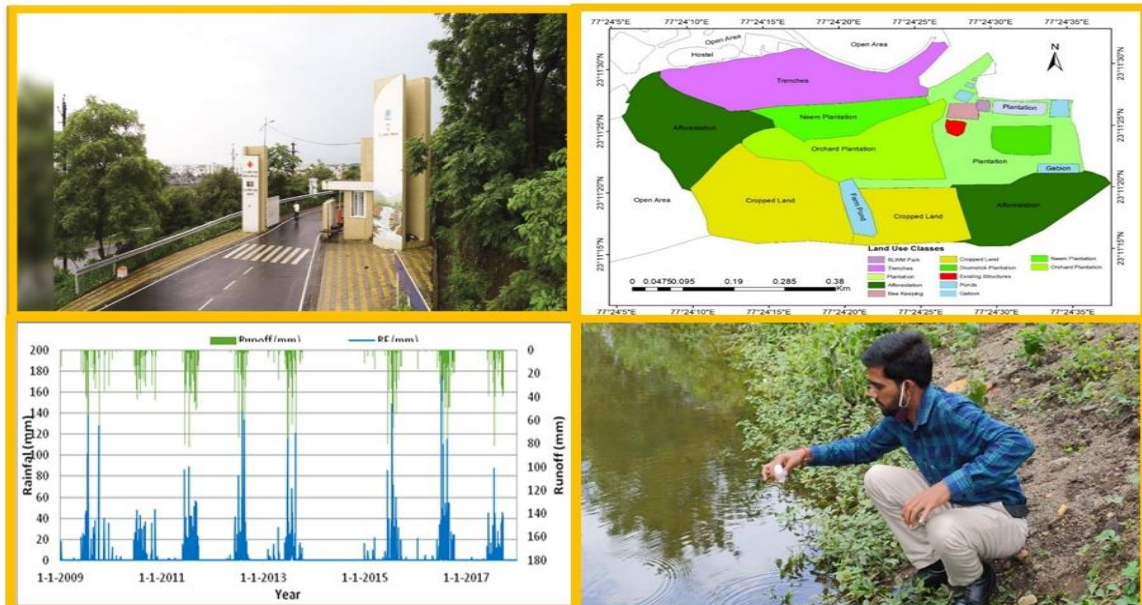


# Impact Assessment Study of Water Harvesting Structures and Soil Water Conservation Measures in WALMI Demonstration Farm Bhopal



## PROJECT REPORT

By  
**National Institute of Hydrology**  
**Central India Hydrology Regional Centre, Bhopal**

## **PREFACE**

The most basic functions of implementing soil and water conservation measures and rainwater harvesting structures are to control runoff, reduce soil erosion, improve soil fertility, conserve moisture, and artificially recharge groundwater. The conservation measures enhance source sustainability due to the building of soil moisture and minimize the loss of nutrients. The Water and Land Management Institute (WALMI), Bhopal, a premium training institute under the Ministry of Rural Development, Government of Madhya Pradesh has implemented watershed management practices, rainwater harvesting structures, soil, and water conservation measures, and natural resources management practices such as agronomic, mechanical and biological measures in the phased manner as its social responsibility in their Demonstration Farm located in WALMI Campus. WALMI, Bhopal wanted to assess the impact of these interventions on groundwater recharge and soil erosion. On request from WALMI Bhopal, the National Institute of Hydrology, CIHRC Bhopal carried out a study through scientific investigation of these aspects and prepared this report.

In the study, a detailed survey for all mechanical, biological, and agronomic measures undertaken in WALMI farms was carried out to prepare a GIS database of all interventions. The revised form of the universal soil loss equation (RUSLE) was used to assess the impact of soil conservation measures on the reduction of soil loss from the WALMI farm in the GIS environment. The water balance of all sub-watersheds was carried out to compute groundwater recharge through different rainwater harvesting structures constructed in the WALMI farm. The isotopic analysis of water samples from rain, hand pump, river, borewell, reservoirs, etc. were carried out and analyzed for assessment of the impact of these structures on groundwater recharge.

The study was carried out by Dr. R. K. Jaiswal, Sc-D, Sri R. V. Galkate, Sc-E & Head under the guidance of Dr. A. K. Lohani, Sc-G & Coordinator RC Bhopal with the support of Sri Sukant Jain, Research Scientist, Sri Vivek Morya, JRF, Miss Chanchal, JRF, and Sri Kuldeepak Pal, JRF from NIH RC Bhopal. The WALMI Bhopal has provided the necessary data and information required for the study.

**Dr J. V. Tyagi**  
**Director**

# CONTENT

---

LIST OF FIGURES	v
LIST OF TABLES	vi
ABSTRACT	vii
CHAPTER-I: INTRODUCTION	1
1.1 General	1
CHAPTER-II: STUDY AREA AND DATA USED	5
2.1 Study Area	5
2.2 Data Used	6
CHAPTER-III: OBJECTIVES OF THE STUDY	7
CHAPTER-IV: METHODOLOGY	8
CHAPTER-V: GIS DATABASE AND STATISTICAL ANALYSIS	9
5.1 Development of GIS Database and Preparation of Inventory	9
5.2 Rainfall Analysis	10
CHAPTER-VI: IMPACT OF CONSERVATION MEASURES ON SOIL LOSS	17
6.1 Soil Erosion Model	17
6.1.1 Rainfall erosivity factor (R)	18
6.1.2 Soil erodibility factor (K)	18
6.1.3 Slope length factor (L)	19
6.1.4 Slope steepness factor (S)	19
6.1.5 Crop management factor (C)	20
6.1.6 Support practice factor (P)	20
6.2 Impact assessment of conservation measures on soil loss	21
6.2.1 Soil Erosion Assessment	21
6.2.2 Soil Erosion before and after conservation measures	21
CHAPTER-VII: IMPACT OF WATER HARVESTING MESURES ON GROUNDWATER RECHARGE	27
7.1 Water Balance Analysis for Estimation of Groundwater Recharge	27
7.2 Inflow	28
7.2.1 Runoff estimation from watershed	29
7.2.1.1 SCS CN model	29
7.3 Outflow	32

7.3.1 Evaporation	32
7.3.2 Change in storage and spill	33
7.3.3 Estimation of groundwater recharge	34
7.4 Impact assessment of conservation activities on surface and groundwater regime	37
7.5 Isotopic Analysis	37
7.6 Way forward for Sustainable Development	39
CHAPTER-VIII: CONCLUSIONS	40
ACKNOWLEDGEMENT	41
REFERENCES	42

---

## LIST OF FIGURES

Figure No.	Particulars	Page
Figure 1.1:	Conversion from dry and barren land to green and prosperous land	2
Figure 1.2:	Different phases of soil erosion	2
Figure 1.3:	Soil erosion rate in India	3
Figure 2.1:	Location map of WALMI Campus	5
Figure 2.2:	Google earth engine image and location of different conservation measures	6
Figure 5.1(a):	Photographs for field survey in WALMI farm	11
Figure 5.1(b):	Photographs for field survey in WALMI farm	12
Figure 5.2:	Collection of samples and discussion with residents in nearby locality	13
Figure 5.3:	Different conservation works in WALMI farm	15
Figure 5.4:	Monthly rainfall distribution at Bhopal	15
Figure 5.5:	Annual and monsoon rainfall distribution at Bhopal	16
Figure 5.6:	Seasonal rainfall departure (%) at Bhopal	16
Figure 6.1:	Nomograph for determining the soil erodibility factor	19
Figure 6.2:	Land use maps prior and after soil and water conservation measures	22
Figure 6.3:	Soil loss from WALMI farm before conservation activities	23
Figure 6.4:	Soil loss from WALMI farm after conservation activities	24
Figure 6.5:	Distribution of soil loss prior and after conservation under different classes	26
Figure 7.1:	Watershed boundaries of Recharge structures	29
Figure 7.2:	Rainfall and computed surface runoff	31
Figure 7.3:	Rainfall and computed surface runoff for watershed -1	31
Figure 7.4:	Rainfall and computed surface runoff for watershed -2	32
Figure 7.5:	Daily evaporation and potential evapotranspiration rates	34
Figure 7.6:	Double Ring Infiltrometer test	35
Figure 7.7:	Rate of Infiltration in watershed-1	36
Figure 7.8:	Rate of Infiltration in watershed-2	36
Figure 7.9:	Concentration of $\delta O^{18}$ and $\delta D$ in different water sources	38

## LIST OF TABLES

<b>Table No.</b>	<b>Particulars</b>	<b>Page</b>
Table 1.1:	Soil erosion estimation by different studies in India	3
Table 5.1:	Rainfall statistics at Bhopal	10
Table 5.2:	Conservation measures, water harvesting, and livelihood works in WALMI Farms	14
Table 6.1:	P-factor values for different land use and slope	20
Table 6.2:	Impact of conservation works on soil loss in WALMI Farm	25
Table 7.1:	Details of water harvesting and water conservation structures constructed in the WALMI farm	27
Table 7.2:	Composite curve number for the watersheds of WALMI campus	30
Table 7.3:	Details of Watershed area and runoff generation in the WALMI farms	32
Table 7.4:	Annual Water Balance of ponds and recharge structures in WALMI Farm	37

## ABSTRACT

The water and Land Management Institute (WALMI) is an apex training institute under the Ministry of Rural Development, Govt. of Madhya Pradesh to conduct training programs for officers working in the field of hydrology, water resources, watershed management, agriculture, and other allied fields. The WALMI is situated on a flat-topped plateau called WALMI hills where steep slopes on all sides are prone to soil erosion and most of the water goes as waste in the Kaliasot river. WALMI under its social responsibility and for training and demonstration purposes has developed a demonstration farm in 33.08 ha of land as a state of the art watershed program with soil and water conservation practices and rainwater harvesting techniques through the agronomic, biological, and mechanical measures in a phased manner. Several measures like contour trenches and buds, gabion structures, farm pond, afforestation, Miywaki forestation, etc. have been undertaken to conserve soil and water in the farm. A scientific study has been carried out to assess the impact of these conservation measures on soil loss and groundwater recharge.

A detailed survey of the WALMI farm was carried out to demarcate different measures and to prepare a GIS database. The soil loss from the demonstration farm was computed using the revised universal soil loss equation (RUSLE) depends on GIS-based factors maps representing the rainfall, topographic, soil, crop management, and conservation-based factors. For assessment of groundwater recharge, the water balance of all recharge structures located in the demonstration farm were carried out considering mass balance method based on rainfall and runoff as inputs and evaporation, storage, seepage, and outflow as the major outgoing components from the watersheds. The SCS-CN rainfall-runoff model was used to simulate runoff from each sub-watershed. Soil infiltration tests were carried out using the double-ring infiltrometer to measure the infiltration rate in the watershed.

From the analysis, it has been found that the soil conservation measures adopted in the demonstration farm have helped significantly to arrest soil loss and to reduce soil erosion. The execution of conservation measures in WALMI farms has helped to reduce the average annual soil loss from 45.6 to 16.1 t/ha/yr. The SCS-CN model applied confirmed that on average 2.30 lakh m<sup>3</sup> water is generated annually as a surface runoff from the WALMI watershed area while recharge takes place at the rate of 10 mm/hr. The average annual groundwater recharge from all structures is significant and estimated as 1.86 Lakh m<sup>3</sup> which is 66% of the total rainfall volume received in the WALMI Farm area and it is sufficient to meet the demand of more than 6000 people for the whole year. The assessment through isotopic analysis of water samples from different sources confirmed the recharge and groundwater contribution from these structures in nearby areas.

# CHAPTER-I: INTRODUCTION

## 1.1 General

Soil and water are two important natural resources for the sustainable development of humankind and society at large. The basic principle of integrated watershed management is to use the land according to its capability and treat it as per the requirement. This implies that the application of appropriate soil and water conservation measures through integrated management enhances the soil moisture responsible for healthy vegetation and groundwater recharge that can protect environmental imbalance due to increasing population and industrial development. Conservation activities are more needed in metropolitan and big cities where the pollution load is higher.

Watershed management is those practices and approaches used for rational utilization of land and water resources with minimum hazard to natural resources. The main components of managing the watershed are based on the following two principles:

- Use land according to its capability and treat as per the need
- Ridge to valley concept

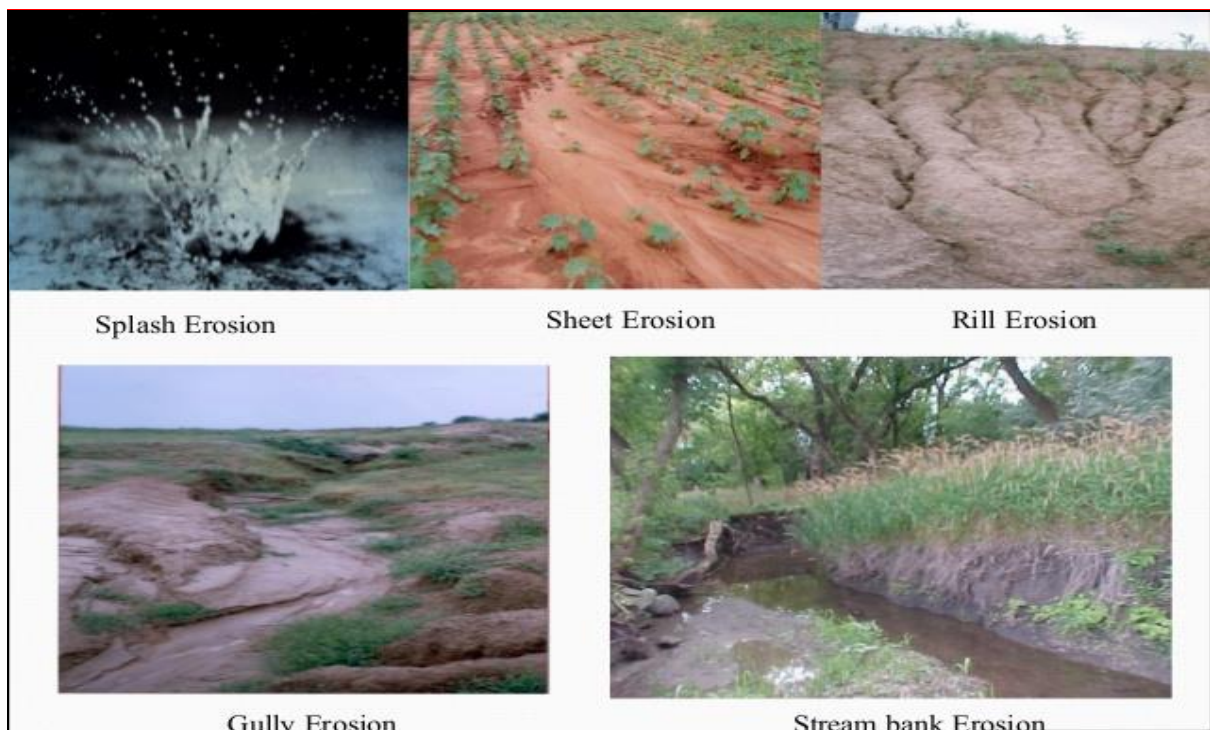
Most management activates are concentrated on reducing the velocity of flowing water. So, when the water flows through minimal velocity, its capacity to erode the topsoil is reduced and at the same time, the flowing water gets more time to infiltrate through the earth's surface and recharge the groundwater. The soil and water conservation works are the main components of any watershed management plan and should be done through agronomic, biological, and mechanical measures. A careful and scientifically designed and implemented management plan can provide manifold benefits and prove to be the key to success for rural India as shown in **Figure 1.1**.

Soil is a natural body containing mineral particles and organic constituents separated into horizons of numerous depths and soil acts as a storehouse for plant nutrients, an environment for microorganisms, and a reservoir that has sufficient water holding capacity for plant growth. Land degradation is the breakdown or loss of soil fertility as a result of soil removal or subtraction of nutrients from water passing over the soil profile. Quality of land and negatively affecting flood formation, livelihoods, and the invention and provision of additional goods and services.



**Figure 1.1: Conversion from dry and barren land to green and prosperous land**

Soil erosion may be defined as the process of detachment or removal, transport, and subsequent deposition on other suitable places is described as soil erosion accompanying geographic procedures or agents such as flowing water, storms, glaciers, and coastal waves. But nowadays it is becoming a serious threat due to improved anthropogenic interventions over the period. The soil erosion affects mainly the damage of the topsoil profile which is the best productive zone having a depth of 20 to 30cm. Increased soil erosion contributes to nutrient loss, which decreases agricultural yield. The destruction of the agricultural lands started from rain splash erosion to sheet erosion, rill, gullies, and lastly to bank erosion that make huge losses to farmers and society as a whole (Figure 1.2).



**Figure 1.2: Different phases of soil erosion**

In India, the annual soil erosion is about 16.35 tons per hectare which indicates the loss of 5334 million tons per year (Narayana and Ram Babu 1983). It was projected that nearly 29 percent of eroded soil is reached and misplaced to sea, 10 percent settled in reservoirs (therefore the storage volume gets decreased up to 2 % yearly) then 61 percent is purely shifted from one place to another. Soil erosion estimation by different studies in India is shown in Table 1.1.

Table 1.1: Soil erosion estimation by different studies in India

Studies	Region (Mha)
The National Bureau of Soil Survey & Land Use Planning (NBSS & LUP, 2005)	119.19
Sehgal and Abrol (1997)	167.0
Sehgal and Abrol (1994)	162.4
National Commission on Agriculture (1976)	150.0

The ISO-erosion map showing the lines joining the same rate of erosion has been presented in **Figure 1.3** where it can be seen that the central Indian region has a high soil erosion rate in the range of 10 to 20 t/ha/yr.

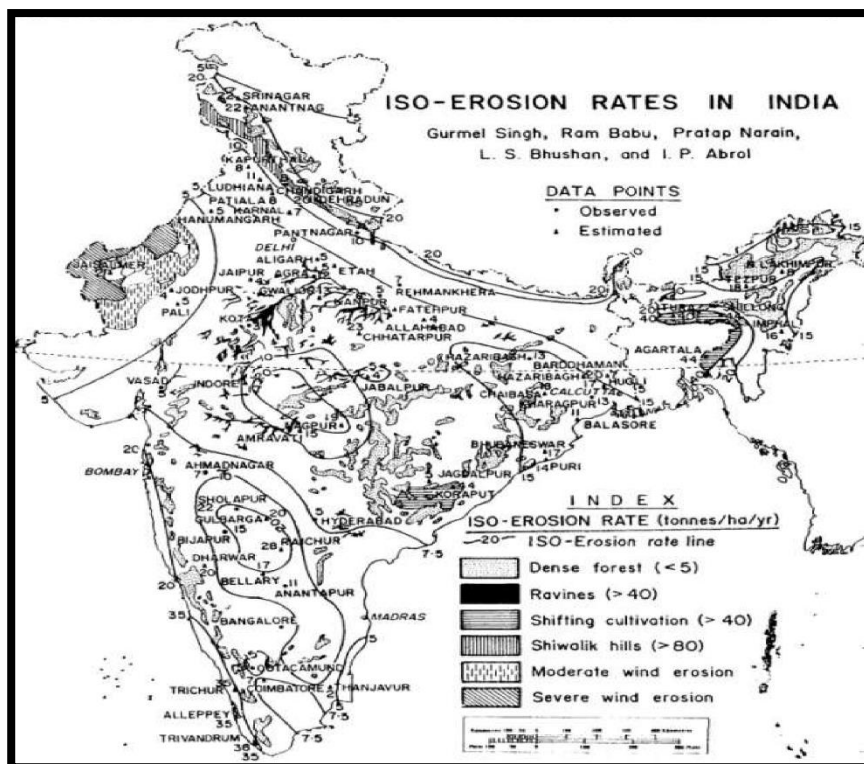


Figure 1.3: Soil erosion rate in India (<http://www.ciesin.columbia.edu/docs/002-413/Figure1.gif>)

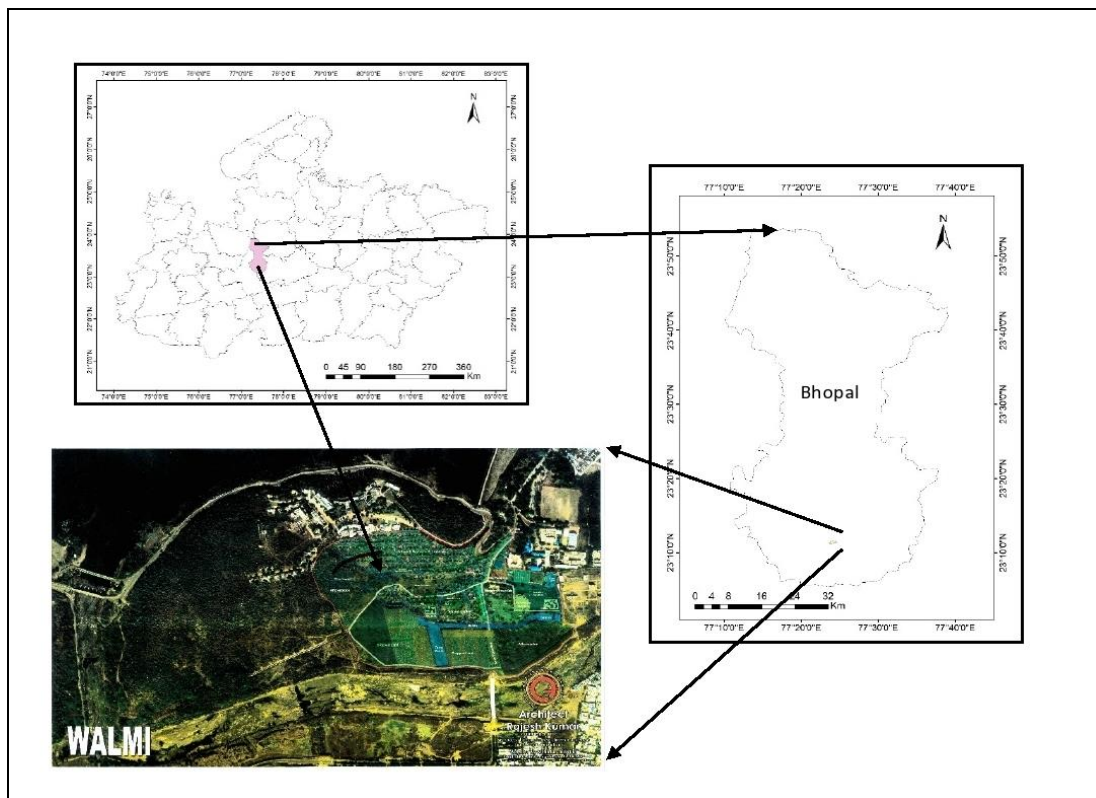
The uneven spatial and temporal distribution with the concentration of rainfall in only monsoon months motivates and forces to use water conservation to recharge groundwater artificially to get the appropriate amount during the summer season. The conservation of water is getting important day by day due to the fast-growing population and drastically reducing the number of rainy days during monsoon. The state of Madhya Pradesh faces a water scarcity problem every year and the most sufferer of this catastrophic event is women who line up long or travel miles for fetching water in rural part.

The Water and Land Management Institute (WALMI, Bhopal) is situated at WALMI hills in Bhopal, the capital city of Madhya Pradesh state. The WALMI is situated on a flat-topped hill with a Kaliyasot reservoir on one side and the river Kaliyasot on the other. Considering the importance of soil and water conservation and livelihood issues, the WALMI is doing significant mechanical, biological conservation measures along with other eco-management activities in its 33.08 ha farm and other areas. The construction of several soils and water conservation and water harvesting structures has been carried in different phases and WALMI Bhopal wanted to study and assess the impact of these interventions based on scientific analysis. The WALMI complex is well known for its greeneries and innovation for soil and water conservation, vertical farming, use of waste products, etc. in Madhya Pradesh. In this background, the Central India Hydrology Regional Centre Bhopal of National Institute of Hydrology has carried out a technical assessment of the impact assessment of interventions and other resource management works on hydrological regime in WALMI farms and the nearby area.

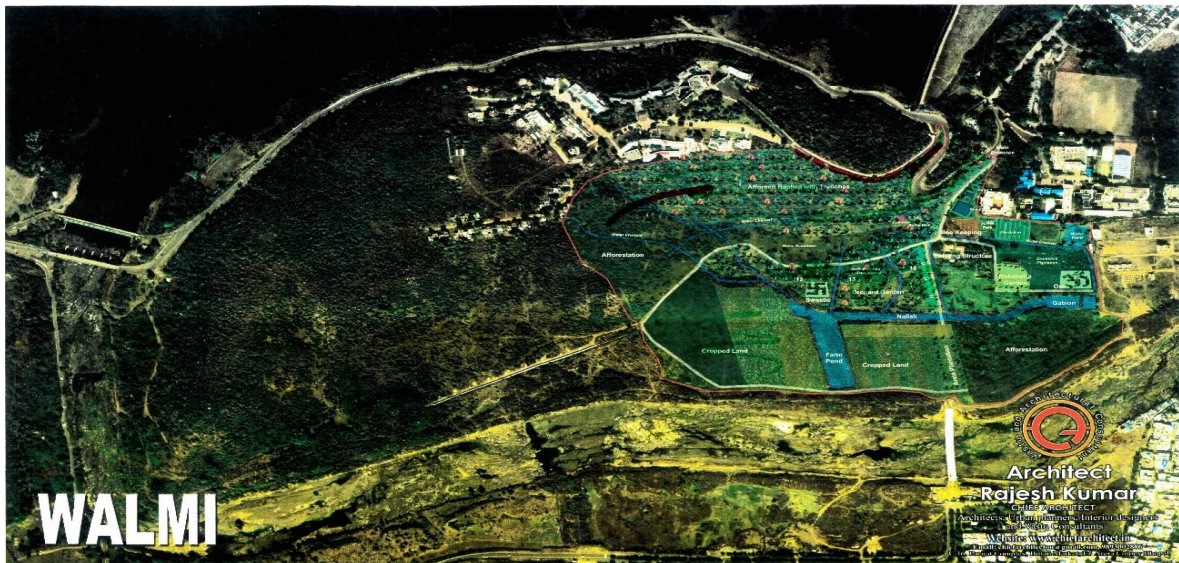
## CHAPTER-II: STUDY AREA AND DATA USED

### 2.1 Study Area

Water and Land Management Institute (WALMI), Bhopal is situated on hills near Kaliasot dam in the capital of Bhopal. The WALMI is situated on a flat hillock surrounded by a beautiful valley and steep slope land subjected to a high rate of soil erosion. The WALMI has developed a 33.08 ha farm where different agronomic, biological, and mechanical soil and water conservation and water harvesting structures including trenches, boulder bunds, gabion structures, farm ponds, afforestation, plantation, and beekeeping, organic manure for society education. Appropriate plants suitable for the region were selected and the Miyabaki tree plantation system was adopted for sustainable plant growth. The water and soil conservation activities have been implemented in a phased manner in the WALMI farm and it was imperative to evaluate the impact of these structures on recharge of groundwater along with control of soil erosion and soil moisture maintenance. The base map of WALMI and farm are presented in **Figure 2.1** and Google image in **Figure 2.2**



**Figure 2.1: Location map of WALMI Campus**



**Figure 2.2: Google earth engine image and location of different conservation measures**

The boundary of the WALMI farm is displayed with the red line and different types of structures, afforestation areas, plantations, ponds, gabions, and well-managed cropped areas are shown. The total area of the WALMI farm is about 33.08 ha where soil and water conservation measures were taken in a phased manner.

## 2.2 Data Used

In the study, a detailed survey of the study area was carried out to develop a spatial database of WALMI Farm. The rainfall data of the Bairagarh rain gauge station of the India Meteorological Department (IMD) from 1980 to 2017 was used for statistical analysis, drought analysis, runoff computation, and soil loss estimation. The climatic data of the Bhopal station collected from IMD was used to compute evaporation from the free water surface. The Survey of India toposheet, google map, soil map from the National Bureau of Soil Survey and Land-use Planning (NBSSLUP), Nagpur was used for the preparation of land use and soil map of the study area. The infiltration tests were conducted using a double-ring infiltrometer to compute the infiltration rate in the WALMI farms. Water samples were collected from the WALMI farm and nearby areas and analyzed at the laboratory of NIH Roorkee for isotopic analysis.

### **CHAPTER-III: OBJECTIVES OF THE STUDY**

The impact assessment studies are being carried out to understand desired benefits from works carried out for specific purposes and to decide the future course of action to achieve the goals. The soil and water conservation measures consist of different mechanical, biological, and agronomic activities to recharge groundwater and build surface storages. The present study mainly focused on the assessment of the impact of different mechanical and biological activities carried out by WALMI on the hydrological regimes, especially on soil and water with the following objective.

- Impact of conservation activities on soil erosion
- Impact of watershed practices and water harvesting activities on surface and groundwater regime
- The way forward for sustainable development and management of conservation activities

## **CHAPTER-IV: METHODOLOGY**

The impact of measures for soil and water is well known but in the absence of more comprehensive evidence, it is frequently used to refute particular positions. To validate such variable evidence, a comprehensive and scientific study based on spatial and GIS-based approaches can be used to understand the benefits and trade-offs, and synergies of different interventions to meet social targets. The methodology for impact assessment analysis consists of the following steps.

### **1. Impact of conservation measures on soil loss**

#### **a. Development of GIS database and Perpetration of Inventory**

- i. Field Survey
- ii. Base map preparation
- iii. Intervention mapping
- iv. Thematic maps

#### **b. Soil erosion modeling**

- i. RUSLE model

#### **c. Rainfall-runoff modeling**

- i. SCS-CN model

### **2. Impact of water harvesting measures on groundwater recharge**

- i. Recharge estimation
- ii. Evaporation
- iii. Sample survey
- iv. Isotopic Analysis for impact assessment

### **3. The way forward for sustainable management**

The objective-wise detailed methodology adopted and results of the study are presented in the subsequent chapters.

## CHAPTER-V: GIS DATABASE AND STATISTICAL ANALYSIS

The soil erosion and groundwater recharge assessment are spatially and temporally varied phenomenon depends on topography, soil, climate, land cover, etc., and hence a GIS database of all varied factors was developed through detailed field survey and data collection from diverse sources.

### 5.1 Development of GIS Database and Preparation of Inventory

Geographic Information System (GIS) plays an important role in generating automated spatial datasets and in establishing spatial relationships. During the last few decades, GIS software has gained importance for generating overlays and making site-specific decisions. Multi-spectral remotely sensed satellite data plays a vital role in the generation of the overlays. Manual integration of the entire surface and sub-surface information requires a huge expenditure of manpower and time. Working on the GIS platform is faster, more accurate, and therefore cost-effective. The integration of satellite imagery and GIS has eased the data integration and analysis of very large data sets. A GIS captures, stores, analyzes, manages, and presents data that is linked to location. In the study, ARC GIS has been used to digitize different raster maps collected from WALMI, field information collected through surveys, and analyze these maps and information to obtained useful results.

WALMI has carried out several soil conservation works in the past demonstration farm, but the exact locations and intensity were not documented properly. Very limited information about different intervention and their actual field location was available with us and hence a detailed field survey of the WALMI farm was carried out to get the exact location of conservation measures, their numbers, and latitude, longitude, etc. The detailed survey was carried out by the staff of NIH Bhopal and WALMI on the farm, where the locations of all previous conservation measures were recorded with the help of GPS. This was very tedious and cumbersome work where every measure needs to be recorded and carried out successfully with the commitment of NIH staff. The WALMI since its inception has carried out different soil and water conservation measures in the demonstration farm for teaching and as a part of its social responsibility. Photographs of the field survey are given in **Figures 5.1(a)** and **5.1(b)**. For determination of groundwater recharge, isotopic analysis of water at different sources like ponds, Kaliasot reservoir, hand pump, bore well were collected and sent to analysis at NIH lab. The photographs of the collection of water samples for

isotopic, interaction and discussion with local people are shown in **Figure 5.2**. The different conservation measures and livelihood works carried out in the farm area are presented in **Table 5.1** and their location in **Figure 5.3**. The measurement of different mechanical, biological and agronomic measures was made to assess the impact of these works. During the survey, contour trenches, bolder bunds, afforestation, Miyawaki plantation, gabions, recharge and collection ponds, basin bunds were collected and all were digitally transferred to the GIS database. This information was further used in the assessment of soil loss and groundwater recharge through GID based modeling technique.

## 5.2 Rainfall Analysis

The WALMI Campus Bhopal has the nearest rain gauge station of IMD at Bairagarh at Bhopal Airport. The Long-term rainfall data from 1980 to 2017 was analyzed and its statistical characteristics are shown in **Table 5.1**.

Table 5.1: Rainfall statistics at Bhopal

<b>Statistic</b>	<b>Monsoon rainfall (mm)</b>	<b>Annual Rainfall (mm)</b>	<b>Rainy days</b>
Average	1024.44	1108.05	51
Std Deviation	260.77	314.69	10
Maximum	1655.70	1883.20	69
Minimum	597.70	724.30	10

The average annual rainfall at Bhopal is observed 1108 mm with a standard deviation of 314 mm indicating the very high temporal variability of rainfall. The Bhopal experiences on average 50 to 55 rainy days every year.

From the rainfall analysis, it is clear that the rainfall at Bhopal is erratic in nature and huge temporal variation which calls for systematic management of water resources and development of water resources, and augmentation of groundwater recharge to meet demands during water scarcity years. Monthly rainfall and monsoon or annual rainfall distribution at Bhopal have been shown in **Figure 5.4** and **Figure 5.5**. It can be seen that Bhopal receives rainfall mainly during the southwest monsoon months from June to September.



**Figure 5.1(a): Photographs for field survey in WALMI farm**



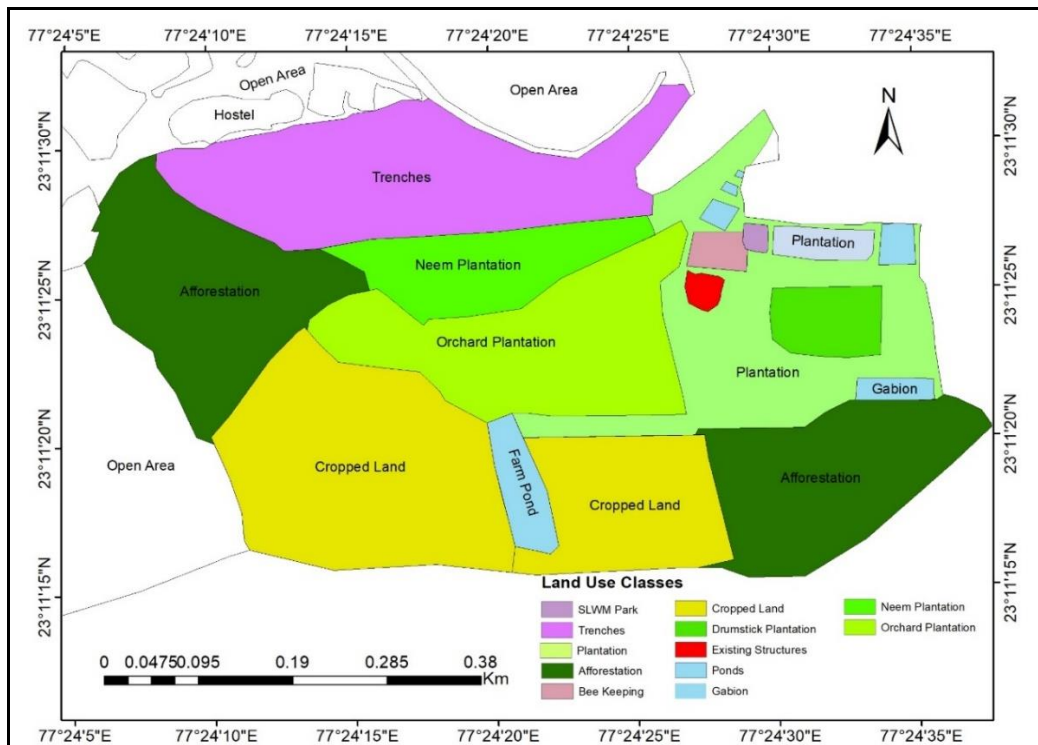
**Figure 5.1(b): Photographs for field survey in WALMI farm**



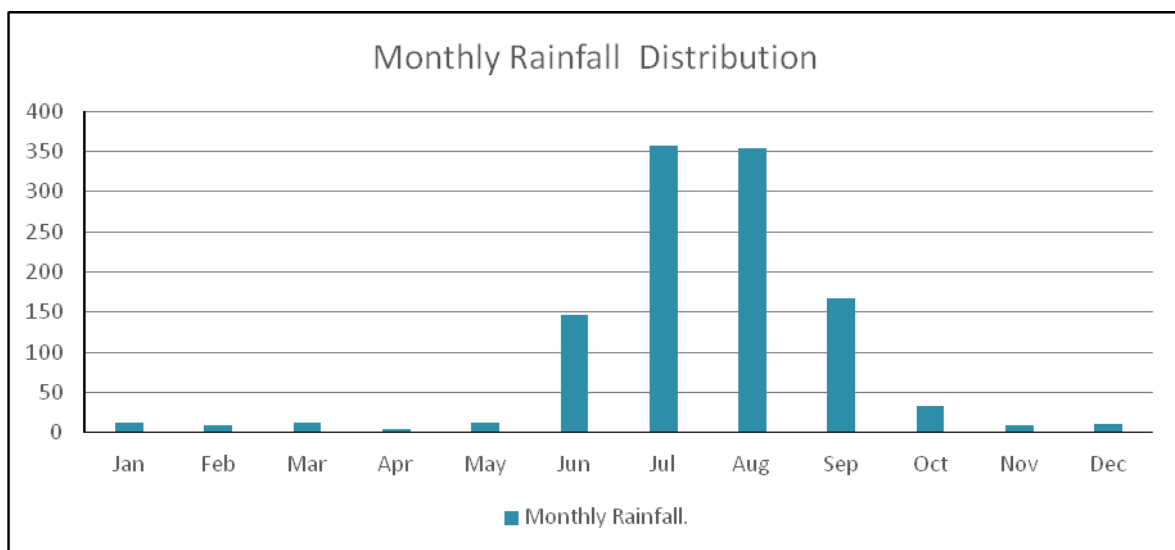
**Figure 5.2: Collection of samples and discussion with residents in nearby locality**

Table 5.2: Conservation measures, water harvesting, and livelihood works in WALMI Farms

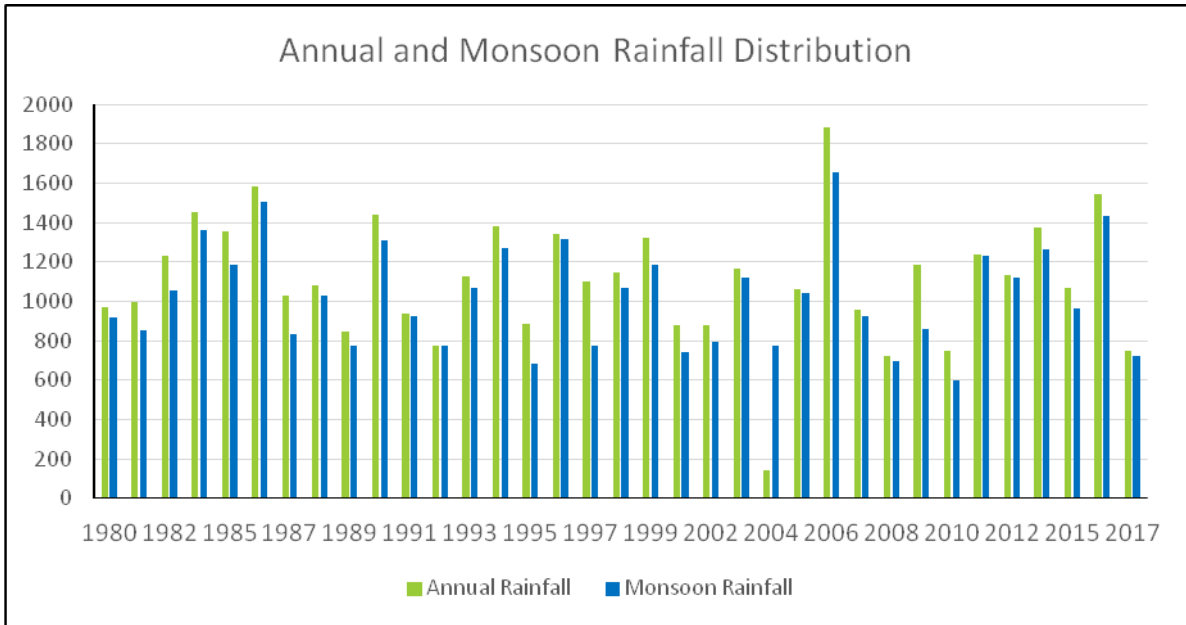
<b>Name/Location</b>	<b>Conservation measures</b>	<b>Shape Area (m<sup>2</sup>)</b>	<b>Area (ha)</b>
Afforestation	Forest	39147.50	3.91
Afforestation near Gabion	Afforestation	33690.44	3.37
Bee Keeping	Bee Keeping	2140.93	0.21
Cropped Land	Cropped Land	53285.23	5.33
Cropped Land (Amla Plantation)	Cropped Land (Amla Plantation)	25167.25	2.52
Drumstick Plantation	Dense Plantation	7722.98	0.77
Gabion	Gabion	1764.16	0.18
Neem Plantation	Plantation	19380.46	1.94
Orchard Plantation with trenches	Plantation	40965.10	4.10
Plantation	dense forest	3218.36	0.32
Plantation	Plantation	43218.35	4.32
Farm Pond	pond	5675.84	0.57
Pond 1	Pond	49.61	0.00
Pond 2	Pond	149.56	0.01
Pond 3	Pond	719.88	0.07
Water Pond	pond	1453.69	0.15
SLWM Park	Settlement	692.64	0.07
Trenches	Trenches	51694.39	5.17



**Figure 5.3: Different conservation works in WALMI farm**

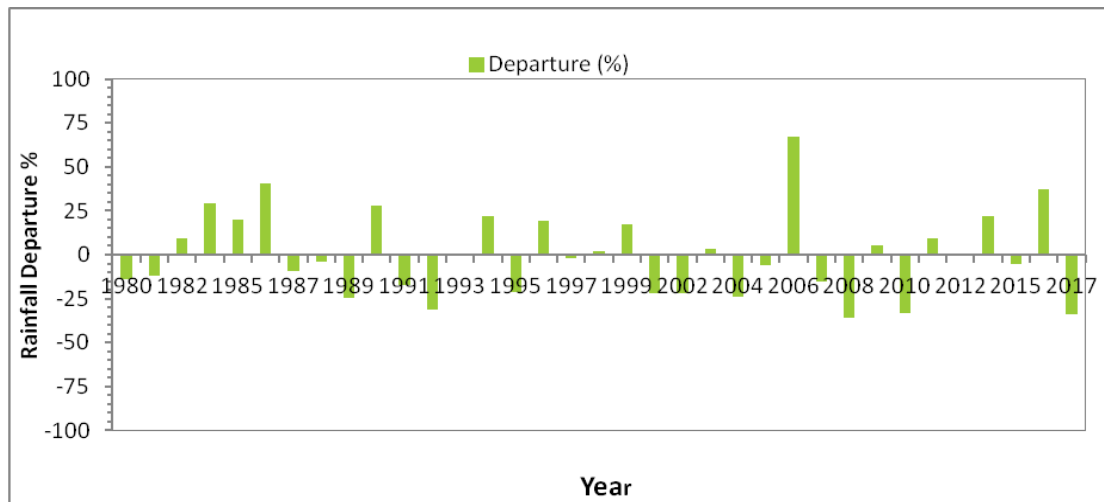


**Figure 5.4: Monthly rainfall distribution at Bhopal**



**Figure 5.5: Annual and monsoon rainfall distribution at Bhopal**

The seasonal rainfall departure analysis of Bhopal shown in **Figure 5.6** indicates the average drought frequency of once in six to seven years as rainfall departure of more than 25% from normal rainfall was found in 6 years of total 37 years data. The rainfall departure analysis confirmed at least one drought after every 6 to 7 years at Bhopal.



**Figure 5.6: Seasonal rainfall departure (%) at Bhopal**

## CHAPTER-VI: IMPACT OF CONSERVATION MEASURES ON SOIL LOSS

Four general factors that influence the magnitude of erosion from a watershed are climate, soils, topography, and land cover. The frequency, intensity, quantity, and duration of rainfall affect soil erosion and sediment transport. Even low-intensity rainfall will induce runoff in areas where soils are easily saturated. Different types of soil have different susceptibilities to erosion. Soil erodibility varies with soil texture (particle size distribution), organic matter content, and structure (particle aggregation). High organic matter content improves the structure and permeability of the soil, and thereby reduces its erodibility. A fine-textured soil with a granular structure is the least erodible. Slope length and slope steepness influence soil erosion and greater slope length below the point where runoff begins to tend to increase the depth and velocity of runoff and thus will detach more soil particles. Cover vegetation absorbs the energy of falling raindrops, provides a physical barrier to particle movement, binds the soil in place with roots, and extracts water from the soil to increase its absorptive capacity. The best management practices (BMP) refer to a variety of agronomic, biological, and mechanical conservation measures to minimize the production and transport of sediments. Erosion and sedimentation can be reduced in three general ways:

- (1) Stopping or minimizing erosion from disturbed areas by conservation measures
- (2) Controlling the erosive impacts of increased or concentrated runoff
- (3) Minimizing opportunities for sediments to be transported to streams

In the present study, the agronomic, biological, and mechanical conservation measures (BMP) developed in the farm of WALMI were evaluated for their competence through a survey during the rainy season, and accordingly affecting factors in the RUSLE model were modified to compute soil loss after application of conservation practices.

### 6.1 Soil Erosion Model

The universal soil loss equation model (USLE) and its revised version RUSLE are the most commonly used in the world for estimating soil loss based on multiple plot studies in the USA (Weismeyer & Smith, 1960). This model represents climate, soil, topographic, land use, and conservation variation with the help of six different factors in the following equation. The parameters of USLE and RUSLE models can be presented as follows:

$$A = R * K * L * S * C * P \quad (6.1)$$

Where, A = Soil loss (t/ha/yr),

R = Rainfall erosivity factor (MJ-mm/ha\*h\*yr)

K = Soil erodibility factor (t\*h/MJ\*mm)

L = Slope length factor (dimensionless)

S = Slope steepness factor (dimensionless)

C = Cover management factor (dimensionless)

P = Supporting practice factor (dimensionless)

### 6.1.1 Rainfall erosivity factor (R)

Rainfall erosivity index (R) implies a numerical evaluation of a rainstorm or of a rainfall pattern which is a function of intensity and duration of rainfall and mass, diameter, and velocity of the raindrop. In India, using 45 stations, distribution in different rainfall zones, simple linear relationship between erosivity index and annual or seasonal rainfall has been developed (Singh et al. 1981)

Annual R factor ( $R_a$ ),

$$R_a = 79 + 0.363 * P_a \quad (6.2)$$

Seasonal R factor ( $R_s$ ),

$$R_s = 50 + 0.389 * P_s \quad (6.3)$$

Where  $P_A$  and  $P_s$  are the annual and seasonal rainfall in mm.

### 6.1.2 Soil erodibility factor (K)

The soil erodibility factor relates to the rate at which different soils erode. K is expressed as soil loss per unit of area per unit of R from a standard plot (a plot of 22.3m long with a uniform slope of 9% under continuous fallow and tilled parallel to the slope). Erodibility varies with soil texture and organic matter content. This factor was originally determined quantitatively from the runoff plots. Various researchers have given K value for different soils for India and abroad used in the USLE model, while RUSLE estimates the K value using textural property, organic contents, textural property, and permeability. The nomograph for the determination of K is given in **Figure6.1** in the study, the standard values for different soils in Indian conditions have been used.

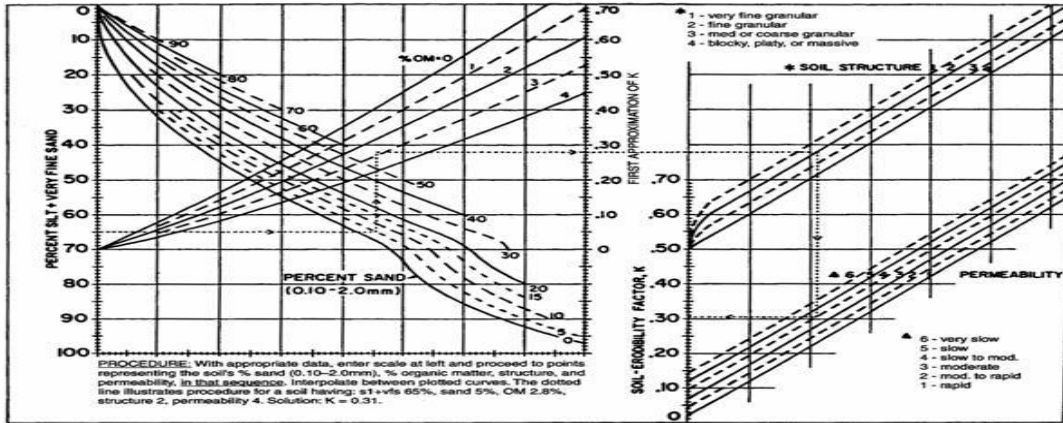


Figure 6.1: Nomograph for determining the soil erodibility factor

### 6.1.3 Slope length factor (L)

The slope length factor (L) is the ratio of soil loss from the field slope length to that from 22.13 m length plots under identical conditions. The L-factor can be computed using the following equation:

$$L = \left( \frac{\lambda}{22.10} \right)^m \quad (6.4)$$

where,  $\lambda$  is the field slope length and can be worked out as;  $\lambda = (\text{level difference/slope}) * 100$  and  $m$  are the exponent varies from 0.2 for slope less than 1%, 0.3 for slope from 1% to 3%, 0.4 for slope from 3% to 5% and 0.5 for slope more than 5% slope.

### 6.1.4 Slope steepness factor (S)

The slope steepness factor is the ratio of soil loss from the field slope gradient to that from the 9% slope under otherwise identical conditions. The following equation suggested by Wischmeier and Smith (1965) has been used for evaluating the slope gradient factor:

$$S = \frac{[0.43 + 0.30G + 0.43G^2]}{6.613} \quad (6.5)$$

Where G is the slope gradient in percent.

The slope length factor (L) and slope steepness factor (S) are computed in combination as SL-factor using the following equation:

$$SL = \sqrt{\frac{l}{22}} [0.065 + 0.045 * s + 0.0065 * s^2] \quad (6.6)$$

Where  $l$  is the slope length and  $s$  is the slope in percent.

### 6.1.5 Crop management factor (C)

The cover management factor (C) and support practice factor are important factors that decide the intensity and impact of soil conservation practices applied in the watershed. The standard values of these factors for limited and conserved conditions for different land uses were used in the analysis. For the determination of the C-factor in RUSLE, the NDVI image is used. The following equation suggested by Van der et al. 1999, 2000 has been used for the estimation of the C-factor which is further modified by (Mokua, 2009).

$$C = Z * \exp\left[\frac{-\alpha - NDVI}{\beta - NDVI}\right] \quad (6.7)$$

For the computation of the value of Z, a scalar graph can be plotted between NDVI and C-factor, and the value of Z has been determined by iterations to scale the values of C-factors from 0 to 1.

### 6.1.6 Support practice factor (P)

The P factor in USLE is expressed as a ratio, which compares the soil loss from the investigated plot cultivated up and down the slope gradient. In the case of the USLE model, the agricultural area of the catchment has been divided into different slope ranges and according to the slope, the values of the P-factor have been assigned. For other land uses, standard values considering no conservation measures have been given. **Table 6.1** indicated the P-factor values for different land uses used in USLE and RUSLE models.

Table 6.1: P-factor values for different land use and slope

S.N.	Land use	Slope (%)	P- Factor	
			USLE model	RUSLE model
1.	Dense forest	All slope	0.8	0.8
2.	Agriculture	0 % to 2 %	1.0	0.6
		2 % to 5 %	1.0	0.5
		5 % to 8 %	1.0	0.5
		8 % to 12 %	1.0	0.6
		12 % to 16 %	1.0	0.7
		16 % to 20 %	1.0	0.8
		More than 20 %	1.0	0.9
3.	Scrub	All slope	1.0	0.8
	Settlement	All slope	1.0	1.0
	Waterbody	All slope	1.0	1.0

## **6.2 Impact assessment of conservation measures on soil loss**

This study aimed to assess the current state of soil erosion in comparison to previous soil erosion before conservation measures using GIS applications in the study area. First, the traditional application of the RUSLE model in assessing erosion, second the application of GIS and remote sensing techniques in predicting and estimating the magnitude and spatial distribution of erosion in WALMI farm using RUSLE. The agronomic, biological, and mechanical conservation measures (BMP) developed in the WALMI farm were evaluated for their competence through a survey during the rainy season, and accordingly affecting factors in the RUSLE model were modified to compute soil loss after application of conservation practices.

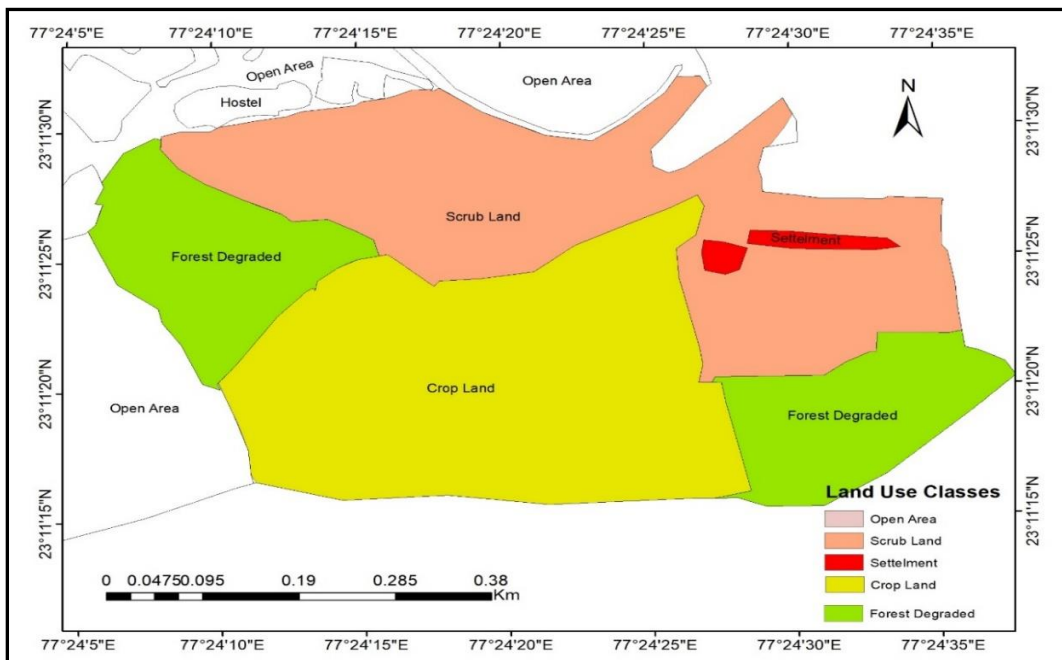
### **6.2.1 Soil Erosion Assessment**

The soil loss from the watershed of WALMI farm before implementation of conservation measures has been assessed in the GIS environment using the RUSLE model. The thematic maps of different factors under minimum or no-conservation conditions (Prior situation) were prepared and integrate to compute soil loss. Initially, rainfall data were analyzed and detailed land use maps before and after conservation were prepared with the past data and field surveys. The land use map prior and after conservation measures are shown in **Figure 6.2**.

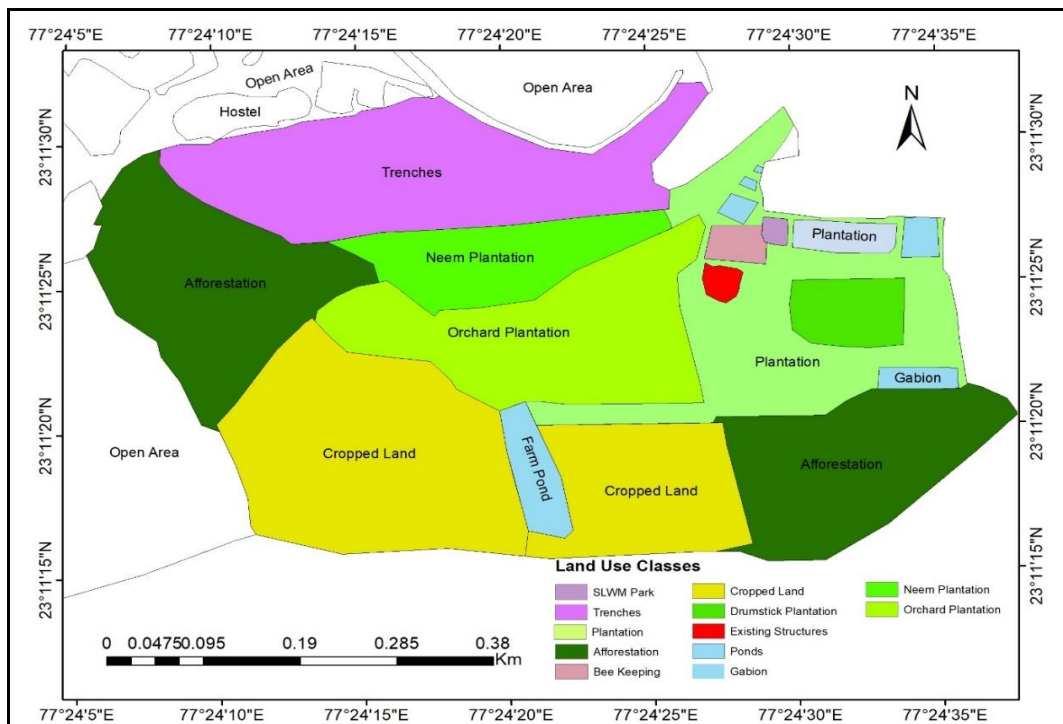
From the land use survey, it has been observed that extensive conservation measures such as trenches, bunds, ponds, plantation, afforestation, and gabion, etc. were constructed by WALMI in the past and they have a visible impact on soil loss and groundwater recharge. Nearly 1800 trenches have been constructed and more than 1000 plants have been planted and grown on the farm.

### **6.2.2 Soil Erosion before and after conservation measures**

For impact assessment of soil and water conservation measures and best management practices (BMPs) on soil loss, the values of C-factor and P-factor were decided/fixed based on the information derived from the field surveys and collected data from the field. The factor map and resultant soil loss after conservation measures are presented in **Figure 6.3**. The factors resultant soil loss map before the conservation measures is presented in **Figure 6.4**. The soil loss before conservation measures was ranged from 1.5 t/ha/yr to 180 t/ha/yr with an average value of 45.6 t/ha/yr.



(a) Prior to conservation activities



(b) After conservation activities

Figure 6.2: Land use maps prior and after soil and water conservation measures

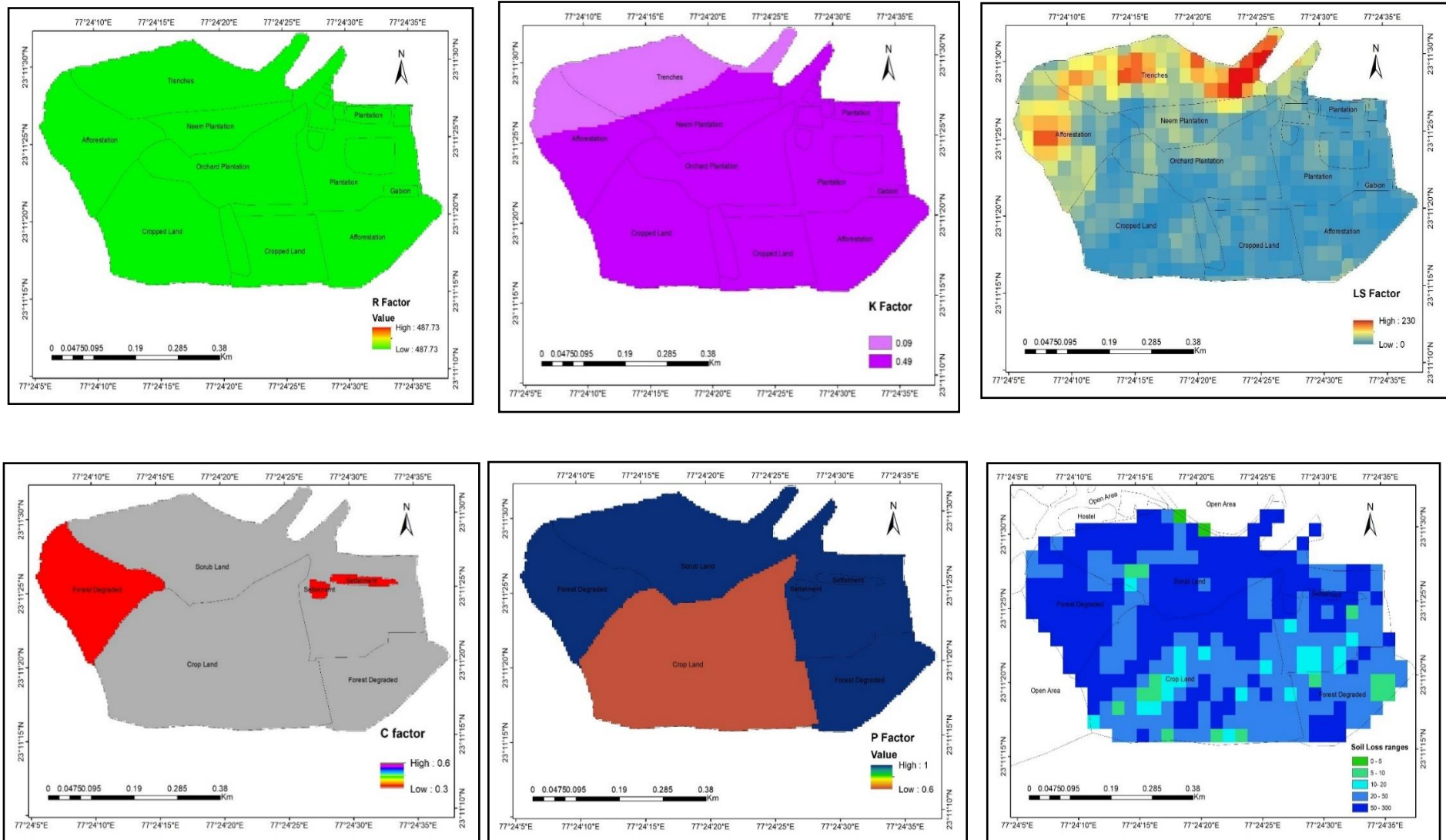


Figure 6.3: Soil loss from WALMI farm before conservation activities

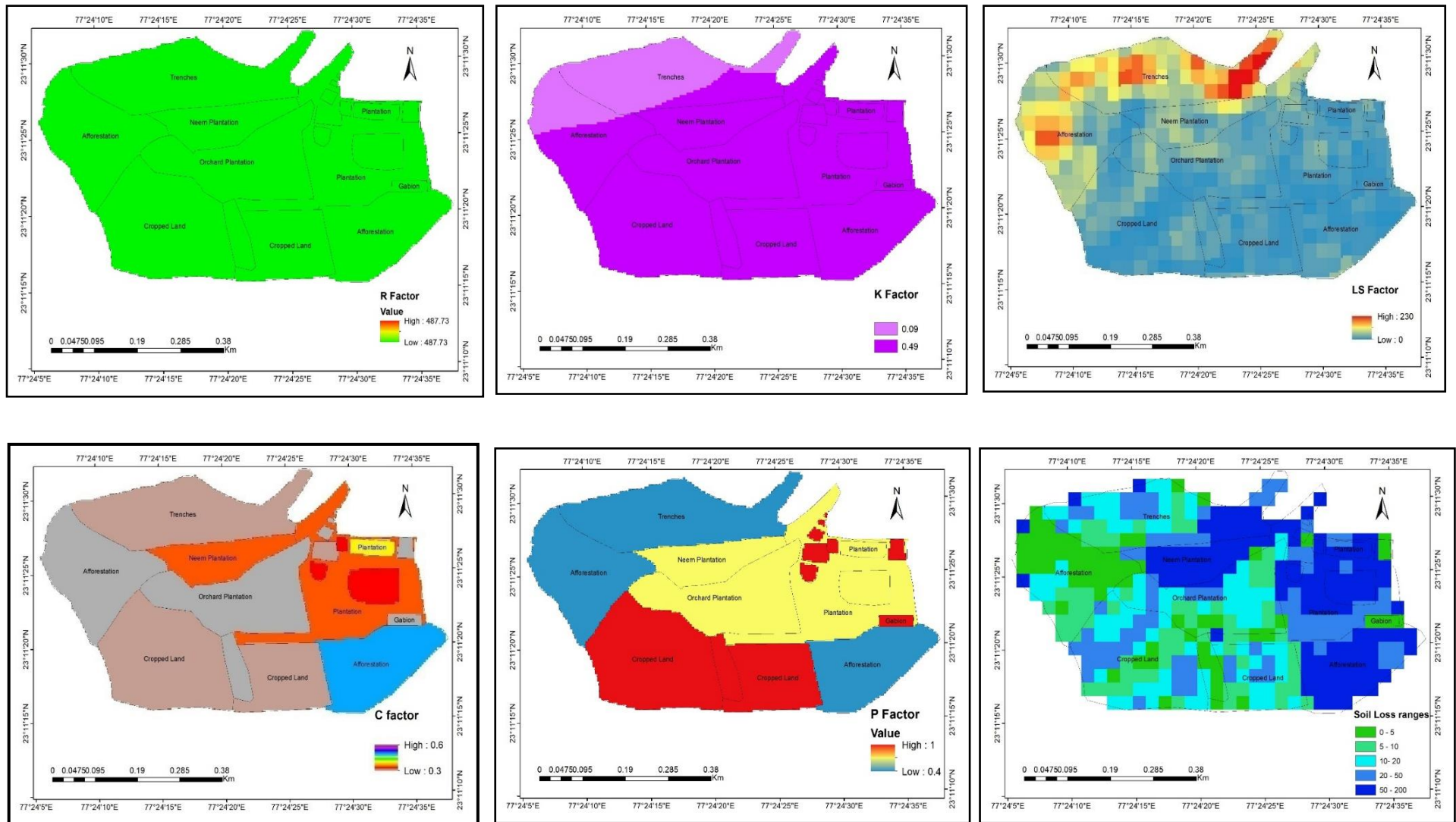
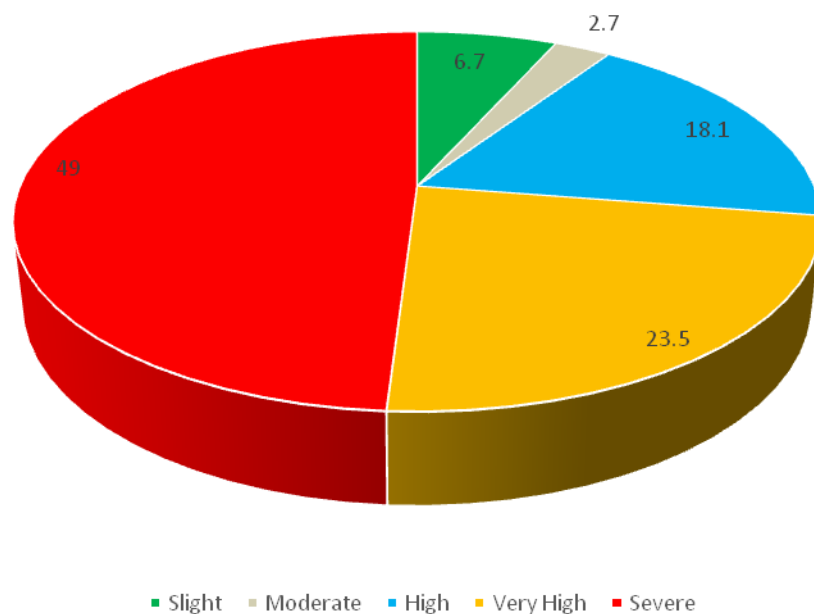


Figure 6.4: Soil loss from WALMI farm after conservation activities

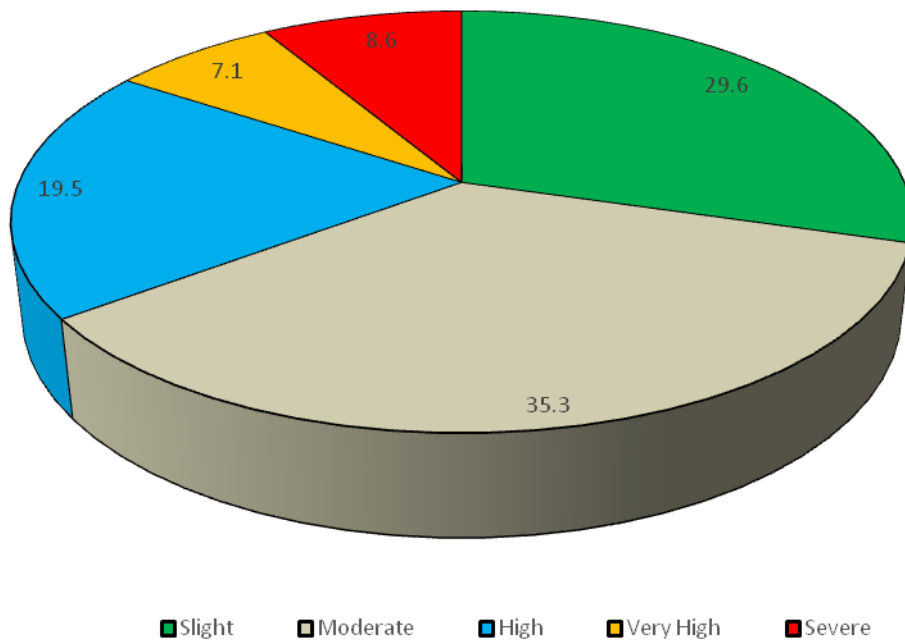
The soil loss from a catchment is mainly a function of conservation measures considering climate, soil, and topography as constant. The soil loss before and after application of scientifically designed BMPs was analyzed and found that the average soil erosion was about 45.6 t/ha/yr before the implementation of conservation measure has reduced to 16.1 t/ha/yr under present condition (BMPs used and conservation works executed). The soil loss from different areas have been classified in five different classes i.e. less than 5 t/ha/yr as slight, 5 to 10 t/ha/yr as moderate, 10 to 20 t/ha yr as high, 20 to 50 t/ha/yr as very high and more than 50 t/ha/yr as severe. The distribution of soil loss in different classes is presented in **Table 6.2** and **Figure 6.5**.

Table 6.2: Impact of conservation works on soil loss in WALMI Farm

Soil loss class	Range (Tonn/ha/ha)	Prior conservation works		After conservation works	
		Area (ha)	Percentage	Area	Percentage
Slight	Less than 5	2.22	6.7	9.78	29.6
Moderate	5 to 10	0.89	2.7	11.66	35.3
High	10 to 20	5.99	18.1	6.45	19.5
Very high	20 to 50	7.78	23.5	2.35	7.1
Severe	More than 50	16.2	49.0	2.85	8.6



(a) Before conservation activities



**(b) After conservation activities**

**Figure 6.5: Distribution of soil loss prior and after conservation under different classes**

## CHAPTER VII

### IMPACT OF WATER HARVESTING MEASURES ON GROUNDWATER RECHARGE

WALMI Bhopal has its demonstration farm located in the middle area of Bhopal city. The WALMI farms are spread over 33.08 ha area where various NRM (Natural Resources Management) activities such as Agro-forestry, Miyawaki technique for dense forestry, soil and water conservation measures, rainwater harvesting measures for groundwater recharge, Beekeeping, solid waste management, etc. are being carried out. These activities aim to improve soil, water, and air quality in the region through the development of an improved ecosystem, reduction of soil erosion, and artificial recharge of groundwater. For augmentation of groundwater recharge and soil conservation, numbers of water harvesting and water conservation structures are constructed in the WALMI farms. These structures include farm ponds, gabions, LBS (Loose Boulder Structures), SBS (Sandbag structures), and Trenches. The storage capacity of individual structures is calculated based on the physical measurements of these structures details of which are given in **Table 7.1**. The total capacity of these seven structures is worked out as 16602.13 m<sup>3</sup>.

Table 7.1: Details of water harvesting and water conservation structures constructed in the WALMI farm

Sr No	Name of Structure	Area/Size (m <sup>2</sup> )	Depth (m)	Volume (m <sup>3</sup> )
1	Major Farm Pond	5675.84	1.5	8513.75
2	Gabion Check dam	1764.16	1.5	2646.24
3	Pond 1	49.61	1.5	74.41
4	Pond 2	149.56	1.5	224.34
5	Pond 3	719.88	2.5	1799.70
6	Water Pond 4	1453.69	1.0	1453.69
7	Trenches and others	5400	0.35	1890.00
			<b>Total Volume</b>	<b>16602.13</b>

#### 7.1 Water Balance Analysis for Estimation of Groundwater Recharge

The water balance equation works on the principle of conservation of mass can be used to compute groundwater recharge. The groundwater recharge estimation in WALMI farms has been carried out by estimating daily inflow and outflow components of the system for developing a single water balance equation for all ponds, trenches, and conservation structures. The WALMI farm has seven water recharge structures and is considered as one

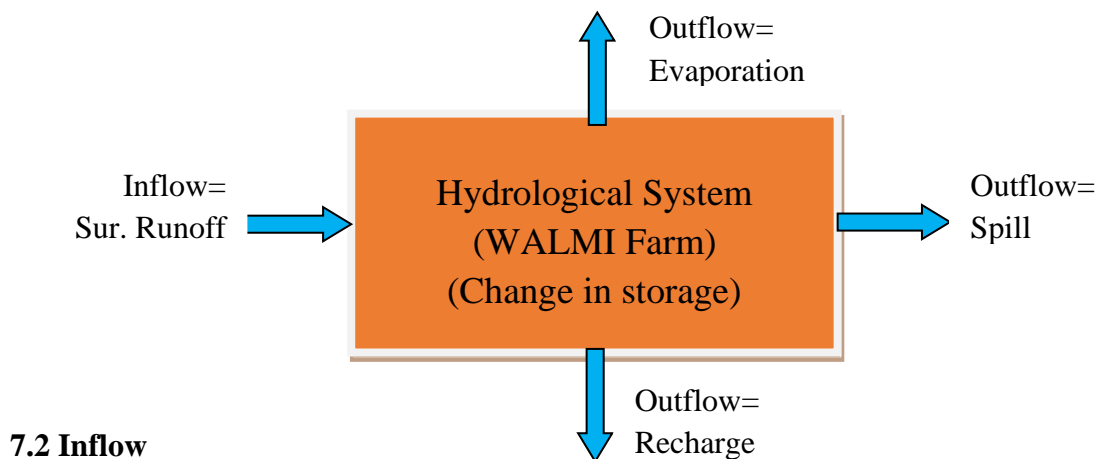
single unit and lumped modeling was conducted to make the calculation simple. The basic continuity equation for the water balance of a system can be written as:

$$\text{Inflow} = \text{Outflow} + \text{Change in storage} \quad (7.1)$$

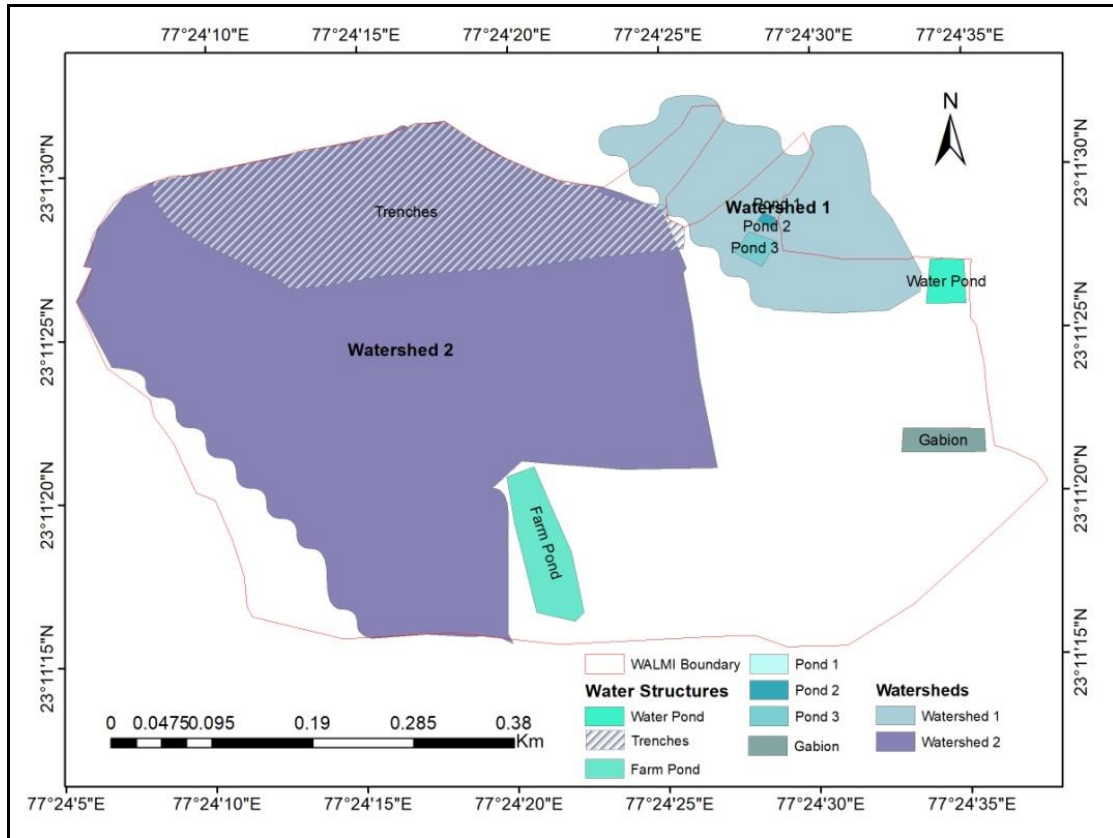
The water balance equation developed for the WALMI farm can be summarized and written as :

$$\text{Runoff} = \text{GW Recharge} + \text{Evaporation} + \text{Change in storage} + \text{Spill} \quad (7.2)$$

Runoff generated from 25.64 ha of watershed area in the WALMI farms is considered as the main inflow component contributing to recharge ponds and other structures. The groundwater recharge is dependent on the infiltration rate of the soil and the storage capacity of the recharge structures. The evaporation occurred from the surface of the water is also one of the main outflow components responsible for major loss from the structures. Change in storages in structures and spill quantity is dependent on the inflow and capacity of the structures. The inflow computation runoff is estimated using the SCS-CN model. All inflow and outflow components of the water balance equation were evaluated independently using climatic and meteorological data from 2009 to 2017 as discussed below.



The major inflow component of the water balance equation is the daily runoff which is computed using the SCS-CN model. For the estimation of runoff, the WALMI farm is divided into two sub-watersheds. The area of these watersheds and runoff generated from these watersheds. The runoff water from Watershed-1 contributes to the Farm Pond for storage of water, gabions, Trenches, and runoff from Watershed-2 contributes to the Pond1, Pond 2, Pond 3, and one newly constructed Water Pond for recharge as shown in **Figure7.1**.



**Figure 7.1: Watershed boundaries of Recharge structures**

### 7.2.1 Runoff estimation from watershed

The daily runoff volume from WALMI farm two Watersheds have been computed using the SCS-CN rainfall-runoff model using 9 years of daily rainfall data from 2009 to 2017. In the SCS-CN model, land use and soil maps can be crossed in a GIS environment to determine the composite curve number of the basin which is further used to determine daily surface runoff.

#### 7.2.1.1 SCS CN model

The Soil Conservation Services- Curve Number (SCS-CN) model is a widely used model to compute surface runoff from a catchment developed by United State Development Agency (USDA). This model converts rainfall to runoff using a single parameter called curve number can be determined using the physical characteristics of the basin. The following formulae are used to predict surface runoff.

$$Q = \frac{(P - I_a)^2}{(P - I_a + S)} \quad (7.3)$$

Where,  $I_a = 0.2S$  for antecedent moisture condition II (AMC II), Q is the surface runoff in mm, P is the rainfall in mm, Ia is the initial abstraction, S is the surface retention can be computed by the following equation.

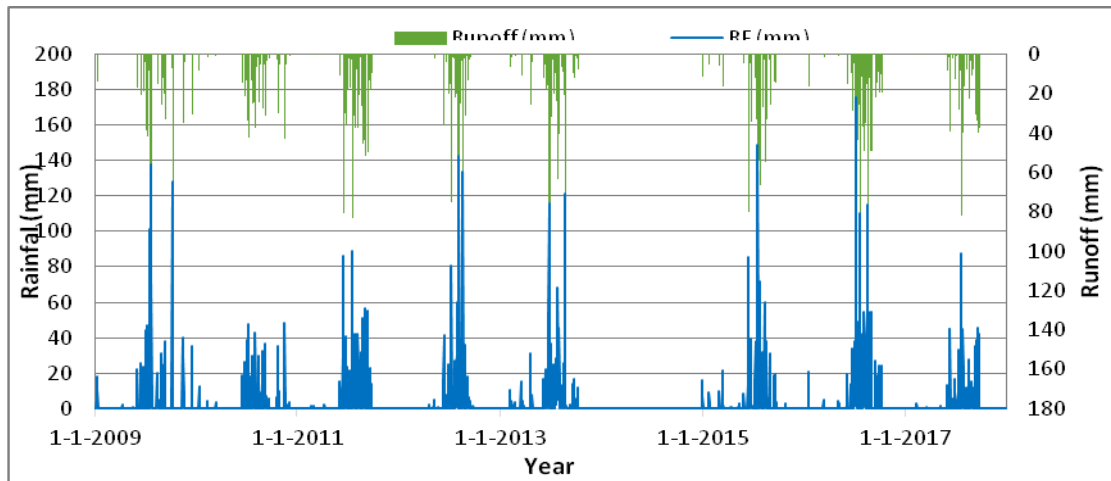
$$S = \frac{25400}{CN} - 254 \quad (7.4)$$

Where, CN is the curve number depends on soil type, land use, management practices, and antecedent moisture condition. The CN values as defined in the SCS table are used in the model and modified for antecedent moisture condition I (dry condition), II (average condition), or III (wet condition) in the model. The curve number used in the model is a parameter that defines the production of surface runoff based on land use, soil cover, moisture condition, and land management used in the watershed. In the SCS-CN model, land use and soil maps can be crossed in a GIS environment to determine the composite curve number of the basin which is further used to determine daily surface runoff. The composite curve number for watersheds of WALMI is shown in **Table 7.2**.

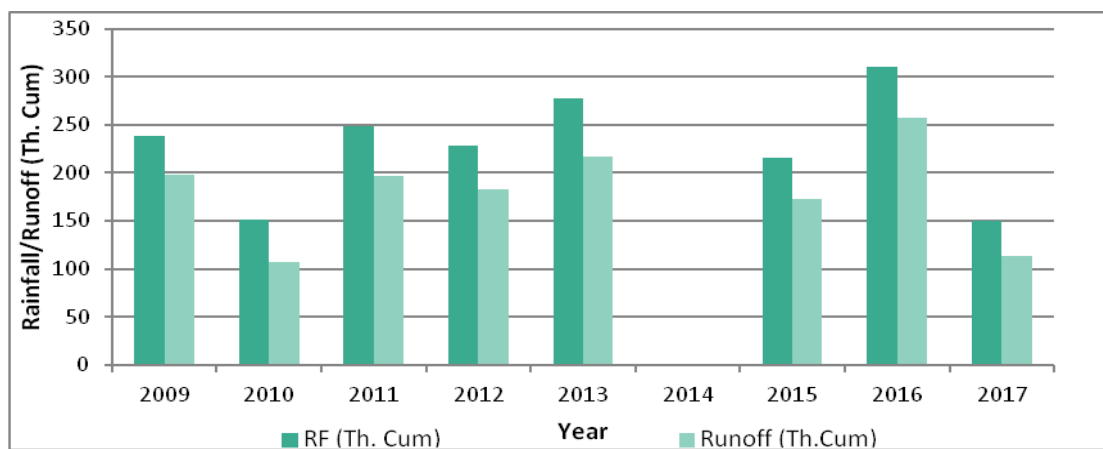
Table 7.2: Composite curve number for the watersheds of WALMI campus

S.No	Name	Soil Group	CN Value	Area (Ha)
1	Existing Structures	B	82	0.12
2	SLWM Park	B	82	0.07
3	Farm Pond	B	100	0.57
4	Water Pond	B	100	0.15
5	Plantation	B	78	0.32
6	Drumstick Plantation	B	78	0.77
7	Cropped Land	B	75	7.85
8	Afforestation	B	58	7.28
9	Gabion	B	100	0.18
10	Pond 3	B	100	0.07
11	Pond 2	B	100	0.01
12	Pond 1	B	100	0.00
13	Trenches	B	100	5.17
14	Orchard Plantation	B	58	4.10
15	Plantation	B	58	4.27
16	Bee Keeping	B	74	0.21
17	Neem Plantation	B	58	1.94
<b>Total area</b>				33.08
<b>Composite curve number (CCN)</b>			70.74	

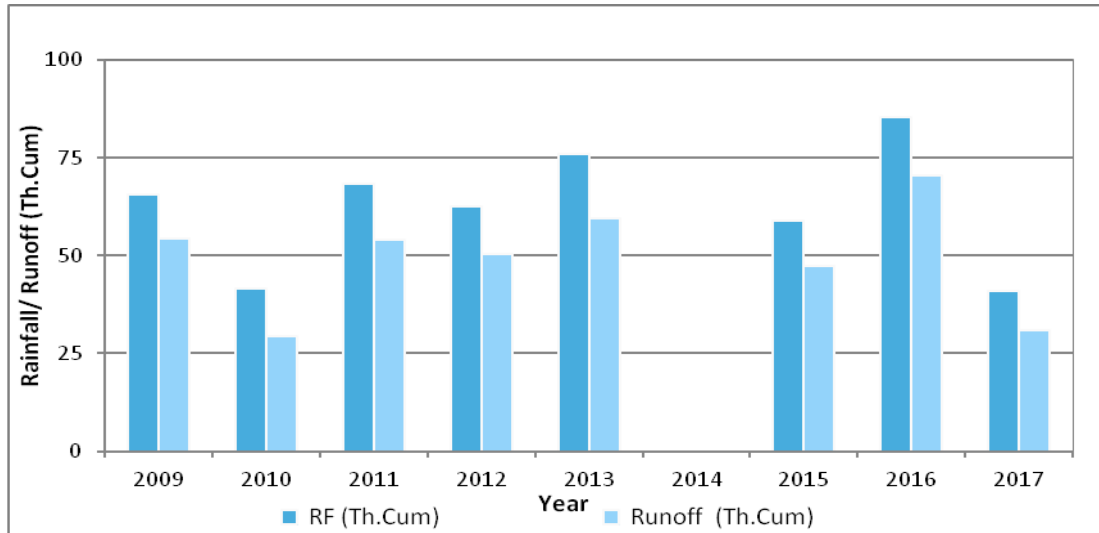
A program in excel for computation of daily runoff has been developed and daily rainfall of Bhopal Rain Gauge station from 2009 to 2017 (with a gap of 2014) has been used for computation of surface runoff to reach the outlet of these sub-watersheds shown in **Figure 7.2**. The daily rainfall and computed surface runoff using the SCS CN model for the WALMI are presented in **Figure 7.3** (Watershed-1), and **Figure 7.4** (Watershed-2).



**Figure 7.2: Rainfall and computed surface runoff**



**Figure 7.3: Rainfall and computed surface runoff for watershed -1**



**Figure 7.4: Rainfall and computed surface runoff for watershed -2**

The daily runoff time series was estimated for two selected watersheds using the SCS-CN method, and it was then used as an inflow component in the water balance equation. The areas of two selected watersheds that are contributing runoff to water storage structures and average runoff volume generated from these two watersheds are given in **Table 7.3**.

Table 7.3: Details of Watershed area and runoff generation in the WALMI farms

Watershed Boundary	Water Bodies	Watershed Area (m <sup>2</sup> )	Total surface runoff generated (m <sup>3</sup> )
Watershed 1	Farm Pond, Gabions, Trenches	201312.20	13050.00
Watershed 2	Pond1, Pond 2, Pond 3, New Water Pond	27599.25	3477.73

### 7.3 Outflow

The three main outflow components considered in the water balance equation of recharge structure are evaporation, spill or overflow, and groundwater recharge from storage structures. The methodology used for the computation of these three outflow components and the results of the analysis is discussed below in detail.

#### 7.3.1 Evaporation

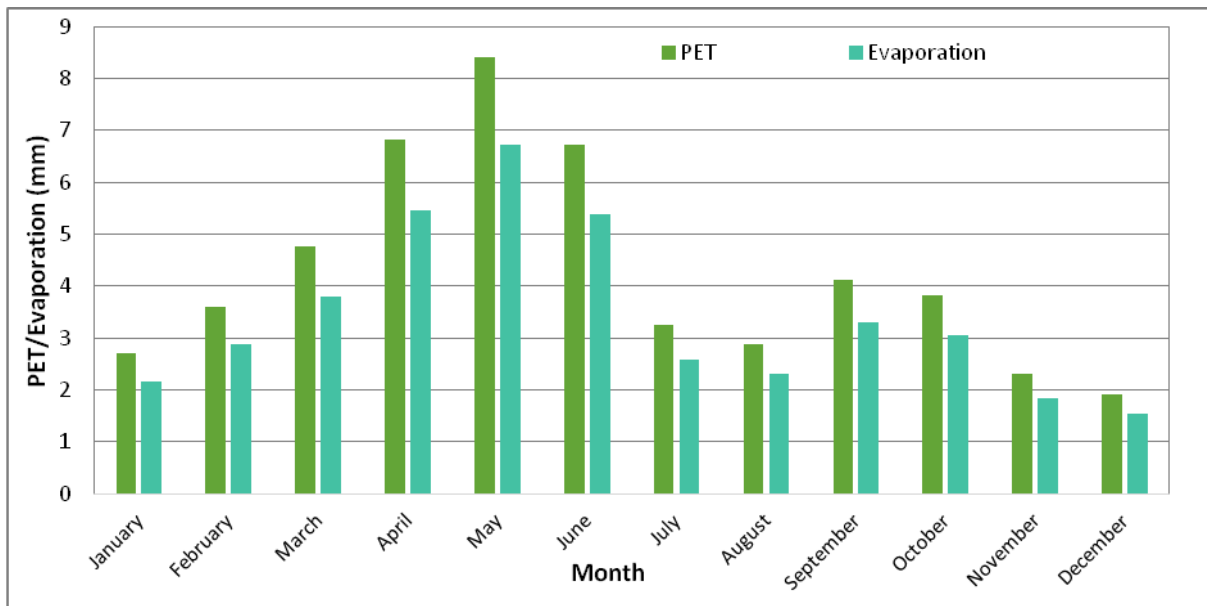
Studies have shown that the oceans, seas, lakes, and rivers provide nearly 90 percent of the moisture in the atmosphere via evaporation, with the remaining 10 percent being

contributed by plant transpiration. Evaporation causes a major loss from the water bodies. The evaporation data of the Bhopal station was not available hence the potential evapotranspiration (PET) has been estimated using the Modified Penman method using climatic data of the Bhopal station of IMD. The suitable coefficient of 0.8 was used to estimate daily evaporation from daily PET and used in the water balance equation.

The evaporation data of the Bhopal station was not available hence the potential evapotranspiration (PET) has been estimated using the Modified Penman method using climatic data of the Bhopal station of IMD. The suitable coefficient of 0.8 was used to estimate daily evaporation from daily PET. The average annual PET and evaporation have been observed as 1558 and 1168 mm respectively. The daily evaporation and potential evapotranspiration (PET) rate shown in **Figure 7.5**.

### **7.3.2 Change in storage and spill**

Change of storage in the storage structure and spill from the structures is dependent on the inflow runoff from the watershed and the capacity of those recharge structures. During heavy rainfall and consecutive rainy days, the inflow runoff exceeds the capacity of the recharge structure, and the excess water spills out from the storage structure. During moderate rainfall conditions, the runoff may not exceed the capacity of the structure. However, the water stored in the storage structure is lost due to evaporation losses and a part infiltrates to groundwater. During monsoon, the process filling of storage structure, spill, and volume of groundwater recharge will depend upon the number of rainfall events, their intensity, and duration contributing runoff to the storage structure, which ultimately will contribute to the groundwater recharge. These conditions are taken care of in formulating water balance equations and calculations thereupon. The total storage capacity of water harvesting and water conservation structures constructed in the WALMI farm has been calculated based on the physical measurements of length, breadth, and depth of individual structures. The total capacity of all water storage structures is worked out as 16602.13 m<sup>3</sup> as given in Table 7.1.



**Figure 7.5: Daily evaporation and potential evapotranspiration rates**

### 7.3.3 Estimation of groundwater recharge

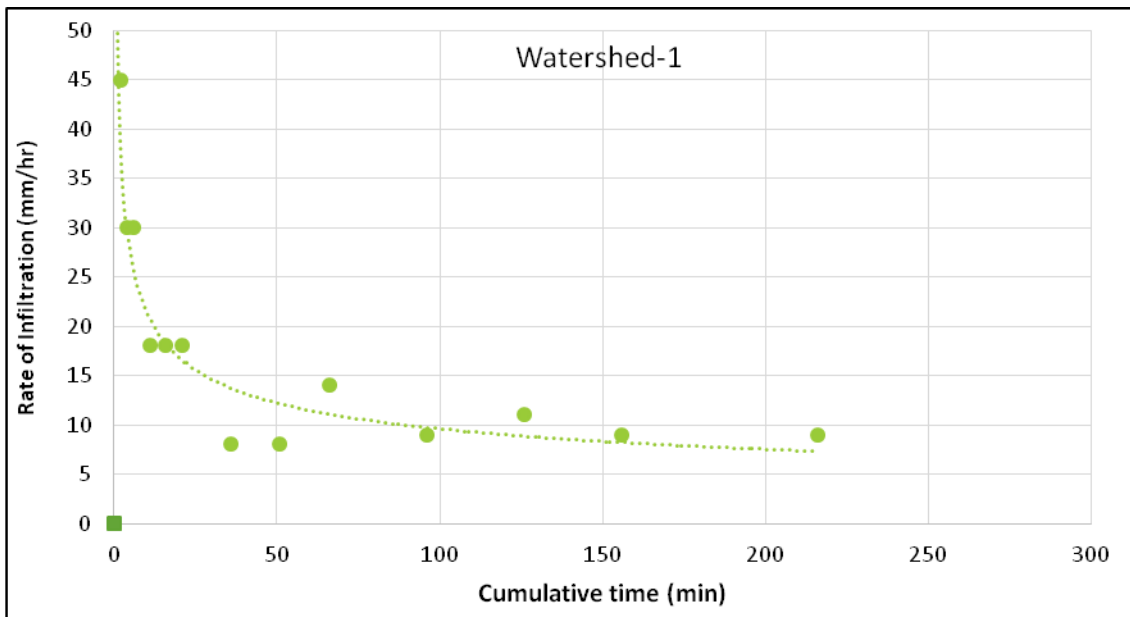
Groundwater recharge is the primary process through which water enters an aquifer. Water recharge either naturally or artificially. In artificial recharge, the runoff is retained in that areas from where it can enter the aquifer at a higher rate. The soil, geology, topography, land use and rainfall characteristics are important factors to decide the amount of groundwater recharge. In the present study, the computation of groundwater recharge from water conservation and rainwater harvesting in the WALMI farm was the major objective. To achieve this, a single water balance equation was set up for all seven water storage structures located in the WLAMI Farm. The water balance equation was developed as a lumped equation and was run on a daily time step. Infiltration rates at the bed of recharge structures were used to estimate the groundwater recharge from these structures on daily basis. For the estimation of infiltration rate, a double ring infiltration test was conducted in the WLAMI farm. The infiltration tests were conducted in the beds of water steerage structures contributing runoff from watershed-1 and watershed-2 as shown in **Figure 7.6**. The standard procedure was adopted to compute the constant rate of infiltration from two different sites in the WALMI farm.



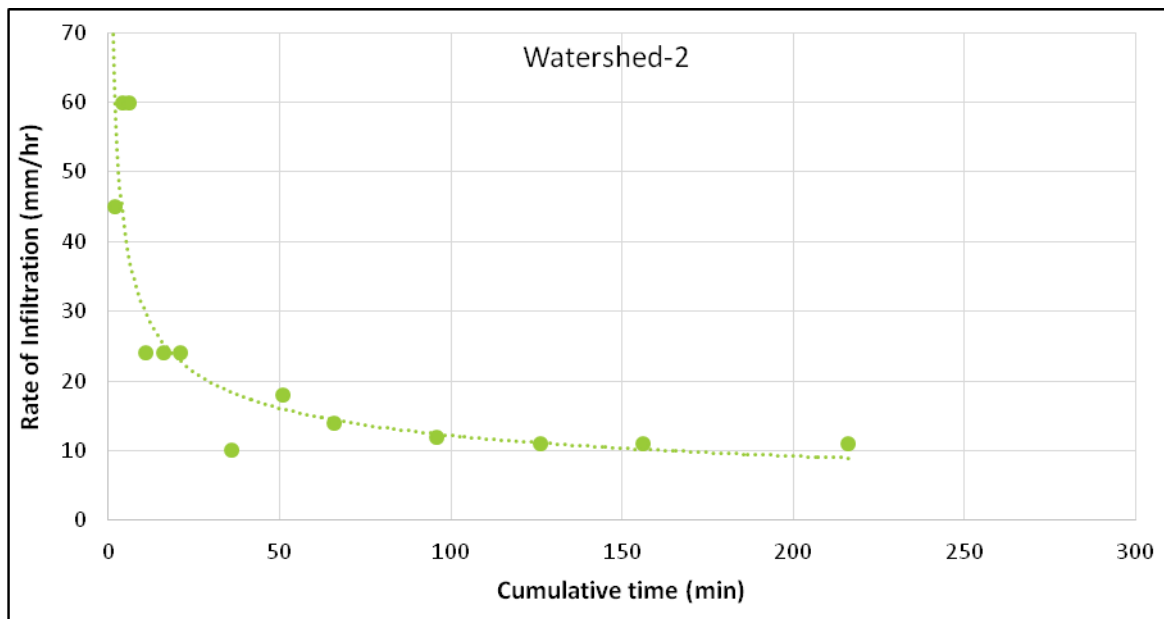
**Figure 7.6: Double Ring Infiltrometer test**

Infiltration is the process of water penetrating the ground surface. The intensity of this process is called the infiltration rate. The infiltration rate is the velocity or speed at which water enters the soil. It is usually measured by the depth (in mm) of the water layer that can enter the soil in one hour. Two cylinders (rings) of infiltrometer are inserted vertically into the soil about 5cm from the surface where the measurement had taken. After filling the outer ring with water, then the inner ring, to approximately 5-10 cm, started measuring immediately to determine the infiltration curve, by determining the drop in the water level in the inner ring during a certain time interval of which is 2, 3, 5, 15, 30, and 60 minutes the graph is plotted. The measurement exclusively takes place in the inner ring through which the water runs virtually vertically. To achieve good measuring results some important factors had taken into account which may influence the measurement like the surface vegetation, the extent to which the soil has been compacted, the soil moisture content, and the soil layers. At last, when the infiltration rate has reached a constant value then stopped taking readings. In this way, infiltration tests had been done in watershed-1, watershed-2, and readings were taken.

Most of the recharge structures in the field have soil loam type of clay and have good infiltration capacity and a high rate of recharging groundwater. The constant rate of infiltration rate in watershed-1 is 9 mm/h and in watershed-2 is 11 mm/h, and the average infiltration rate of the WALMI farm is 10 mm/hr as shown in **Figure 7.7** and **Figure 7.8**.



**Figure 7.7: Rate of Infiltration in watershed-1**



**Figure 7.8: Rate of Infiltration in watershed-2**

The total watershed area of WALMI Farms is 33.08 ha, out of that 25.64 ha watershed area contributes to these seven-water harvesting and water conservation structures constructed in the farm as details mentioned in the above Table 7.1. The southwest monsoon is the main source to contribute runoff from watershed to fill those structures and which are mainly contribute to groundwater recharge through infiltration.

#### 7.4 Impact assessment of conservation activities on surface and groundwater regime

The water balance equation works on the principle of conservation of mass was used to compute groundwater recharge. The groundwater recharge estimation in WALMI farms has been carried out by estimating daily runoff as an inflow and evaporation, spill and infiltration contributing groundwater recharge as an outflow component of the single and lumped water balance equation for all ponds, trenches, and conservation structures. All seven structures constructed in the farm were considered as one single unit and lumped for calculation purposes.

Change in storage in all recharges structures and spill from the structures is dependent on the inflow runoff and capacity of those recharge structures. The water balance analysis has been carried out on daily basis for estimation of groundwater recharge from recharge structures in WALMI Farms and the annual water balance is presented in **Table 7.4**.

Table 7.4: Annual Water Balance of ponds and recharge structures in WALMI Farm

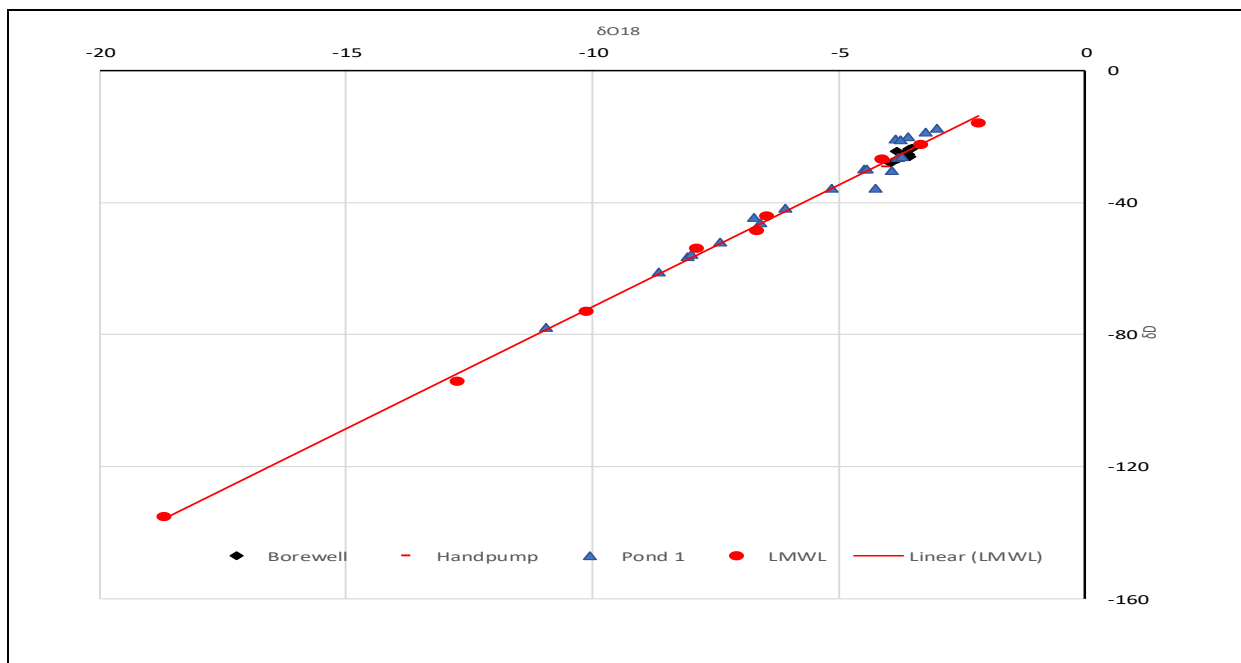
Year	Rainfall (Lakh m <sup>3</sup> )	Inflow (Lakh m <sup>3</sup> )	Outflow (Lakh m <sup>3</sup> )			Change in storage (Lakh m <sup>3</sup> )
		Runoff	GW Recharge	Evaporation	Spill	Storage in structure
2009	3.040	2.526	1.867	0.031	0.628	0.681
2010	1.928	1.362	1.334	0.027	0.000	0.000
2011	3.169	2.509	2.346	0.039	0.123	1.701
2012	2.900	2.336	1.729	0.029	0.578	1.128
2013	3.526	2.775	2.013	0.043	0.718	1.531
2014		-	-	-	-	-
2015	2.738	2.188	1.739	0.031	0.418	1.165
2016	3.969	3.271	2.495	0.037	0.738	2.452
2017	1.918	1.444	1.389	0.026	0.029	0.290
<b>Average</b>	<b>2.809</b>	<b>2.301</b>	<b>1.864</b>	<b>0.033</b>	<b>0.404</b>	<b>1.119</b>
<b>Percent</b>		<b>82</b>	<b>66</b>	<b>1</b>	<b>14</b>	<b>40</b>

From Table 7.4 showing water balance analysis of ponds and recharge structures in sub-watershed area of 25.64 ha in WALMI Farm it is seen that average annual quantity of water received in the form of rainfall is 2.809 lakh m<sup>3</sup>. Out of it average annual runoff generated is 2.301 Lakh m<sup>3</sup>, which is 82% of the rainfall volume. Out of which annual losses due to evaporation from surface and spill from all seven recharge structures are estimated as 0.033 (1%) and 0.404 (14%) lakh m<sup>3</sup> respectively. The average annual groundwater recharge

estimated from all structures is 1.864 Lakh m<sup>3</sup>, which is 66 % of the rainfall volume received in sub-watershed. Thus it can be seen that the rainwater harvesting structures and soil and water conservation measures adapted in 25.64 ha of sub-watershed in WALMI Farm are significantly contributing to the groundwater recharge in this area. This additional recharge augmented from WALMI Farms through seven recharge structures has been found helpful to improve the groundwater scenario in the WALMI Farms and downstream area of the WALMI campus as well.

### 7.5 Isotopic Analysis

In the study, water samples of rainfall, ponds situated in the WALMI farm, borewell, and hand pumps in downstream localities were collected and analyzed for isotopes of oxygen ( $\delta O^{18}$ ) and hydrogen ( $\delta D$ ) to assess the movement of rainfall through different phases on the earth. The graphical representation of different water samples is presented in **Figure 7.9**. The results of the analysis suggested that all the samples have the source as rainfall. The water samples from the borewell and handpump have a similar signature as ponds and water storage structures located in WALMI farms. This implies that there is a significant contribution from recharge structures of WALMI FARM along with rainfall to borewells and hand pumps in the nearby areas of WALMI Farm.



**Figure 7.9: Concentration of  $\delta O^{18}$  and  $\delta D$  in different water sources**

## **7.6 Way forward for Sustainable Development**

The scientific analysis for groundwater recharge estimation and soil loss analysis confirmed the significant impact of rainwater harvesting and conservation works carried out by WALMI on the ecosystem, soil moisture, groundwater recharge, and water availability in the region. It is recommended to use the appropriate conservation measures in the remaining areas of the WALMI farm. Regular operation and maintenance are key to the success of any watershed management and hence it is recommended to carry out routine maintenance of structures and desilting of ponds. Some of the gabion structures and trenches need immediate maintenance for their functioning and recharge. The water storage pond the downstream of WALMI farm should be desilted to store more water. Although WALMI is doing considerably well in plantation and afforestation works, still more areas can be brought under afforestation in the form of Miyawaki plantation. The oxygen eco-farm developed by WALMI may become an example in the state. There is a need for wide publicity at local and state levels regarding conservation works. The college students, government officials, NGOs and local people should be encouraged to take advantage of the demonstration facilities developed in the WALMI farm.

## CHAPTER-VIII: CONCLUSIONS

The Water and Land Management Institute, Bhopal is a premier organization that has constructed several conservation measures including contour trenches, bunds, gabion structures, afforestation, plantation, recharge ponds, etc. in to reduce soil loss and artificially recharge groundwater in the 33.08 ha of WALMI demonstration farm. A systematic and scientific study was carried out for assessment of the reduction of soil loss due to conservation measures and recharge of groundwater due to water harvesting structures. The soil loss was assessed through the RUSLE model and groundwater recharge was assessed using the water balance approach.

Based on the findings of this study, it can be concluded that trenching and plantation can be taken as a means to combat the impacts of land degradation due to the loss of soil fertility by water erosion, and as mitigation against impacts of climate change. The land capability analysis-based soil conservation measures taken in WALMI farm have emerged as the most sustainable solution to improve ecosystem services. The following are the important conclusions from the study:

- A detailed survey of the study area was conducted to identify different conservation measures in the WALMI farm.
- Afforestation, Miyawaki plantation, gabion structures, trenches, water storage, and recharge ponds, etc. are the important conservation measures applied in WALMI farm in different periods.
- GIS database created in the study will be helpful to WALMI to maintain the records of conservation activities.
- The average annual rainfall in the region is about 1108 mm with 51 number rainy days. The rainfall departure analysis indicated one drought after every 6 to 7 years at Bhopal.
- The execution of conservation measures in WALMI farms has helped to reduce the average annual soil loss from 45.6 to 16.1 t/ha/yr.
- The watershed area having severe soil erosion rate (more than 50 t/ha/yr) was 49% before conservation measures which has been found reduced significantly to 9% after adopting soil conservation measures.

- The SCS CN model applied in watersheds of 25.64 ha confirmed that on average 2.301 Lakh m<sup>3</sup> water is generated as surface runoff.
- The infiltration tests conducted in different soils on the farm found that the average rate of a constant rate of infiltration is 10 mm/hr.
- The water balance of different recharge structures confirmed that the average annual evaporation from recharge structures is 0.033 Lakh m<sup>3</sup> and the average spill is 0.404 Lakh m<sup>3</sup>.
- The average annual groundwater recharge from all structures in WALMI Farm is 1.86 Lakh m<sup>3</sup> which is 66% of the rainfall volume and it is found very significant in terms of groundwater table improvement in WALMI farm and its adjoining areas.
- The artificial recharge of groundwater in WALMI farms is sufficient to meet the demand of more than 6000 people for a year.
- The qualitative assessment through isotopic analysis of water samples from different sources confirmed the groundwater recharge through recharge structures to borewells and hand pumps in the nearby areas of WALMI Farm.
- A significant improvement in eco-diversity has been observed due to intensive conservation measures.
- Miyawaki type of forest development done by WALMI can be applied in another region of MP also.

## **ACKNOWLEDGEMENT**

The authors are thankful to the Director, WALMI Bhopal, and Director NIH Bhopal for providing continuous support and motivation for the study. Our sincere thanks are also due to the faculties and staff of WALMI Bhopal and NIH Bhopal for providing data and surveys conducted for the study. The authors are thankful to the India Meteorological Department for providing rainfall and climatic data. Our thanks to NBSSLUP, Nagpur for providing soil maps. The authors are also thankful to the Nuclear Hydrology laboratory of NIH Roorkee for isotopic analysis of water samples.

## REFERENCES

- Narayana VVD, Babu Ram (1983) Estimation of soil erosion in India. *Journal of Irrigation and Drainage Engineering*. 109(4):419–434
- National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) (2005) Annual Report 2005, Nagpur; NBSS&LUP: Nagpur, India.
- National Commission of Agriculture (1976) Report of the National Commission on Agriculture, National Commission of Agriculture; Government of India, New Delhi, India, 427–472.
- Renard K, Foster G, Weesies G, McCool D, Yo-der D (1997) Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE), *Agricultural Handbook No. 703*, 65–100, <https://doi.org/10.1201/9780203739358-5>,
- Sehgal J, Abrol IP (1994) *Soil degradation in India: status and impact*, Oxford and IBH, New Delhi, India, p. 80.
- Wischmeier WH, Smith DD (1958) Rainfall energy and its relationship to soil loss. *Transactions of American Geophysical Union* 39, DOI: 10.1029/TR039i002p00285.

## Study Group

<b>Director, NIH</b>	: Dr. J. V. Tyagi
<b>Coordinator, RC Bhopal</b>	: Dr. A. K. Lohani, Scientist-G
<b>Head, RC Bhopal</b>	: Sh. R. V. Galkate, Scientist-E
<b>Principal Investigator</b>	: Dr. R. K. Jaiswal, Scientist-D
<b>Co-Principal Investigator (NIH)</b>	: Sh. R. V. Galkate, Scientist-E
<b>Co-Principal Investigator (WALMI)</b>	: Dr. Ravindra Thakur, Associate Professor Sh. Vivek Bhatt, Associate Professor
<b>Supporting Staff</b>	: Sh. Sukant Jain, Research Scientist Sh. Vivek Morya, JRF Miss Chanchal Kumari, JRF Sh. Kuldeepak Pal, JRF