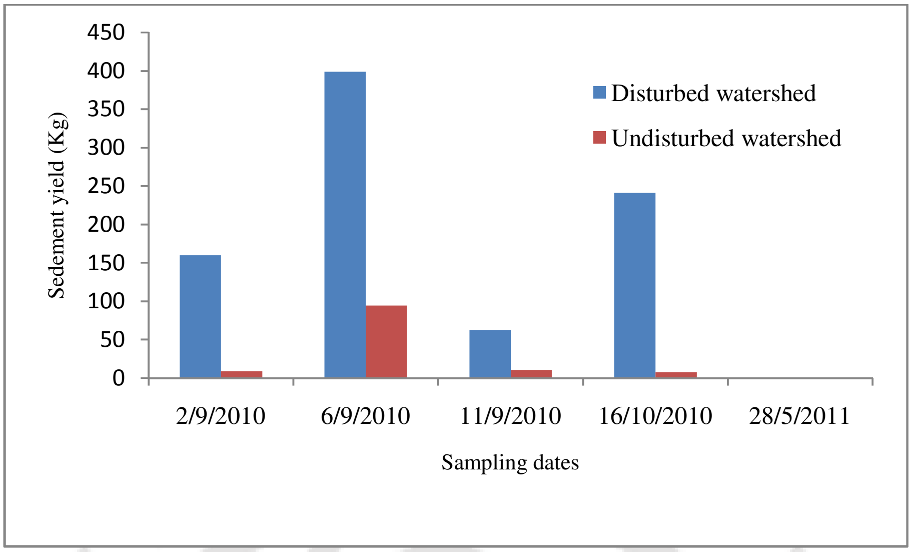


Figure 4.12: Total sediment yield in the disturbed and undisturbed watersheds for some rainfall events

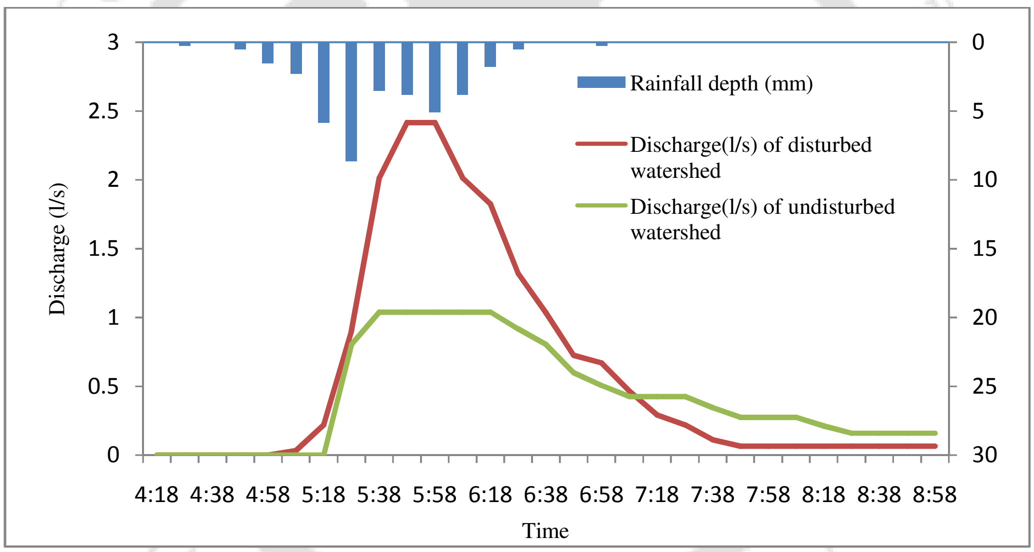


Figure 4.13: Discharge hydrograph for 28/5/2011

The total runoff volume showed good correlation with 30 min rainfall intensity (Figure 4.14) and the runoff varies almost linearly with the 30m intensity rainfall in case of the undisturbed watershed. In case of the disturbed watershed, the relation was non-linear. The linear correlation was better for the undisturbed watershed (0.94) than that of the disturbed watershed (0.83), indicating comparatively irregular runoff behavior for the disturbed watershed. The correlation between 30min rainfall intensity and total sediment yield for the storm events (Figure 4.15) was higher for the disturbed watershed (0.7) compared to that of the undisturbed watershed (0.5). In case of the undisturbed watershed, sediment yield became significant only after the rainfall intensity reached a threshold value. For the studied watershed, sediment yield was significant only beyond 30min rainfall intensity of 75mm.

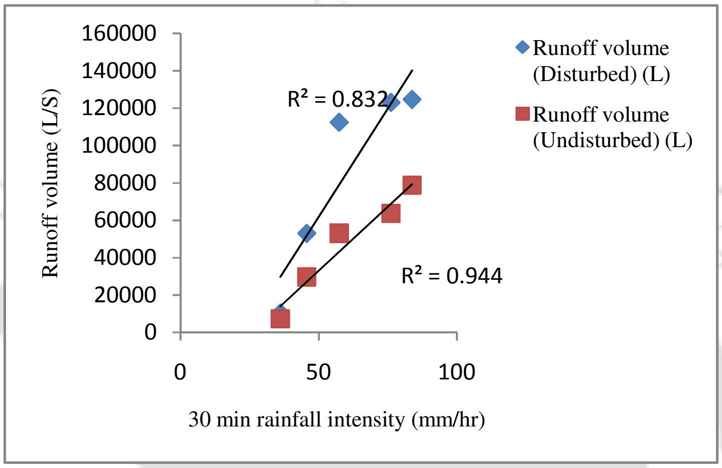


Figure 4.14: Correlation between 30 min rainfall intensity and runoff volume

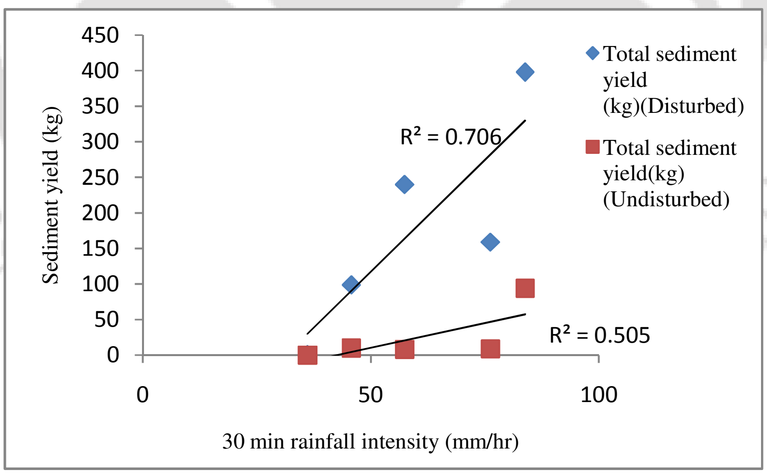


Figure 4.15: Correlation between 30 min rainfall intensity and sediment yield

Study of Particle Size Distribution of Disturbed and Undisturbed Watershed

The particle size distributions of the sediment transported by the runoff from the disturbed and undisturbed watershed are presented in Table 4.2 and shown in the Figure 4.16 and Figure 4.17. The figures imply that in the disturbed watershed samples, the particles are more uniformly distributed than the samples of undisturbed watershed. Also, the sediment sample of undisturbed watershed was observed to have larger particle size than the sediment sample of the disturbed watershed.

Table 4.2: Particle size distribution of sediments eroded from undisturbed and disturbed watershed

Sample type	D 10	D 50	D 90
Undisturbed watershed	8.971 µm	100.877 µm	668.227 µm
Disturbed watershed	11.329 µm	110.519 µm	530.832 µm

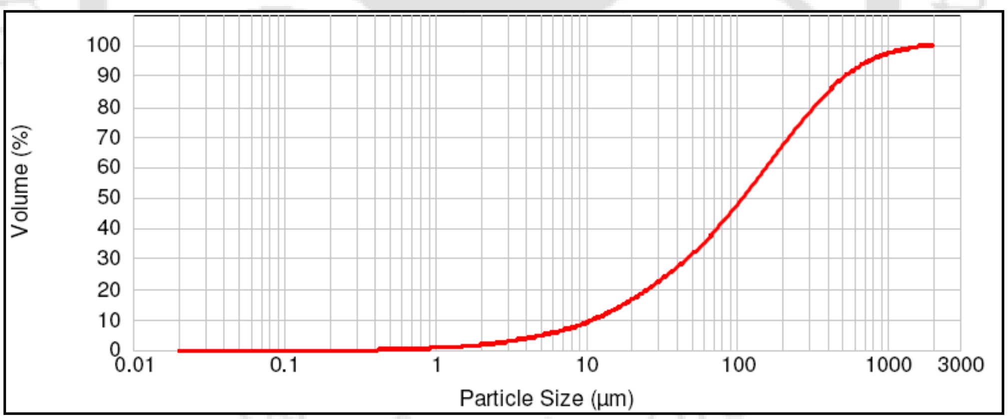


Figure 4.16: Particle size distribution of sediment eroded from disturbed watershed

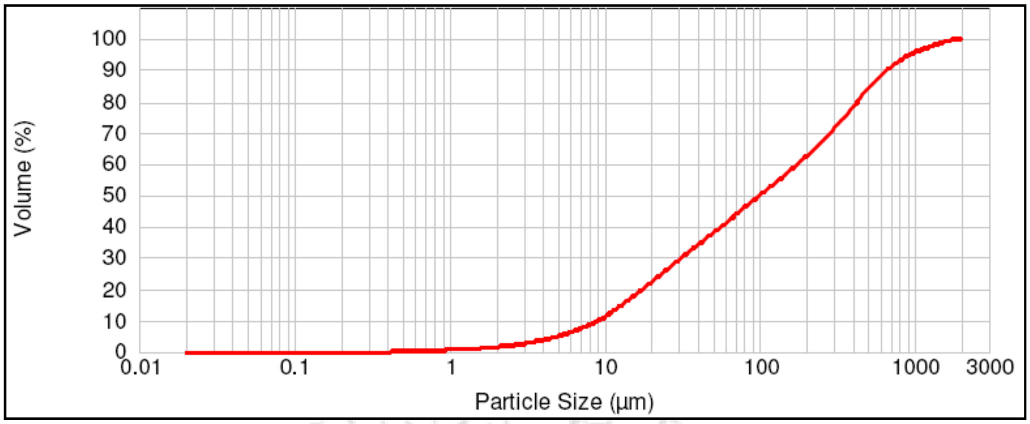


Figure 4.17: Particle size distribution of sediment eroded from undisturbed watershed

4.6.2. COMPARISON OF RAINFALL AND RUNOFF WATER CHEMISTRY

4.6.2.1 Chemical Characteristics of Rainwater

(a) pH, EC and TDS of rainwater

The rainwater was generally slightly acidic in nature with low electrical conductivity and low TDS concentration. pH values during the study period was almost consistent except for the month of July 2010, when the value was marginally alkaline. The TDS value of the rainwater was up to a maximum value of 20 mg/L. However TDS value was below detectable level in the month of August 2010. It indicated low concentration of ionic constituents. The average value, range and standard deviation of the pH, EC and TDS are presented in Table 4.3. The variation pH, TDS and EC are also presented in Figure 4.18 and Figure 4.19.

Table 4.3: pH, EC and TDS of rainwater

	pH	EC(µS/cm)	TDS(mg/L)
Average	6.6	17.1	16.4
Standard deviation	0.25	6.25	6.74
Range	6.3-7.1	7.7-24	0-20

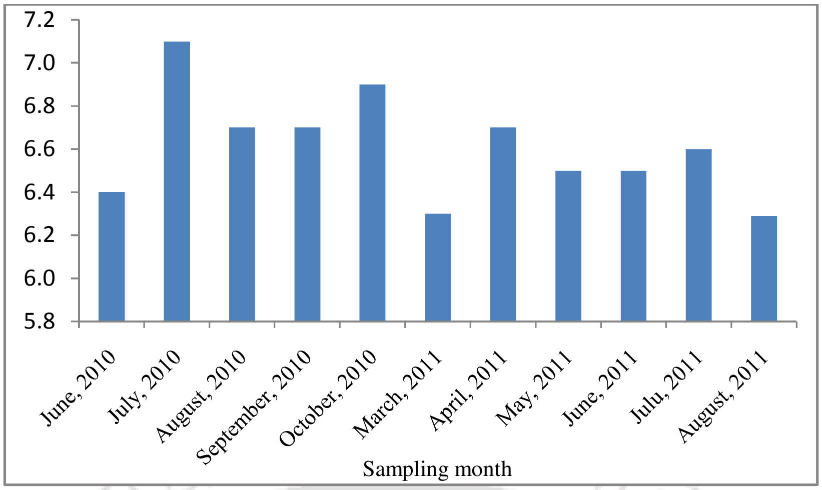


Figure 4.18: Variation of pH in rainwater samples collected at different times

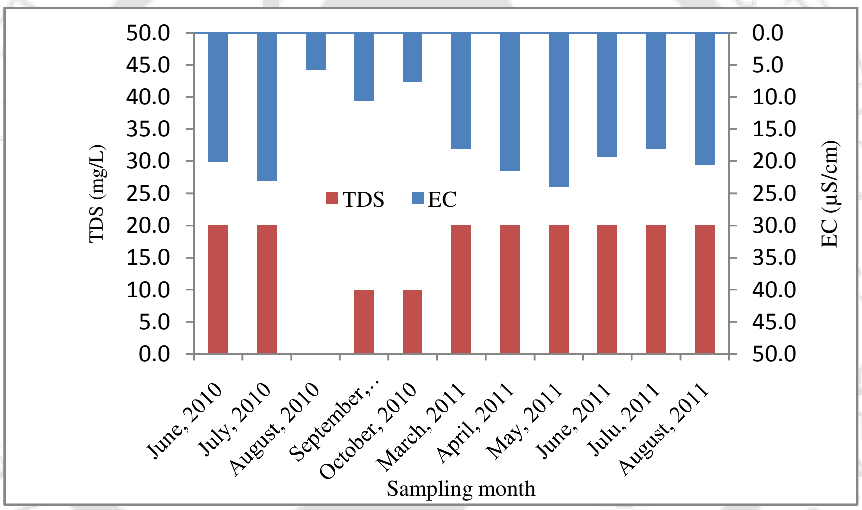


Figure 4.19: Variation of EC and TDS in rainwater samples collected at different times

(b) Ionic constituents present in rainwater

In Table 4.4, mean, standard deviation and range of the ions in the rainwater samples for the period June 2010 to August 2011 are presented. The rainwater is mainly constituted by bicarbonate ions (50%), followed by SO_4 (25%), Ca (19%), Na (2%), Cl (2%), K(1%) , F(1%) and trace of Mn (0.07%). The month wise distribution is presented in Figure 4.20. Presence of other heavy metals, Pb, Cd, Cr, Ni and Fe could not be detected during the study period. NO_3 and PO_4 was not detected during the study period. Month wise variation of the studied ionic constituents are low, the highest deviation was for Bicarbonate (3.1), followed by SO_4 and Ca. Presence of Mn ion was comparatively low, the month wise variation of Mn is presented in Figure 4.21. In rainwater, no hardness was detected throughout the study period. No harness was observed in rainwater.

Table.4.4: Analysis of rainwater chemistry

	Na	K	Ca	Cl	F	SO_4	HCO_3	Mn
Mean (mg/L)	0.26	0.23	2.49	0.20	0.05	4.24	6.10	0.008
Range (mg/L)	0.07-0.6	0.13-0.34	0.035-5.58	BDL-0.6	BDL-0.14	3.8-5.7	2-14	BDL-0.02
Standard deviation	0.15	0.09	1.50	0.14	0.04	1.56	3.11	0.007

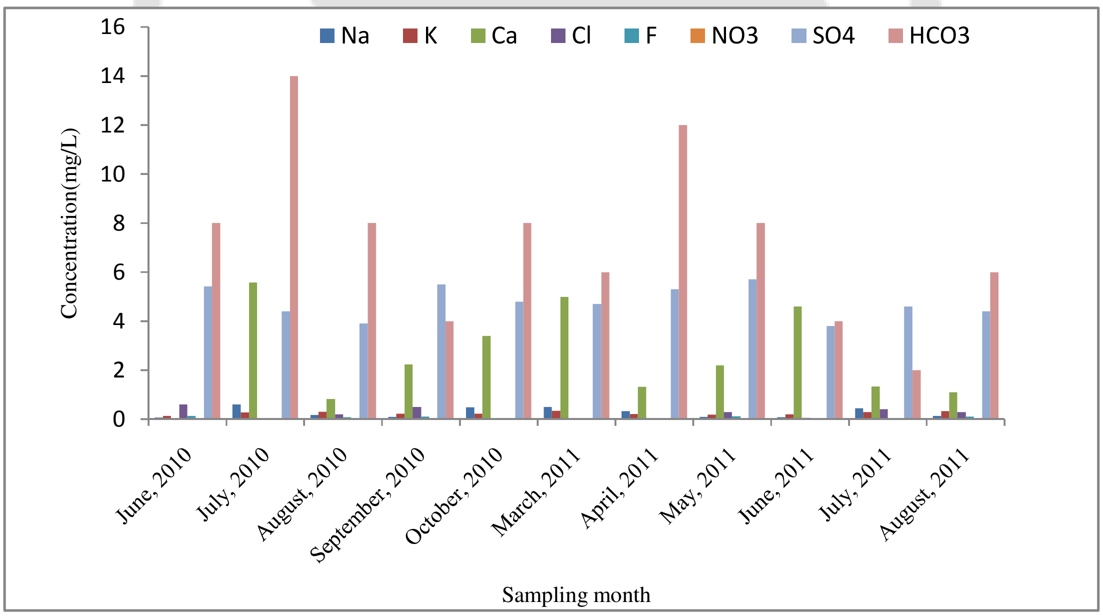


Figure 4.20: Month wise variation of ionic concentrations in rainwater

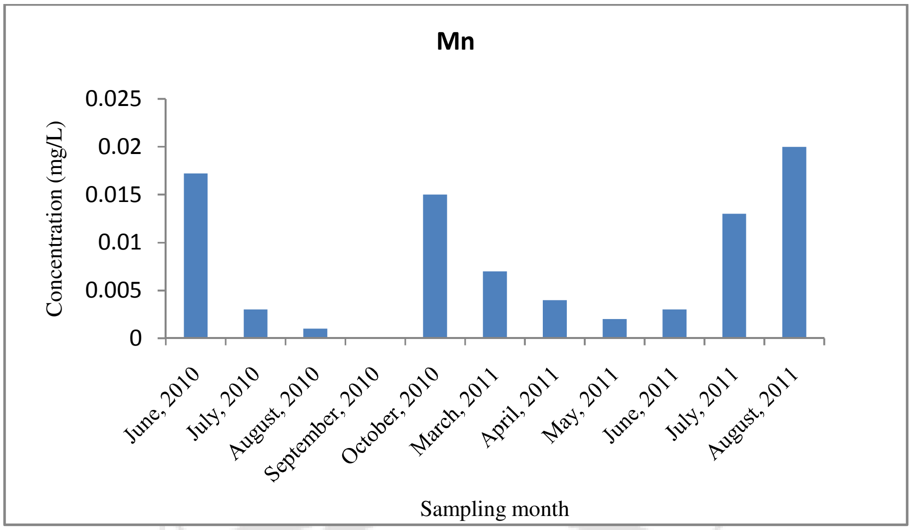


Figure 4.21: Month wise variation of Mn concentration in rainwater

4.6.2.2 Chemical Characteristics of Runoff

Runoff samples for some rainfall events from the disturbed watershed (average sediment concentration 1370 mg/L) and undisturbed watershed (average sediment concentration 340 mg/L) were analyzed. The variation of pH values in all the samples was random and the average pH value is higher than the pH of rainwater. The variation of pH in the runoff of the disturbed and the undisturbed watershed samples for 28 rainfall events are presented in Figure 22.

There is a significant difference in EC and TDS values of runoff samples from disturbed and undisturbed watersheds (Figure 4.23 and Figure 4.24). The EC and TDS values in the runoff samples for 28 rainfall events were usually higher in case of the disturbed watershed than the undisturbed watershed. This indicated that higher sediment concentration in the runoff samples of disturbed watershed contribute more ionic species than the undisturbed watershed.

The mean, standard deviation and range of pH, EC and TDS values for the 28 rainfall events are presented in Table 4.5.

(a) pH, EC and TDS of runoff

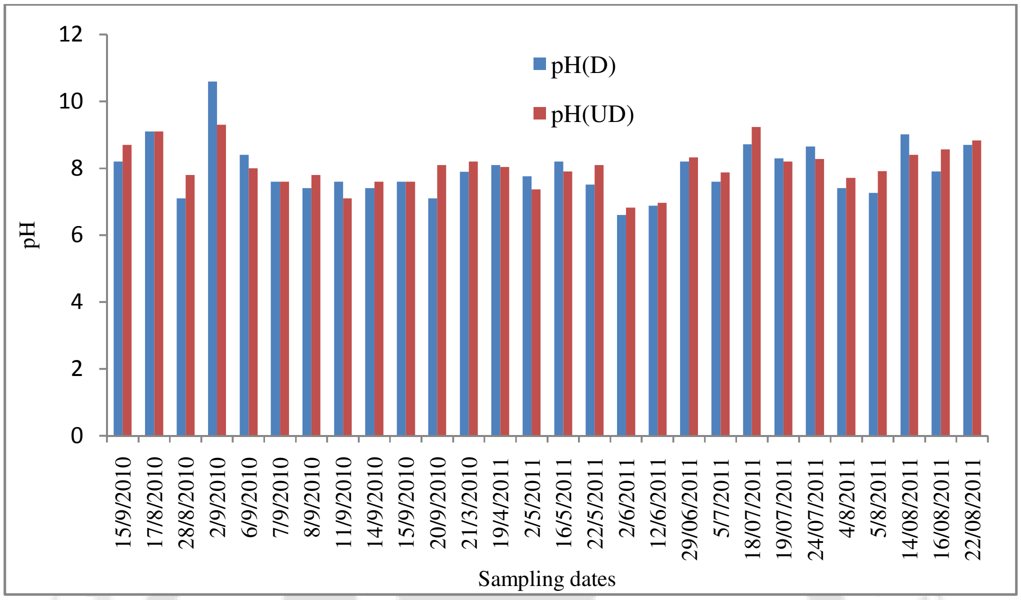


Figure 4.22: pH values in runoff of disturbed (D) and undisturbed (UD) watersheds

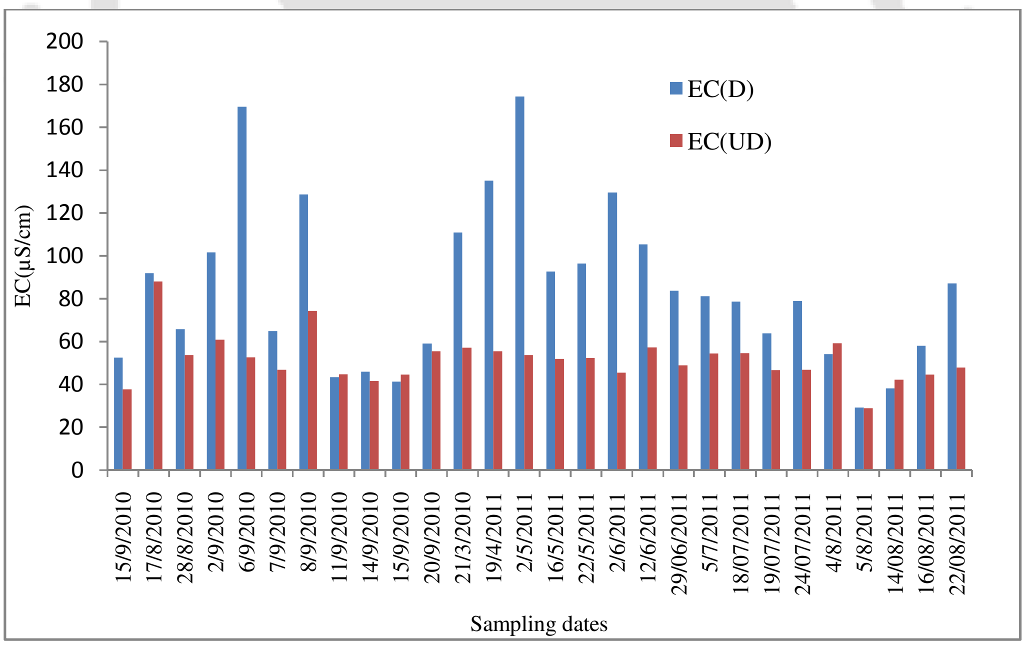


Figure 4.23: EC values in runoff of disturbed (D) and undisturbed (UD) watersheds

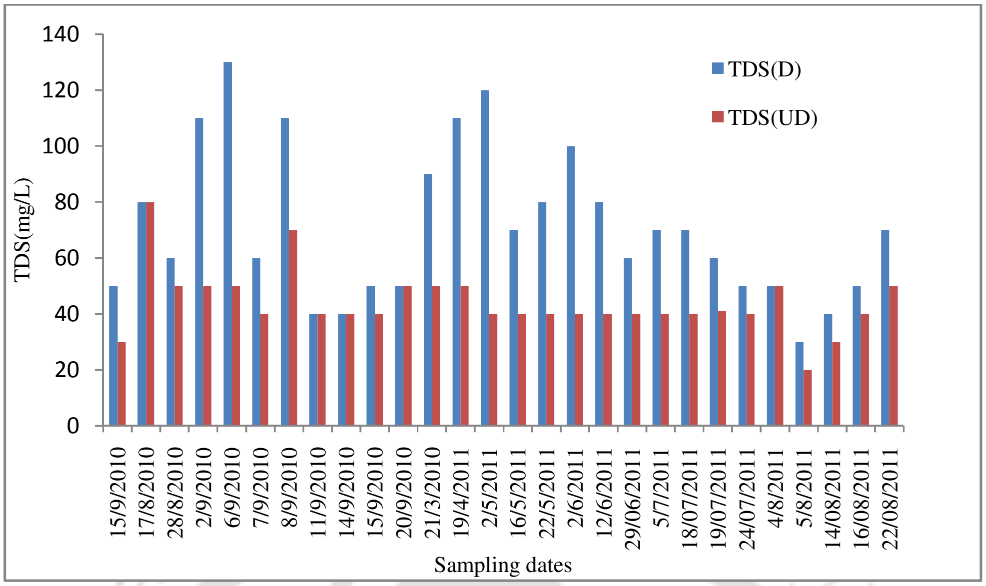


Figure 4.24: TDS values in runoff of disturbed (D) and undisturbed (UD) watersheds

Table 4.5: pH, EC and TDS values of runoff of disturbed (D) and undisturbed watershed (UD)

	pH(D)	EC(D) (µS/cm)	TDS(D) (mg/L)	pH(UD)	EC(UD) (µS/cm)	TDS(UD) (mg/L)
Mean	7.9	84.33	70.71	8.05	51.7	43.96
Standard deviation	0.82	37.66	26.93	0.62	11.0	11.32
Range	6.6-10.6	29.8- 74.3	30-130	6.8-9.3	28.9-88	20-80

(b) Ionic constituents present in runoff

Besides monitoring the pH, EC and TDS, runoff samples from disturbed and undisturbed watersheds for 12 rainfall events were collected for a detail analysis of water chemistry of runoff. The details of the mean, standard deviation and range of the analyzed water quality parameters are presented in the Table 4.6 and Table 4.7. Runoff samples acquired significant amount of ions compared to the rainwater and was generally higher for the runoff samples of the disturbed watershed. In Figure 4.25 and Figure 4.26, variation in bicarbonate and hardness values for the runoff samples of disturbed and undisturbed watersheds for the different rainfall events are presented. The HCO_3 concentration was found to be always higher in the disturbed watershed than the undisturbed watershed. Bicarbonate concentration was nearly consistent in the undisturbed watershed than the disturbed watershed. In the disturbed watershed, a random variation was observed. The hardness concentrations in the runoff samples were observed to be as more in the disturbed watershed than the undisturbed watershed, indicating that higher sediment concentration had led to increased in the hardness of runoff.

The bicarbonate was observed as the major constituents of runoff. Significant concentration of Na, K, Ca and traces of Fe and Mn was observed for the runoff of both the disturbed and undisturbed watershed. In Figure 4.27 and Figure 4.28, variation in the ionic concentration in the runoff samples of different rainfall events of disturbed and undisturbed watershed are presented respectively. Presence of Pb, Cd and Ni was not detected in the runoff samples of both the watersheds. The average ionic concentration was found to be in the following order:

$$HCO_3^- > Ca > K > Fe > Na > Mn$$

After HCO_3, Ca concentration was highest in the runoff samples of both the watersheds compared to the other ions. However, in the disturbed watershed, for some rainfall events, K concentration turns out to be as high as Ca concentration.

Detail graphical comparison of ionic concentrations for Cl, F, NO_3, SO_4 and PO_4 in rainwater and runoff are not presented as, the differences in average ionic concentrations of these ions were found to be insignificant (Table 4.7) for the studied watershed.

Table 4.6: Ionic contents in runoff (cations and trace metal)

Parameters		Na	K	Ca	Pb	Cd	Ni	Fe	Mn	Hardness as $CaCO_3$
Disturbed watershed	Average (mg/L)	0.41	6.96	9.50	-	-	-	1.37	0.01	32.07
	Range (mg/L)	0.06-0.78	0.3-24.9	1.99-25.9	BDL	BDL	BDL	BDL-3.9	0.01-0.024	10-80
	Standard deviation	0.22	8.23	8.91	-	-	-	1.45	0.01	21.02
Undisturbed watershed	Average (mg/L)	0.40	1.45	5.07	-	-	-	0.61	0.01	17.33
	Range (mg/L)	0.06-0.7	0.3-4.1	1.1-12.3	BDL	BDL	BDL	BDL-1.7	BDL-2.22	6-40
	Standard deviation	0.23	1.10	3.67	-	-	-	0.65	0.01	12.04

Table 4.7: Ionic contents in runoff of (anions)

Parameters		HCO_3	Cl	F	NO_3	SO_4	PO_4
Disturbed watershed	Mean (mg/L)	39-143	0.25	0.06	BDL	6.24	BDL
	Range (mg/L)	66	BDL-0.65	BDL-0.19	BDL	3.9-7.7	BDL
	Standard deviation	28.9	0.2	0.05	BDL	1.9	BDL
Undisturbed watershed	Mean (mg/L)	17-46	0.3	0.08	BDL	8.4	BDL
	Range (mg/L)	33	BDL-0.9	BDL-0.23	BDL	4-7.9	BDL
	Standard deviation	10	0.4	0.2	BDL	2.1	BDL

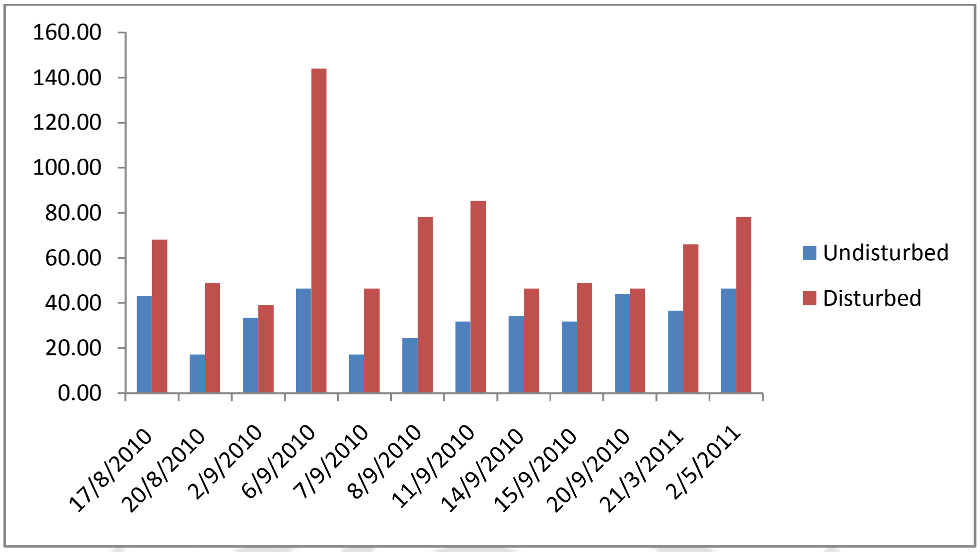


Figure 4.25: Bicarbonate in runoff samples of disturbed and undisturbed watersheds

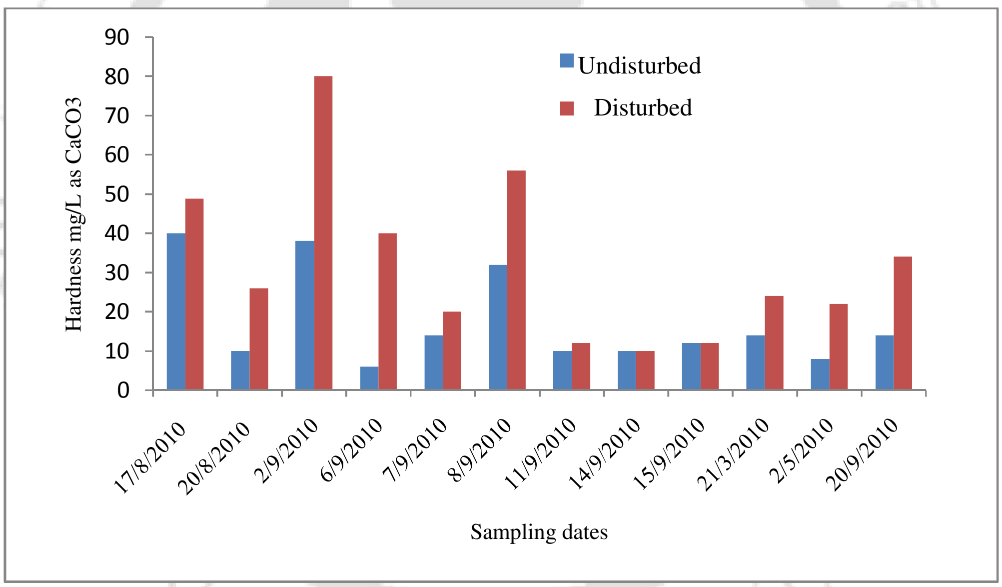


Figure 4.26: Hardness in runoff samples of disturbed watershed and undisturbed watersheds

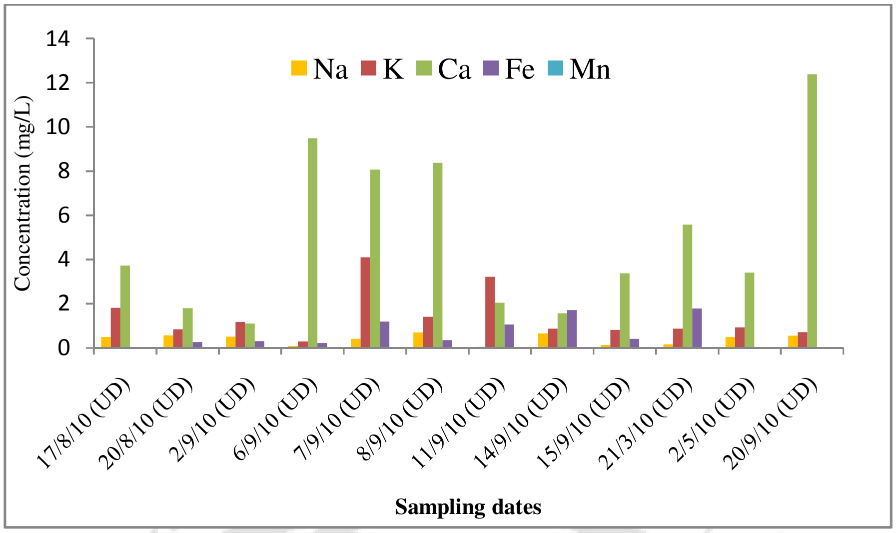


Figure 4.27: Ionic concentration in runoff samples of undisturbed watershed (UD)

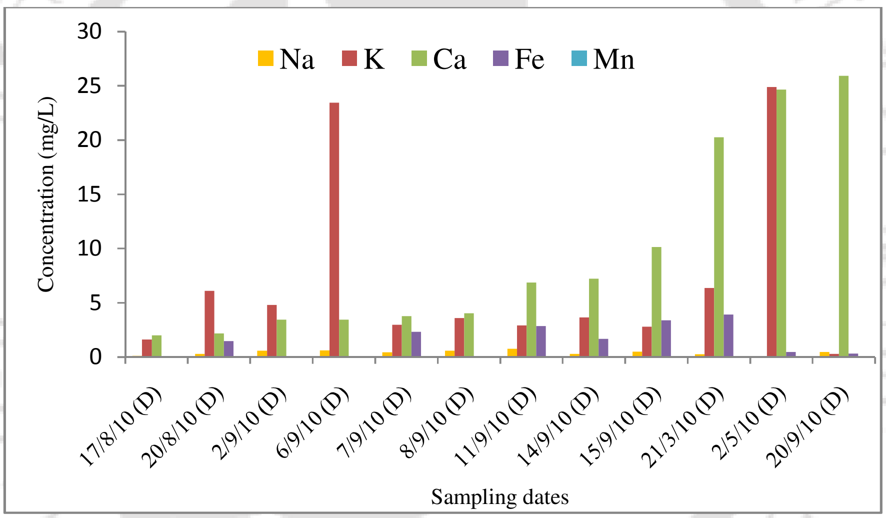


Figure 4.28: Ionic concentration in runoff samples of disturbed watershed (D)

4.6.2.3 Differences in Chemical Characteristics of Runoff and Rainwater

When the rainwater passed over the land surfaces as runoff, the basic water chemistry in these two phases differ significantly. A study was carried out by Yair et al. (1991) on chemistry of rainfall and runoff water of an arid limestone hillside of northern Negev, Israel with basic water quality parameters (Na, K, Ca, Mg, Cl, SO_4 and HCO_3). They reported that runoff water is enriched on an average by a factor of 2 in comparison with rainwater.

The runoff samples that were collected from the two watersheds of IITG were free from any anthropogenic source of pollution. Any change in the runoff water quality than that of the rainwater, must be contributed by the land surfaces of the watershed area, with the runoff from the watershed having significantly higher sediment concentration (disturbed watershed) having significantly higher ionic concentration.

In this study the water chemistry of rainwater was taken as average rainwater quality observed over a year and water chemistry of runoff samples were taken as average value of all the runoff generating storms during the same year. The differences in average values of pH , EC, TDS, HCO_3, Na, Ca, K, and Mn in rainwater and runoff samples of disturbed and undisturbed watersheds are presented in Figure 4.28, Figure 4.29, Figure 4.30, Figure 4.31, Figure 4.32, Figure 4.33 and Figure 4.34 .

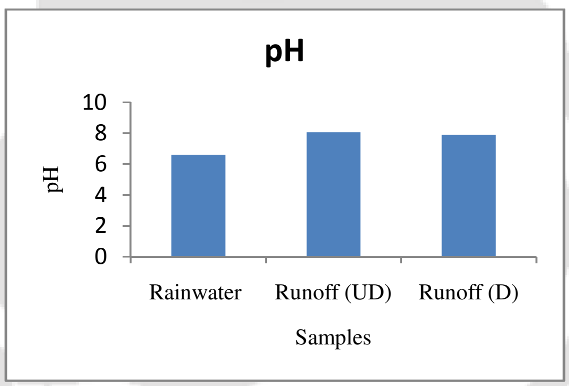


Figure 4.29: Differences in pH values in rainwater and runoff samples of disturbed (D) and undisturbed (UD) watersheds

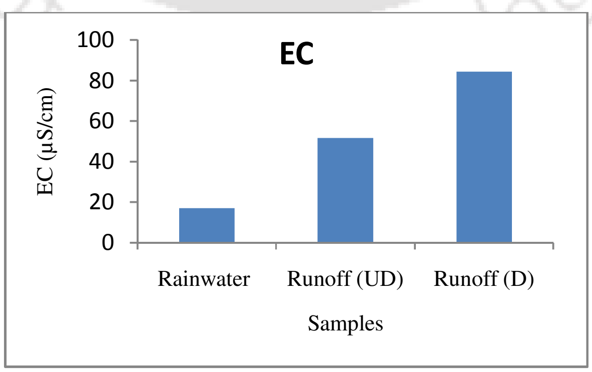


Figure 4.30: Differences in EC values in rainwater and runoff samples of disturbed (D) and undisturbed (UD) watersheds

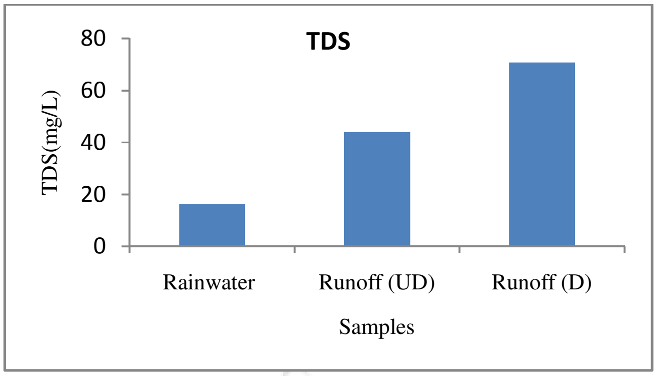


Figure 4.31: Differences in TDS values in rainwater and runoff samples of disturbed (D) and undisturbed (UD) watersheds

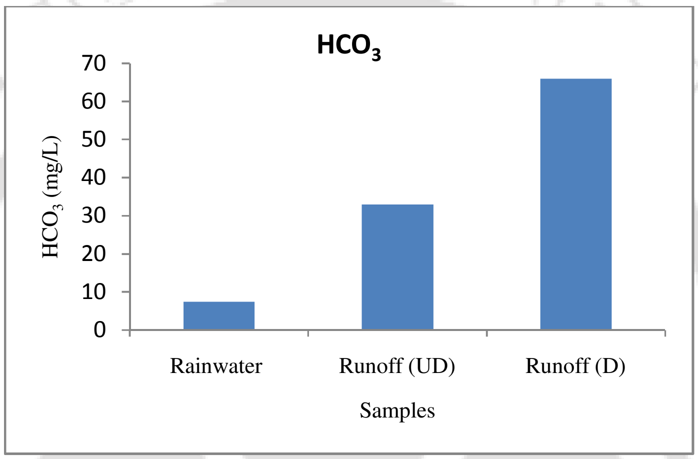


Figure 4.32: Differences in average bicarbonate concentrations in rainwater and runoff samples of disturbed (D) and undisturbed (UD) watersheds

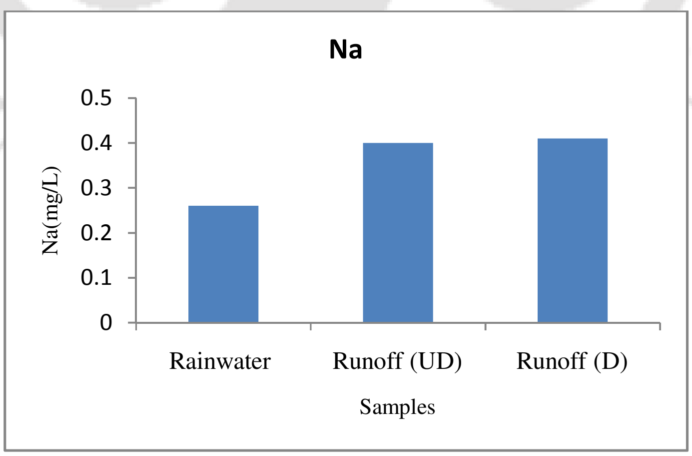


Figure 4.33: Differences in average Na concentrations in rainwater and runoff samples of disturbed (D) and undisturbed (UD) watersheds

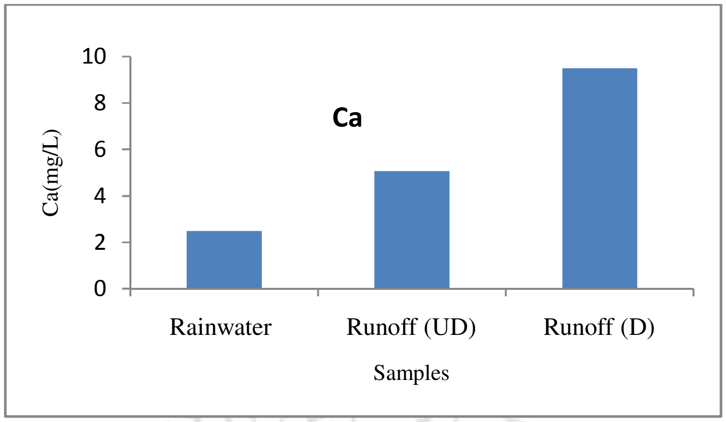


Figure 4.34: Differences in average Ca concentrations in rainwater and runoff samples of disturbed (D) and undisturbed (UD)watersheds

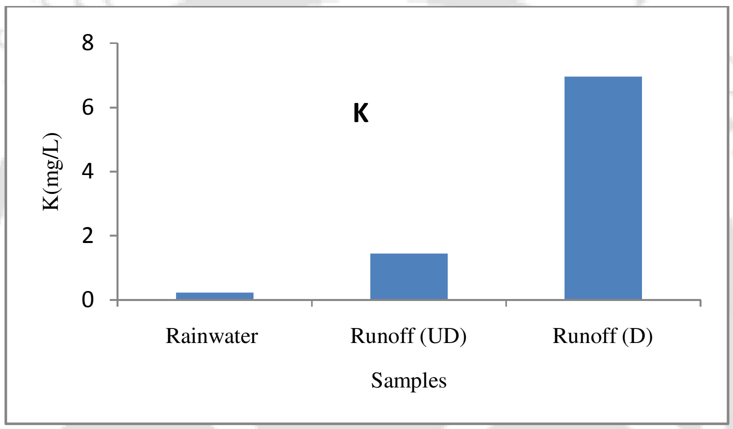


Figure 4.35: Differences in average K concentrations in rainwater and runoff samples of disturbed (D) and undisturbed (UD) watersheds

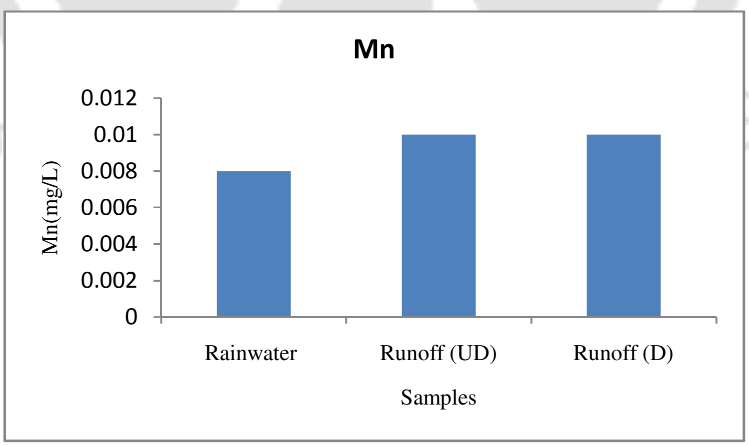


Figure 4.36: Differences in average Mn concentrations in rainwater and runoff samples of disturbed (D) and undisturbed (UD) watersheds

The ionic contribution of watershed area (soil surface) to the runoff was assessed by calculating the percentage increase of the average values of the water quality parameters in the runoff of disturbed and undisturbed watersheds compared to that of rainwater (Table 4.8 and Figure 4.37). The pattern of percentage increase is similar in case of both the watersheds; the percentage increase is in the following order:

$Fe>K>HCO_3>Ca>Na>Mn$

The pH values in the runoff samples increased by 16% (disturbed watershed) and 18 % (undisturbed watershed) than the rainwater and the difference in sediment concentration did not seem to have significant effect on pH change, after achieving the saturation point. Higher sediment concentration seems to have significant effect in the TDS and EC values of runoff. The EC values of the undisturbed watershed increased by 67 %, where as in disturbed watershed the EC values increased by 80%. Also The TDS values of the undisturbed watershed increased by 63%, where as in disturbed watershed the TDS value increased by 77%. This clearly indicated that the higher sediment yield contribute more dissolved ions to the runoff water.

Table 4.8: Ionic contribution of watershed area (soil surface) to the runoff

Contribution by watershed area (%)	Average sediment concentration (mg/L)	pH	EC	TDS	Hardness as $CaCO_3$	HCO_3	Na	K	Ca	Fe	Mn
Runoff (UD)	340	18	67	63	100	78	35	84	51	100	20
Runoff (D)	1370	16	80	77	100	89	37	97	74	100	20

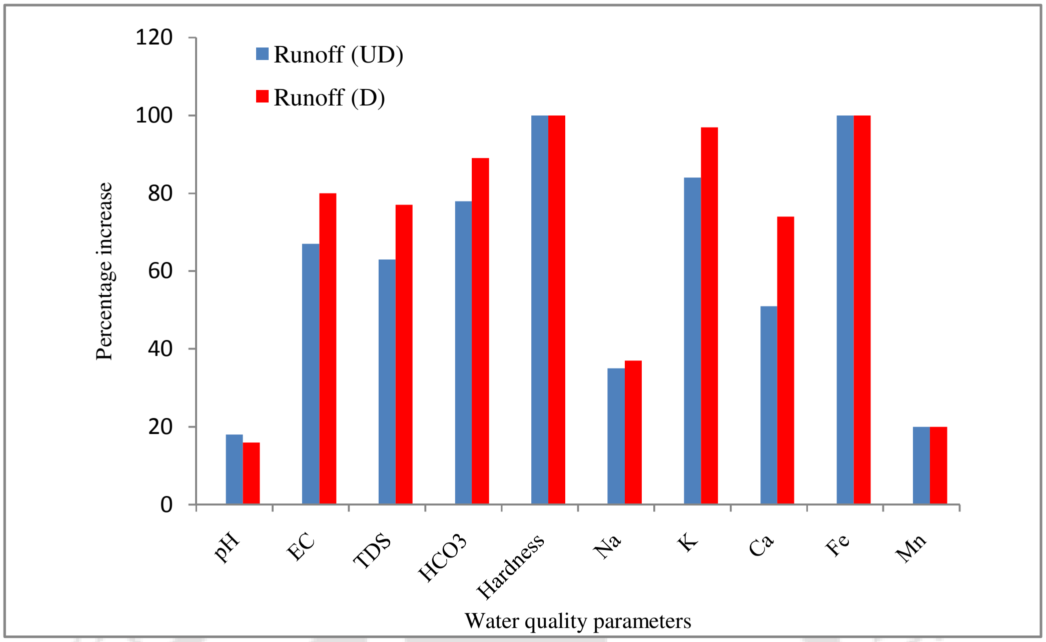


Figure 4.37: Percentage increase of water quality parameter values in runoff in the disturbed (D) and undisturbed (UD) watersheds

4.6.3. SEDIMENT YIELD CHARACTERISTICS OF SOME COMPETITIVE EMPs

As discussed in section 4.5, erosion control capability of two vegetative measures, namely, grass and Golden glory was compared with that of barren land. Grass showed a higher efficiency than Golden glory (Table 4.9). However, compared to barren land, Golden glory too could reduce sediment yield to a great extent. The experimental study on EMPs demonstrated that the application of EMPs can reduce soil erosion from a disturbed watershed area to a significant extent. The experimental study on two EMPs demonstrated good potential in controlling sediment yield as compared to sediment yield from barren land. Grass was observed to have potential of controlling sediment yield from 75% to 100% (average = 88%), whereas Golden glory had shown 36% to 97% efficiency (average = 64%).

Table 4.9: Sediment yield form the EMP strips

Date	Rainfall intensity (mm/hr)	Duration (min)	Barren (Kg)	Grass (Kg)	Golden glory (Kg)	Relative efficiency compared to barren land (%)	
						Grass	Golden Glory
2/5/2011	8.1	130	1.30	0.00	0.13	**100**	90
8/5/2011	9.1	30	0.51	0.18	0.31	**65**	**38**
16/5/11	5.6	150	0.07	0.01	0.02	86	71
22/5/11	29.4	210	1.17	0.01	0.04	99	**97**
24/5/11	2.5	30	0.01	0.00	0.00	**100**	80
28/5/11	38.1	130	0.14	0.01	0.03	96	80
2/6/2011	27	70	0.66	0.00	0.10	**100**	85
10/6/2011	3.04	140	0.58	0.00	0.04	**100**	93
12/6/2011	24.3	60	0.52	0.00	0.14	99	74

Particle size distribution of sediments eroded from the EMP strips

The particle size distributions of the sediment transported by the runoff from the barren land, Grass, Golden glory are presented in Table 4.10 and shown in the Figure 4.38, Figure 4.39 and Figure 4.40.

From these figures, it is clear that the particle size distribution is more uniformly graded in case of barren strip as compared to grass strip and the golden glory strip. This is because the surface of the bare land remains exposed to the direct impact of rain drop and surface runoff and thus because of splash erosion the soil gets detached and become finer. On the other hand with the coverage of grass or golden glory, the soil surface never gets subjected to the direct impact of rain drop. Runoff water caries some soil particles. A fraction of such eroded sediment gets detached during the process of transportation, whereas some fractions do not get completely detached and their apparent sizes remain larger. Because of this the delivery ratio for a land covered by grass or golden glory will also be less as compared to the bare land. This will help in avoiding sediment deposition problem in the drains located in the plain area. Whereas, finer particle moving from a bare land will reach the drains in the plains after getting transported by the relatively high velocity flow from the hilly terrain and will ultimately deposit in the drains and channel of plain area, as flow velocity drops in flat valley. This leads to reduction of carrying capacity of the drains causing flood during monsoon.

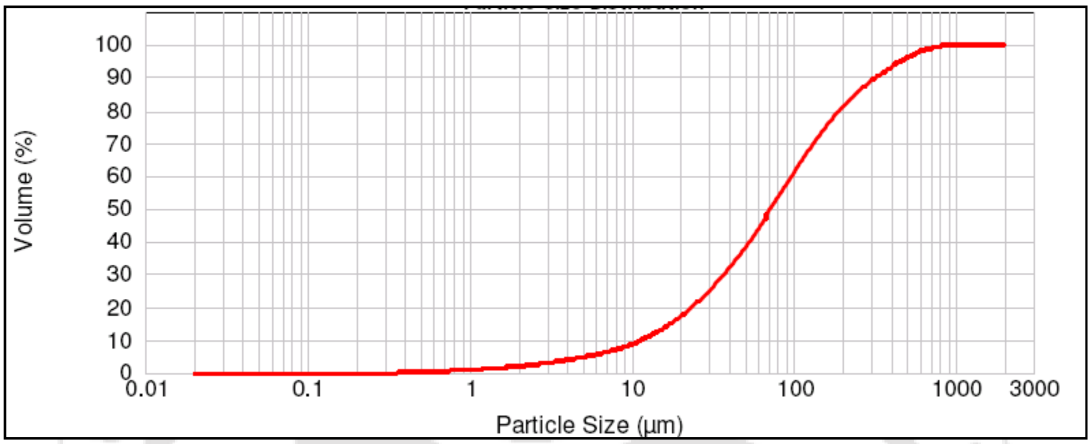


Figure 4.38: The particle size distribution in the sediments eroded from the barren strip

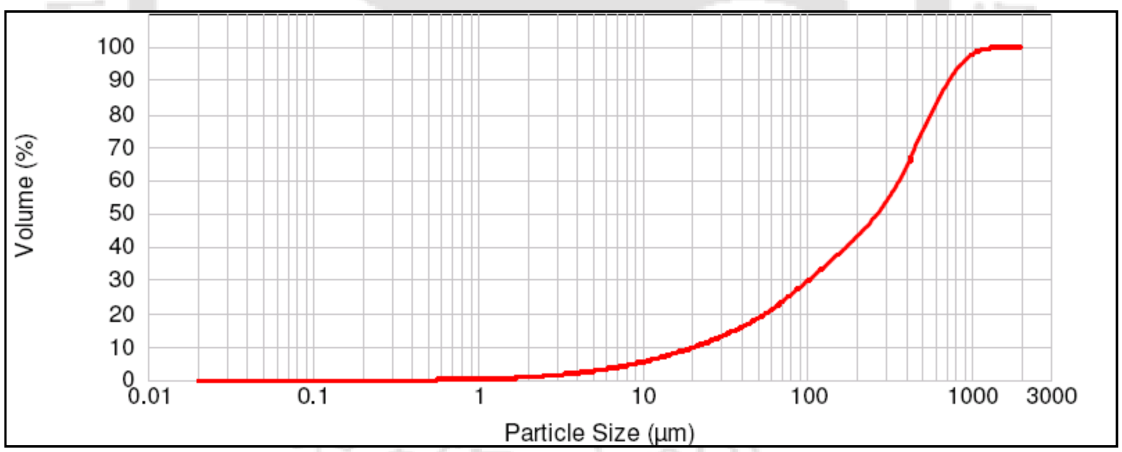


Figure 4.39: The particle size distribution in the sediments eroded from the grass strip

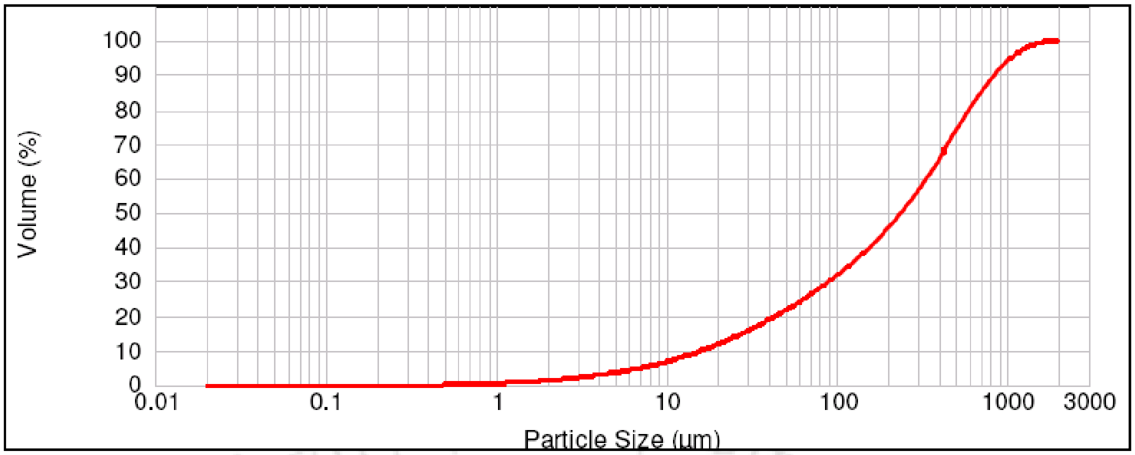


Figure 4.40: The particle size distribution in the sediments eroded from the Golden glory strip

Table 4.10: Particle size distribution of sediments eroded from the EMP strips

Sample type	D 10	D 50	D 90
Bare land	11.604 µm	72.642 µm	318.241 µm
Grass	21.071 µm	266.855 µm	734.995 µm
Golden glory	16.29 µm	237.225 µm	843.34m

4.7. CONCLUSIONS

Disturbed condition of a watershed significantly alters the sediment and water yield characteristics of the watershed. From the field based experimental study it was observed that the difference in runoff from the disturbed and undisturbed watersheds varied from 3% to 54% and sediment yield difference varied from 2% to 20% for rainfall events of different intensities and durations.

The study on water chemistry of rainfall and runoff has revealed that the significant changes in the basic chemical composition occur when the rainwater passes over land surfaces as runoff. The runoff collected from the experimental watersheds of IIT Guwahati was observed to have higher ionic concentration as compared to the average ionic concentration of the rainwater samples of the same locality. As the studied watersheds are free from any sort of anthropogenic pollution, therefore the enrichment that was added to the runoff water quality must be contributed by the land surface of the watershed area.

Also, the disturbed watershed which is having comparatively higher sediment concentration in its runoff water than the undisturbed watersheds, do have higher dissolved ionic concentration. For the studied ions, the percentage contributions from the soil surface was found in the order as Fe>K>HCO_3>Ca>Na>Mn. Therefore, considering the fact that soil and sediment can significantly contribute towards chemical enrichment of runoff, it is important to study their leaching behavior in water to have a better idea on possible contribution of dissolved loads by soil and sediment in downstream water bodies. Therefore, a batch leaching study was conducted for soils with different level of contaminations to study the leaching characteristics of different ions into water. The detail of the study is presented in chapter 5.

The study on sediment control efficiency of two competitive EMPs, *Paspalum conjugatum* (Poaceae) and *Tradescantia zebrine* (Commelinaceae) in 45^0 slope, showed that grass has sediment control efficiency up to 88% and *Tradescantia zebrine* has sediment control efficiency of 64% compared to that of bare land. Both these species were found to be convenient in terms of installation, maintenance and esthetic point of view. Therefore, grass and Golden glory can be conveniently used as sediment control measures in hilly urban areas with fair amount of success. Based on the study found in literature (Anbumozhi et al., 2005; Maillard et al.,2008; Parajuli et al.,2008) it is expected that the vegetative sediment controlling EMPs will also offer additional benefit of nutrient loss from soil and screening of non point source pollutant generated at its upstream.

Chapter 5

LEACHING BEHAVIOUR OF SOIL AND IT'S CONSIDERATION IN DECIDING OPTIMAL EMPs

5.1. INTRODUCTION

This chapter contains the study on leaching behaviour of soil and sediment and the application of the leaching study in determining the minimum required of sediment yield from a watershed.

5.2. SCOPE OF THE LEACHING STUDY

Soils and sediments significantly influence the composition of water coming in contact with them. Soil releases nutrients and heavy metals to surface water and ground water through the process of leaching. This process occurs in three ways – (i) when the rainwater moves over soil surfaces as runoff (Saarijärvi et al., 2004; Schipper et al.,2008) (ii) when the rainwater/runoff percolates through the soil profile to ground water (Hansen and Djurhuu., 1997) and (iii) leaching from bed sediments of water bodies (Jain and Ram,1997; Jiang et al., 2008; Butler, 2009).

It is important to study the leaching behaviour of soil to understand their role in modifying water composition. In this chapter, the total leachable amounts of cations and some trace metals of concern from the surface soils have been evaluated and their role in influencing surface water chemistry has been assessed with the help of experimental and field based observations. Attempt has been made to finally establish a limit of permissible/desirable sediment yield from a catchment by considering the leaching behaviour of the studied ions. These limits have been used as constraints while determining optimal Ecological Management Practices.

5.3. METHODOLOGY

5.3.1. COLLECTION OF SOIL SAMPLES FOR LEACHING STUDY

Soil and sediment samples from eleven different sites of Guwahati City, Assam, India were collected for studying the leaching behaviour of the soil. Guwahati, the capital city of Assam exhibits high soil erosion rate from its urbanized hilly catchments leading to their subsequent deposition in the natural and manmade drainage systems. In this study, samples from hilly and valley areas of the city were collected. Effort was made to collect samples from various parts of Guwahati to make the sampling representative of the entire city. Emphasis was also given for collecting samples from the Games village area of the city, which was taken up for a case study for analysing applicability of the optimal EMP models presented in chapter 6. The locations of the sampling sites are shown in Figure 5.1 and described in Table 5.1.

5.3.2. DETERMINATION OF pH OF SOIL AND SEDIMENTS

The standard BIS Code IS 2720-Part 26(1987, Reaffirmed-2002) has been followed for determination of pH of soil and sediment samples. Following the procedure of IS: 2720 (part1)-1983, the soil samples were oven dried (105^0C -110^0C) for 24 hrs and then were sieved with 425 μ IS sieve. 30 gm of the soil from each sample was taken in a 100 ml beaker and 75 ml of distilled water was added to it. The suspension was stirred for a few seconds and allowed to stand for 1 hr by covering it with a cover glass. The solution was occasionally stirred and stirred well immediately before testing. The pH of the sample was measured with a portable pH meter (Make: Wagtech).The reading of the blank solution (distilled water) was subtracted from all the sample readings.

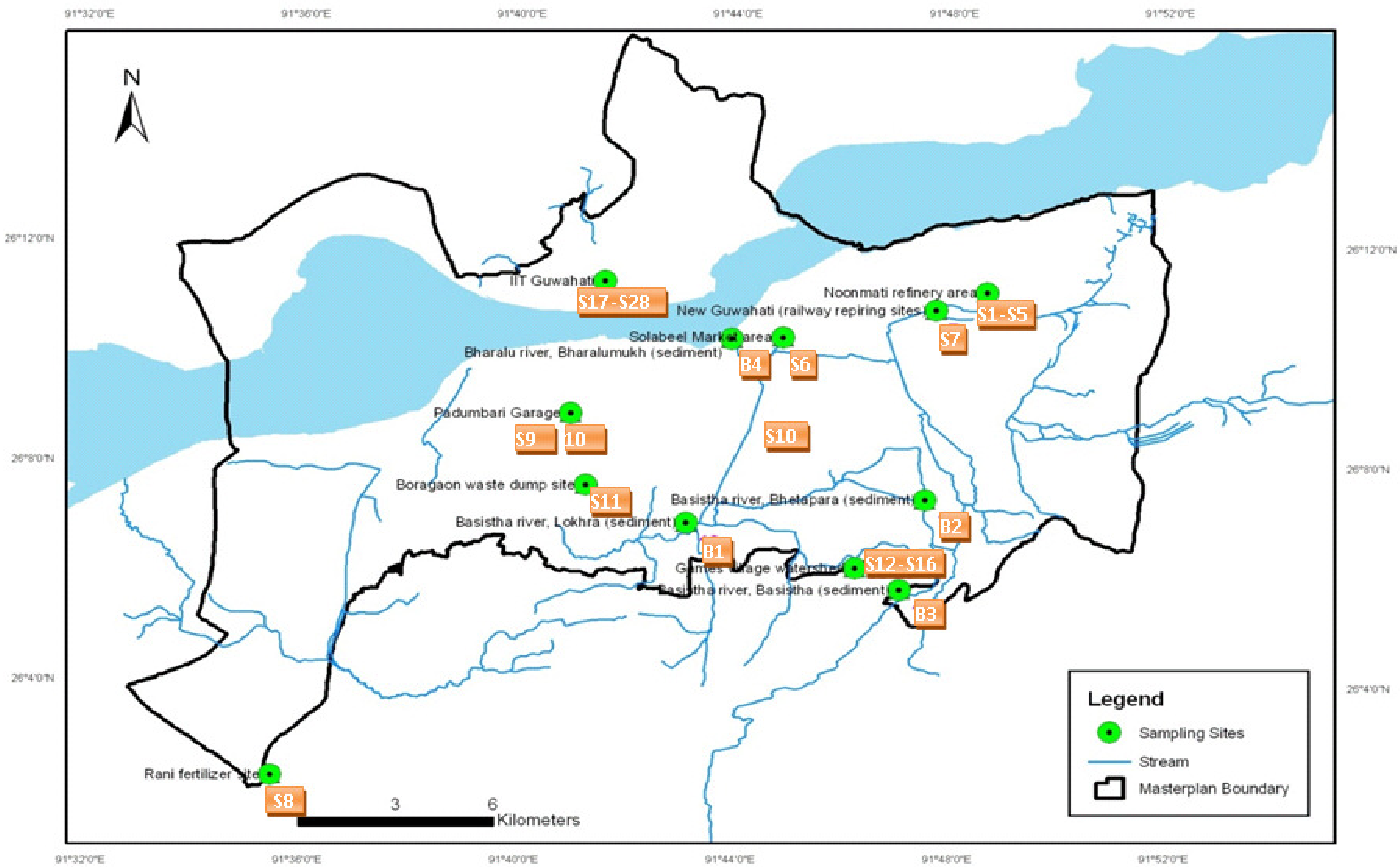


Figure 5.1: Map of the study area with location of the sampling sites

Table 5.1: Description and code assigned for the soil sampling sites

Code	Place	Description	Sample type
S1	Noonmati refinery hospital road side	Outside the campus of an industrial area(refinery), low level of soil contamination is expected	Surface soil
S2	Outside refinery (near equalizer tank)	Outside the campus of an industrial area(refinery), low level of soil contamination is expected	Surface soil
S3	Refinery (Near railway -GR-S1)	Inside the campus of an industrial area(refinery), moderate level of soil pollution is expected	Surface soil
S4	Refinery (GR-S2)tank area	Inside the campus of an industrial area(refinery), moderate level of soil pollution is expected	Surface soil
S5	Refinery (GR-new tank farm area	Inside the campus of an industrial area(refinery), moderate level of soil pollution is expected	Surface soil
S6	Solabeel market area	Fish market area , very high organic contamination is expected	Surface soil
S7	New Guwahati Lokoshed area	An intense railway repairing site, soil contamination with oil and grease are expected	Surface soil
S8	Rani fertilizer industry	Outside the campus of a fertilizer industry	Surface soil
S9	Kiron automobile	Garage site, with various kind of vehicle repairing activities and standing site of automobiles	Surface soil
S10	Podumbari garage	Small car repairing site	Surface soil
S11	Boragaon waste dump	A municipal waste dumping site	Surface soil
S12-S15	Games village	Hilly Barren area due to human intervention	Surface soil
S17-S27	Experimental watershed IITG	A vegetated area in a hilly undisturbed watershed	Surface soil
B1	Basistha river, Kotabnari, Lokhra	River site with very turbid (almost dark) which receives a great deal of effluents from small scale industries and domestic effluents, moderately polluted site	River bed sediment
B2	Basistha river, at Bhetapara	River site with very turbid water , the location receives domestic effluents, moderately polluted site	River bed sediment
B3	Basistha river, at Basistha	River site with clear water just at immediate downstream, unpolluted	River bed sediment
B4	Bharalu river, at Bharalumukh	A highly polluted river site just at the confluence of river Bharalu, dark-turbid water, highly waste loaded.	River bed sediment

5.3.3. DETERMINATION OF ELECTRICAL CONDUCTIVITY (EC) OF SOIL AND SEDIMENTS

The standard BIS Code (IS 14767: 2000) was followed for determination of electrical conductivity of soil and sediment samples. The soil samples were air-dried and sieved through a 2mm sieve. Then 20 g of the sample was taken in a conical flask and 40 ml of water was added. The conical flasks were covered with cotton and placed in a horizontal shaking machine for 30 min. Then each sample was transferred into a beaker and the electrical conductivity of the samples was measured with a portable EC meter (Make: Wagtech). The reading of the blank solution (distilled water only) was subtracted from all the sample readings.

5.3.4. SOIL DIGESTION METHOD

Extraction of trace metals from soil samples was carried out by following the standard ASTM methodology (D 3974-81, Reapproved 2003, Digestion Practice A). The soil samples were dried overnight at 105^0C until a constant weight was achieved and allowed to cool in a desiccator. The 4gm of the dried samples were taken into a beaker and 100 ml of distilled water was added. Then 1ml of Nitric acid and 10ml of Hydrochloric acid were added to the solution. The beaker was covered with a watch glass and heated on a hotplate at 95^0C. The beaker was removed from the hot plate when the solution remained to 10-15ml. The solution was allowed to cool at the room temperature. The solution was transferred to a 50ml volumetric flask and diluted to the volume of the flask. For determining concentration of elements for each dry sample, following formula was used:

$$C = \frac{(Q \quad S)\times V}{U} \qquad (5.1)$$

Where,

Q= Concentration of the elements in the digested soil sample, µgm/ml

S=Concentration of the element found in the reagent blank, µgm/ml

V=Volume of the extract =50ml

U= Weight of the sample corrected to a dried sample at 105^0C= 4 gm

C= Trace element per gm of the dry sample, in µgm

For determination of the concentration of the metal in the wet sample following formula was used:

$$A = \frac{C \times B}{100} \tag{5.2}$$

A=C * B/100

Where

A= Metal per gm of the wet sample, in µgm

C= Trace element per gm of the dry sample, in µgm

B= Percent solid of the sample, which is determined as

$$B = \frac{M \times 100}{N} \tag{5.3}$$

Where

M= Dry weight of the sample obtained after drying overnight in oven at 105^0C

N= Weight of the sample before drying

5.3.5. SOIL LEACHING STUDY

To study the leaching properties of soil, standard Toxicity Characteristic Leaching Procedure (TCLP) developed by US EPA (Townsend, 2003) was followed. The test involves extracting the elements from a 100gm size reduced sample (425 µsieved) with distilled water. A specific L/S ratio (liquid to solid ratio); 20:1 was maintained and the mixture was rotated for 18±2 hr at 30rpm. The sample was then filtered and the filtrate was analysis of heavy metals and cations.

5.3.6. DETERMINATION OF pH AND ELECTRICAL CONDUCTIVITY (EC) OF LEACHATE SAMPLES

The pH and EC of the leachate samples were tested immediately after filtration by the portable pH meter (Wagtech) and EC meter (Wagtech).

5.3.7. ANALYSIS OF IONIC CONCENTRATION OF LEACHATE SAMPLES

The digested soil samples and the leachate samples were analysed for Na, K, Ca and trace metals (Fe, Mn, Ni, Pb and Cd) by following the procedure as described in 4.4.1.

5.4. RESULTS AND DISCUSSION

5.4.1. LEACHING OF SOIL AND SEDIMENT

Comparison of rainfall and runoff water quality of the experimental watershed of IIT Guwahati, established that the soil surfaces contribute significant amount of nutrients and dissolved ions. The contribution of ions and nutrients are observed to be more with higher sediment yield. Thus, the process of leaching from the soil surfaces plays a significant role in influencing the runoff water quality. To understand the process of leaching, 32 soil samples from different (11) sites were collected and their leaching behaviour was studied. The collected samples also covered soils from commercial and industrial dumping sites (sample code from S1-S11). Samples from residential hilly areas (sample code from S12-S16) and totally natural unpolluted sites (sample code from S17-S28) were also collected. Four samples from river bed sediments (sample code from B1-B4) were too collected.

The mean, standard deviation and range of pH, EC along with the detectable ionic species as observed in the leachate samples are presented in Table 5.7. The average leaching was observed in the following order:

Ca>Fe>K>Na>Mn>Pb>Ni

As indicated by standard deviation values, the variability of the values are observed to be very high except for Pb and Ni. In this study , Cr and Cd was not detected in the leaching test.

Table 5.2: Summary of the results of leaching study for the collected samples

	pH(L)	EC(L) (µS/cm)	Na (L) (µgm/gm)	K (L) (µgm/gm)	Ca (L) (µgm/gm)	Pb (L) (µgm/gm)	Ni (L) (µgm/gm)	Fe (L) (µgm/gm)	Mn (L) (µgm/gm)
Average	7.41	74.17	44.26	53.07	166.05	2.01	1.31	61.57	17.42
Standard deviation	0.60	88.89	99.05	88.26	200.80	1.02	0.74	74.11	23.50
Range	6.1-8.2	9.6-432	BDL-571	1-394	1.2-687	0.2-3.4	0.08-2.36	BDL-188	0.06-64.5

The variation of pH in all the samples was almost consistent (Figure 5.2), significant variation was observed for EC values (Figure 5.3), indicating the variability in the ionic concentrations through all the samples.

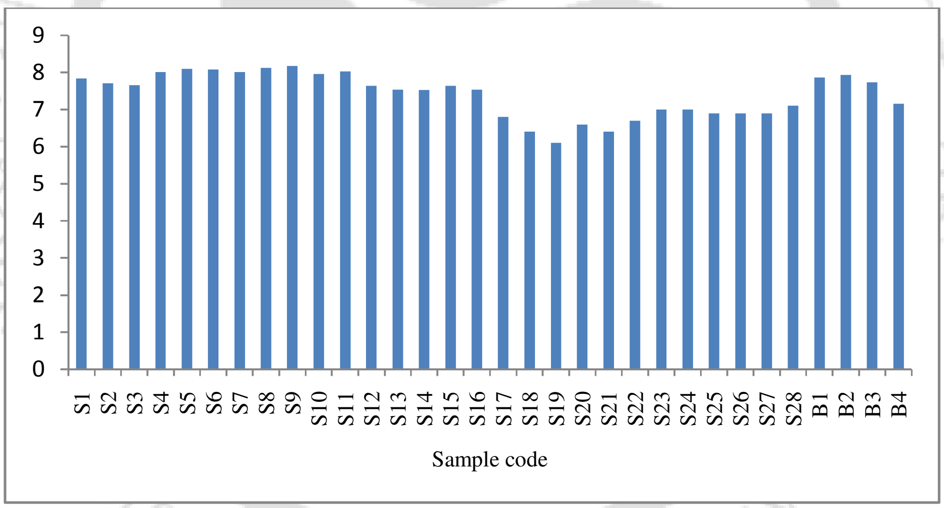


Figure 5.2: pH values in the leachate samples

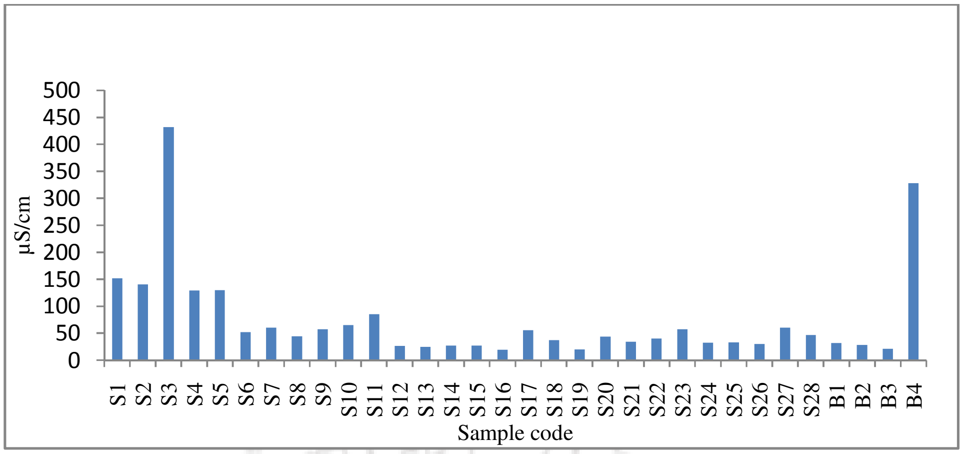


Figure 5.3: EC values in the leachate samples

In Figure 5.4, the variation of Na, K and Ca in the leachate samples are shown. The leaching of Na, K, Ca is higher for the soil samples from the urban areas representing comparatively polluted sites (sample code S1-S11)and also for river bed sediments (sample code B1-B4) than the samples that are from the hilly watershed areas (sample code S12-S28) ,i.e. in Games village watershed and experimental watershed. The leaching of Pb and Ni were more in the soil samples from the urban areas (sample code S12-S16) compared to the samples from the hilly watershed areas (Figure 5.5), except for one samples from the experimental watershed of IIT Guwahati site. The leaching of Fe and Mn was much higher for the soil samples of experimental watershed of IIT Guwahati site (sample code S17-S28) than the other sites (sample code S1-S16) (Figure 5.6), except the Fe leachate for bed sediment of Basistha river (sample code B2).

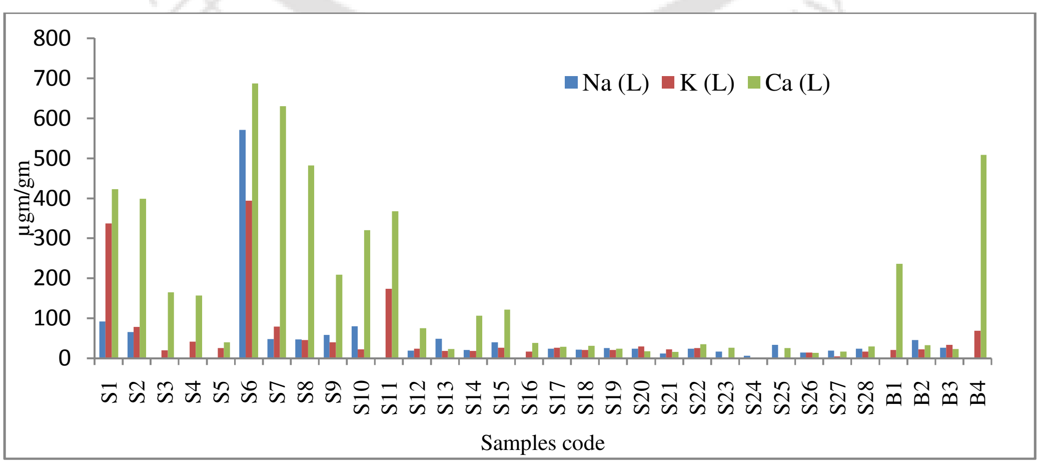


Figure 5.4: Na, K and Ca concentrations in the leachate samples

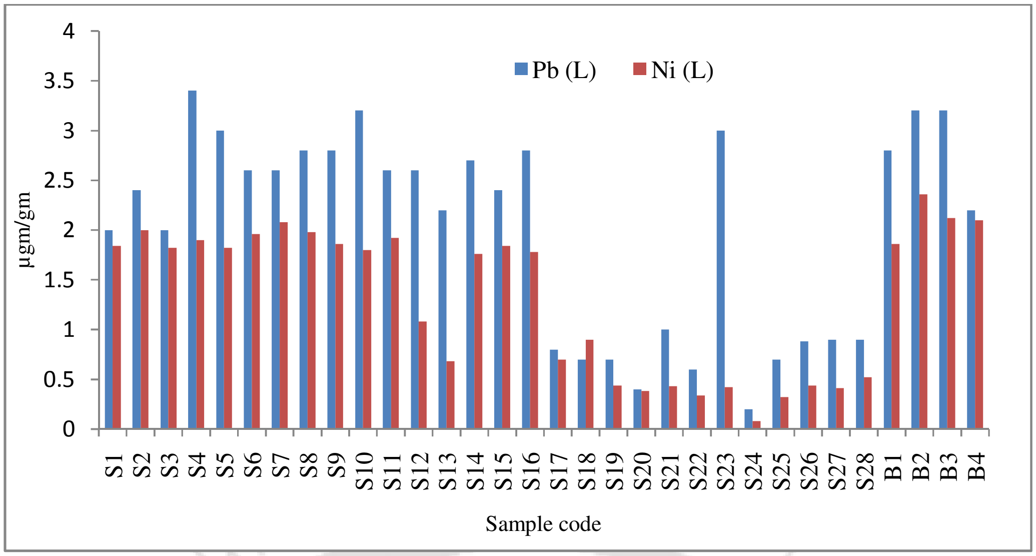


Figure 5.5: Pb and Ni concentrations in the leachate samples

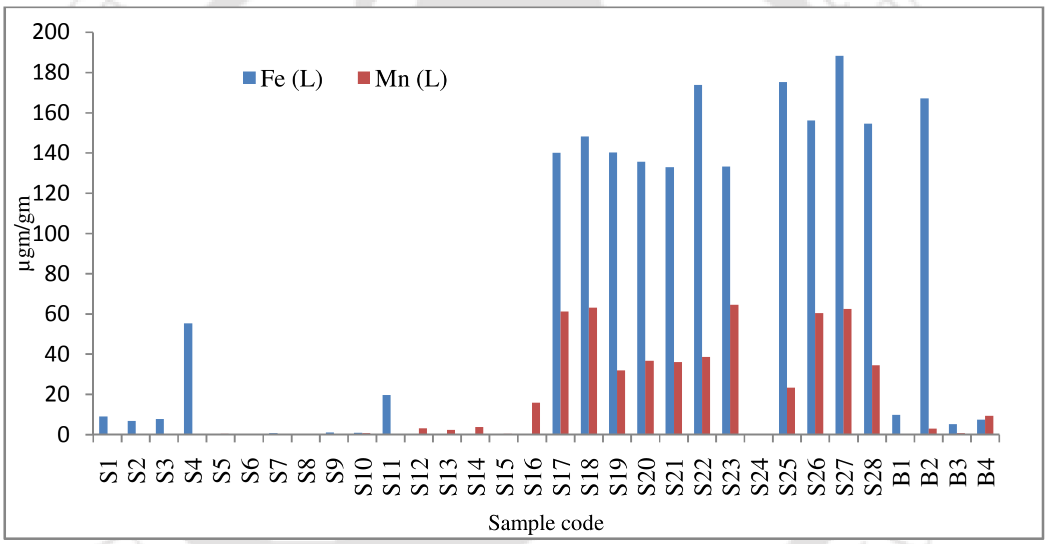


Figure 5.6: Fe and Mn concentrations in the leachate samples

Relation of leachate concentrations with initial concentrations of elements in the soil

The correlation matrix (Table 5.3) of the leachate quantities and their initial concentrations in the soil samples indicated:

(i) The soil pH has moderate positive correlation (0.72) with the pH of the soil leachate.

(ii) The soil EC has moderate positive correlation (0.69) with the EC of the soil leachate.

(iii) The initial concentration of Na in soil has moderate positive correlation (0.69) with initial concentration of Pb in soil.

(iv) The initial concentration of Na in soil has moderate positive correlation (0.78) with K of the soil leachate.

(v) The initial concentration of Na in soil has very good positive correlation (0.97) with Na of the soil leachate.

(vi) The initial concentration of K in soil has moderate positive correlation (0.77) with initial concentration of Ca in soil.

(vii) The initial concentration of K in soil has moderate positive correlation (0.67) with initial concentration of Fe in soil.

(viii) The initial concentration of Ca in soil has moderate positive correlation (0.72) with initial concentration of Pb and Fe in soil.

(ix) The initial concentration of Ca in soil has good positive correlation (0.81) with the pH of the soil leachate.

(x) The initial concentration of Ca in soil has moderate positive correlation (0.77) with the Pb leaching.

(xi) The initial concentration of Ca in soil has good positive correlation (0.84) with the Ni leaching.

(xii) The initial concentration of Ca in soil has moderate negative correlation (-0.72) with the Fe leaching.

(xiii) The initial concentration of Ca in soil has moderate negative correlation (-0.71) with the Mn leaching.

(xiv) The initial concentration of Pb in soil has moderate positive correlation (0.74) with the Na leaching.

(xv) The initial concentration of Pb in soil has moderate positive correlation (0.78) with the K leaching.

(xvi) The initial concentration of Ni in soil has moderate positive correlation (0.76) with the initial concentration of Fe in soil.

(xvii) The initial concentration of Ni in soil has moderate positive correlation (0.71) with the Ni leaching.

(xviii) The initial concentration of Fe in soil has moderate positive correlation (0.75) with the Pb leaching.

(xix) The initial concentration of Fe in soil has moderate positive correlation (0.74) with the Ni leaching.

(xx) The pH of the leachate has good positive correlation (0.84) with the Pb leaching.

(xxi) The pH of the leachate has good positive correlation (0.83) with the Ni leaching.

(xxii) The pH of the leachate has moderate negative correlation (-0.73) with the Fe leaching.

(xxiii) The pH of the leachate has moderate negative moderate correlation (-0.79) with the Mn leaching.

(xxiv) The Na leaching has moderate positive correlation (0.76) with the K leaching.

(xxv) The Pb leaching has good positive correlation (0.83) with the Ni leaching.

(xxvi) The Ni leaching has moderate negative correlation (-0.72) with the Mn leaching.

(xxvii) The Fe leaching has good positive correlation (0.83) with the Mn leaching.

Table 5.3: Correlation coefficient of all soil and leachate samples

	pH (S)	*EC(S)*	*Na (S)*	*K (S)*	*Ca (S)*	*Pb (S)*	*Ni (S)*	*Fe (S)*	*Mn (S)*	*pH(L)*	*EC(L)*	*Na (L)*	*K (L)*	*Ca (L)*	*Pb (L)*	*Ni (L)*	*Fe (L)*	*Mn (L)*
pH (S)	1.00																	
EC(S)	0.42	1.00																
Na (S)	0.12	0.02	1.00															
K (S)	0.34	0.06	0.13	1.00														
Ca (S)	0.57	0.24	0.28	**0.77**	1.00													
Pb (S)	0.37	0.16	**0.69**	0.46	**0.72**	1.00												
Ni (S)	0.23	0.33	-0.01	0.57	0.66	0.48	1.00											
Fe (S)	0.25	0.28	-0.03	**0.67**	**0.72**	0.40	**0.76**	1.00										
Mn (S)	-0.11	0.03	0.09	0.31	0.24	0.30	0.49	0.63	1.00									
pH(L)	**0.72**	0.35	0.14	0.64	**0.81**	0.51	0.50	0.65	0.16	1.00								
EC(L)	0.31	**0.69**	-0.06	0.02	0.12	0.16	0.48	0.17	0.12	0.17	1.00							
Na (L)	0.20	0.06	**0.97**	0.23	0.41	**0.74**	0.06	0.04	0.08	0.26	-0.08	1.00						
K (L)	0.40	0.06	**0.78**	0.25	0.38	0.64	0.19	0.07	0.07	0.37	0.14	**0.76**	1.00					
Ca (L)	0.49	0.26	0.49	0.40	0.68	**0.78**	0.59	0.28	0.01	0.57	0.32	0.54	0.69	1.00				
Pb (L)	0.52	0.27	0.03	0.61	**0.77**	0.43	0.58	**0.75**	0.33	**0.84**	0.12	0.14	0.18	0.41	1.00			
Ni (L)	0.62	0.37	0.12	0.62	**0.84**	0.51	**0.71**	**0.74**	0.22	**0.83**	0.33	0.20	0.37	0.63	**0.83**	1.00		
Fe (L)	-0.55	-0.35	-0.10	-0.60	**-0.72**	-0.46	-0.64	-0.65	-0.25	**-0.73**	-0.26	-0.18	-0.31	-0.54	-0.64	-0.67	1.00	
Mn (L)	-0.63	-0.35	-0.09	-0.62	**-0.71**	-0.40	-0.52	-0.59	0.02	**-0.79**	-0.23	-0.18	-0.31	-0.50	-0.63	**-0.72**	**0.83**	1.00

The two sets of samples from the experimental watershed and the Games village watershed were studied separately to see the behaviour of leaching within them.

5.3.3. LEACHING BEHAVIOUR OF SOIL OF EXPERIMENTAL WATERSHED OF IIT GUWAHATI

In Table 5.4, the leaching percentage and average leaching in experimental watershed of IIT Guwahati is presented. For the samples of the experimental watershed of IIT Guwahati, the percentage leaching is in the following order:

Na>Mn>Pb>Ni>Ca>K>Fe

The average leaching is observed in the order as follows :

Fe>Mn>Ca>Na>K>Pb>Ni

In Figure 5.7, Figure 5.8, Figure 5.9, Figure 5.10, Figure 5.11, Figure 5.12 and Figure 5.13, correlations between the actual concentration in soil and leached concentrations for Mn, Pb, Fe, Ni, Na, Ca and K are presented. There was good correlations for Mn (0.85), Pb(0.94) and Ni(0.8). Moderate correlation was observed for Fe (0.69) and Ca(0.74); whereas K(0.46) and Na(0.54) had poor correlations.

Table 5.4: Percentage leaching and average leaching in the samples of experimental watershed of IIT Guwahati

	Na	K	Ca	Pb	Ni	Fe	Mn
Range of Percentage leaching from the initial concentration in soil (%)	13-38	0.1-2	1.7-6.9	2.5-10	4.8-9.7	0-1.4	0.5-14.5
Average leaching (µgm/gm)	20	15	22	0.89	0.44	139	42

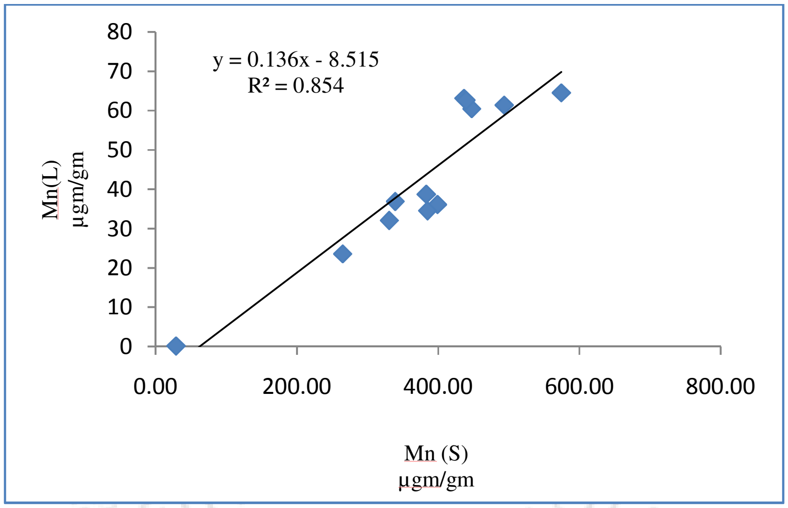


Figure 5.7: Correlation between concentration of Mn in soil (S) and leachate (L)in the samples of experimental watershed of IIT Guwahati

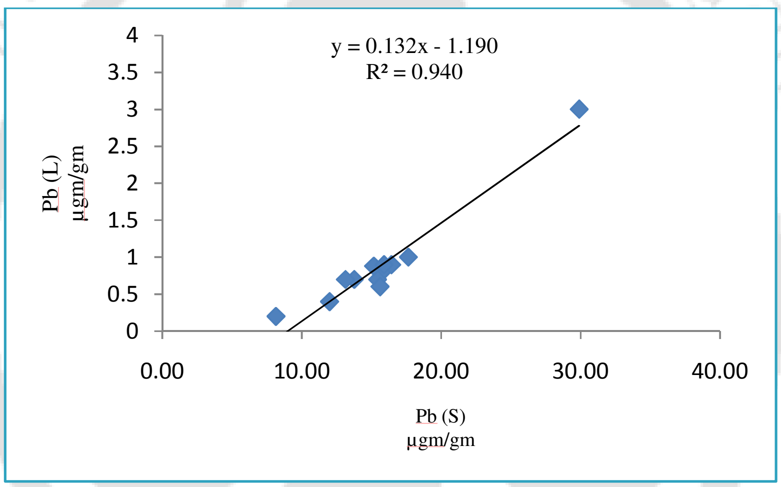


Figure 5.8: Correlation between concentration of Pb in soil (S) and leachate (L) in the samples of experimental watershed of IIT Guwahati

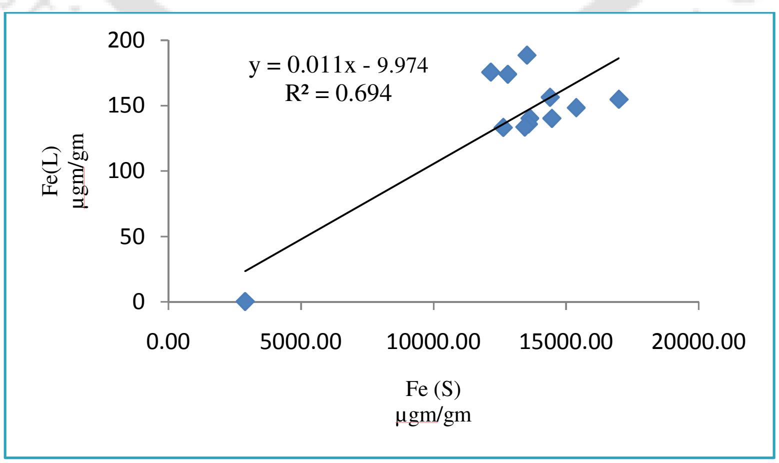


Figure 5.9: Correlation between concentration of Fe in soil (S) and leachate (L) in the samples of experimental watershed of IIT Guwahati

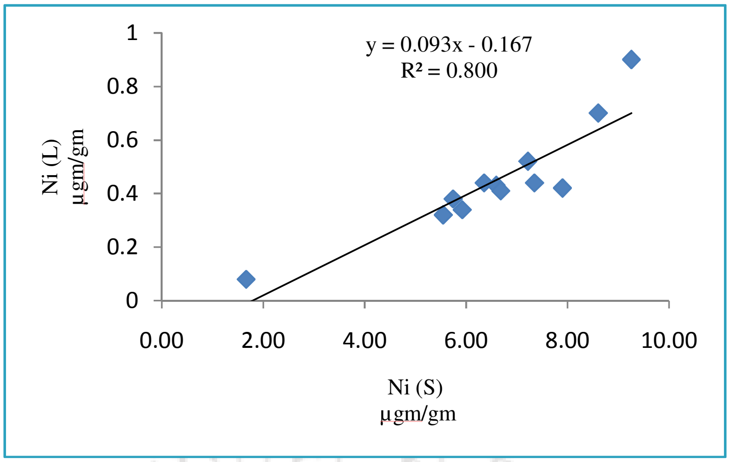


Figure 5.10: Correlation between concentration of Ni in soil (S) and leachate (L)in the samples of experimental watershed of IIT Guwahati

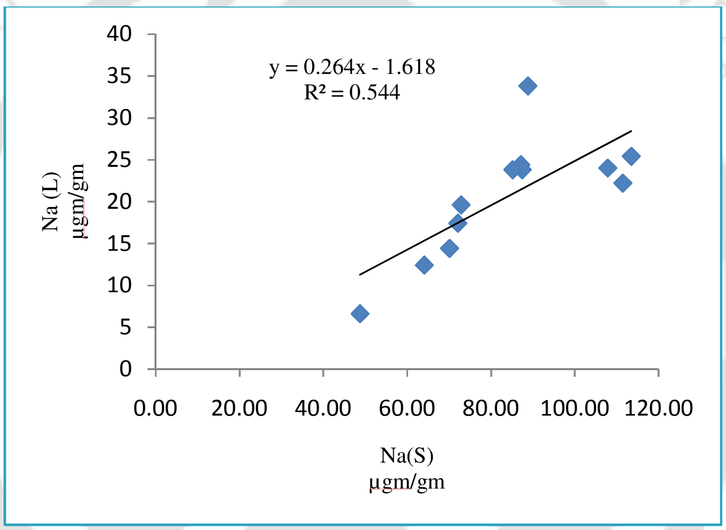


Figure 5.11: Correlation between concentration of Na in soil (S) and leachate (L) in the samples of experimental watershed of IIT Guwahati

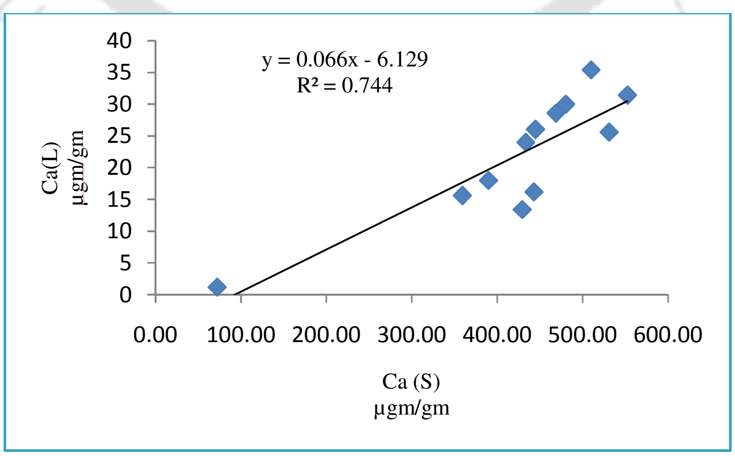


Figure 5.12: Correlation between concentration of Ca in soil (S) and leachate (L) in the samples of experimental watershed of IIT Guwahati

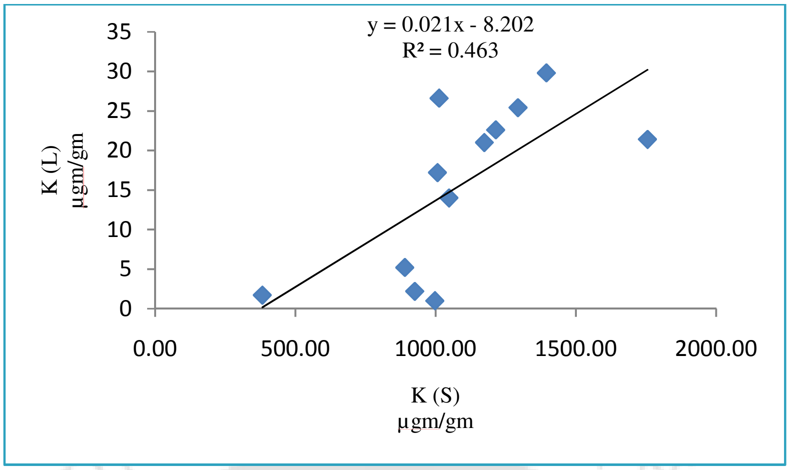


Figure 5.13: Correlation between concentration of K in soil (S) and leachate (L) in the samples of experimental watershed of IIT Guwahati

5.3.4. LEACHING BEHAVIOUR OF SOILS OF GAMES VILLAGE WATERSHED

In Table 5.5, the percentage leaching and average leaching in Games Village Watershed is presented. For the samples of this site, the percentage leaching is in the following order:

Na>Pb>Ni>Ca>K>Mn

The average leaching is observed to be in the order as follows:

Ca>Na>K>Mn>Pb>Ni

For this site, no Fe leaching was observed. Also, good correlation between the actual concentration in soil and leachate concentration was observed for Na(0.91), K (0.89)and Ca (0.86).In Figure 5.14, Figure 5.15, Figure 5.16, Figure 5.17 and Figure 5.18 correlations between the actual concentration in soil and leachate concentrations for Na, K ,Ca, Ni and Mn is presented.

Table 5.5: Percentage leaching and average leaching in the samples of Games village watershed

	Na	K	Ca	Pb	Ni	Mn	Fe
Percentage of leaching (%)	4-87%	0.35-0.89%	1.2-4.2%	6.3-7.1%	4.4-7.1%	0.01-0.03	BDL
Average leaching (µgm/gm)	26	21	73	3	1.4	5	BDL

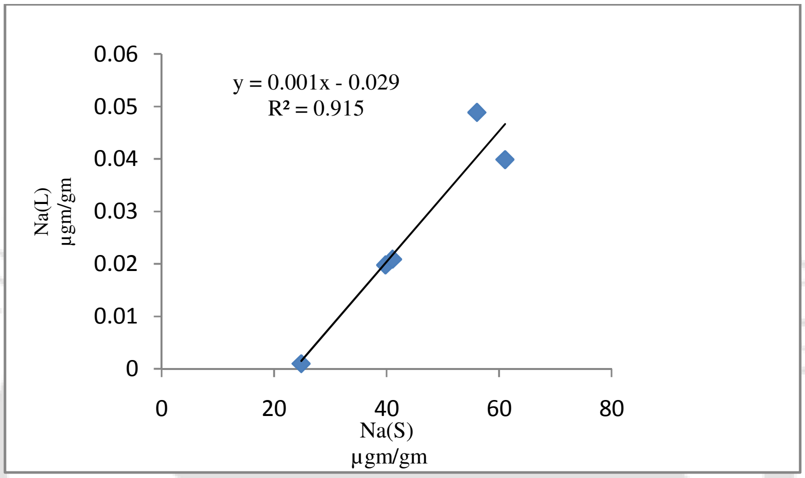


Figure 5.14: Correlation between concentration of Na in soil (S) and leachate (L) in the samples of Games village watershed

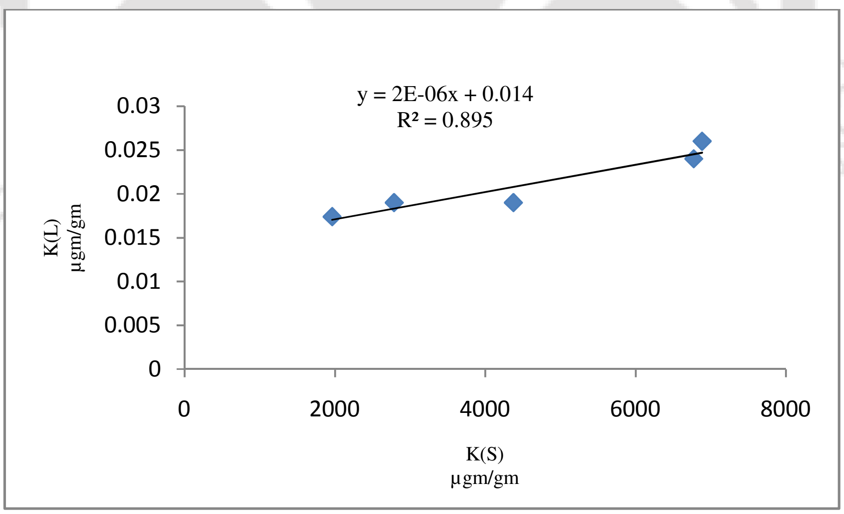


Figure 5.15: Correlation between concentration of K in soil (S) and leachate (L) in the samples of Games village watershed

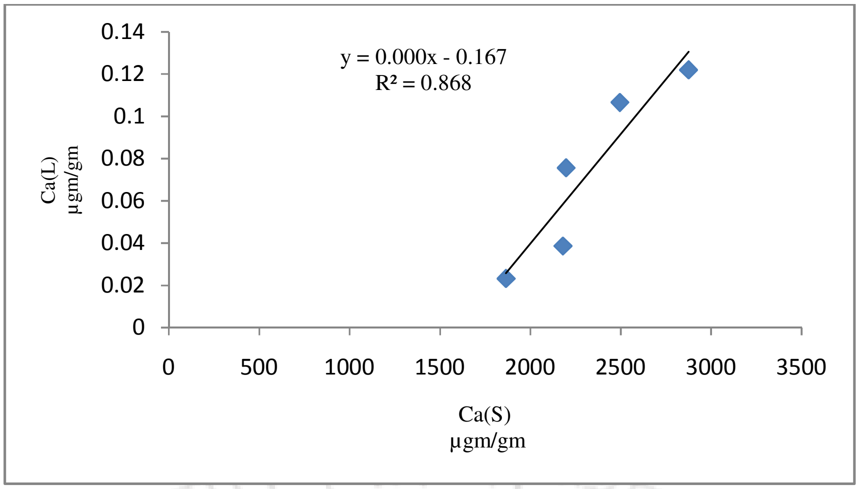


Figure 5.16: Correlation between concentration of Ca in soil (S) and leachate (L) in the samples of Games village watershed

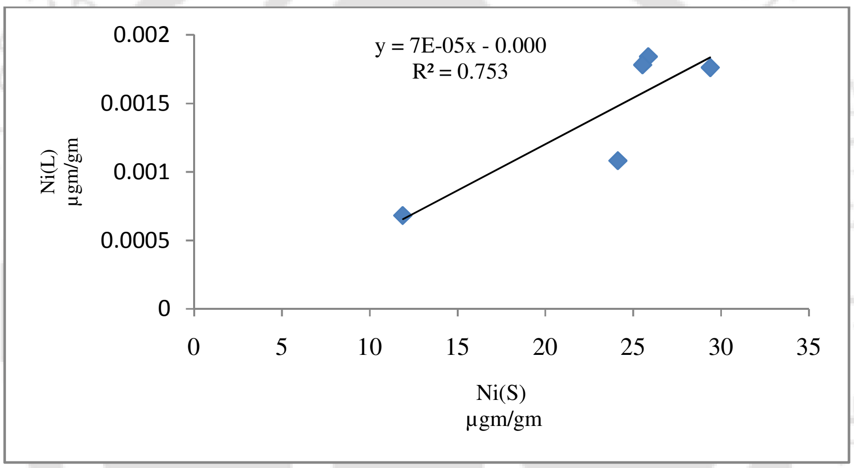


Figure 5.17: Correlation between concentration of Ni in soil (S) and leachate (L) in the samples of Games village watershed

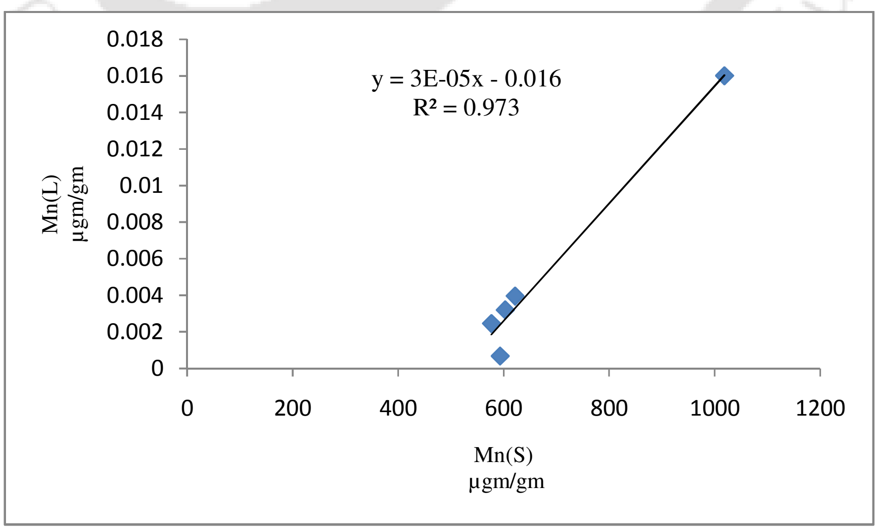


Figure 5.18: Correlation between concentration of Mn in soil (S) and leachate (L) in the samples of Games village watershed

5.3.5. LEACHING BEHAVIOUR OF BED SEDIMENTS

To have an idea about the leaching behaviour of the bed sediment of urban rivers, samples from 4 sites (sample code B1-B4) were collected, of which 2 sites were moderately polluted (sample code B1-B2), one was unpolluted (Sample code B3) and one was highly polluted (sample code B4). Leaching from bed sediment was similar to that of surface sediment. However, the leaching behaviour varied from site to site. The concentration of leachates and their initial concentrations for Na, K, Ca, Pb, Ni, Fe and Mn are presented in Figure 5.19, Figure 5.20 Figure 5.21, Figure 5.22, Figure 5.23, Figure 5.24 and Figure 5.25. The samples containing higher Na concentration also had higher leaching concentration. The K leaching was significantly low, except for the sample from the highly polluted sites i.e .at Bharalu River at Bharalumukh (sample code B4). The Ca leaching was also not significant, except for the sample from the Bharalu river bed sediment at Bharalumukh (sample code B4) and Basistha river bed sediment at Kotabnari, Lokhra (sample code B1). The leaching concentrations of Pb and Ni were almost similar in all the samples and their initial coenceatrion did not seem to affect their leaching. However, Fe and Mn did not follow any trend in their leaching behaviour.

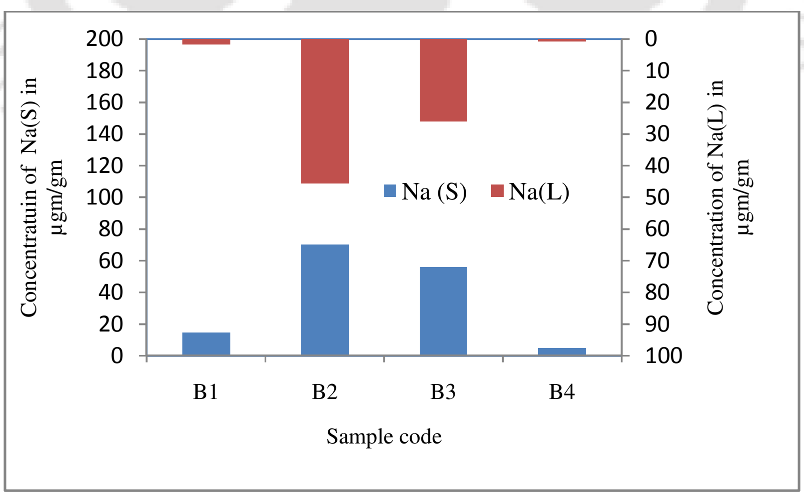


Figure 5.19: Na concentration in the bed sediment and leachate samples

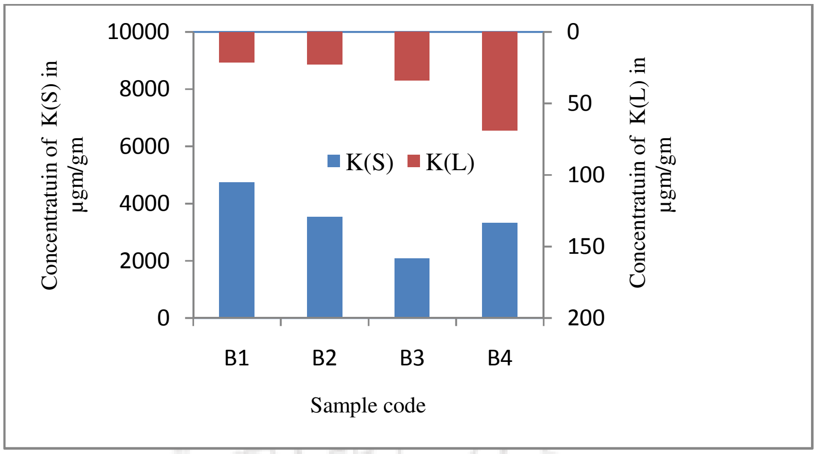


Figure 5.20: K concentration in the bed sediment and leachate samples

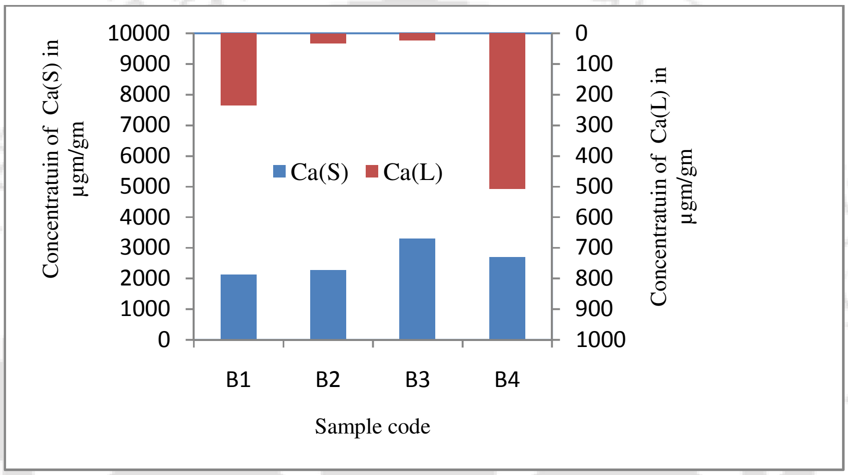


Figure 5.21: Ca concentration in the bed sediment and leachate samples

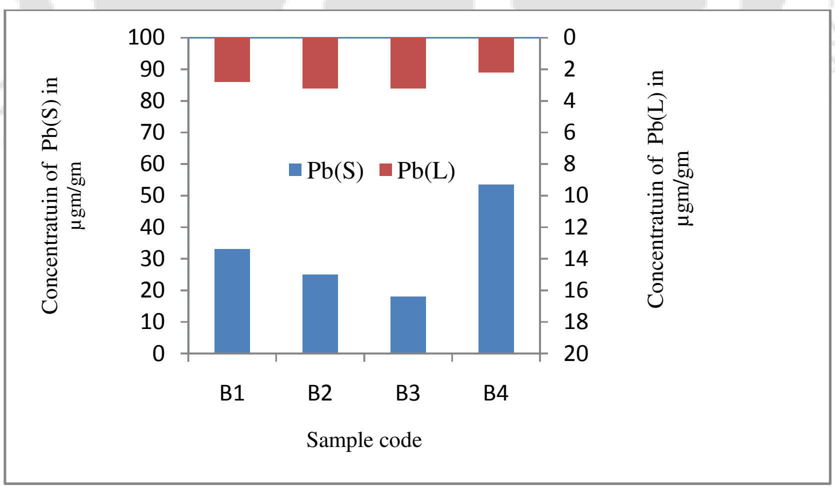


Figure 5.22: Pb concentration in the bed sediment and leachate samples

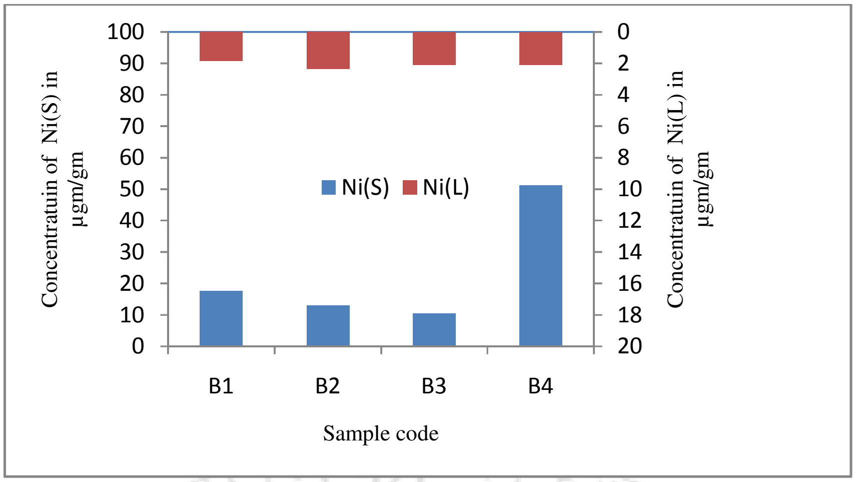


Figure 5.23: Ni concentration in the bed sediment and leachate samples

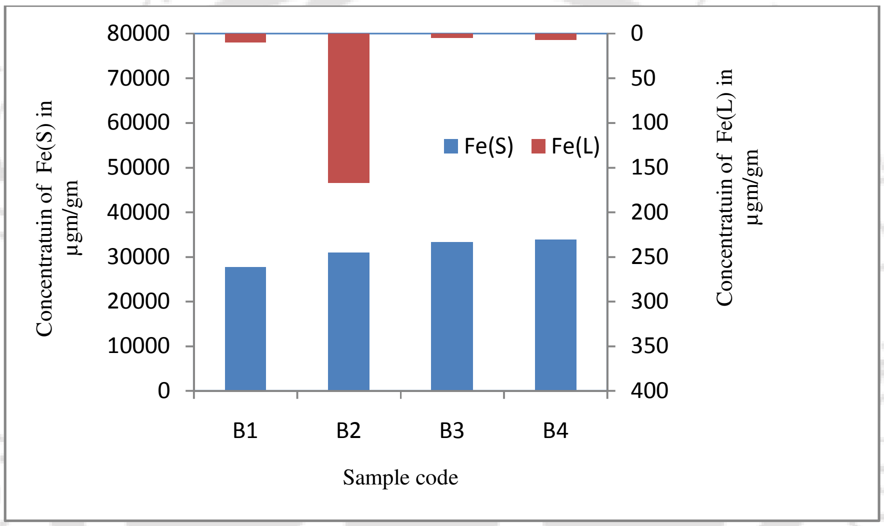


Figure 5.24: Fe concentration in the bed sediment and leachate samples

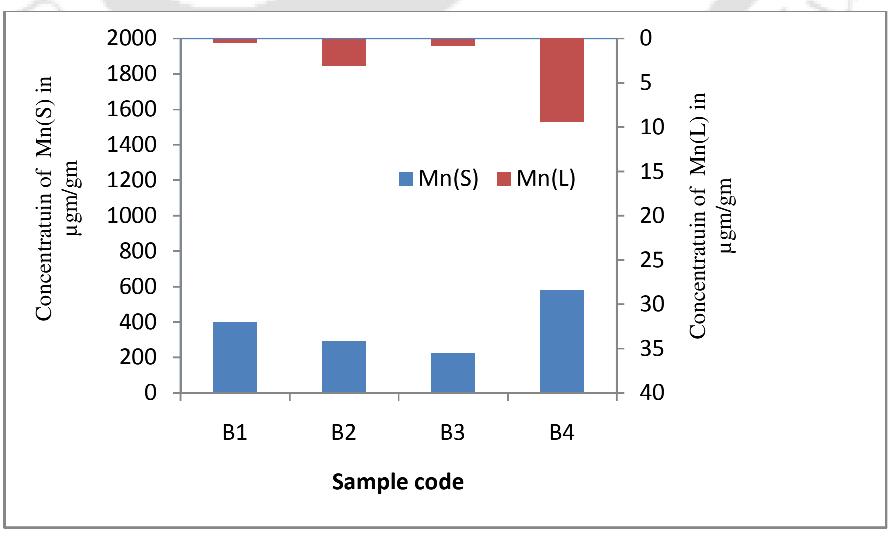


Figure 5.25: Mn concentration in the bed sediment and leachate samples

5.4. QUANTIFYING THE IMPACT OF SOIL LEACHING ON WATER QUALITY

Soil erosion from the studied watershed area delivers significant amount of sediment to the downstream water bodies. Sediments are the source of substrate nutrients, and micro- and macro flora and fauna that are the basic need for the living aquatic resources. However, the current excess sediment yield creates lots of detrimental effect for the receiving water body.

Natural sediments are the source of dissolved minerals to the water bodies and govern the water quality dynamics in the water column. Sediments are also the site for growth and survival of aquatic flora and fauna, which in turn interferes with the water quality. However, when sediment gain in a water body becomes too high beyond the desirable limit, it releases dissolved nutrients and pollutants in excess amount. This over nourishment condition is often detrimental to the water body, because it may lead to conditions like eutrophication. Contaminated sediments from anthropogenic sources often become undesirable for a water body due to their addition of toxic ionic species into the receiving water (Jain and Ram., 1997, Butler, 2009). Sediment, itself a pollutant, is also a carrier and sink for other pollutants like nitrate, phosphate and faecal bacteria (Jain et al., 1997; Crabil et al., 1999; Bai et al. ,2005; Stutter et al. ,2008; Butler 2009). Sediment particles reduce transparency of a water body and increase turbidity. This in turn may impair the Dissolved Oxygen (DO) level in water, which is harmful for the aquatic community. Besides, sediment particles provide sorption sites for other pollutants like nitrate, phosphate, heavy metals and faecal bacteria (Lau et al., 1999; Mayer et al., 1999; Jamieson et al., 2005). Thus soil erosion from watershed areas and their subsequent deposition into the water bodies have range of implications to surface water quality.

Sediment loss occurs due to natural and anthropogenic soil erosion. The natural soil erosion process is on equilibrium with the natural soil regeneration process for a well vegetated area. However, anthropogenic activities like clearing of vegetation, cutting of slope etc make the process of soil erosion much faster and thus sediment loss occurs at a very high rate. This accelerated rate of soil loss could not keep a balance with the natural soil regeneration process and thus balance between loss and generation is interrupted. This creates a deficit for the soil environment of a watershed and this affects the other activities of the watershed like vegetation growth, slope stability, water flow, basin morphology and stream characteristics.

The soil particles are associated with nutrients and organic matter that are required to support vegetative growth in a watershed. The process of soil erosion leads to a very high yield of sediment for a watershed and thus sediment transfer due to soil erosion also made deficit of essential nutrients required for a watershed. When soil erosion occurs in a watershed, sediment particles ultimately find their ways into the water bodies. Some parts of these sediments are deposited on the bed of the water bodies and some remain in suspension throughout the water column. These sediments release its exchangeable ionic species to the water through the process of leaching unless the saturation limit of the water is reached.

Some of the physical effects of sediment on water bodies are:

(i) Rising of the bed level of water bodies

(i) Increased turbidity of water

(ii) Changing of the morphology

(iii) Reduction in the water carrying capacity

(iv) Effect on the flow dynamics

The chemical effects of sediment on water bodies:

(ii) Providing nutrients through the process of leaching

(iii) Reduction in Dissolved Oxygen

(iv) Adsorption/release of pollutants from/to water

The biological effects of sediment on water bodies:

(i) Carries micro- and macroflora and fauna to the water bodies that are the basic need for the living aquatic resources

(ii) Provides site for growth of microorganisms

(iii) Interferes with survival faecal bacteria

Also, some impacts observed due to sediment loss by watersheds are:

(i) Changes the basin morphology

(ii) Changes the vegetation growth

(iii) Induces slope instability

(iv) Changes the water flow direction and quantity

(v) Changes the stream characteristics

(vi) Induces loss of fertile top soil

(vii) Induces loss of soil micro flora and fauna

The desirable maximum limit of sediment yield from a watershed is the limit beyond which the soil erosion creates undesirable impact on slope stability, basin morphology, stream characteristics and soil fertility.

The desirable minimum limit of sediment yield from a watershed can be taken as the natural rate of soil erosion which is in equilibrium with the natural soil regeneration process, when the watershed is under ideal vegetative cover with existence of all three levels of canopy covers and in fully undisturbed state.

The desirable maximum limit of sediment gain by a water body is the limit beyond which there is undesirable impact on morphology, aquatic habitat and water chemistry of the water body.

The desirable minimum limit of sediment gain by a water body is the limit which is required by the water body to maintain the natural morphology, water quality dynamics and aquatic habitat.

Qualitative threshold of nutrient loss therefore should be such that the soil erosion must not reduce the fertile condition of the watershed that is required for the normal vegetation growth.

Quantitative threshold of nutrient loss therefore should be such that the soil erosion must not create slope instability and should not create any undesirable change of the basin morphology.

The equilibrium between sediment loss by a watershed and gain by a receiving water body is the limit at which the rate of soil erosion from the watershed can maintain the normal function of the watershed in a sustainable manner. The released sediment from the watershed should not create any undesirable impact on the downstream water body in terms of physical, chemical and biological characteristics of the water body.

5.4.1. ESTIMATION OF NUTRIENTS AND METAL FLUX FROM A SMALL PART OF THE GAMES VILLAGE WATERSHED

With the understanding of the leaching behaviour of soil from the Games village watershed, the amount of nutrients and metal loss from a small part of Games village watershed has been estimated. The study area covered an area of about 0.17 km^2 and the RUSLE model was applied to determine the annual soil loss from the area in natural as well as disturbed conditions (Table 5.6). The average ionic concentration of various nutrients and metals as obtained in the soil of the Games village watershed, the amount of annual nutrient/ metal loss from the area that goes as sediment loss was computed (Table 5.7). Then by taking the average value of leaching concentration, the loss of leachable amount from the area in a year was computed. The value clearly showed that a significant amount of nutrient and metal loss occurs annually (Table 5.8).

Table 5.6: Determination of annual soil loss using RUSLE in a small part of the Games village watershed

Area	Sediment yield in natural condition	Sediment yield in disturbed condition
0.17 km^2	2116970 kg	9738063 kg

Table 5.7: Computed nutrient/ metal loss from the area

Computed Nutrient/ metal loss	Na	K	Ca	Pb	Ni	Fe	Mn
Natural (kg)	94	9647	4916	81	49	80778	1445
Disturbed (kg)	434	44377	22615	371	228	371577	6647

Table 5.8: Loss of leachable amount from the area

Loss of leachable amount	Na	K	Ca	Pb	Ni	Mn
Natural (kg)	55	45	155	5	3	11
Disturbed (kg)	254	205	713	25	14	51

5.4.2. SETTING UP THE LIMIT FOR MINIMUM SEDIMENT YIELD REQUIRED BY WATER BODIES

As soil and sediments contribute essential dissolved ion to water through the process of leaching, total curtailment of sediment from a watershed area to its out let may make the downstream water body under nourished, which will unable to support the downstream aquatic ecosystems. Therefore, with the understanding of leaching study presented in this chapter, a procedure for determining the minimum required sediment yield from a watershed to maintain required water quality level at downstream has been presented.

As of now, no definite guidelines regarding minimum requirement of dissolved ions in water bodies was found to be recommended in the literature. Therefore, to establish a procedure for the study area, 5% of the desirable upper limits of respective constituents have been considered as required limit of dissolved load in water to sustain the aquatic ecosystem. This value has been assumed just to develop a procedure and therefore, should not be considered as a suggested guideline. The primary purpose of considering a minimum limit is to highlight the need of determining such a minimum required value.

Let us consider a watershed as shown in the Figure 5.26. If $(Xr)_i$ mg/L is the concentration of a particular water quality parameter (WQ_i) required as per region specific water quality guideline at the watershed outlet, which is connected with a higher order stream. Let $(X_{up})_i$ mg/L is the concentration of WQ_i that is coming from upstream of S.

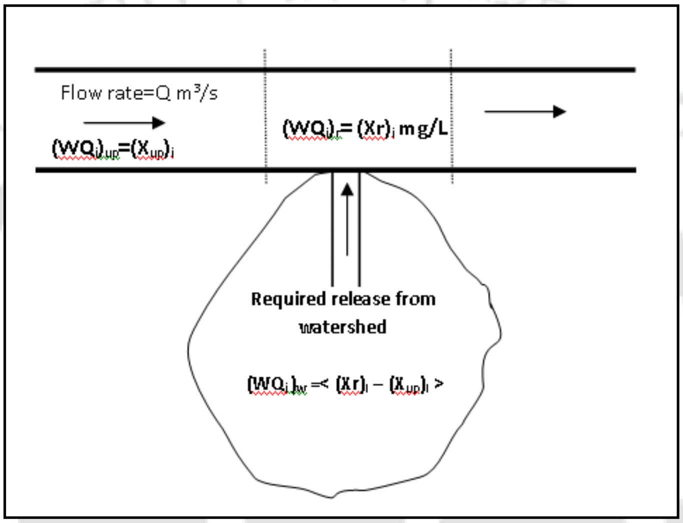


Figure 5.26: Diagrammatic representation of minimum sediment yield requirement form watershed

If X_i- $(X_{up})_i \leq 0$, for all i, then there is no requirement of WQ_i from the watershed. Thus sediment release required is also nil.

If for some i;

X_i- $(X_{up})_i \geq 0$, then there is requirement of WQ_i from the watershed.

Say X_i- $(X_{up})_i = y_i$ (mg/L)

Now, if Q m^3/s is the average flow rate at the watershed outlet.

Then the total volume of water at the watershed outlet in a year can be determined as follows:

V= Q x 365 x 60 x60 (L)

Now , if y mg/L is the required concentration of WQ_i in the watershed outlet, then total mass of the WQ_i annually required is $Z_i=V . y$ (mg)

If 1 mg of sediment can contribute r mg of WQ_i (this can be obtained from the leaching study), then sediment release requirement is

S = r x Z (mg), subject to the condition that $(X_{up})_i + Z_i \leq (X_{permissible})_i$, for all i.

If $(X_{up})_i + Z_i \geq (X_{permissible})_i$, then adjust sediment yield by compromising with the minimum desired limit and maintaining the maximum permissible limit.

5.4.3. ESTIMATION OF THE MINIMUM REQUIRED SEDIMENT YIELD FROM THE GAMES VILLAGE WATERSHED

In a water body, there should be always some need of dissolved ions for the growth and survival of aquatic ecosystem. As rainwater has very low ionic concentration, soil and sediment generally contribute the required additional ionic load through the process of leaching. Therefore, full curtailment of sediment from watershed may not be always advisable for the benefit of the downstream aquatic ecosystem.

The minimum sediment requirement for a small watershed of area 0.17 km^2, located at the Games village area of Guwahati, was estimated by following the procedure mentioned in section 5.3.8. For this, a water quality analysis was carried out at Basistha River, which is at 100 m upstream of the confluence of this watershed. The results obtained are presented below in Table 5.9.

Table 5.9: Water quality of Basistha River at Basistha Mandir, Guwahati
(100 m upstream of the confluence of the study watershed)

Parameters	pH	TDS (mg/L)	Cl (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	SO_4 (mg/L)	K (mg/L)
Measured value	7.8	40	0.2	7.2	3.6	5.3	11	7.1
Norms (maximum desirable limit)	6.5-8.5 (BIS)	500 (BIS)	250 (BIS)	75 (BIS)	30 (BIS)	100 (WHO)	150 (BIS)	10 (WHO)
Required limit (considering 5% of the desirable limit)	-	25	12.5	3.75	1.5	5	7.5	0.5

BIS: Bureau of Indian Standard specification, WHO: World Health Organization guidelines

The water quality data have shown that the all studied water quality parameters are within the required limits and there is no deficit or requirement of any additional dissolved loads at the downstream of the studied watershed. As such, there is no requirement of sediment release from the studied watershed.

5.5. CONCLUSIONS

The study of leaching behavior of different soil types has indicated that the leaching of dissolve nutrients and trace metals varies with site condition and background condition as well as level of saturation. For example, the leaching of Na, K and Ca is higher for the soil samples from the urban areas representing comparatively polluted sites than the samples that are from the hilly watershed areas i.e. in Games village watershed and the experimental watershed of IIT Guwahati. The leaching of Pb and Ni were more in the soil samples from the urban areas compared to those of the samples from the hilly watershed areas. Similarly, the leaching of Fe and Mn was found to be higher for the soil samples of the experimental watershed of IIT Guwahati, which is a site covered with natural vegetation. Thus, it is difficult to suggest a generalised leaching behaviour for these soils. Overall analysis of all the samples from the 11 sites has revealed that the soil samples with high initial concentration of ions also leach out more ions. Though a more or less linear trend was observed between the ions present in soil and their subsequent amount of leaching, this may not be always true for all ions and all samples. For samples of experimental watershed of IIT Guwahati, Mn, Pb, Ni and Ca have shown good correlation between their initial concentration in soil and the amounts of leaching. On the other hand, for samples of Games village watershed Na, K, Ni and Mn have shown good correlation between their initial concentration in soil and amount of leaching, while Fe leaching was not detected. In the study of bed sediment leaching, the sample from the polluted sites showed higher leaching of K, Ca and Mn.

The results of determination of the major cations and trace metals in soil and their amount of leaching into water is used to estimate the annual loss of nutrients and trace metals that occurs due to soil erosion from the area. The area of the study watershed is a small part of Games village watershed, with an area of 0.17 km^2. As obtained from RUSLE model, yearly soil loss is 2116970 kg (natural condition) and 9738063 kg (disturbed condition with residential development). Surface soil samples collected from this site were studied for their ionic content and leaching behaviour. Using these results, for the two scenarios -natural and disturbed, the computed nutrient and metal loss along with the leachable amount present in the soil were estimated and it was observed that watershed area loses significant amount of nutrients and trace metals annually and fraction of it can go to water as dissolved ion.

A process of determining the minimum sediment yield required from a watershed has been suggested by using the trend of soil leaching behaviour. The described method considers the role of soil and sediment in contributing dissolved load into a water body. Incorporation of the role of soil and sediment in absorbing and adsorbing pollutants from water will enhance the understanding for determination of minimum requirement of sediment yield from a watershed.

Chapter 6

OPTIMAL ECOLOGICAL MANAGEMENT PRACTICES (EMPs)

6.1. INTRODUCTION

This chapter contains development of optimization model for obtaining optimal EMP combination for an area at minimum cost for restricting the sediment and water yield from the area within a desirable limit. The optimization problem was formulated for two different scenarios- (i) Small watershed having a plot with single ownership and (ii) A relatively large watershed having several plots with multiple ownership. Results obtained by applying these models to a micro watershed of Guwahati city, Assam, are presented in this chapter. The sensitivity analysis carried out for some important model parameters for the study watershed is also presented in this chapter. Sustainability aspect of such EMP based landuse planning project are investigated critically and scope of taking advantage of carbon sequestration potential of EMPs to make it sustainable by earning financial benefit in terms of carbon credit has also been analyzed using an multiobjective optimization model for maximizing carbon sequestration and presented towards end of this chapter.

6.2. SCOPE OF APPLYING EMPs AND OPTIMIZING EMP COMBINATION

Release and transport of nonpoint source pollutants from the catchment can be controlled to a great extent in a sustainable way through land management practices. While emphasis is increasing on structural measures, like pond, retaining wall, etc non structural measures can also be used for controlling non point source pollutants and water yield. A judicious combination of structural and non structural measures can provide a sustainable solution to the problems that arise due to increase release of runoff and non point source pollutants from the upper catchment.

Based on this idea, the concept of Ecological Management Practices (EMPs) has been developed, which can be defined as eco friendly sustainable management practices used for maintaining and enhancing land-uses in a natural way. In other words, EMPs are basically sustainable measures that consist of combination of different structural and non structural land management practices adopted for controlling runoff volume and yield of sediments and other pollutants from an area and transport of the same by the runoff.

EMPs like contour terracing, mulching, grass, shrubs, detention/retention pond, buffer zone with vegetation and tree, sediment trap, rainwater harvesting systems and vegetated waterways are commonly used for controlling sediment yield and runoff volume from land surface. One of the natural land covers, wetlands and swamps were observed to be a good non point pollutant trap (Robb, 1992; Smith, 2001). Knowing the effectiveness of wetlands to control non point source pollution, construction of wetlands as a pollution control measure was also suggested by Wang et al., (2006) and Moreno et al., (2007). Besides, some studies have also reported effectiveness of detention pond in controlling non point pollution like sediment and nutrient. Hsieh and Yang (2007) used optimization method and an annual average reservoir water quality model to develop optimal Best Management Practice (BMP) strategy for controlling non point pollution in the Fei-Tsui Reservoir watershed; they suggest installation of several detention ponds in the watershed to attain oligotrophic conditions in the reservoir. The riparian buffer zones with grass and forest were also reported to be effective in controlling non point source pollution in some of the recent studies by Anbumozhi et al. (2005), Shiono et al. (2007) Maillard and Santos (2008) and Parajuli et al. (2008). Besides the traditional practices, some new ideas on landuse management practices like wood filters (Boving and Neary, 2007) and biofilter (Hatt et al., 2009) for controlling non point pollution have also immerged in recent years

Suitable EMPs for urban areas

While many investigators have reported successful application of land management practices for controlling non point source pollution, study towards application of such practices in urban sector is limited. So far, there is no well established EMP recognized as suitable for urban residential developments. However, various traditional land management practices as described in the previous section are available for controlling sediment yield and runoff volume from agricultural areas. These practices, if suitably modified considering the necessity of an urban area, can also be used for land management of urban residential areas. Some of possible EMPs for urban residential areas are suggested below:

(i) Grass land: Grass reduces the velocity of surface runoff, minimizes the impact of rain on soil, and its root system helps in increasing infiltration. In urban area, grass land can also serve as open land that is needed according to the municipal rules.

(ii) Forest land: Tree canopy reduce the direct impact of rain on soil. Besides, forest land, covered with falling leaves, also reduces the surface runoff velocity and increases infiltration. Falling leaves and decaying branches act as mulches and thus tree cover can control sediment yield and runoff volume.

(iii) Covering rain impacted areas with pebble, vegetation or wood chips: Erosive power of rain drop depends on size of rain drop and its falling height. Size of rain drop that falls from inclined roof of a house become quite large and thus strikes the ground with very high erosive power. Thus, the portion of ground lying below the line of the roof edges is prone to more erosion as the accumulated rain over the roof falls with a high velocity and with larger drop size. Such drop line areas of water around the house can be covered with pebble or wood chips or erosion resisting vegetation can be allowed to grow, which protect the soil from the direct impact of rain drop and also allow more infiltration.

(iv) Detention drain and Retention pond: To capture the excess surface runoff, detention drains can be constructed across the slope and retention ponds can be constructed in a suitable location. This can minimize downstream erosion and flooding.

(v) Vegetated waterways: If the paths (or channels) of accumulated surface runoff are covered with vegetations, then the vegetation provide an obstruction to the flowing water. It reduces velocity and hence the erosive power of the flowing water. This reduces erosion of channel bed and bank and prevents gully formation. Root systems of a vegetated waterway not only increase bondage of soil and make it resistant to water erosion, but also promote infiltration. Depending on the status of degradation of the waterway, different types of vegetation can be suggested.

(vi) Rainwater harvesting system: Rainwater harvesting is a technique of collection and storage of rain water in surface (storage tanks) or sub surface aquifer before it is lost as surface runoff. Rainwater harvesting system helps in reducing the peak runoff and also recharges ground water. The collected rainwater through the rainwater harvesting system can also be used during the period of water shortage.

6.3. CONCEPT OF OPTIMAL EMPS FOR CONTROLLING SEDIMENT AND WATER YIELD FROM HILLY URBAN AREAS

Scope of using optimization technique for landuse planning for achieving sustainable solutions to wide range of environmental problems has drawn attention of researchers in recent years (Seppelt and Voinov,2002; Wang and Huang. 2004; Gabriel et al. ,2006; Holzkamper et al.,2007; Riveira et al. 2008; Lin et al. 2009). In case of urban development in hilly terrain, soil erosion is the major cause of hazard like flood, water quality degradation and slope instability. In this study, allocation of EMPs at minimum possible cost for managing sediment and water yield from hilly urban watershed is done through a watershed based optimization models. Keeping in mind various socioeconomic issues that may arise due to different ownership of different plots, optimization model has been developed for following two different situations:

Case A: This represents residential development in a watershed, where the entire watershed is under single ownership and spatial location of EMPs within the watershed is not an issue provided total capital and maintenance cost of EMPs for the entire plot remains minimum. In this situation the entire watershed can be considered as a single plot. The optimization problem for this purpose has been formulated as a LPP model to limit sediment and water yield from the plot to a desired level at minimum cost. This model is named as OPTEMP-LS (**OPT**imal **EMP** model with **L**inear programming for a watershed having **S**ingle ownership)

Case B: This approach can be applied to a relatively large watershed, where there may be several plots in sequence from upstream to downstream under different ownership. Two kinds of models as described in B1 and B2 have been developed for this purpose.

B1. A LPP model that consider different EMPs in different plots as separate variables and allocation is done with constraints for their upper limit, lower limit etc with respect to their respective plots while limiting the sediment and water yield at the outlet of the entire watershed. This model is called as OPTEMP-LM (**OPT**imal **EMP** model with **L**inear programming for a watershed having **M**ultiple ownership)

B2. In this approach the problem is formulated as a DP model by considering each plot from upstream to downstream to represent stages of DP. Optimal EMP combination and respective optimal cost for different discrete sediment yield for each of the plot is first determined by applying the OPTEMP-LS model. Then the optimal EMP combinations obtained from different discrete sediment yield are used as input for the recursive equation of the DP model. This model basically determines the sediment release combination for different plots, which minimizes the cost subject to the other constraints and thus indirectly gives the best EMP combination for the entire plot. This model is called as OPTEMP-LDM (**OPT**imal **EMP** model with **L**inear and **D**ynamic programming for a watershed having **M**ultiple ownership)

Details of these models and their performance are presented in the following sections.

6.4. MODEL FORMULATION

6.4.1. MODEL FORMULATION FOR A WATERSHED WITH SINGLE OWNERSHIP: OPTEMP-LS MODEL

The objective is to minimize the total EMP cost for controlling annual sediment yield and peak discharge from a plot. The constraints are as follows:

(i) Sediment yield restriction: Annual sediment yield from a plot after installation of EMPs should be greater than or equal to the required minimum sediment yield and less than or equal to the maximum allowable sediment yield. This constraint ensures that sediment yield remain within a permissible upper and lower bound value. Sediments may also have some vital role like contributing essential ions to water and absorbing pollutants from water, which help in maintaining ecosystem. Therefore these services require a minimum amount of sediment yield. On the other hand, higher sediment yield causes several problems such as removal of fertile soil, clogging of drains and reduction of carrying capacity of drains. To avoid such problem, allowable sediment yield should be kept lower than a permissible limit. In this study, the constraint of sediment yield is addressed by using the Revised Universal Soil Loss Equation (RUSLE).

(ii) Peak discharge restriction: The water yield from the plot should not exceed the maximum and minimum allowable limit for peak discharge from the plot after implementation of EMPs. In absence of other acceptable criteria, the minimum required amount of peak flow is set as the value of peak discharge from the area with natural land cover condition. The maximum value is set considering the maximum flow carrying capacity of the downstream channels. In this study, the constraint of desirable peak discharge is addressed by using the Rational method.

(iii) EMP area suitability constraints: Area of an EMP in a plot cannot exceed the suitable area available in that plot for that EMP. Also, an EMP is allowed only when suitable area available for the EMP in that plot is greater than a minimum feasible area required for implementation of that particular EMP.

(iv) Maximum area available for EMPs: No EMP is allowed within the coverage area of the plot, as this area will be used for construction of houses.

(v) Owner's choice for EMPs: The owner of the plot may have choice for some EMPs and no choice for some other. The EMP area should not go beyond the maximum and minimum area for that particular EMP according to owner's choice.

Mathematical formulation

The problem stated above can be written as,

Objective function

$$\text{Minimize} Z = \sum_{i=1}^{n} (Cc_i + Cm_i) a_i \tag{6.1}$$

Constraints:

Sediment yield constraints

$$S_{min} \leq RK(LS) \left\{ \sum_{i=1}^{n} c_i a_i + \sum_{j=1}^{m} (A_j - \sum_{i=1}^{n} a_i) c_j + CcAc \right\} P \leq S_{max} \tag{6.2}$$

Peak discharge constraints

$$Q_{min} \leq \left[\left\{ \sum_{i=1}^{n} RC_i a_i + \left(\sum_{j=1}^{m} A_j - \sum_{i=1}^{n} a_i\right) Rc_j + (RcAc) \right\} \div A \right] IA \leq Q_{max} \quad (6.3)$$

Available EMP area constraints

$$\sum_{i=1}^{n} a_i \leq AL = A - AC_{max} \quad (6.4)$$

Suitable EMP area constraints

$$a_i \leq as_i \quad (6.5)$$

Owner choice constraints

$$(a_{max})_i \geq a_i \geq (a_{min})_i \quad (6.6)$$

Non negativity constraints

$$a_i \geq 0 \quad (6.7)$$

where,

i= 1,2,……n, where, n is number of possible EMPs that are considered for the study

j= 1,2,……m, where m is the number of different landcover in the plot except the EMPs and coverage area

$(Cc)_i$ = Capital cost of the i^{th} EMP (₹)

$(Cm)_i$ = Maintenance cost of the i^{th} EMP (₹)

a_i = Area of the i^{th} EMP in the plot (m^2)

S_{min} = Minimum sediment yield required from the plot (tonnes/yr)

S_{max} = Maximum sediment yield allowed from the plot (tonnes/yr)

A=Area of the plot (m^2)

R = Rainfall and runoff erosivity index of the plot (100 ft·tonf·in/acre/hr/yr)

K = Soil erodibility factor of the plot (tonnes/acre per unit of R),

LS = LS factor of the plot (dimensionless)

C_i = cover factor for the i^{th} EMP in the plot (dimensionless)

A_j = Area of the j^{th} land cover in the plot (m^2)

C_j= Cover factor for the j^{th} land cover in the plot (dimensionless)

Q_{max} = Maximum allowable peak rate of runoff from the plot (cumec)

Q_{min} = Minimum allowable peak rate of runoff at downstream from the plot, (cumec)

RC_i = Runoff coefficient for the i^{th} EMP in the plot (dimensionless)

RC_j= Runoff coefficient for the j^{th} landcover in the plot (dimensionless)

Rc = Runoff coefficient of the coverage area (dimensionless)

Ac= Coverage area of the plot (m^2)

I = Maximum intensity of rainfall for the time of concentration of the selected design storm for the plot (mm/hr)

$(as)_i$= Suitable area available for i^{th} EMP in the plot (m^2)

$(a_{min})_i$ = Minimum area required for i^{th} EMP (m^2)

AL= Total available EMP area in the plot (m^2)

C_{max} = Maximum coverage allowed in the plot (m^2)

$(a_{min})_i$ is the minimum area kept for i^{th} EMP in the plot according to owner's choice (m^2)

$(a_{max})_i$ is the maximum area kept for i^{th} EMP in the plot according to owner's choice (m^2)

6.4.2. MODEL FORMULATION FOR LARGE WATERSHED WITH DIFFERENT OWNERSHIP

Two kinds of models have been investigated in this section. One is the LPP approach, called the OPTEMP-LM model for the entire watershed but having different plots and other one is the DP, called the OPTEMP-LDM model with input from individual stage from the OPTEMP-LS model.

(a) OPTEMP-LM Model

Mathematical formulation

Objective function: Minimization of construction and maintenance cost for the EMPs in p number of plots

$$\text{Minimize} Z = \sum_{k=1}^{p} \sum_{i=1}^{n} (Cc_{ik} + Cm_{ik}) a_{ik} \quad (6.8)$$

Where,

i= 1,2,……n, where, n is number of possible EMPs that can be applied

k=1,2,3….p, p is the number of plots in the watershed

Cc_{ik} = Capital cost of the i^{th} EMP in the k^{th} plot (₹)

Cm_{ik} = Maintenance cost of the i^{th} EMP in the k^{th} plot (₹)

Constraints:

Sediment yield constraints:

$$St_{min} \le \sum_{k=1}^{p} [R_K K_K (LS)_k \{ \sum_{i=1}^{n} c_{ik} a_{ik} + \sum_{j=1}^{m} (A_{j_k} - \sum_{i=1}^{n} a_{i_k}) c_{ik} + Cc_k Ac_k \} P_k] \le St_{max} \quad (6.9)$$

Peak discharge constraints:

$$Q_{k\,min} \le [\{ \sum_{i=1}^{n} R_k C_{ik} a_{ik} + (\sum_{j=1}^{m} A_{j_k} - \sum_{i=1}^{n} a_{i_k}) Rc_{j_k} + (Rc_k Ac_k) \} \div A_k] IA \le Q_{k\,max} \quad (6.10)$$

Available EMP area constraints:

$$\sum_{i=1}^{n} a_{i_k} \le AL_k = A_k - A_k C_{k\,max} \quad (6.11)$$

Suitable EMP area constraints:

$$a_{k_i} \le as_{k_i} \quad (6.12)$$

Owner’s Choice constraints:

$$(a_{max})_{k_i} \geq a_{k_i} \geq (a_{min})_{k_i} \qquad (6.13)$$

Non negativity constraints:

$$a_{k_i} \geq 0 \qquad (6.14)$$

where,

j= 1,2,……m, where m is the number of different landcover in the plot except the EMPs and coverage area

$(Cc)k_i$ = Capital cost of the i^{th} EMP in the k^{th} plot (₹)

$(Cm)k_i$ = Maintenance cost of the i^{th} EMP in the k^{th} plot (₹)

a_{ki} = Area of the i^{th} EMP in the k^{th} plot (m^2)

St_{min} = Minimum sediment yield required from the watershed (tonnes/yr)

St_{max} = Maximum sediment yield allowed from the watershed (tonnes/yr)

A_k=Area of the k^{th} plot in the watershed (m^2)

R_k = Rainfall and runoff erosivity index of the k^{th} plot (100 ft·tonf·in/acre/hr/yr)

K_k = Soil erodibility factor of the k^{th} plot (tonnes/acre per unit of R),

$(LS)_k$ = LS factor of the k^{th} plot (dimensionless)

$C_{i\,k}$ = cover factor for the i^{th} EMP in the k^{th} plot (dimensionless)

$A_{j\,k}$ = Area of the j^{th} land cover in the k^{th} plot (m^2)

$C_{j\,k}$ = Cover factor for the j^{th} land cover in the k^{th} plot (dimensionless)

Qk_{max} = Maximum allowable peak rate of runoff from the k^{th} plot (cumec)

Qk_{min} = Minimum allowable peak rate of runoff at downstream from the k^{th} plot, (cumec)

RC_{ki} = Runoff coefficient for the i^{th} EMP in the k^{th} plot (dimensionless)

RC_{kj}= Runoff coefficient for the j^{th} landcover in the k^{th} plot (dimensionless)

Rc_k = Runoff coefficient of the coverage area in the k^{th} plot (dimensionless)

Ac_k= Coverage area of the plot (m^2) in the k^{th} plot

I_k = Maximum intensity of rainfall for the time of concentration of the selected design storm for the k^{th} plot (mm/hr)

$(as)_{ki}$= Suitable area available for i^{th} EMP in the k^{th} plot (m^2)

$(a_{min})_{ki}$ = Minimum area required for i^{th} EMP in the k^{th} plot (m^2)

AL_k= Available EMP area in the k^{th} plot (m^2)

C_{kmax} = Maximum coverage allowed in the k^{th} plot (%)

$(a_{min})\ k_i$ is the minimum area kept for i^{th} EMP in the plot according to owner's choice in the k^{th} plot (m^2)

$(a_{max})\ k_i$ is the maximum area kept for i^{th} EMP in the plot according to owner's choice in the k^{th} plot (m^2)

(b) OPTEMP-LDM Model

In the OPTEMP-LM model, numbers of variable representing EMPs increase with the increase in number of plot. Therefore, with large number of EMPs and with large number of plots, the numbers of variables in the model becomes considerably high, which may sometimes become problem from computational point of view. Therefore, a model with DP approach is developed (OPTEMP-LDM), where number of variable remains same as number of EMPs considered for the study. Here number of stages increases with increase in number of plots, which is computationally advantageous.

In the OPTEMP-LDM model, the watershed is considered as combination of various plots belongs to different land owners. Plots from upstream to downstream in sequence were considered as stages for the DP model. The OPTEMP-LS model provides optimal combination of EMPs for the different plots of the watershed for various desired sediment yield and peak discharge from the plots. The optimal values obtained for each of these plots for different sediment and peak discharge values are then used in the DP model to obtain optimal combination of EMPs for the entire watershed for desired sediment yield and peak discharge at the outlet of the watershed.

The sequence of plots considered in the DP model is as shown in the Figure 6.1.

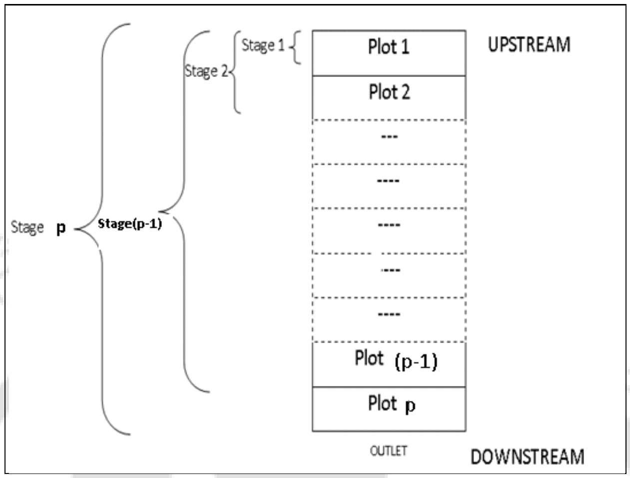


Figure 6.1: Arrangement of the plots

Objective function: To determine the best combination of EMPs for the entire watershed so that the otherwise allowable coverage area of the watershed can be developed completely at minimum cost maintaining sediment yield and peak discharge from the watershed within permissible limits.

Recursive equation:

f= cost of EMP combination

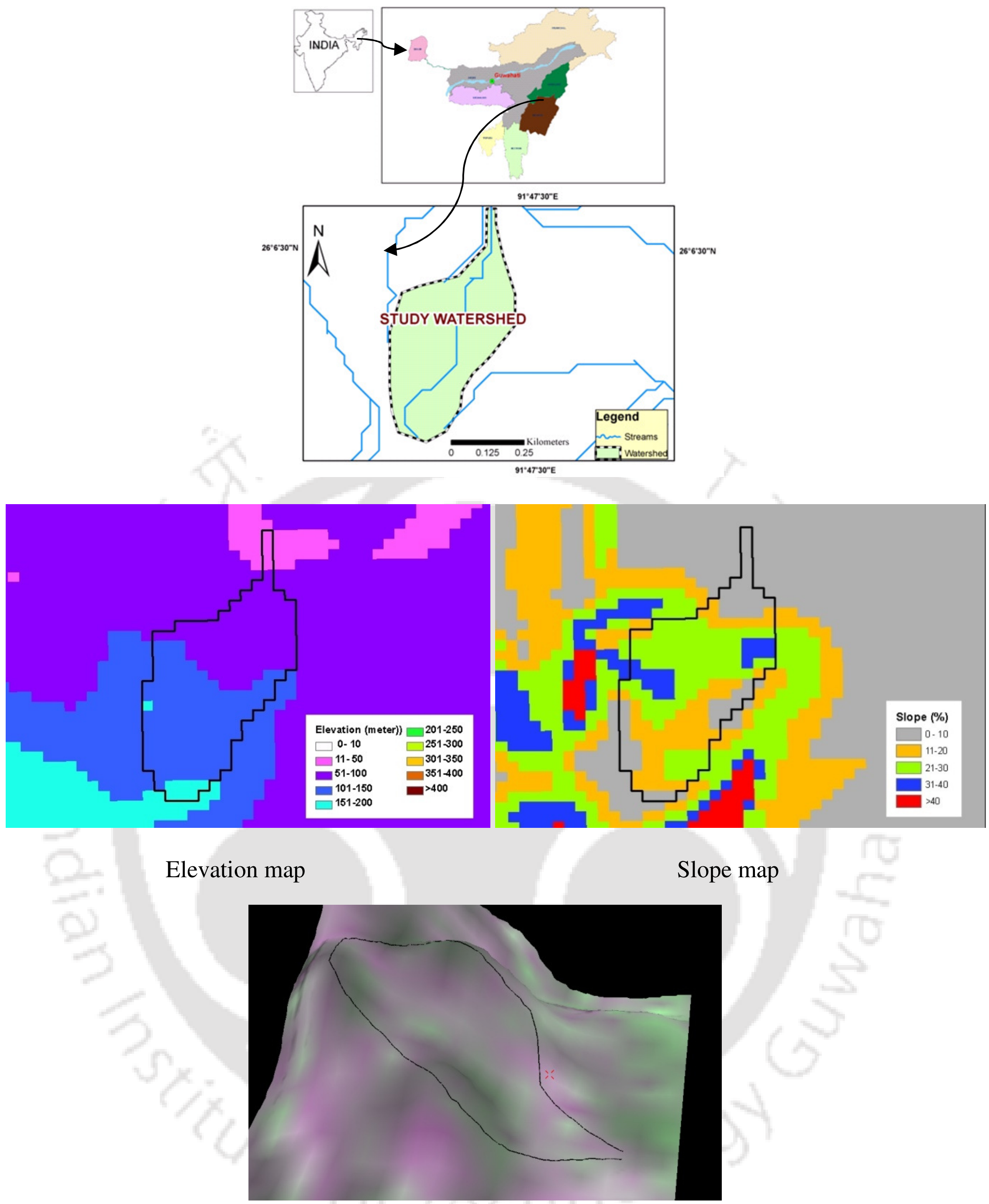
$$f^{p}(S_p) = \text{Min}\,[Z(X_p,Q_p) + f^{p-1}(S_p - X_p)] \quad (6.15)$$

where, $S_p$is the state variable representing amount of sediment yield from the p^{th} stage, and X_p is the trial discrete sediment yield from the current plot in p^{th} stage and $f^{p-1}(S_p-X_p)$ is the optimal cost of EMPs combination up to the previous stage for allowing (S_p-X_p) sediment yield from (p-1) stage. $Z(X_p,Q_p)$ is the cost of the EMPs for sediment yield X_p and is it peak discharge of Q_p

6.5. CASE STUDY

6.6.1. APPLICATION OF THE OPTEMP-LS MODEL AND SENSITIVITY ANALYSIS OF THE MODEL PARAMETERS

A micro watershed of Guwahati (0.17 km^2) is considered for application of the optimization model to select optimal EMP combinations for the watershed from a set of feasible EMPs. An area of this size, if developed as a housing complex owned by single owner, can be modeled by using the OPTEMP-LS model. The study watershed is located near the Games village area of Guwahati, a site having potential for residential development in its hilly parts as well. The watershed delineation was carried out initially by using ASTER DEM data in ArcSwat and the selected watershed was refined following the drainage line of SoI toposheets. The TIN model for the area was developed by using 20 m contour interval obtained from SoI toposheets(1:500000 scale). From the TIN, the slope and aspect map of the area was developed. The slope ranges from 0 to 40% and elevation values of this area ranges from 11m to 200m. The major soil type of this watershed is fine and coarse loamy type as obtained from soil map of Assam Remote Sensing Application Centre (ARSAC). The study area is presented in Figure 6.2 along with the elevation map, slope map, and the 3D view of the watershed.



Elevation map Slope map

3D View

Figure 6.2: The study watershed

EMP Consideration

We considered three types of EMPs in this study-Grass, Garden (grass, flower, vegetable bushy vegetation) and Detention pond. Grass is traditionally practiced for controlling sediment yield, grazing purposes and as lawns as they are easy to grow and maintain. Therefore grass is observed to have significant potential as one of the EMPs for hilly areas of Guwahati. The main reason of selecting garden as EMP is that many owners prefer gardening (kitchen gardens/flower) as their hobby or for economic benefit, which has capability of controlling sediment yield and runoff generation. Detention pond that can be used to captures rainwater and runoff, is observed to have highest potential of controlling sediment and water yield from a watershed area and thus is an important EMP for areas with high sediment yield.

Cost per unit area of the considered EMPs are estimated based on the prevailing market rate of the study area and are tabulated in Table 6.1.

Table 6.1: Cost of EMPs considered for the study

EMP No	EMP name	Material cost ₹/ sq m	Construction cost ₹/ sq m	Maintenance cost (yr) ₹/ sq m
EMP1	Grass	100	20	240
EMP2	Garden having grass and bushy vegetation/ vegetable garden	150	20	120
EMP3	Detention pond	0	200	100

Parameters of the RUSLE model

Available literatures, as given below, helped in considering the values of the model parameters.

(i) Rainfall erodibility factor (R): A study conducted by Sarma et al. (2005) found the R value to be 544 for Guwahati City. In this study the R value was taken as 544.

(ii) Soil Erodibility factor (K): For calculation of K value, the soil map for the area was referred and K value for each soil type was taken from the USLE table. The average K value for the entire plot is commutated by weighting over entire area.

(iii) Slope-Length factor (LS): Slope map generated in ArcGIS was used to calculate the LS factor. From the slope map, the slope value for each pixel was taken and its corresponding length was considered as length for that slope. Slope-Length factor for each of the pixel was then determined using the following equation

$$LS = \left[0.065 + 0.0456(\text{slope}) + 0.006541(\text{slope})^2\right]\left[(\text{slopelength}) \div 72.5\right]^{NN} \quad (6.16)$$

Where, Slope = Slope steepness (%), Slope length = Length of slope (ft),NN = Slope steepness factor, ranging from 0.2–0.5.

LS value for the entire plot was determined by taking arithmetic average of LS value computed for each of these pixels.

(iv) Cover factor (C): The cover factor for the various land cover is considered based on available literature (USDA Agricultural Handbook, 1978; Toy et al., 1998; Sarma et al., 2005; Jabbar et al. 2005; Wall et al., 2002) and are given in Table 6.2.

(v) Practice factor (P): The P factor was considered equal to 1, as impact of different EMPs are introduced indirectly by modifying the C factor of USLE.

Parameters for the Rational method

(i) Runoff coefficient (RC): The runoff coefficients for various land cover were considered based on available literatures (Sarma et al 2005; Iowa Storm Water Management Manual, 2008) and are given in Table 6.2.

(ii) Rainfall intensity (I): To determine the design rainfall intensity, time of concentration for the area was first determined by using the Kirpich formula. The intensity of the designed rainfall is determined by using the intensity duration curve developed by Sarma and Goswami (2004) for the area under study for duration equal to time of concentration.

$$I = 51.307\, e^{\,0.2179D} \quad (6.17)$$

where I=Intensity (mm per hr); D=duration (hr)

We obtained the intensities of the design rainfall for the area as 50 mm/hr.

(iii) Area of the plot*:* The area were directly be read from the ArcGIS shapefile.

Table 6.2: The USLE cover factor and the Rational method's runoff coefficient for the various land covers

Land Cover	USLE Cover factor	Rational method Runoff coefficient
Built up area	0	1
Built up area with rainwater harvesting system	0	0.8
Forest	0.1	0.2
Barren land	1	0.5
Grass	0.01	0.2
Garden having grass and bushy vegetation/shrub/vegetable garden	0.01	0.3
Detention pond	0	0

Other consideration for the optimization model

(i) Coverage in the plots: As per the guidelines followed in the State of Assam, India; we took 60% coverage area as allowable maximum coverage which includes the area required for infrastructural facilities for that area.

(ii) Suitable area for EMPs: Suitability conditions for the EMPs are considered as given in Table 6.3.

Table 6.3: Suitability conditions considered for EMPs in the study

EMP	EMP1	EMP2	EMP3
Suitable soil type	Loamy	Loamy	All, except rock
Suitable slope range	All	0-60%	0-45%
Elevation	All	All	< 800 m

By superimposing the soil map, slope map and DEM of the plots in ArcGIS, we found that all the three EMPs are suitable for the area.

(iii) Total maximum EMP area: The EMPs will not be allowed within the coverage area. Therefore we considered 40% of the total area as the total maximum EMP area.

(iv) Owner's choice for EMPs: The owner of the plot may have special choice for some EMP and no choice for some other. A hypothetical owner's choice was considered for the study and is presented in Table 6.4.

Table 6.4: Summary of the model parameters considered OPTEMP-LS model

Area (km^2)	Soil Erodibility Factor	Slope Length factor	Feasible EMP areas	Owner's choice for EMP
0.17	0.17	5.31	EMP1: max = AL EMP2: max=50% of AL EMP3: 25 % of AL	EMP1: min= 20% of AL, max = 50% of AL EMP2: min=4% of AL, max=40% of AL EMP3: min =0, max =25% of AL

(v) Maximum and minimum sediment yield and peak discharge: Allowable sediment yield from the plot was estimated by computing sediment yield from the plot for its natural land cover condition using RUSLE method. This value was considered as the permissible sediment yield when 60% of the area is used for constructing building and rest for EMPs. The value of maximum allowable sediment yield from the area was thus obtained as 2000 tonnes/ yr. As the studied watershed is small, sediment delivery ratio of the watershed is taken as 1.

As discussed in the section 5.4.3, for the study watershed it was found that there is no sediment requirement from the watershed area for the required norms of water quality at the outlet point. Therefore, minimum sediment requirement (S_{min}) was considered as zero.

The peak discharge from the area with and without built up area was calculated using the Rational method. The value of peak discharge obtained with natural cover was considered as the lower limit of peak discharge (Q_{min}). Maximum allowable peak discharge (Q_{max}) was estimated based on the safe carrying capacity of the drainage system at downstream. In this study, we considered Q_{max} as 2 times of the Q_{min}. Thus we got 0.5 to 1.5 cumec as the peak discharge range for the area.

We found that for some of the plots, restricting peak discharge within the maximum permissible limit becomes impossible even after applying lowest water yielding EMPs in the entire available EMP area. Thus solution of the optimization model becomes infeasible. Such situations left us with two options:

(i) Application of EMPs within the coverage area in the form of rainwater harvesting or other water retention structures.

(ii) Reduction of coverage area percentage from the otherwise permissible limit.

Thus in case of infeasible solution option (i) and (ii) are tried in sequence to obtain a feasible solution. A study conducted by Sarma et al. (2006) revealed that the runoff coefficient of building area can be reduced from 1 to 0.8 by adopting rooftop rainwater harvesting. This value was considered in this study.

(a) Results of OPTEMP-LS Model

We solved the OPTEMP-LS model using the 'Linprog' function of the Optimization toolbox of MATLAB 7 and the results obtained are presented below. The differences in sediment yield and peak discharge before and after implementation of EMPs are presented in Figure 6.3 and 6.4.

Table 6.5: Results of the OPTEMP-LS model

Owner's choice condition	EMP1	EMP2	EMP3	Peak discharge (cumec)	Sediment Yield (tonnes/yr)	Cost (₹)
	(Area in m^2)					
without owner choice	1327	34906	17453	1.42	2000	15836417
with owner choice	13963	27925	11855	1.43	2000	16681347

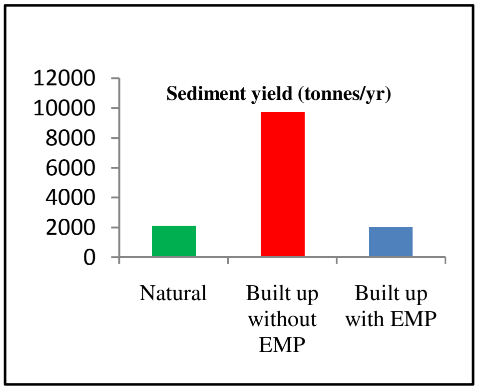


Figure 6.3: Sediment yield scenarios for different conditions

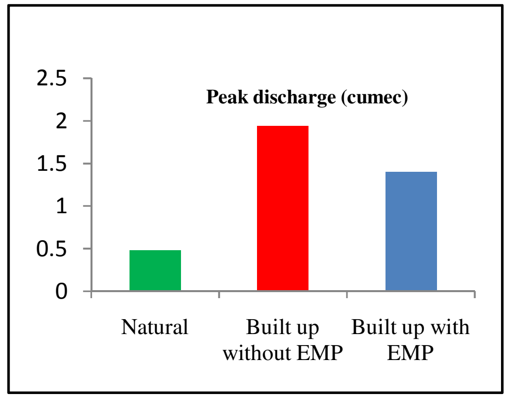


Figure. 6.4: Peak discharge scenarios for different conditions

(b) Sensitivity Analysis

In developing country like India, because of financial constraints, many a time it becomes difficult to carryout detail site investigation or determining value for different model parameters. Therefore, knowing precision requirement for each of these model parameters is very essential to make optimal planning for their estimation. We carried out sensitivity analysis of different model parameters to know how their variations influence the model output. Change in total cost and change in optimal EMP combinations for a variation in the value of the model parameters up to ± 40% of their initial value were analysed to assess the degree of sensitivity. Sensitivity analysis is carried out for those model parameters whose values are not very certain. In this study, we did not carry out sensitivity analysis for RUSLE cover factor for detention pond, barren land, coverage area, and runoff coefficient of barren land, coverage area, detention pond, as value of these parameters are certain.

Thus following parameters were considered for analysis:

i. Rainfall erosibility factor (R)

ii. Soil erodibility factor (K)

iii. Slope length factor (LS)

iv. Cover factor of Grass (C1)

v. Cover factor of Garden(C2)

vi. Runoff coefficient of Grass(RC1)

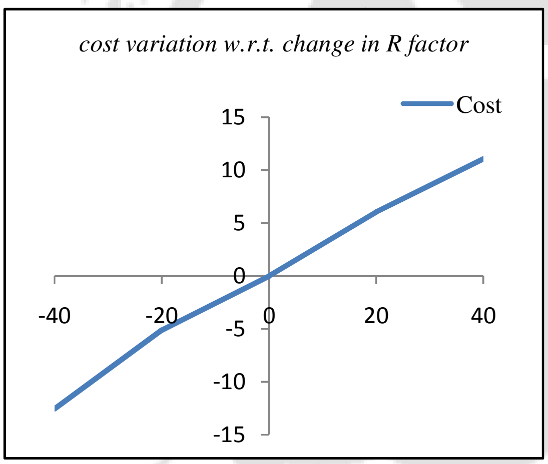
vii. Runoff coefficient of Garden(RC2)

viii. Rainfall intensity factor(I)

We found that percentage increase in EMP cost vary almost linearly with percentage increase of R value. Cost increases by 5% for 20% increase in R factor and it reaches 10-12% for 40% increase in R factor. Cost decreases by 5% for a decrease of 20% in the R factor, but cost reduces at a faster rate for a decrease in R factor beyond 20%. Figure 6.5 shows the percentage variation in the cost with respect to the percentage variation of R factor. Change in the optimal EMP combination for different values of R factor is shown in Figure 6.6. Similarly, percentage increase in EMP cost with respect to changes in K and LS factors showed a similar trend (Figure 6.7 and Figure 6.9). With ±40% change in the values of K and LS, EMP cost increases and decreases by 10% almost linearly. Change in the optimal EMP combination for different values of K and LS factor are shown in Figurer 6.8 and Figure 6.10. Thus these three parameters are moderately sensitive.

The cover factor of grass and garden did not show any significant deviation in EMP areas and cost. However, the runoff coefficient of garden is observed to be moderately sensitive towards the increase in its runoff coefficient value (Figure 6.11), but did not show any percentage deviation in cost due to decrease in its value up to 40%from its initial value. For a 20 % increase in its runoff coefficient value, its cost increases by 5% and for a 40% increase in runoff coefficient, total cost increases by 10-12%. This is because the increase in runoff coefficient values means decrease in its efficiency to reduce peak discharge. So, to compensate the peak discharge reduction there is a need to increase higher efficient EMPs for reducing peak discharge, which are of higher cost. Change in the optimal EMP combination for different values of garden's runoff coefficient is shown in Figure 6.12.

I factor was observed as highly sensitive towards increase in its value. There is a linear increase in the cost component up to 10% increase. From 10% to 20 % increase in I, there is no change in the EMP cost, but beyond 20 % increase, the model gives infeasible solution (Figure 6.13) indicating that with such high intensity it is not possible to have water yield within permissible limit. However, no significant deviation in cost is observed for decrease in I factor. Change in the optimal EMP combination for different values of I factor is shown in Figure 6.14.



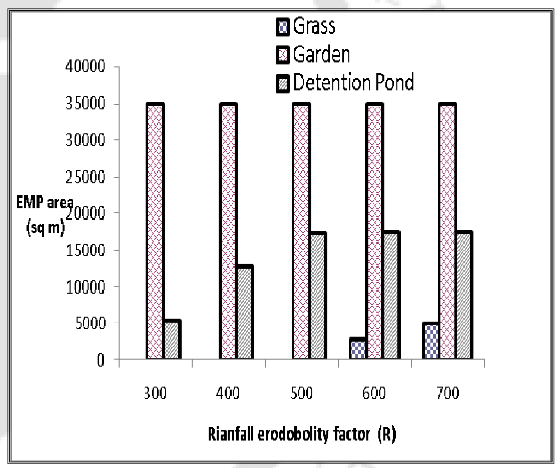
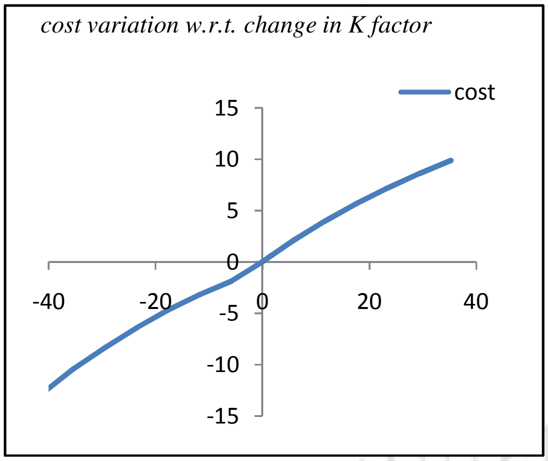


Figure 6.5: Percent variation in cost Vs percent change in R

Figure 6.6: EMP combination for different R factor



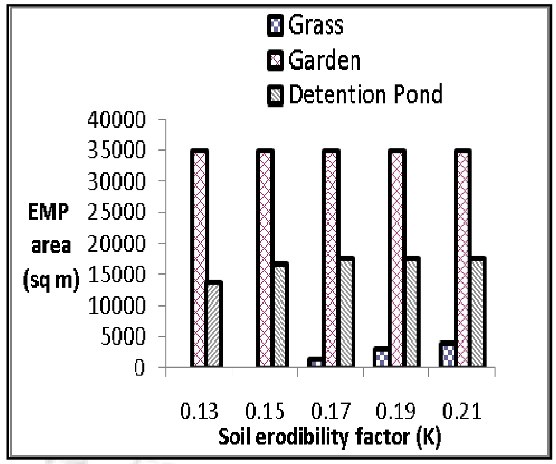
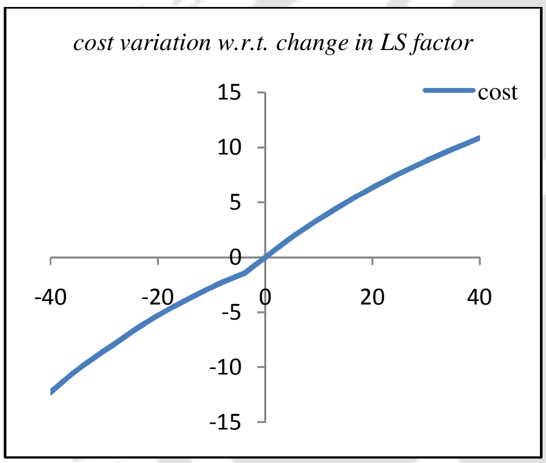


Figure 6.7: Percent variation in cost Vs percent change in K

Figure 6.8: EMP combination for different K factor



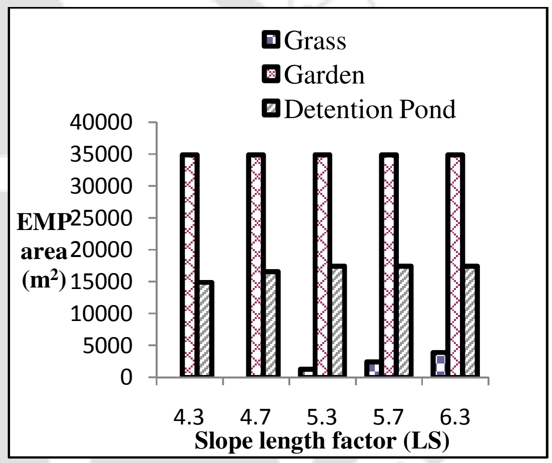
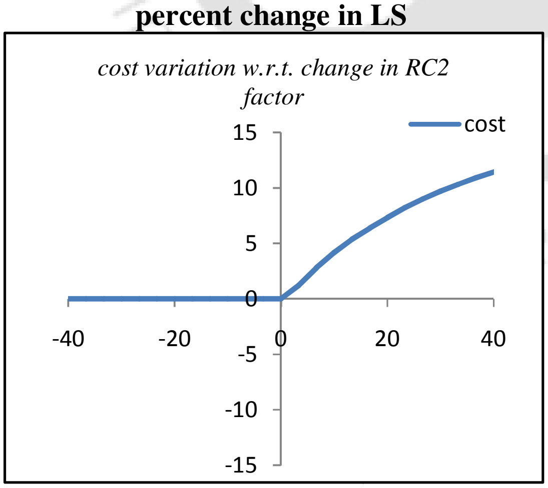


Figure 6.9: Percent variation in cost Vs percent change in LS

Figure 6.10: EMP combination for different LS factor



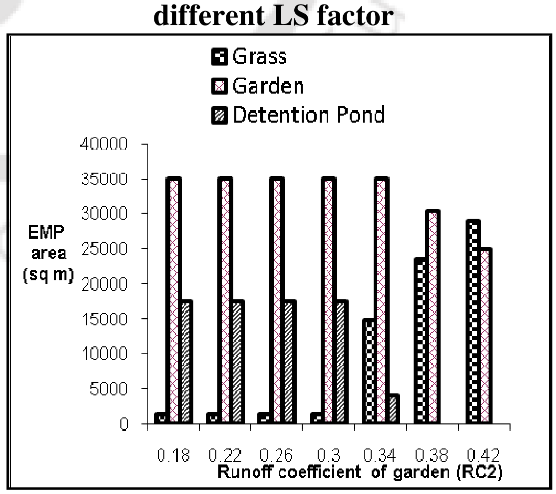


Figure 6.11: Percent variation in cost Vs percent change in runoff coefficient of garden(RC2)

Figure 6.12: EMP combination for different runoff coefficient of garden (RC2)

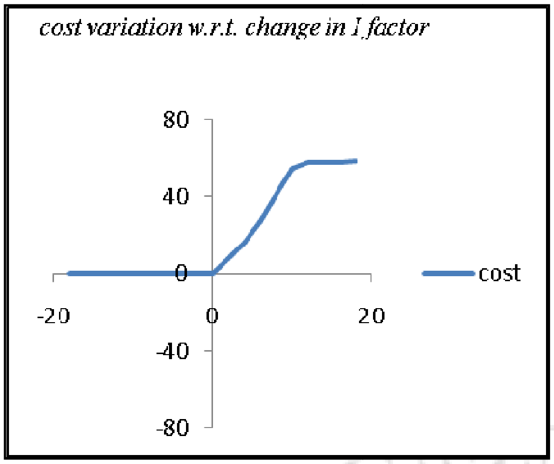


Figure 6.13: Percent variation in cost Vs percent change in I

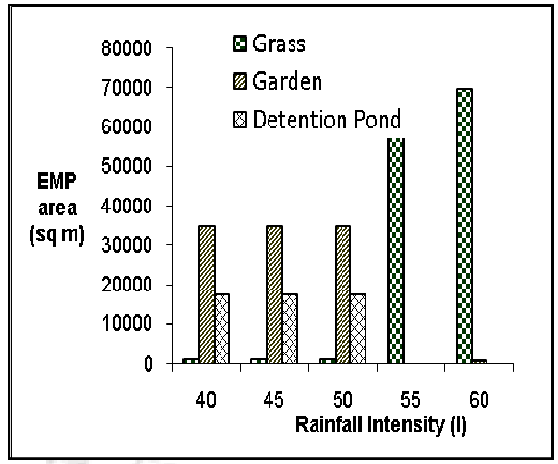


Figure 6.14: EMP combination for different I factor

6.6.2. MODEL APPLICATION FOR WATERSHED CONSISTING OF DIFFERENT PLOT UNDER MULTIPLE OWNERSHIP

In this case, the watershed area of 0.17 km^2 (Figure 6.1) was considered to be consisting of four different plots under different ownership. Both OPTEMP-LL and OPTEMP-LDL models have been applied and compared. In this case, the watershed in divided into four plots as shown in the Figure 6.15. The different criteria for these four plots are given in Table 6.6.

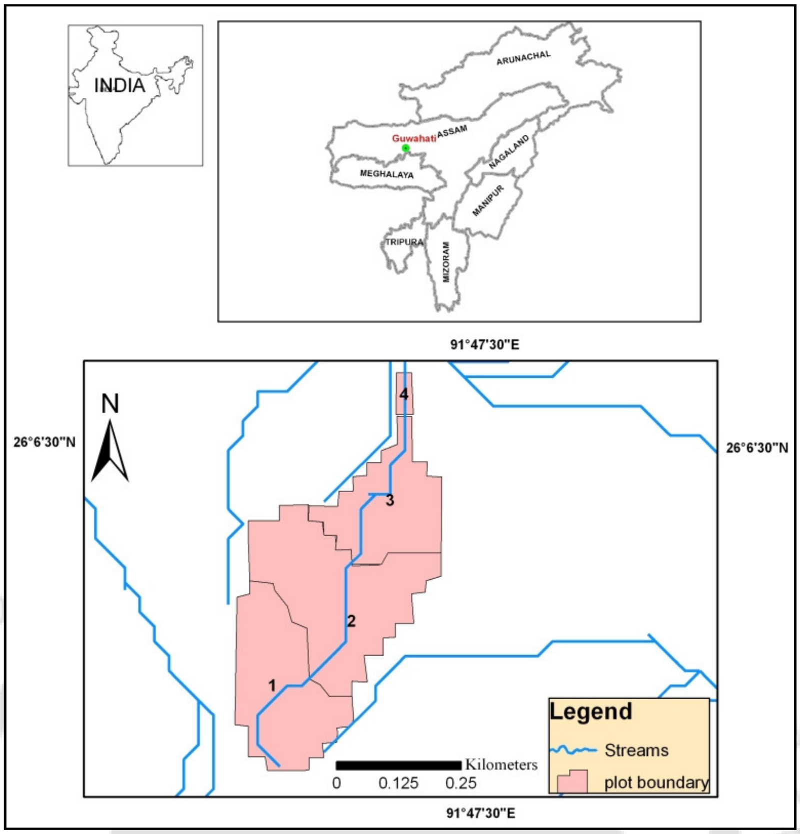


Figure 6.15: The study area showing the four plots

Table 6.6: Summary of the model parameters considered in the OPTEMP-LM and OPTEMP-LDM model

Plot no	Plot area (m^2)	Soil Erodibility factor	Slope Length factor	Owner's choice for EMP
Plot 1	55665	0.3	3.44	EMP1: min= 2% of AL, max = AL EMP2: min=5% of AL, max=75% of AL EMP3: min =20% of AL, max =50% of AL
Plot 2	73971	0.13	4.86	EMP1: min= 60 % of AL, max =90% of AL EMP2: min=5% of AL, max=75% of AL EMP3: min =5% of AL, max = AL
Plot 3	42154	0.13	3.72	EMP1: min= 0, max AL EMP2: min=0, max= AL EMP3: min =0, max =AL
Plot 4	2741	0.13	0.24	EMP1: min= 2% of AL, max = AL EMP2: min=5% of AL, max=75% of AL EMP3: min =0, max =0

In this case, allowable peak discharges are considered as given in Table 6.7.

Table 6.7: The allowable peak discharge values for different plots considered in the OPTEMP-LM and OPTEMP-LDM model

Plot no	Allowable peak discharge (cumec)
Plot 1	Qmin=0.15,Qmax=0.46
Plot 2	Qmin=0.21,Qmax=0.62
Plot 3	Qmin=0.12,Qmax=0.35
Plot 4	Qmin=0.01,Qmax=0.02

(a) Results of OPTEMP-LM Model for the Four Plots

Results of the OPTEMP-LM considering four plots in the watershed are presented in Table 6.8.

Table 6.8: Results of the OPTEMP-LM considering four plots in the watershed

Plot	Sediment yield in plots (tonnes/yr)	Peak discharge in plots (cumec)	EMP1 (Grass) area (m^2)	EMP2 (Garden) area (m^2)	EMP3 (Detention pond) area (m^2)	Costs (₹)
Plot1	454	0.46	3901	11133	5566	6303035
Plot2	1055	0.41	17753	1479	3687	7926349
Plot3	485	0.23	8016	0	4214	4150080
Plot4	6	0.02	0	0	0	0
Total in the watershed	2000	1.12	29670	12612	13467	18379464

(b) Results of OPTEMP-LDM Model for the Four Plots

The results obtained from the OPTEMP-LS model are used as input to the OPTEMP-LDM model for determining the optimal combination of EMPs for the entire watershed for an allowable sediment yield of 2000 tonnes/yr at the watershed outlet. As the exact delivery ratios from the plots were not known, to be on conservative side sediment delivery ratios for all plots were considered as 100%. The model was run for different discretized values of sediment yield as below:

OPTEMP-LDM(1): OPTEMP-LDM model for sediment yield discretization of 1

OPTEMP-LDM(2): OPTEMP-LDM model for sediment yield discretization of 2

OPTEMP-LDM(5): OPTEMP-LDM model for sediment yield discretization of 5

OPTEMP-LDM(10): OPTEMP-LDM model for sediment yield discretization of 10

The results obtained are presented in Table 6.9.

Table 6.9: Results of the OPTEMP-LDM model for different discretization values of sediment yield for the entire watershed

Sediment yield in plots (tonnes/yr)	OPTEMP-LDM (1)	OPTEMP-LDM (2)	OPTEMP-LDM (5)	OPTEMP-LDM (10)
Plot 1	1571	1572	1570	1580
Plot 2	217	216	220	220
Plot 3	206	206	205	200
Plot 4	6	6	5	0
Peak discharge in plots (cumec)	OPTEMP-LDM (1)	OPTEMP-LDM (2)	OPTEMP-LDM (5)	OPTEMP-LDM (10)
Plot 1	0.25	0.25	0.25	0.25
Plot 2	0.29	0.29	0.29	0.29
Plot 3	0.23	0.23	0.23	0.23
Plot 4	0.02	0.02	0.02	0.02
EMP1 in plots (m^2)	OPTEMP-LDM (1)	OPTEMP-LDM (2)	OPTEMP-LDM (5)	OPTEMP-LDM (10)
Plot 1	445	445	445	445
Plot 2	17762	17753	17802	17802
Plot 3	15009	15009	15019	14985
Plot 4	0	0	0	0
EMP2 in plots (m^2)	OPTEMP-LDM (1)	OPTEMP-LDM (2)	OPTEMP-LDM (5)	OPTEMP-LDM (10)
Plot 1	11133	11133	11133	11133
Plot 2	9205	9220	9146	9146
Plot 3	0	0	0	83
Plot 4	87	87	257	87
EMP3 in plots (m^2)	OPTEMP-LDM (1)	OPTEMP-LDM (2)	OPTEMP-LDM (5)	OPTEMP-LDM (10)
Plot 1	4518	4514	4522	4482
Plot 2	1479	1479	1479	1479
Plot 3	0	0	0	0
Plot 4	0	0	0	0
Costs in plots (₹)	OPTEMP-LDM (1)	OPTEMP-LDM (2)	OPTEMP-LDM (5)	OPTEMP-LDM (10)
Plot 1	4744155	4742954	4745355	4733351
Plot 2	9507602	9508864	9504645	9504645
Plot 3	5403189	5403189	5406717	5418550
Plot 4	25233	25233	74555	25233

(c) Comparison of OPTEMP-LM and OPTEMP-LDM

The OPTEMP-LM model and the OPTEMP-LDM model are compared and the graphical comparisons of different aspects are presented in Figure 6.16 through 6.24.

In Figure 6.16, the total cost of EMPs for the entire watershed as obtained from the OPTEMP-LM and OPTEMP-LDM models are shown, where about 8% reduction in total cost in the OPTEMP-LM is observed compared to the OPTEMP-LDM.

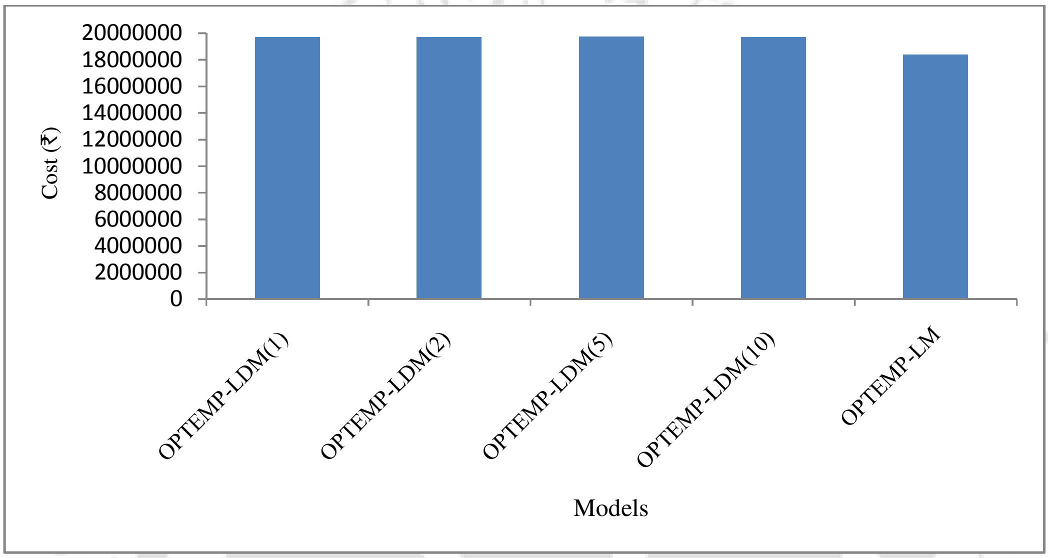


Figure 6.16: Comparison of total cost of EMPs for the watershed as obtained from OPTEMP-LM and OPTEMP-LDM with different discretized values

In Figure 6.17, the cost of EMPs for the four plots of the watershed as obtained from the OPTEMP-LM and OPTEMP-LDM are shown. It is observed that in plot 1, cost is higher in case of OPTEMP-LM than the OPTEMP-LDM, whereas in plot 2 and plot 3, cost is much lower in the OPTEMP-LM compared to the OPTEMP-LDM.

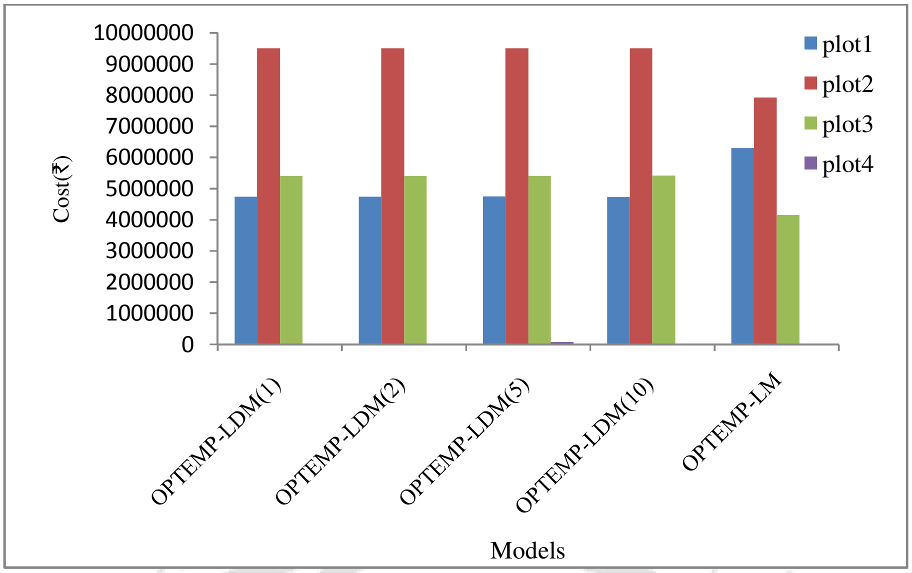


Figure 6.17: Comparison of individual cost for plots of the watershed as obtained from OPTEMP-LM and OPTEMP-LDM with different discretized values

In Figure 6.17, the maintenance cost of EMPs for the four plots of the watershed as obtained from the OPTEMP-LM and OPTEMP-LDM are shown in plot 1, maintenance cost is higher in case of OPTEMP-LM than the OPTEMP-LDM, whereas plot 2 and plot3, cost is lower in the OPTEMP-LM compared to the OPTEMP-LDM.

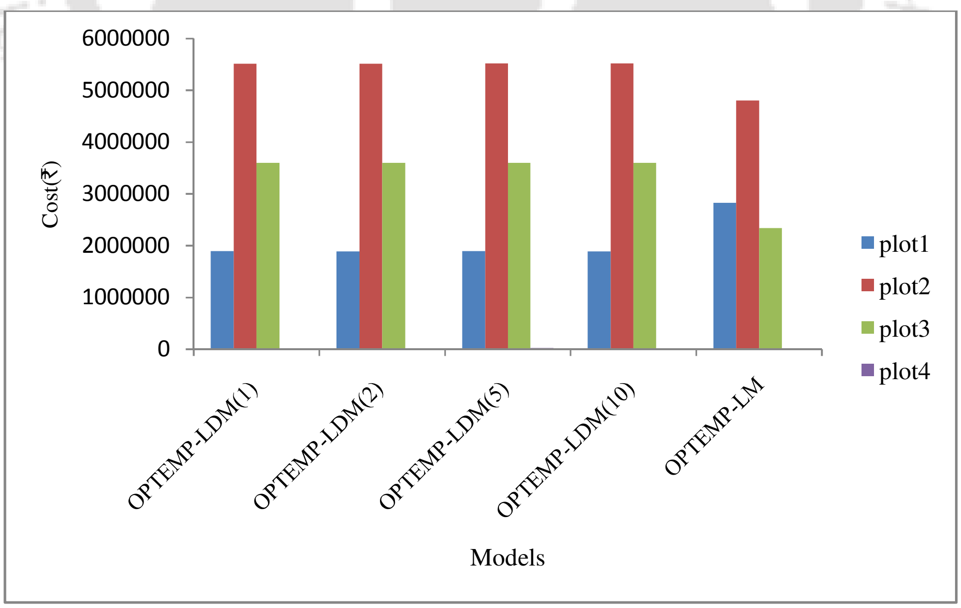


Figure 6.18: Comparison of total maintenance cost in the plots of the watershed as obtained from OPTEMP-LM and OPTEMP-LDM with different discretized values

Figure 6.19, results of the OPTEMP-LM and OPTEMP-LDM model for the annual sediment yield from the four plots of the watershed are shown. OPTEMP-LM is giving higher sediment yield for plot 2 and plot 3 than the OPTEMP-LDM, however the sediment yield for plot 1 as given by OPTEMP-LM was less than the half of that given by the OPTEMP-LDM.

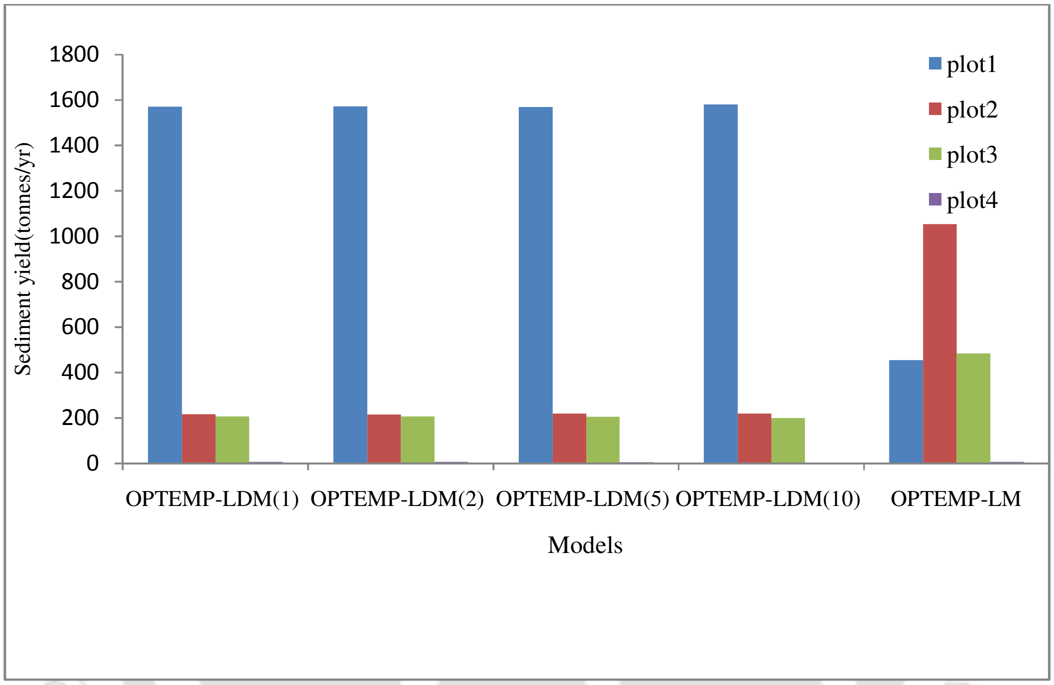


Figure 6.19:Comparison of total annual sediment yield from the watershed as obtained from OPTEMP-LM and OPTEMP-LDM with different discretized values

Figure 6.20, results of the OPTEMP-LM and OPTEMP-LDM model for the peak discharge from the four plots of the watershed are shown. For plot 3 and plot 4, peak discharge given by OPTEMP-LDM and OPTEMP-LM is same, where as OPTEMP-LM is giving higher peak discharge plot- 1 than the OPTEMP-LDM. As a whole the total peak discharge from the watershed is observed to be higher in OPTEMP-LM than the OPTEMP-LDM.

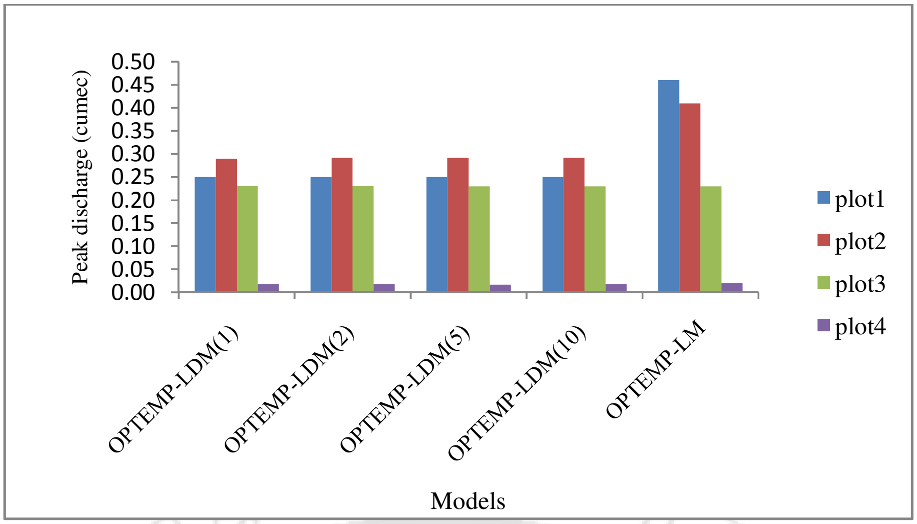


Figure 6.20: Comparison of peak discharge from the different plots of the watershed as obtained from OPTEMP-LM and OPTEMP-LDM with different discretized values

Figure 6.21 shows the area of EMP1 (Grass) as computed by the OPTEMP-LM and OPTEMP-LDM models for the four plots of the watershed. In plot 1, the area of grass is higher in OPTEMP-LL than the OPTEMP-LDM, in plot 2 there is no change in the grass area, whereas in plot 3 the grass area is lower in OPTEMP-LM than the OPTEMP-LDM. No grass area was given to plot 4 by the OPTEMP-LM and OPTEMP-LDM.

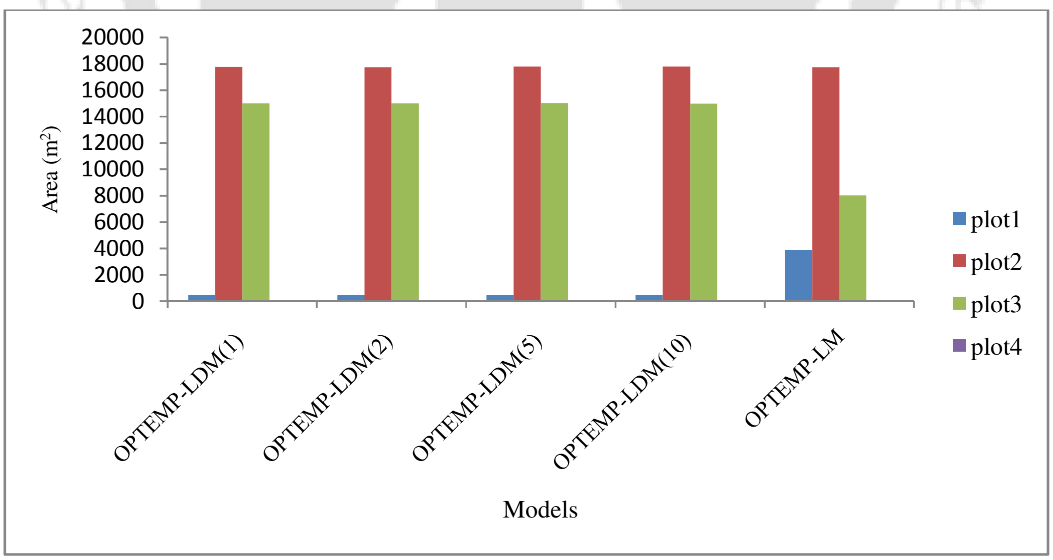


Figure 6.21: Comparison of Grass area (EMP1) in the plots of the watershed as obtained from OPTEMP-LM and OPTEMP-LDM

Figure 6.22, results of the OPTEMP-LM and OPTEMP-LDM model for area of EMP2 (Garden) from the four plots of the watershed are shown. In plot 1, the area of garden is same in OPTEMP-LL and OPTEMP-LDM, but in plot 2 the area of garden is much lower in OPTEMP-LM than the OPTEMP-LDM. No area was given to plot 4 by the OPTEMP-LM.

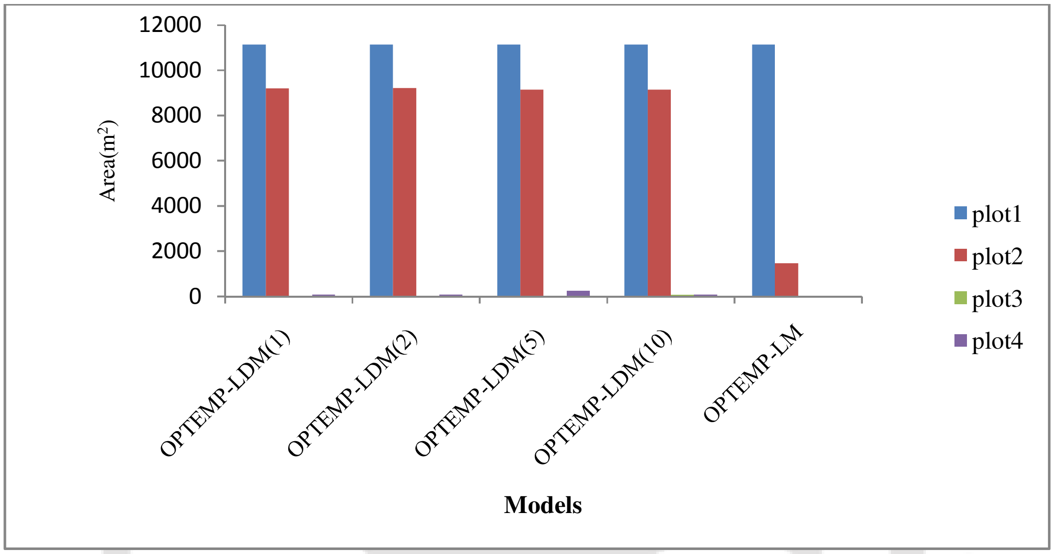


Figure 6.22: Comparison of Garden area (EMP2) in the plots of the watershed as obtained from OPTEMP-LM and OPTEMP-LDM with different discretized values

In Figure 6.23, results of the OPTEMP-LM and OPTEMP-LDM model for area of EMP3 (Detention pond) from the four plots of the watershed are shown. In plot 1, plot 2 and plot 3, the area of detention pond is higher in OPTEMP-LM than the OPTEMP-LDM. No Detention pond area was given to plot 4 by the OPTEMP-LM and OPTEMP-LDM.

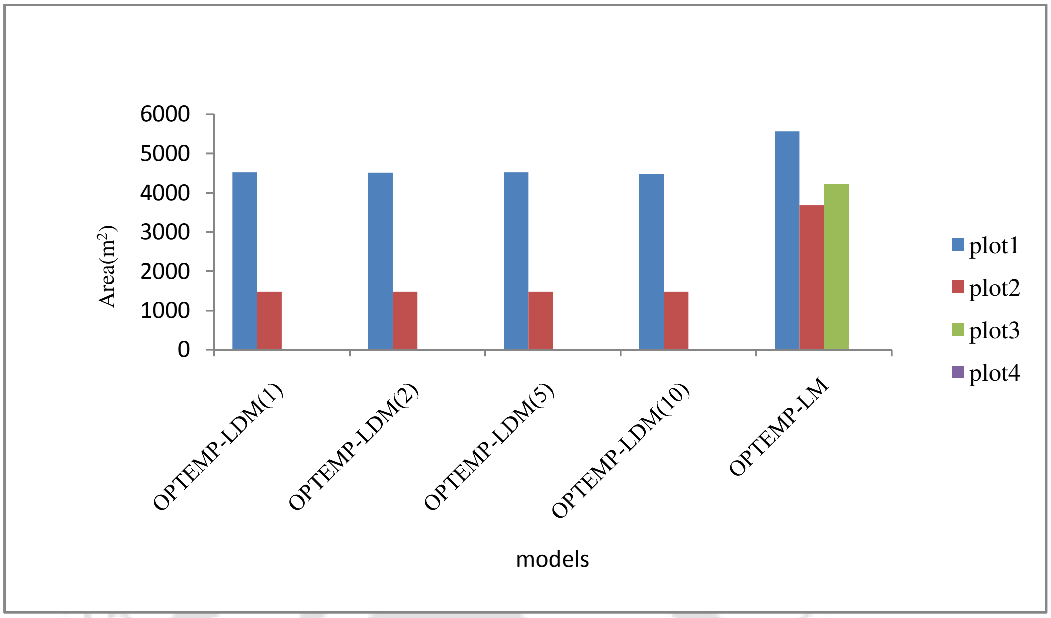


Figure 6.23: Comparison of Detention pond area (EMP3) in the plots of the watershed as obtained from OPTEMP-LM and OPTEMP-LDM with different discretized values

Reduction in sediment yield achieved by the OPTEMP-LDM model from different plots was found to be commensurate with the estimated sediment yield from these plots if no EMPs are applied. On the other hand, the OPTEMP-LDM model reduced the sediment yield to a much lower value in the plot 1. All OPTEMP-LDM models gave almost similar pattern in sediment yield from the four plots. Figure 6.24 shows the plot of sediment yield given by the OPTEMP-LM and OPTEMP-LDM models for different plots against the corresponding sediment yield from the respective plots if no EMPs were applied. It is interesting to note that though the sediment yield without application of EMP is highest from the plot 1, OPTEMP-LM, allocates EMPs in such a way that sediment yield from plot 1 reduces to a much lower value. Thus the EMP cost for the plot 1 become much higher as compared to that of the plot 2 and plot 3. Thus maintenance cost of plot 1 will also be higher In case of different ownership such distribution, which makes the highest sediment yielding plot to spend less, may not be acceptable to owners of other plot. From this point of view the result of OPTEMP-LDM is preferable though total EMP cost is marginally higher (7%) than that of the OPTEMP-LM.

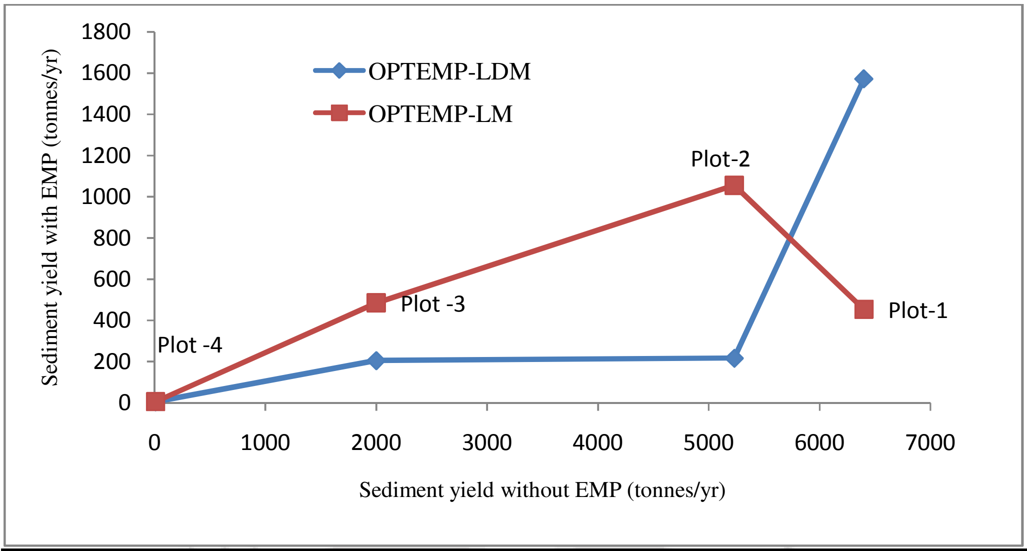


Figure 6 .24: Plot of sediment yield with EMP as given by OPTEMP-LM and OPTEMP-LDM(1) against the sediment yield from the respective plot without EMP

6.7. SUSTAINABILITY ANALYSIS

The sustainability of the implemented EMPs can be analyzed from two aspects. First is the sustainability of EMPs from their physical survivability, i.e. the vegetative measures implemented must be able to survive in the local climate and topography. This can be ensured by selecting the vegetative EMPs that use time tested local vegetation. Similarly considering soil type and slope, one can specify the areas where a potential EMP can survive.

Second is the economic sustainability. From the socioeconomic study (presented in section 3.5.2) it is seen that the cost required for implementation and maintenance, as given by the optimization models, may not be easily affordable for the people living in the hilly terrain of a country like India. So far implementation cost is concern, this being one time investment, may be managed from governmental fund. However managing maintenance cost may be difficult to be supported by the government. Depending on the community, it may be possible to maintain the implemented EMPs, through self help group.

Considering the current emphasis towards mitigation of climate change, another idea of deriving partial financial support from industries towards implementation/maintenance of these EMPs by utilizing carbon sequestration potential of vegetative EMPs is presented below.

6.7.1. SUSTAINABILITY THROUGH MAXIMIZATION OF CARBON SEQUESTRATION OF EMPs

Carbon sequestration is the process of removing carbon from the atmosphere and depositing it in a carbon reservoir. During photosynthesis, trees convert carbon dioxide and water into sugar molecules and oxygen

$$6CO_2 + 6H_2O + \text{sunlight} \dashrightarrow C_6H_{12}O_6 + 6O_2 \quad (6.18)$$

The 40% of the mass of the sugar molecule comes from carbon and 45% of the dry mass of a tree comes from carbon (ESA21, 2011).

Lal (2004) stated that soil carbon sequestration implies the removal of atmospheric CO_2 by plants and storage of the fixed C through incorporation into soil organic matter. Soil erosion also led to great reductions of soil organic carbon (SOC) storage in China (Shi et al., 2009). According to Wang et al. (2011) there is a significant negative impact of soil erosion on SOC sequestration. Thus, restricting soil erosion through vegetative practice is also important from soil carbon sequestration point of view.

Some of the EMPs have great potential in sequestrating atmospheric carbon and thus can help in alleviating the adverse effect of climate change. In recent years, there is a growing concern for increasing carbon sequestration through vegetation and forest for mitigating the climate change impacts. The forest ecosystem not only stores atmospheric carbon as biomass but also as soil organic carbon. Jong et al. (2000) while estimating the carbon sequestration potential of different forest types, agriculture and pasture of Chiapas, Southern Maxico, found that the management of natural forests and secondary vegetation has enormous potential for carbon sequestration. Freibaue et al. (2004) provided a quantitative estimation of the soil carbon sequestration potential of agricultural soil with different measures based on the available literature, where the potential soil carbon sequestration rate for grassland and wetlands were given as 0.022-0.7 tonnes C/ ha/ yr and 0.1-1 tonnes C /ha/ yr respectively. According to Lal (2005) the rate of SOC sequestration and the magnitude and quality of soil carbon stock depends on the complex interaction between climate, soils, tree species and management, and chemical composition of the litter as determined by the dominant tree species. Therefore, the rate of carbon accumulation and its distribution within the soil profile differs among tree species (Jandl et al., 2007). Different vegetative and landcovers have different carbon sequestration potential which also varies place to place. A specific study was conducted by Lasco et al. (2002) in the Leyte Geothermal Reserve of Philippines for determination of the total carbon sequestration of different vegetation based on biomass change. According to their study, carbon sequestration per unit area of different vegetations is tabulated below (Table 6.10):

Table 6.10: Total carbon sequestration of different vegetation based on biomass change of Leyte Geothermal Reserve

Land use	C sequestration (t/ha)
Forest	0.92
Shrubs/bush land	4.29
S.macrophylla plantation	3.28
A mangium plantation	18.77
G.arborea plantation	8.21
Grasslands	0.00
Coconut	4.78
Rice	0.00
Abaca/banana	0.00

While maintenance of vegetation is important for carbon sequestration, industries, which are responsible for green house gas (GHG) emission, also has a moral responsibility of contributing towards enhancing carbon sequestration wherever possible. Therefore they can logically compensate GHG production by earning carbon credit. Thus if a hilly residential area can be developed to have maximum carbon sequestration through application of EMPs then a polluting industry can be ask to implement and maintain such EMPs area to earn carbon credit in proportion to their GHG emission. This approach will make the EMP implementation project a sustainable one.

Considering this, optimization model is developed for selection of EMPs in such a way that it restricts sediment and water yield from the watershed within the permissible limit and also maximize its carbon sequestration capacity at minimum possible cost.

Objectives

The problem is formulated in two different forms:

1) As a single objective optimization problem to minimize the cost considering benefit from carbon sequestration, and

2) Multiobjective optimization problem with following objectives:

a) Maximization of carbon sequestration from the area

b) Minimization of construction and maintenance cost for the EMPs

Constraints

- Limit sediment and water yield from the watershed to a desired level
- Owners choice for EMPs
- Topographic condition of the area
- Other limitation for urban ecosensitive areas from town planning and building byelaw point of view

6.7.2. PROBLEM FORMULATION

(a) **Option 1: OPTEMP-CSL** (**OPT**imal **EMP** model considering benefits from Carbon **S**equestration with **L**inear programming)

Objective function:

Here the objective function is formulated as

Minimization Z= Net cost

Where,

Net cost (total cost – benefits obtained from carbon sequestration)

Mathematically,

$$Minimize Z = \left[\sum_{i=1}^{n} \left(Cc_i + Cm_i \right) a_i \quad - \sum_{i=1}^{n} (B_{CS})_i a_i \right] \tag{6.19}$$

Where

i= 1,2,……n, where, n is number of possible EMPs that are considered in the study

Cc_i = Capital cost of the i^{th} EMP in the plot (₹)

Cm_i = Maintenance cost of the i^{th} EMP in the plot (₹)

$(B_{CS})_i$= Benefit from i^{th} EMP in the plot (₹)

a_i = area of the i^{th} EMP in the plot (m^2)

Constraints:

Constraints are kept same as given in equation 6.2, equation 6.3, equation 6.4, equation 6.5, equation 6.6 and equation 6.7.

(b) Option 2: OPTEMP-CSMO (OPTimal **EMP** model considering for **C**arbon **S**equestration with **M**ulti**O**bjctive optimization)

In this approach, the Laxicographic method of solving multiobjective optimization is considered. In this method, first the objective functions are ranked according to the priority. Then the first ranked objective function is optimized subjected to the given constraints but without considering the existence of other objective function. Then the second rank objective function is optimized subjected to the given constraints plus an additional constraint that the value of first ranked objective function should not change. Similarly each of the objective function are optimized in order of their rank and by adding an additional constraint that value of the higher order objective function must remain same, as that of their solution already obtained.

In this formulation, there are two objective functions which are ranked as follows;

Rank-1 objective function: Maximization of carbon sequestration of EMPs in the watershed

Rank-2 objective function: Minimization of total cost of EMPs in the watershed

Mathematical formulation

Rank -1 Objective function:

$$\text{Maximize} Z_1 = \sum_{i=1}^{n} CS_i \, a_i \tag{6.20}$$

Where

CS_i = Amount of carbon sequestration (tonnes/yr) from the i^{th} EMP in the plot having an area of a_i

Rank- 2 Objective function:

$$\text{Maximize} Z_2 = \sum_{i=1}^{n} (Cc_i + Cm_i) \, a_i \tag{6.21}$$

Constraints:

Constraints are kept same as given in equation 6.2, equation 6.3, equation 6.4, equation 6.5, equation 6.6 and equation 6.7.

6.7.3. MODEL APPLICATION

Three types of EMPs namely Grass, Shrubs and Forest are considered for the study watershed (Figure 6.2) with varied carbon sequestration, sediment yield, water yield behavior and construction and maintenance cost as given in Table 6.12. The exact value of carbon sequestration for the considered EMPs in the Northeastern region of India are not found in literature and thus these values were considered as given in the Table 6.10. Also due to lack of appropriate data, soil carbon sequestration by these vegetative measures are not considered in this study, therefore actual benefits of carbon sequestration is higher than that the value considered in this study.

Table 6.11: Sediment yield and peak discharge constraints considered in the OPTEMP-CSL and OPTEMP-CSMO model

Allowable sediment yield	Allowable peak discharge
Max =2000 tonnes/yr Min =0	Max =1.5 cumec Min= 0.5 cumec

Table 6.12: EMP parameters considered in the OPTEMP-CSL and OPTEMP-CSMO model

EMP	EMP name	Carbon sequestration (tonnes/m^2)	RUSLE Cover factor	Rational method Runoff coefficient	Total Cost (₹/m^2)
EMP1	Grass	0	0.01	0.2	360
EMP2	Shrubs	0.00429	0.01	0.3	290
EMP3	Forest	0.00092	0.1	0.2	350

Other values of the model parameters for the study watershed are considered as given in Table 6.2, Table 6.3 and Table 6.4.

Carbon sequestration in monetary terms

A reported by Jones and Ball (2010) 1 tons of carbon sequestration is equivalent to €18. In this study, this value is considered as monetary gain from per ton of carbon sequestration.

Therefore, 1 tonnes of CO_2 = ₹ 1250

(a) **Results of OPTEMP-CSL Model**

Table 6.12: Results with OPTEMP-CSL model

Grass (m^2)	Shrub (m^2)	Forest (m^2)	Peak discharge (cumec)	Sediment yield (tonnes /yr)	Carbon sequestration (tonnes/yr)	Total Cost without considering carbon sequestration (₹)	Cost considering benefits from Carbon sequestration (₹)	Reduction in cost (₹)
18956	34906	0	1.47	2000	149	16947075	16753150	193924

With the OPTEMP-CSL model, it is seen that a reduction in cost of ₹193924 can be achieved by considering benefit from carbon sequestration.

(b) **Results of OPTEMP-CSM Model**

In this approach, first the carbon sequestration is maximized subjected to other constraints and this gives that maximum carbon sequestration of 165.81tonnes/yr can be achieved with the EMP combination costing about ₹2.03 Cores (Case A of Table 6.13) with sediment yield of 1000 tonnes/yr and peak discharge 1.43 cumec. Now considering this value in the constraint function along with other constraints, the model is run for minimizing the total cost of EMPs for the plot (Case B1 of Table 6.13). This gives the optimal EMP cost as ₹1.73 with carbon sequestration value of 165.80 tonnes/yr with sediment yield of 2000 tonnes/yr and peak discharge 1.47 cumec. The need and scope of compromising between carbon sequestration and cost is analyzed utilizing the same model. For the purpose of analysis the optimization model was run by reducing some carbon sequestration value by some percentage in step by step manner and computing the minimum cost achieved for each of these carbon sequestration values. Results obtain are presented in (Case B2 to B7 of Table 6.13). In this scenarios sediment yield and peak discharge are found to be same as B1.

Comparisons of all these scenarios are presented graphically in Figure 6.25 to Figure 6.27. In Figure 6.25, variation of total EMP cost with carbon sequestration is presented and the reduction in carbon sequestration is associated with reduction in total EMP cost. However, reduction of the value of the carbon sequestration value beyond 10% (Figure 6.26) cannot reduce the cost, rather it increases the cost, and thus beyond 10% reduction is not beneficial in total cost reduction of EMPs. In Figure 6.27, EMP combinations with all these different scenarios are presented, where EMP with highest carbon sequestration capacity and low cost found to be consistent for all scenarios. For percentage decrease in allowable carbon sequestration value, EMP areas were adjusted with mutual increase and decrease between Grass (comparatively high cost, no carbon sequestration potential) and Forest (comparatively medium cost, medium carbon sequestration capacity).

Table 6.14: Results with OPTEMP-CSMO model

Case	Description	Grass (m^2)	Shrub (m^2)	Forest (m^2)	Peak discharge (cumec)	Sediment yield (tonnes /yr)	CS (tonnes /yr)	Cost in Cores (₹)
A	CS maximization without considering cost	11412	34906	17453	1.43	1000	165.81	2.034
B1	Minimization of cost with constraint of CS= potential maximum CS	3095	34906	17447	1.47	2000	165.80	1.734
B2	Minimization of cost considering CS= 1% less than potential maximization CS	4733	34906	15645	1.47	2000	164.14	1.730
B3	Minimization of cost considering CS= 5% less than potential maximization CS	11287	34906	8436	1.47	2000	157.51	1.714
B4	Minimization of cost considering CS= 10% less than potential maximization CS	19079	34783	0	1.47	2000	149.22	1.696
B5	Minimization of cost considering CS= 11% less than potential maximization CS	19466	34397	0	1.47	2000	147.56	1.698
B6	Minimization of cost considering CS= 12% less than potential maximization CS	19852	34010	0	1.47	2000	145.90	1.701

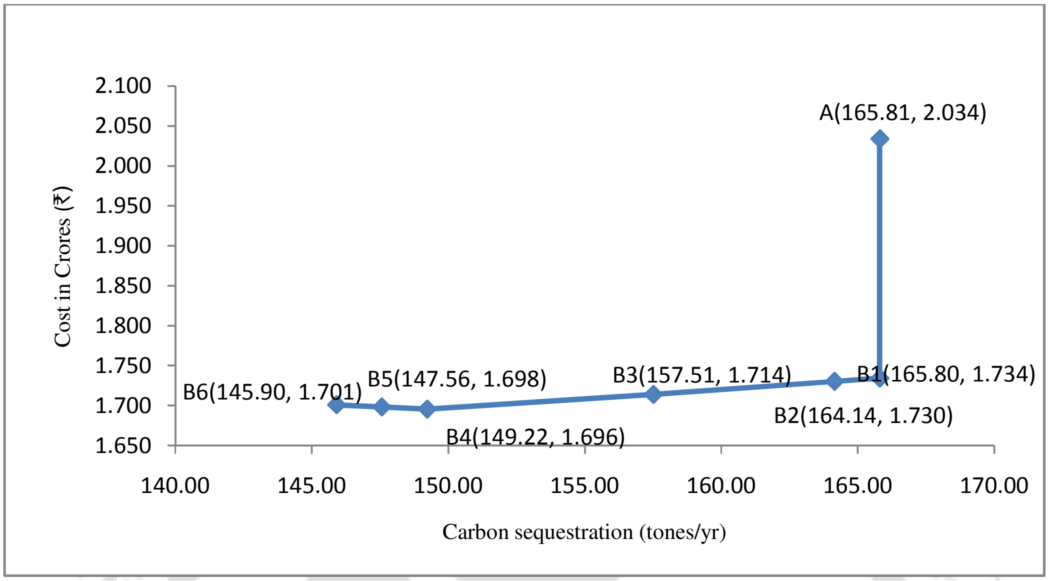


Figure 6 .25: Variation of cost with carbon sequestration

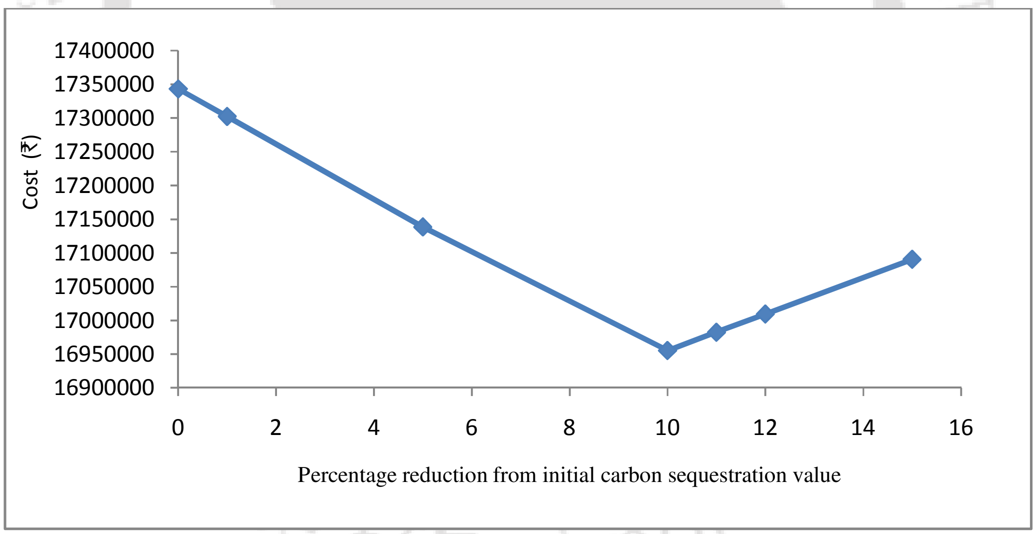


Figure 6.26: Changes in total cost with percentage reduction in carbon sequestration

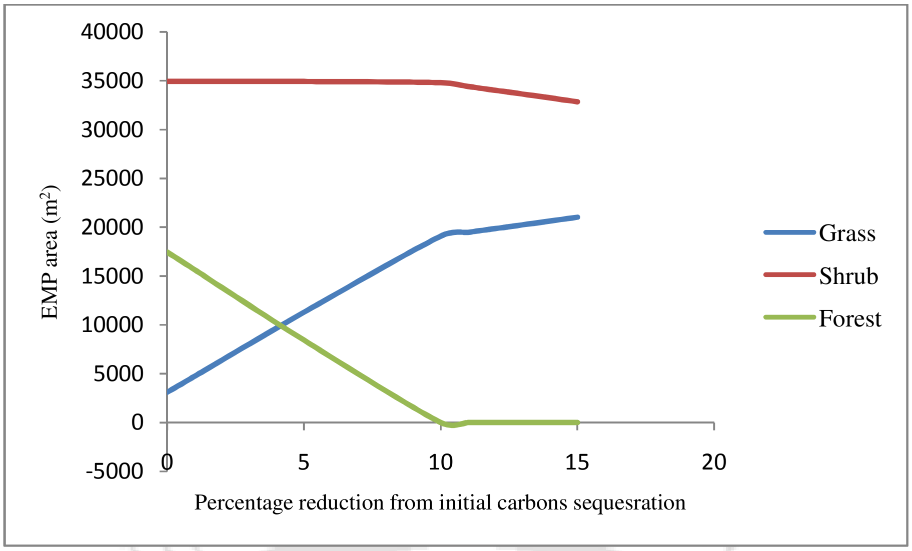


Figure 6.27: Changes in EMP areas with percentage reduction in carbon sequestration

6.8. CONCLUSIONS

Ecological Management Practices (EMPs) are suitable and efficient measures for tackling problems of high sediment yield and runoff generation from a hilly watershed. In this study, a scientific way of developing hilly watersheds with optimal Ecological Management Practices (EMPs) is presented considering their hydrological behavior along with the relevant implementation constraints imposed by the plot owners and topographical conditions. Therefore an optimization model was developed with an objective to minimize the total implementation and maintenance cost of EMPs for a hilly watershed subjected to the constraints of desired sediment yield and peak discharge, maximum allowable EMP area, owner's choice and suitability conditions of EMPs.

The optimization model has been developed for two different situations: Model-A (plots with single ownership) and Model-B (Plots with scope of multiple ownerships). In Case A, the entire watershed was considered to be under single ownership and thus considered as a single plot. The optimization problem for this purpose was formulated as a LPP and named as OPTEMP-LS. In Case B, the watershed was considered to be consisting of several plots in sequence from upstream to downstream under different ownership. This approach can be applied to a relatively large watershed and two kinds of models namely OPTEMP-LM and OPTEMP-LDM were formulated. In OPTEMP-LM, different EMPs in different plots of the watershed was taken as separate variables and allocation was done with constraints for their upper limit, lower limit etc with respect to their respective plots while limiting the sediment and water yield at the outlet of the entire watershed. In OPTEMP-LDM model, the problem was formulated as a dynamic programming model by considering each plot from upstream to downstream to represent stages of OPTEMP-LDM. Optimal EMP combination and respective optimal cost for different discrete sediment yield for each of the plot was first determined by applying the OPTEMP-LS model. Then the optimal EMP combinations obtained for different discrete sediment yield were used as input for the recursive equation of the OPTEMP-LDM model. This model basically determines the sediment release combination for different plots, which minimizes the cost subject to the other constraints and thus indirectly gives the best EMP combination for the entire plot.

The model is formulated as a linear programming model through application of two most robust hydrological models – (i) RUSLE model to address desirable sediment yield constraints (ii) Rational method to address desired peak discharge constraints. The desired limits of sediment yield and peak discharge are set as the maximum and minimum values of sediment yield and peak discharge. The minimum value sediment yield corresponds to the downstream requirement of sediment yield from ecological requirement point of view (if any); the maximum value corresponds to the limit beyond which the sediment yield may create hazards like drainage congestion and impairment of water quality. The minimum limit of peak discharge is the volume of runoff required as sustainable drainage flow, and the maximum value corresponds to the volume of runoff that can create flood hazard at the downstream. The model is suitable for individual level as well as community level planning of EMPs for a hilly area. One can conveniently apply the proposed model if the entire watershed is considered for development as a single unit. However, one can also apply the model to a plot within a watershed with the condition that sediment or runoff generated in other parts of the watershed will not enter into the plot or in other word, a systematic drainage system will carry the outflow from each plot to the drainage directly.

The OPTEMP-LS was applied to a micro watershed of Guwahati, Assam, India with three EMPs, namely: Grass, Garden and Detention pond, an optimal combination of EMPs are obtained which satisfies all constraints for the watershed at its minimum possible cost. The topographic and other landuse related parameters for this study area is obtained by using ArcGIS 9.3 and the Optimization tool box of MATLAB is used for solving the problem. The sensitivity analysis of the model parameters for the OPTEMP-LS model showed that the results are highly sensitive to rainfall intensity; whereas rainfall erodibility factor, soil erodibility factor, slope length factor and runoff coefficient of garden are observed to be moderately sensitive. Comparing the degree of sensitivity of model parameters, it is suggested that utmost importance should be given in determining the value of design rainfall intensity by referring site specific intensity duration curve.

The models OPTEMP-LM and OPTEMP-LDM for watershed with several plots under different ownership were also applied to the same micro watershed of Guwahati and found that both the models can handle different criteria of different plots of a watershed. The model OPTEMP-LM found to give better optimal EMP combination for the watershed from financial point of view compared to the model OPTEMP-LDM. However, in the OPTEMP-LM model, numbers of decision variable increase in multiple of number of plots which is computationally expensive. On the other hand, in OPTEMP-LDM model, number of variable remains same as number of EMPs considered for the study and number of stages only increases with increase in number of plots. Thus OPTEMP-LDM may be preferred over OPTEMP-LM for watershed having large number of plots with several feasible EMPs

In this chapter, an idea for enhancing sustainability of EMP project by utilizing carbon sequestration potential of vegetative EMPs was also explored. Many industries are responsible for producing green house gases and therefore they can logically compensate their GHG production by earning carbon credit. Thus if a hilly residential area can be developed to have maximum carbon sequestration through application of vegetative EMPs then a polluting industry can be asked to contribute fully or partially towards implementation and maintenance of such EMPs area to earn carbon credit as compensation for their GHG emission. Considering this an optimization model is developed for selection of EMPs in such a way that it restrict sediment and water yield from the watershed within the permissible limit and also maximizes its carbon sequestration capacity at minimum possible cost. Two options are presented (1) A Linear Programming Problem approach (OPTEMP-CSL model) which minimizes *total cost – benefits obtained from carbon sequestration* subjected to other constraints (2) A multi-objective approach (OPTEMP-CSMO model) which handles two objectives: maximization of carbon sequestration and minimization of total cost of EMPs subjected to other associated constraints. The application of the model to the micro watershed of Guwahati showed that benefits from carbon sequestration reduce the total EMP cost.

The models described in the study are application of optimization techniques with hydrological models and GIS, which are capable of providing economic solution in selecting management practices to tackle two independent but interconnected problems - soil erosion and high runoff generations from hilly urban watersheds. Judicious selection of EMPs can reduce their expenditure to a great extent, therefore cost effective and economic selection of EMPs is very important in view of a country's economy. Besides, selection of management practices by considering their hydrological behavior can enhance their sustainability in long run. Therefore for urban developments in hilly watersheds, these models can assist in suggesting modification of its landscape ecology in an ecologically and economically sustainable way.

The model capabilities can also be tested with other hydrological models like Modified Universal Soil Loss Equation (MUSLE) and sediment hydrograph, when EMPs are required towards obtaining event based control of soil erosion from the watershed area. SCS –CN method can also be used instead of Rational methods for the areas where controlling total flow volume is of more importance. Use of more advanced hydrological models with GIS interface to obtain more precise selection of EMPs through this optimization model can be explored further. Scope of improving the result by applying other solution algorithms like GA may also be tried, which can handle any non-linear relationship in the objectives and constraint functions.

In this study, the model is formulated considering urban developments in a new watershed; however EMPs can also be applied to a degraded watershed by considering its available areas for EMP, based on exiting landuse and other associated constraints related to EMP selection. This will give how best a degraded watershed can be managed to have desirable sediment and water yield at the downstream with least disturbance to the existing land use pattern. Also, instead of considering minimization of the total EMP cost for construction and maintenance; emphasis may be given to either construction cost or maintenance cost based on the priority of the planner.

Chapter 7
SUMMARY AND CONCLUSIONS

7.1. INTRODUCTION

In this chapter, a summarization of the works performed in this study followed by major conclusions is presented. Scope of further extension of this research work is also stated.

7.2. SUMMARY

Haphazard and unplanned urbanization is converting many eco-sensitive areas into multi-hazard zones. That hills and plains of Northeastern part of India is now experiencing hazards in the form of flood and landslide is a typical example of impact of rapid unplanned urbanization on ecosystem. Urbanization is unavoidable and therefore to have a hazard free urban area in a hilly eco-sensitive area, that too in an economically poor country, is a real challenge. Seeking an answer to this, development of a systematic procedure for prioritizing degraded urban watershed, analyzing impact of such degradation, and suggesting optimal management practices for sustainable development of hilly urban area was considered as the major objectives of this research work.

Review of literature on geoinformatic has revealed that spatio-temporal analysis capabilities of geoinformatics can be utilized conveniently for prioritization of intervention in degraded watersheds. Review of watershed hydrology has led to a conclusion that while hydrological models can be applied for estimating sediment and water yield from a watershed, field based experimental study is equally important to have better understanding about hydrological behavior of disturbed and undisturbed watersheds, and for estimating efficiency of different EMPs in controlling sediment and water yield. Available literature on leaching behavior of soil was reviewed and it was found that site specific study on leaching characteristic of soil is also important to know scope of water pollution due to soil erosion. Therefore leaching characteristic of soil samples collected from different parts of the metro city of northeast India was studied. Review of past works on application of optimization technique in landuse planning revealed that optimization techniques like linear programming, dynamic programming and multiobjective programming can be applied conveniently for allocating EMPs to make the management practice economically and ecologically sustainable.

A GIS based River Water Quality Information System (RWQIS) has been developed to prioritize degraded watersheds based upon river water quality. The major components of the RWQIS were the river network database and the river water quality database. Additional databases like watershed database and discharge database were also included in this river information system. These databases were made relational, which provides linking of the rivers with their respective water quality data at the geographical location of the sampling sites.

RWQIS was applied to Northeastern region of India and prioritization of degraded urban watersheds was done based on four important water quality parameters namely, DO, BOD, FC and turbidity. Some of these parameters were found to be violating in most of the urban rivers of Northeast India. Two rivers of the Guwahati city-Bharalu and Basistha, were observed to be the most urban impacted, as all these four parameters were found to be violating in several locations of these two rivers. Therefore, the Basistha river watershed and Bharalu river watershed of Guwahati city were considered as the most urban impacted catchments needing immediate attention.

A geoinformatic study along with a questionnaire survey was carried out for analyzing spatiotemporal growth of Guwahati city and following are some important findings:

(a) The built up area in the plains has been observed to be increased from 39 km^2 in 1972 to 126 km^2 in 2000. The built up area in the hills has also showed a rapid increase from 4.8 km^2 (1972) to 40 km^2 (2000) i.e. about 10 times increase in 30 years.

(b) The majority of the built up areas are concentrated in the plain areas of the city; but in recent years, the built up areas are also observed to be expanding in the hilly areas of the city.

(c) The reason of such rapid expansion in the hills is mainly due to the people coming in search of work generally residing in the hills, as they cannot afford the high cost of land in plain area of the city. This has lead to rapid deforestation of the hilly area and has resulted in increased surface erosion from the upper catchments. Plain areas of the city now experience severe flood havoc even during a moderate storm event, as deposition of eroded sediment in the natural and manmade drainage network has reduced their water carrying capacity significantly. The socio economic survey carried out in the hilly areas of the city indicated that emphasis should be given for selecting efficient management practices for controlling such hazard at least possible cost.

To have a better understanding about the impact of unplanned human intervention on hydrological processes in vegetated hilly area and to analyze scope of rectifying such degradation through application of EMPs, an experimental watershed was developed within the campus of IIT Guwahati. The basic objectives of developing the experimental watershed were (i) to investigate the hydrological response of residential development in terms of sediment and water yield, (ii) to create a facility for studying performance of some competitive EMPs in respect of soil conservation capabilities and ease of maintenance, and iii) to conduct experimentation on some selected competitive EMPs. Therefore, to understand runoff and sediment yield characteristic of disturbed and undisturbed watersheds, two adjacent watersheds with similar topographic characteristics were selected for experimental study. One of these watersheds was disturbed partially (20% of the total area of the watershed) by constructing some model houses and the other one is kept as undisturbed. The field based experimental study has shown significant differences in sediment yield and water yield pattern: about 3 -54 times increase in total runoff volume and 2-21 times increase in total sediment yield in the disturbed watershed than the undisturbed watershed.

Also, to see the effect of sediment yield on water quality, the rainfall and runoff water samples were collected from both the disturbed and undisturbed watershed and analysed to see their differences in chemical composition. It was observed that the significant changes in the basic chemical composition occur when the rainwater passes over land surfaces as runoff and also the level of ionic enrichment in the runoff water varies with sediment concentration in the samples. The disturbed watershed which is having comparatively higher sediment concentration in its runoff water than the undisturbed watersheds, do also have higher dissolved ionic concentration. For the studied ions, the percentage contributions from the soil surface was found in the order as Fe>K>HCO_3>Ca>Na>Mn.

To have an idea about sediment control efficiency of EMPs an experimental set up, having facility of studying performance of 3 EMPs at a time, was constructed in the experimental watershed. Varieties of grass species and herbs, apparently looking like having similar erosion control capacity, were identified and based on convenience, one indigenous grass (*Paspalum conjugatum*) and one herb, locally called Golden glory, (*Tradescantia zebrine*) were considered for the comparative study. Erosion control capability of these two vegetative measures was compared with bare land. Grass has been observed to have potential of controlling sediment yield in the range of 75%-100% (average = 88%), whereas has Golden glory has shown 36% -97% efficiency (average = 64%). While grass is highly efficient in controlling sediment yield, Golden glory can reduce soil erosion to a great extend.

Considering the fact that soil and sediment can significantly contribute towards chemical enrichment of runoff, it was important to study their leaching behavior in water to have a better idea on possible contribution of dissolved loads by soil and sediment in downstream water bodies. A batch leaching study was conducted for soils with different level of contaminations to study the leaching characteristics of different ions into water. Soil samples from eleven different sites spreading over the Guwahati city are collected and their leaching behavior for major ions was investigated by applying standard batch leaching test.

The study of leaching behavior of different soil types has indicated that the leaching of dissolved nutrients and trace metals varies with site condition as well as level of saturation. Thus, it is difficult to suggest a generalized leaching behavior for these soils. Overall analysis of all the samples from the 11 sites has revealed that the soil samples with high initial concentration of ions also leach out more ions. Though a more or less linear trend was observed between the ions present in soil and their subsequent amount of leaching, this cannot be expected to be true for all ions and all samples.

The results of determination of the major cations and trace metals in soil and their amount of leaching into water is used to estimate the annual loss of nutrients and trace metals that occurs due to soil erosion from a small part of the Games village watershed (area =0.17 km^2), According to the estimate of RUSLE model, yearly soil loss is 2116970 kg (natural condition) and 9738063 kg (disturbed condition with residential development). Using these results of soil leaching for the samples of this area, the computed nutrient and metal loss along with the leachable amount present in the soil were estimated for the two scenarios -natural and disturbed: and it was observed that watershed area loses significant amount of nutrients and trace metals annually and fraction of it can go to water as dissolved ion.

A method of determining the minimum sediment yield required from a watershed has been suggested by using the trend of soil leaching behavior. The described method considers the role of soil and sediment in contributing dissolved load into a water body.

Finally, the concept of optimal Ecological Management Practices (EMPs) is presented considering their hydrological behavior along with the relevant implementation constraints imposed by the owner and topographical conditions. Considering the need of selecting EMP combinations at a least possible cost, allocation of EMPs for managing sediment and water yield from hilly urban watershed has been done through watershed based optimization models. The models also consider maximum allowable EMP area, owner's choice and suitability conditions for EMPs. In this study, the RUSLE model and the Rational method were used in the optimization models to address constraints of desired sediment yield and peak discharge and the models has been developed for two different situations: plots with single ownership and plots with scope of multiple ownerships. In the multiple ownership situations, the watershed was considered to be consisting of several plots in sequence from upstream to downstream under different ownership. This approach can be applied to a relatively large watershed. The models are:

(a) OPTEMP-LS (**OPT**imal **EMP** model with **L**inear programming for **S**ingle ownership) model: For single ownership situation, the entire watershed was considered to be under single ownership and thus considered as a single plot. This problem is formulated as a linear programming problem.

(b) OPTEMP-LM (**OPT**imal **EMP** model with **L**inear programming for **M**ultiple ownership): In this approach, different EMPs in different plots of the watershed was taken as separate variables and allocation was done with constraints for their upper limit, lower limit etc with respect to their respective plots while limiting the sediment and water yield at the outlet of the entire watershed.

(c) OPTEMP-LDM (**OPT**imal **EMP** model with **L**inear and **D**ynamic programming for **M**ultiple ownership): In this model, the dynamic programming approach was taken by considering each plot from upstream to downstream to represent stages of the model. First the OPTEMP-LS model was applied to find the optimal EMP combination and respective optimal cost for different discrete sediment yield for each of the plot and these data were given as input for the recursive equation of the OPTEMP-LDM model. This model basically gives the sediment release combination for different plots, which minimizes the cost subject to the other constraints and thus indirectly gives the best EMP combination for the entire plot.

The three models, OPTEMP-LS, OPTEMP-LM and OPTEMP-LDM were applied to a micro watershed of Guwahati and Assam, India with three EMPs, namely: Grass, Garden and Detention pond, an optimal combination of EMPs. The topographic and other landuse related parameters required for the study were obtained using ArcGIS 9.3 and the Optimization tool box of MATLAB is used for solving the problem. A sensitivity analysis for the OPTEMP-LS model with the parameters of RUSLE and Rational method were also carried out and or the study watershed the results obtained were found highly sensitive to rainfall intensity; whereas rainfall erodibility factor, soil erodibility factor, slope length factor and runoff coefficient of garden were found to be moderately sensitive

Both the OPTEMP-LM and OPTEMP-LDM models can handle different criteria of different plots of a watershed. The model OPTEMP-LL found to give better optimal EMP combination for the watershed from financial point of view compared to the model OPTEMP-LDM. However, in the OPTEMP-LM model, numbers of decision variable increase in multiple of number of plots which is computationally expensive. On the other hand, in OPTEMP-LDM model, number of variable remains same as number of EMPs considered for the study and number of stages only increases with increase in number of plots. Thus OPTEMP-LDM may be preferred over OPTEMP-LM for watershed having large number plots with several feasible EMPs

Also, an idea for enhancing sustainability of EMP project by utilizing carbon sequestration potential of vegetative EMPs was explored. For this purpose, an optimization problem is formulated for selection of EMPs in such a way it restricts sediment and water yield from the watershed within the permissible limit and also maximizes its carbon sequestration capacity at minimum possible cost. To achieve this, two modeling approaches are presented:

(i) OPTEMP-CSL (**OPT**imal **EMP** model for maximizing **C**arbon **S**equestration with **L**inear programming) model: In this model, minimization of net cost (Net cost=total cost – benefits obtained from carbon sequestration) was considered as objective function subjected to other constraints

(ii) OPTEMP-CSMO(**OPT**imal **EMP** model for maximizing **C**arbon **S**equestration with **M**ulti-**O**bjective programming) model: This is basically a multi-objective approach which handle two constraint- maximization of carbon sequestration and minimization of total cost of EMPs subjected to other associated constraints

The application of the model to the micro watershed of Guwahati showed that benefits from carbon sequestration reduce the total EMP cost.

7.3. CONCLUSIONS

Based upon the study, the following conclusions can be drawn:

(i) River Water Quality Information System (RWQIS) developed in this study can be conveniently used for prioritizing degraded watersheds.

(ii) Application of the RWQIS to Northeastern region of India identified the two watershed of Guwahati City, namely Bharalu River watershed and Baistha River watershed as most urban impacted that needs immediate catchment treatment.

(iii) The geoinformatics study and socioeconomic survey carried out for analyzing spatiotemporal growth of Guwahati city revealed that the city is expanding at a faster rate in the hilly terrain, as plain areas of the city are getting almost saturated resulting in higher unaffordable price for the economically weaker section.

(iv) About 3-54 % increase in total runoff volume and 2-21 % increase in sediment yield in the disturbed watershed than the undisturbed watershed was observed, indicating that even the partial disturbances in a watershed can lead to significant changes in sediment and water yield behavior of the watershed.

(v) Study on erosion control efficiency of competitive EMPs revealed that grass has 75%-100% and golden glory has 36% -97% efficiencies as compared to barren land.

(vi) Comparison of rainwater and runoff water chemistry showed that soil and sediment plays important role in ionic enrichment of runoff water through the process of leaching.

(vii) Optimal EMP models developed were applied to a micro watershed of Guwahati city by utilizing topographic and other model parameters derived from GIS. OPTEMP-LS model can be applied when the entire watershed in under a single ownership or developed as a single plot. OPTEMP-LM and OPTEMP-LDM model are formulated for applying into a watershed having different plots.

(viii) In the case study, OPTEMP-LM was found to give better result from financial point of view compared to OPTEMP-LDM. However, OPTEM-LM model may become computationally expensive when number of plots and EMPs are numerous.

(ix) A sensitivity analysis carried out for the different model parameters used in OPTEMP-LS showed rainfall intensity to be highly sensitive; other factors like rainfall erodibility factor, soil erodibility factor, slope length factor and runoff coefficient of garden were found to be moderately sensitive. Therefore utmost importance should be given in determining the value of design rainfall intensity by referring site specific intensity duration curve.

(x) Though all these optimal EMP models have limitations of handing non linear objective function or constraints, models are considered useful as linearity assumptions made in these models are quite valid for relatively small urban watershed (in the order of $2km^2$). For example unit area cost of EMPs will not vary for such small watershed.

(xi) An idea for enhancing sustainability of EMP project by utilizing carbon sequestration potential of vegetative EMPs was explored by developing optimization model considering carbon sequestration benefit. Maximization of carbon sequestration provides a more attractive EMP combination from carbon credit point of view without increasing the cost component.

7.4. SCOPE OF FURTHER STUDIES

Following possibilities are suggested for further extension of the present work:

- As observed from the leaching study, sediments can contributes nutrients and metals to surface water. On the other hand, sediments may also have some role in absorbing pollutants from water. Such behavior of sediments can be thoroughly investigated to see whether allowable sediment yield can have some additional positive impacts on surface water quality

- Efficiency of EMP can be tested for different slope condition in laboratory and with simulated rainfall, so that experiment can be conducted in a more controlled environment. This will help in deciding efficiencies of different EMPs in different slope conditions.
- In applying the optimization model into a micro watershed of Guwahati, the values of carbon sequestration for the considered EMPs were decided based on the available literature. Laboratory and field experimentation for determining such parameters can give better idea about value of these parameters in local climatic condition.
- The concept of applying EMP to enhance carrying capacity of an already developed hilly urban area, which has otherwise reached its carrying capacity, can also be explored.

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