Local Government Engineering Department (LGED)

Government of the People's Republic of Bangladesh

Draft Final Report on

MONITORING THE PERFORMANCE OF VILLAGE PROTECTION, MODEL VILLAGE, UPAZILA/UNION ROAD, SLOPE PROTECTION

Haor Infrastructure and Livelihood Improvement Project (HILIP)

Report Prepared by:

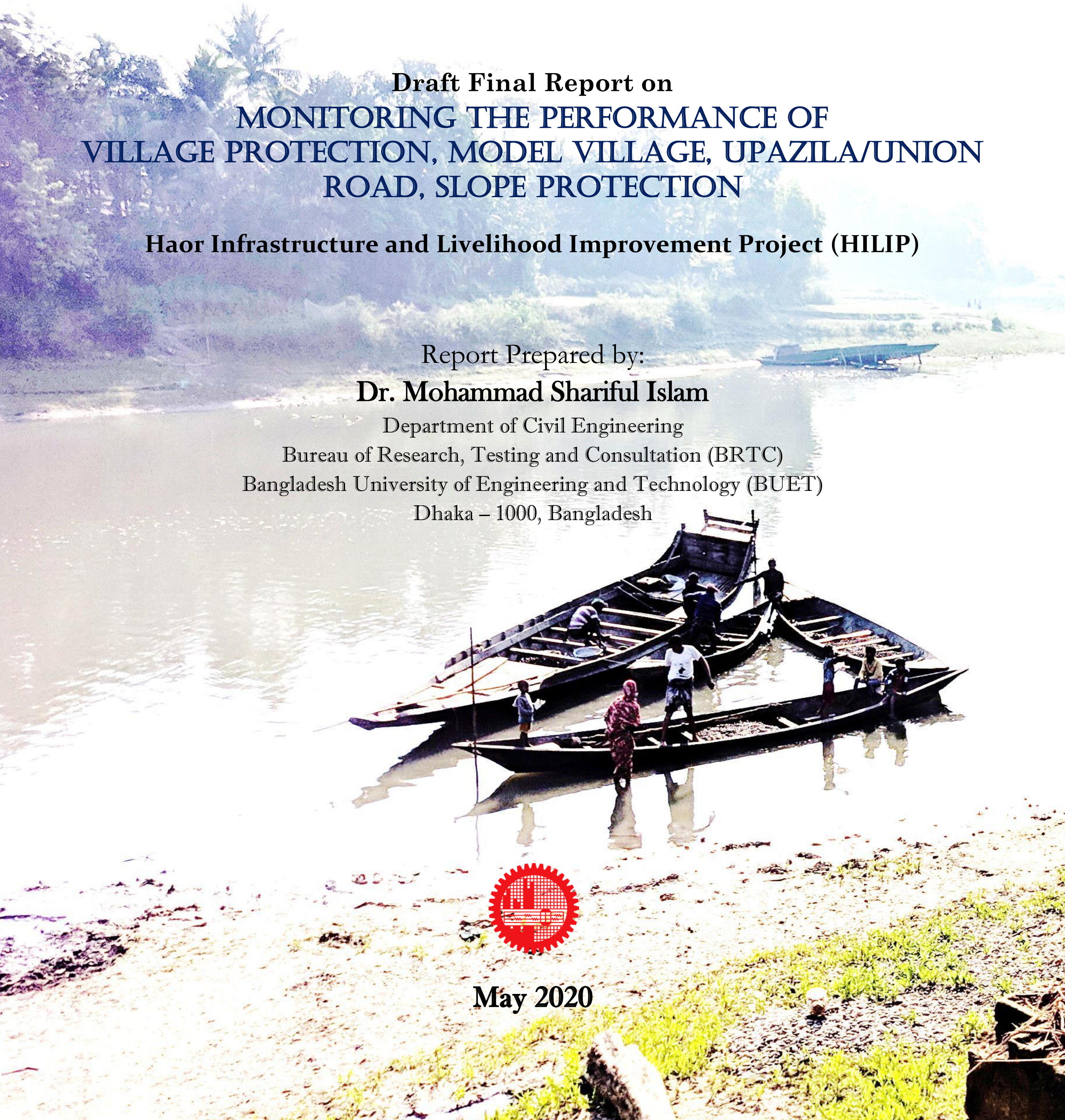
Dr. Mohammad Shariful Islam

Department of Civil Engineering

Bureau of Research, Testing and Consultation (BRTC)

Bangladesh University of Engineering and Technology (BUET)

Dhaka – 1000, Bangladesh



May 2020

CONSULTANTS

Team Leader: Dr. Mohammad Shariful Islam, Professor, Department of Civil Engineering, BUET, Dhaka

Construction Specialist: Dr. Mohammed Kabirul Islam, Professor, Department of Civil Engineering, BUET, Dhaka

CONTRIBUTORS

Botanist: Dr. M. Matiur Rahman, Ex-Director, Bangladesh National Herbarium, M/O Environment and Forest and Climate Change, Dhaka

RESEARCH ASSOCIATES

Engr. Tanzila Islam, Department of Civil Engineering, BUET, Dhaka

Engr. Sadman Hossain, Department of Civil Engineering, BUET, Dhaka

ACKNOWLEDGMENT

The success and final outcome of this project required a lot of guidance and assistance from many people. The members of the Consultant Team are extremely privileged to have got this all along the completion of the research work. All that the team has done is only due to such supervision and assistance and would not forget to thank them. The members of the Consultant team thank the Local Government Engineering Department for awarding this project to the Department of Civil Engineering of Bangladesh University of Engineering and Technology (BUET). The task was found very interesting and innovative by the members of the team. Team members appreciate the opportunity provided to work in such an important project. The team thanks the former Project Director Gopal Chandra Sarkar, new Project Director Abu Zafar Md. Taufique Hasan, Climate Change Specialist Engr. Sadequr Rahman Bhuiyan and Senior Assistant Engineer Md. Ahasanuzzaman of HILIP, LGED.

The consultant team owes their deep gratitude to the funding agency The International Fund for Agricultural Development (IFAD-UN) for providing the great opportunity of research work. The team is thankful to IFAD Mission Leader and consultant, Mr. Dewan Alamgir and Prof. Dr. Md. Shamsul Haque, BUET for their cooperation, suggestion and inspiration for this study.

The team heartily thanks all of the LGED officials, staffs and local engineers of HILIP for their support, accommodation and valuable contribution throughout the project activities and during field visit.

The Consultant Team is thankful to and fortunate enough to get constant encouragement, support and interaction from all local people of the sites which helped them in successfully improving the study work. BUET Team acknowledges the knowledge gathered from the local people of *haor* that they have achieved from their lifelong experiences and struggles. The team is also grateful to the postgraduate students who assisted in conducting the workshops. Finally, the team would like to extend their sincere esteems to the Head of the Department and all staffs of the Department of Civil Engineering, BUET for their timely support.

This report has been prepared by the Team Leader with the support from the Research Associates Engr. Tanzila Islam and Engr. Sadman Hossain. Engr. Tanzila Islam's untiring effort for the model tests and laboratory tests are highly appreciated.

TABLE OF CONTENTS

LIST OF FIGURES

Page No.

LIST OF TABLES

EXECUTIVE SUMMARY

A research project entitled "Monitoring the Performance of Village Protection, Model Village, Upazila/Union Road Slope Protection" was awarded to the Department of Civil Engineering, Bangladesh University of Engineering and Technology (BUET), Dhaka by Local Government Engineering Department (LGED), Government of the People's Republic of Bangladesh (GoB). The contract agreement was signed between BRTC, BUET and LGED; on 10th June, 2018. The Government of the People's Republic of Bangladesh received funds from IFAD for implementation of the Climate Adaptation and Livelihood Protection (CALIP), which is a supplementary project of "Haor Infrastructure and Livelihood Improvement Project" (HILIP). The assignment was carried out for a period of 22 months. The core objectives of the research work were to monitor and document the performance of haor infrastructure slope protection measures using suitable plant species that can provide sustainable, environmentally safe and economically feasible anti-erosion cover of upazila/union roads, *killa*s and villages thereby making *haor* villages and roads climate resilient.

After agreement, an "Inception Report" was provided to LGED on 1st September, 2018. The 1st quarter report was submitted on 13th February, 2019. The 2nd, 3rd, 4th quarter report and draft annual report have also been submitted on 29th May 2019, 31st October 2019, 27th January 2020 and 18th February 2020, respectively. The annual report was submitted on May 2020. Site visits were conducted in Brahmanbaria, Habiganj, Kishoreganj, Netrokona and Sunamganj within 14th January to 30th August. Five district workshops were held at the district Headquarters with LGED officials, Field Engineers and local people within 31st August 2019 to 11th December 2019.

This Draft Final report covers the methodology of the project, observations obtained from the site visits and findings from model study, field study, district workshops at Brahmanbaria, Habiganj, Kishoreganj, Netrokona and Sunamganj, and finally cost analyses of bio-engineering practices applied on field.

The growth of vetiver was very well in all haor districts in terms of the growth of root, shoot and number of tillers grown per clump. Performance of vetiver alone or along with CC block in slope protection was satisfactory in those sites, where the plantation was done with correct species, watering was done and proper care was taken. However, in those cases, where the growth of vetiver tillers was disturbed due to poor maintenance, no trimming, watering and nursing in proper time, garbage disposal, growth of unexpected vegetation etc.; overall performance in slope protection was not good. It was also observed that in many cases, the thorough state of embankment was adverse due to the damage of slope, shoulder, pavement body etc. by human activities.

Along with vetiver, some species of plants were found abundantly in haor basin, among them kansh (*Saccharum spontaneum*), dholkolmi (*Ipomoea fistulosa*), koroch (*Pongamia pinnata*), jiga (*Lannea coromandelica*), hijal (*Barringtonia acutangula*) can also take an important role for slope protection. Some plants were found responsible for retarding growth of vetiver, like assamlata (*Eupatorium odoratum*), which must have to be uprooted. Total construction cost is documented in this report, which showed that bio-engineering methods using vetiver system is more feasible in case of sustainability, eco-friendliness and compatibility than traditional practices of slope protection by solid blocks. In this report, necessary recommendations are provided for improvement of the study areas based on collected data and physical observations. Based on overall activities, an installation guideline is provided in this report as a protection system of haor infrastructures.

CHAPTER ONE

INTRODUCTION AND PROJECT BACKGROUND

CHAPTER ONE: INTRODUCTION AND PROJECT BACKGROUND

1.1 Introduction

The *haor* basin in north-eastern part of Bangladesh is subjected to special agro-ecological and climatic conditions. These areas suffer from extensive annual flooding often more than once in a year during April-May and again during June-October. Strong wave action (locally called '*afal*'), which occurs every year, adds to the vulnerability, as it can potentially wash away the artificially raised homestead lands and pose a major threat to villagers in the *haor* area causing erosion ultimately leading to slope failure in different modes. '*Afal*' means tremendous wave action which has duration of 3 to 5 days with a height of 4 - 8 meter. In this context, protection of *haor* infrastructures is consequential for maintaining communication in these areas. The conventional methods that have been used for village protection and slope protection were relatively expensive and often not sustainable in the long run. Alternative low-cost options are sought and consequently appropriate bio-engineering techniques that can augment village protection methods stability of slopes needs to be investigated.

The Government of the People's Republic of Bangladesh (GoB) has received funds from the International Fund for Agricultural Development (IFAD) for implementation of the Climate Adaptation and Livelihood Protection (CALIP), a supplementary project of Haor Infrastructure and Livelihood Improvement Project (HILIP) of the Local Government Engineering Department (LGED). This is expected to help communities to adapt to climate change, reduce potential damage, and create new opportunities to cope with the consequences of climate variability. HILIP started its activities from July 2012 and that of CALIP from July 2014, which is continued up to March 2020. The project intends to apply part of the proceeds of the IFAD grant to cover expenditures for monitoring the performance of village protection methods as well as model village, upazila road slope protection in collaboration with reputable Bangladeshi academic institutions. The research study entitled "Monitoring the Performance of Village Protection, Model Village, Upazila/Union Road Slope Protection" had been conducted by the collaboration of LGED and Bangladesh University of Engineering and Technology (BUET). The study was conducted in 28 upazilas (administrative unit) of five districts namely Brahmanbaria, Habiganj, Kishoreganj, Netrokona and Sunamganj. After submitting an inception report, based on the activities of site visit, monitoring, and model study 1st, 2nd, 3rd and 4th quarter report; draft annual report and annual report was submitted within the project time by BUET team.

1.2 Background

Early floods in the *haor* areas are flash floods, damaging standing Boro rice, the main crop of the region while late floods in June-October damage Aus and Aman rice, as a result of inundation of crop land during wet season for 6 to 7 months. These are important crops in relatively highland areas along major rivers and canals surrounding the *haor*. Such occurrence of flood makes livelihoods vulnerable and it limits the potential of agricultural production and growth of rural enterprise. Rural poor households in the area depend upon fisheries and various off-farm activities for livelihood. The transport infrastructure is poorly developed with submergible rural roads providing connectivity during the dry season with boats being the main mode of transport during the wet season. The poor transportation network limits access to markets, agricultural production and off-farm employment opportunities, all of which adversely affect economic growth. Further, the poor transport network limits access to social services like health and education and centers of administration and judiciary. Protection of villages against flood and wave action, proper management of the fishery resources and securing existing livelihoods such as crop and animal production are critical for poor rural households living in the *haor* region. Severe damage of the river embankments occur frequently due to flash floods. Maintenance of embankment and road network remains a critical issue to address. Low shear strength of soil and erosion of top soil are the main causes of waterside infrastructure failures in Bangladesh, including *haor* areas. Usually the velocity of flow remains from 1 to 2 m/s in the *haor* region of Bangladesh.

This research is an innovative pilot activity which will assess the prospects of using bio-engineering methods for environmental friendly village protection and road slope protection. Studies in many countries around the world have revealed that embankment stability can be escalated by using bio-engineering techniques and capable of providing for long-term sustainable low-cost and low maintenance solution for slope protection (Islam et al., 2013; Islam et al., 2017; Islam and Badhon, 2020; Islam et al., 2020, Islam et al., 2020a). The variations of root matrix and strength also have an effect in the increase of soil shear strength, which means different species of vegetation provides different factor of safety.

1.3 Project Objectives

The main objectives of this project are stated below:

(1) To make *haor* villages and roads more climate resilient using suitable plant species and slope protection practices; that can provide sustainable, environmentally safe and economically feasible anti-erosion cover for *haor* infrastructures (road slope, village island, *killa*s, model village and *beel* banks).

(2) To monitor and document the performance of village protection using soil bio-engineering i.e., CC blocks, treated bamboos, vetiver to protect the *haor* infrastructures.

1.4 Outline of the Chapters

The contents of each chapter are as followings:

Chapter One includes the complications of *haor* areas, background and objectives of this project along with the chapter outlines.

Chapter Two presents the methodology of the project which includes the time schedule of the project, selected study areas in *haor* region and types of its infrastructures. This chapter also discusses on the model study and field implementation procedure by different bio-engineering design types.

Haor soil properties, outcomes from the model studies and performances of the pilot studies have been discussed in Chapter Three, along with the workshop outcomes and cost analyses among different protection methods.

Chapter Four presents the guideline by vetiver based bio-engineering method for the protection of *haor* infrastructures and similar geographical conditions.

Conclusions and recommendations obtained from the studies provided in Chapter Five.

CHAPTER TWO

METHODOLOGY

CHAPTER TWO: METHODOLOGY

2.1 Introduction

The study was carried out over a period of twenty two months. The initial part of the work plan contained reconnaissance and topographic survey of the project area, collection & review of all previous secondary data/information/reports/documents, development of tools for data collection. The second phase consisted of field survey, data collection, data analysis, laboratory and model study, cost-estimation of slope protection measures. The remaining part of the overall work plan comprises of performance monitoring, data processing, synthesizing and development of guidelines for slope protection of *killas, beels* and roads, and dissemination of the knowledge through district and national workshops. This chapter presents the methodology used for the study.

2.2 Organization and Work Schedule

The professional staff composition consists of a Team Leader (Geotechnical and Vetiver Specialist), Construction/Transportation Specialist and a Botanist. The relevant administrative staff and supporting staff assisted key staff during the whole project time. The supporting staff consists of two Research Associates.

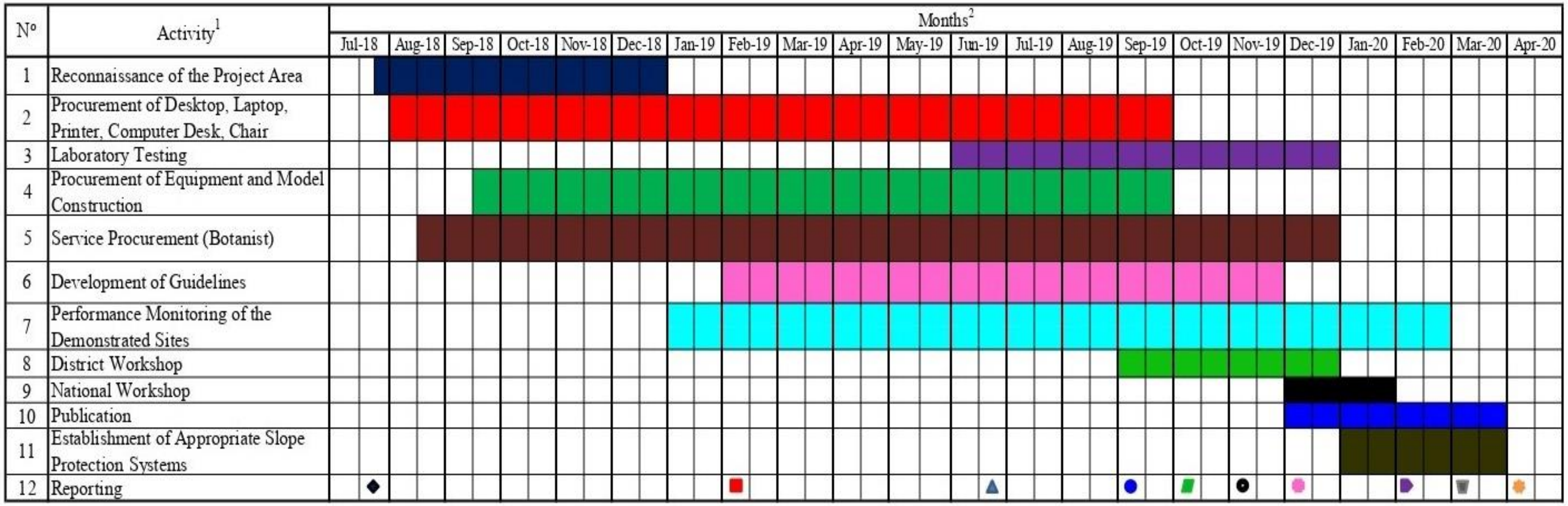
Initial project duration was 15 months, and the project time period was extended to 22 months at 20th August 2019 without changing any budget for proper completion of monitoring and reporting up to 30th March 2020. The final activity flow diagram is shown in Figure 2.1.

2.3 Project Area and Study Locations

The project area consists of 5(five) *haor* districts which includes 28 *upazilas*. For monitoring of these areas within the short time frame mentioned in the assignment, *haors* from selected *upazilas* of each district was chosen after consulting with LGED officials. The project location of HILIP is shown in map in Figure 2.2 and tabulated in Table 2.1. These representative *haor* areas have been selected on the basis of topographical (shallow, mid and deep *haor*), ecological and socio-economic parameters so that monitoring of these areas can be completed within the assigned time frame.

Table 2.1: Overall Project Area

District	Name of Upazilas	Number of *Upazilas*
Sunamganj	Sunamganj Sadar, Tahirpur, South Sunamganj, Bishwambarpur, Jamalganj, Derai, Sulla, Chhatak, Dowarabazar, Dharmapasha, & Jagannathpur	11
Habiganj	Azmiriganj, Lakhai, Baniachong	3
Netrokona	Khaliajuri, Kolmakanda, Modon, Mohanganj	4
Kishoreganj	Itna, Mithamoin, Austogram, Nikli	4
Brahmanbaria	Nasirnagar, Nobinagar, Sarail, Ashuganj, Brahmanbaria Sadar, Bancharampur	6
	Total	**28**



[1]Indicate all main activities of the assignment, including delivery of reports (e.g: inception, interim, and final reports), and other benchmarks such as Client approvals. For phased assignments indicate activites, delivery of reports, and benchmarks separately for each phase.

[2]Duration of activities shall be indicated in the form of a bar chart. Months are counted from the start of the assignment.

- ◆ Inception Report
- ■ 1st Quarter Report
- ▲ 2nd Quarter Report
- ● 3rd Quarter Report
- ▰ 4th Quarter Report
- ● Half Yearly Report
- ● Draft Annual Report
- ▶ Final Annual Report
- ▼ Draft Final Report
- ● Final Report

Figure 2.1: Final Activity Flow Diagram for the Research Project Entitled "Haor Infrastructure and Livelihood Improvement Project"

Figure 2.2: HILIP Project Location on Bangladesh Map

The proposed quantity of the sample size and monitored sample size within the agreed time frame are presented in Table 2.2.

Table 2.2: Proposed Sample Size for Monitoring

Name of the Component	Target Quantity	Completed Quantity
Model Village	1	0
Village protections	20	11
Slope protection of *Killas*	5	1
Slope protection of *Beels*	5	0
Upazila/Union road slope protection	10 km	4.4 km

The model village was not visited because it was not constructed yet. As *haor* is a combination of cluster of *beels,* it is difficult to differentiate from other water bodies. So *beel* slope protections were not possible to visit apart.

2.4 Design Types

Four different engineering models were tested for the village protection against wave action. Landscape level reforestation were undertaken to recreate natural wave barriers (there is significant carbon sequestration potential and quantification were undertaken). The existing protective works are summarized below.

Type I: Protective Measure with Bamboo and Chailya Grass

The required materials for this design type are treated bamboo, chailya grass, soil, geo-jute and bamboo pegs. The LCS labor is the mode of implementation. The recommended construction sequence is given below:

(i) Preparing 1:1.1.5 slope with 1 m wide berm at mid-level
(ii) Filling 250 mm thick earth
(iii) Compacting slope manually with 10 kg rammer
(iv) Placing geo-jute on the prepared slope
(v) Providing bamboo palisades with seasoned and treated bamboos @ 300 mm interval (as shown in Figure 2.3)
(vi) Bamboo to be removed and preserved for reuse immediately after wet season
- Care taking by LCS for the first two seasons
-Tree plantation with Hizol and Koros @ 2.5 m c/c and 5 m from row to row (if land is available)

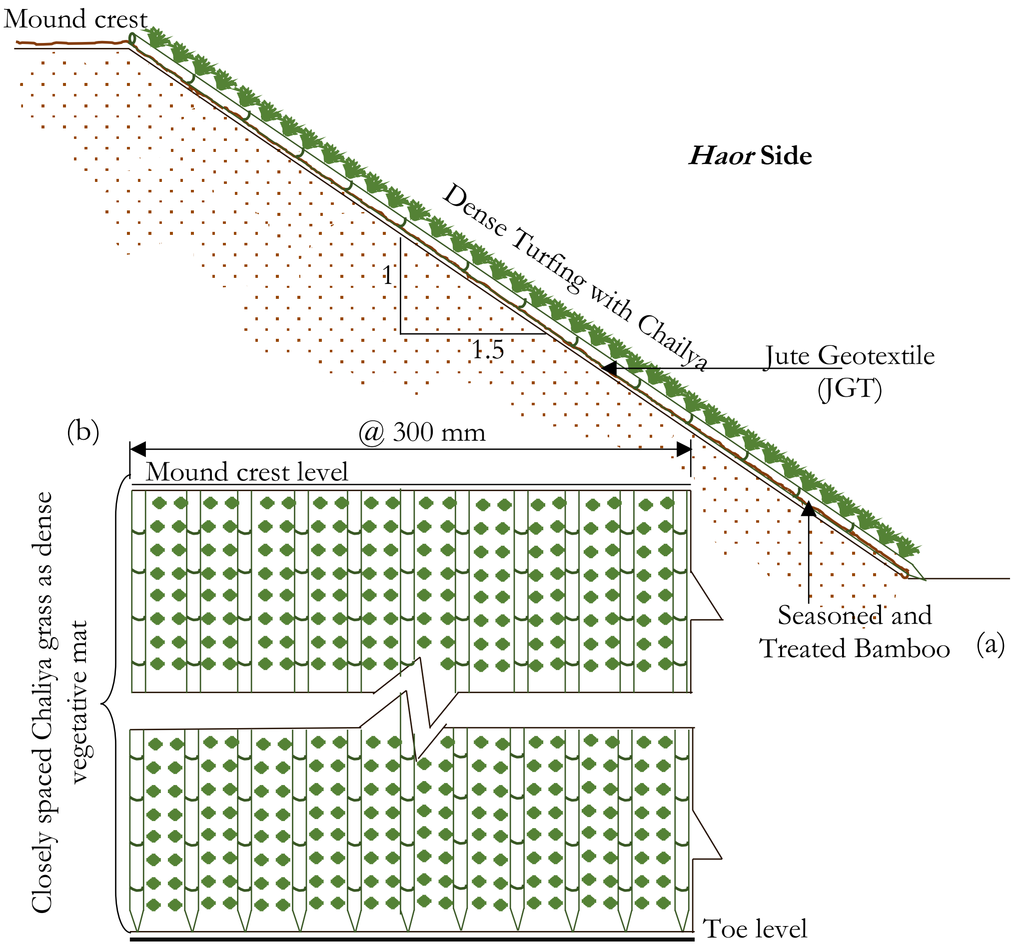


Figure 2.3: Schematic Drawing of Design Type I, (a) Cross Sectional View; and (b) Plan View (Redrawn from HILIP, 2017)

Type II: Protective Measure with Vetiver Grass

The required materials for this design type are Vetiver grass, soil and geo-jute. The LCS labor is the mode of implementation. This type is recommended for light to moderate waves and with less erosion record. The recommended construction sequence is given below:

(i) Preparing 1:1.1.5 slope with 1 m wide berm at mid-level
(ii) Filling 250 mm thick earth
(iii) Compacting slope manually with 10 kg rammer
(iv) Placing geo-jute on the prepared slope
(v) Placing Vetiver in grid pattern @2m×1m interval (as shown in Figure 2.4)
(vi) Fencing (if needed) may be provided to protect Vetiver from animal
- Care taking by LCS for the first two seasons
-Tree plantation with Hizol and Koros @ 2.5 m c/c and 5 m from row to row (if land is available)

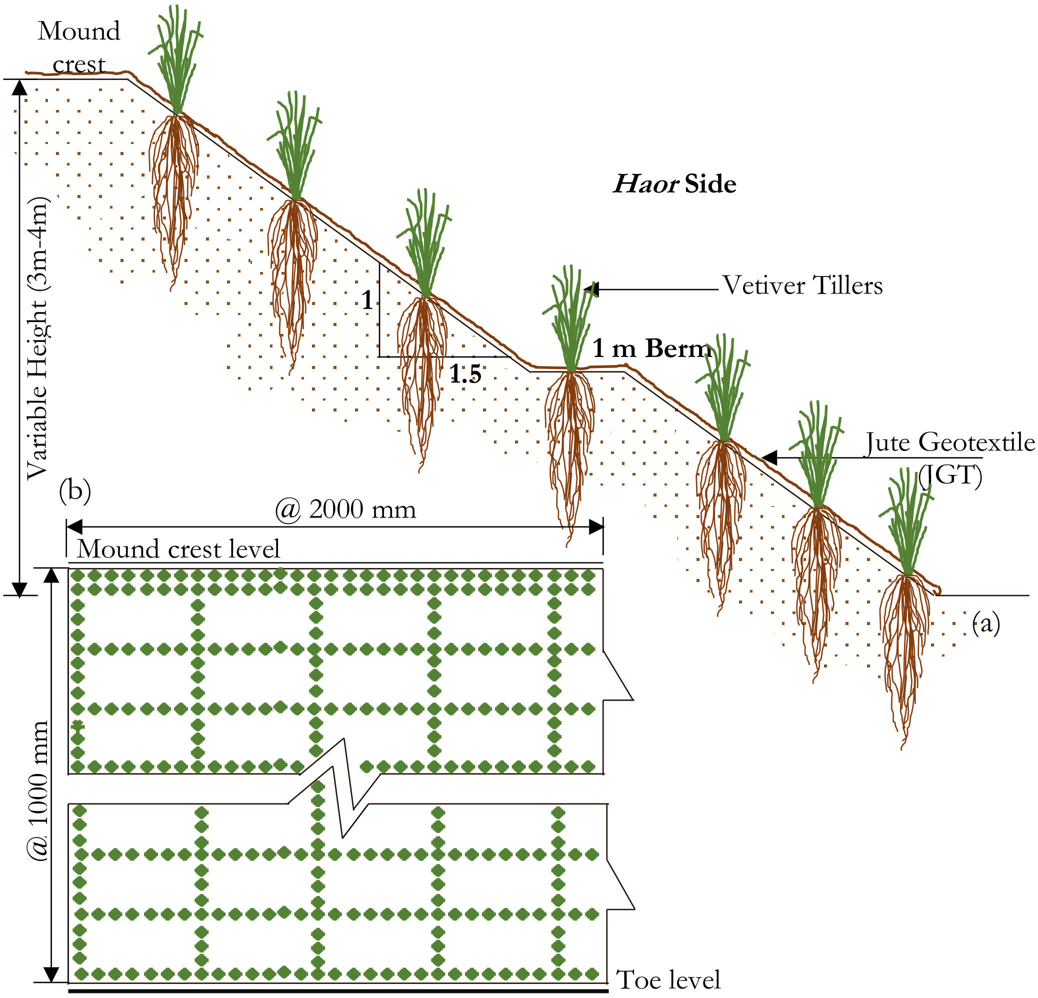


Figure 2.4: Schematic Drawing of Design Type II, (a) Cross Sectional View; and (b) Plan View (Redrawn from HILIP, 2017)

Type III: Protection by CC Hollow Blocks along with Toe Wall and Vetiver

The required materials for this design type are CC block (450×450×75 mm) with 150 mm dia hole at center, vetiver grass, soil, brick, sand, cement and geo-jute. The LCS labor is the mode of implementation. This type is recommended for moderate to deep *haor* area with severe erosion record.

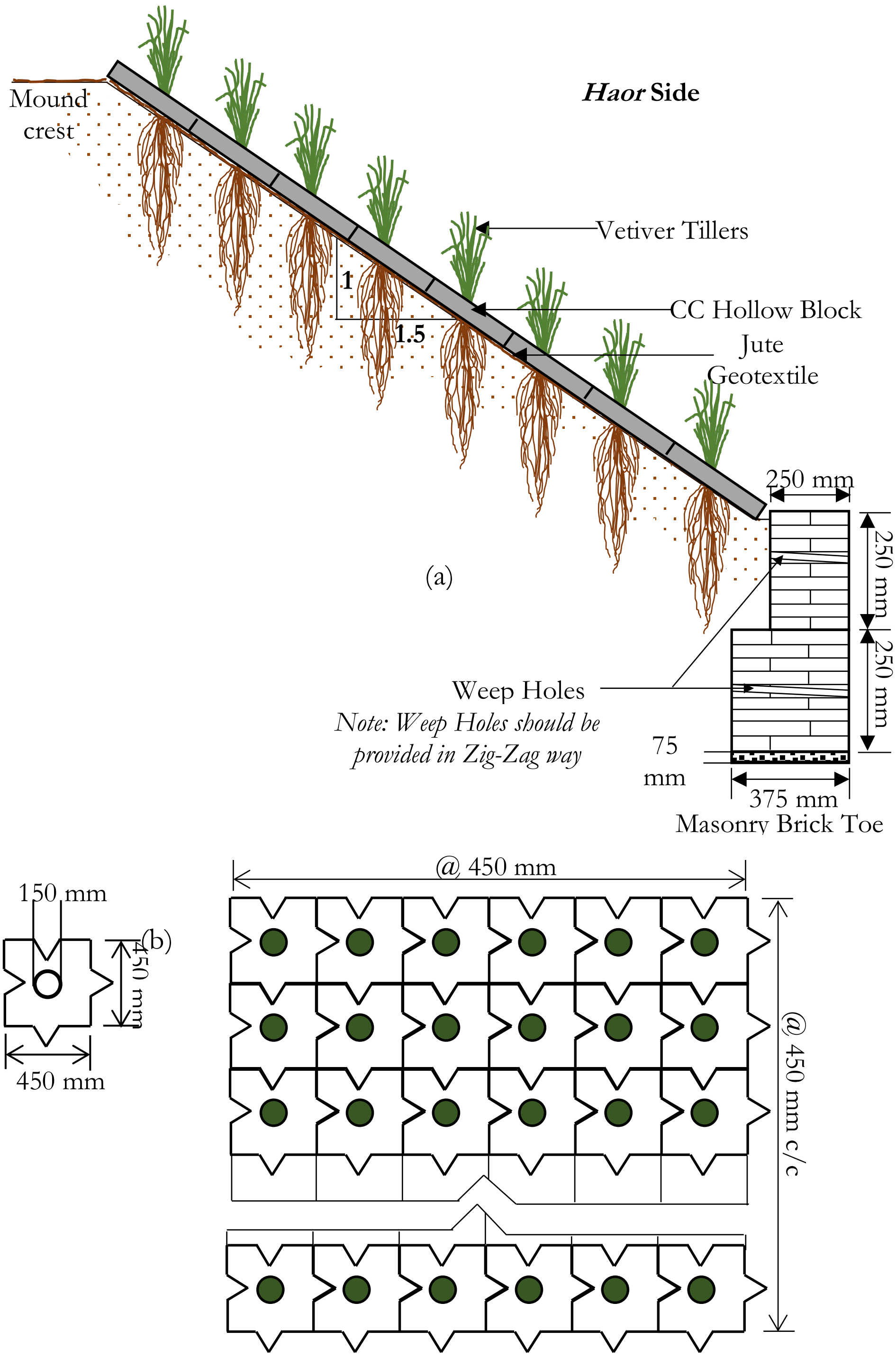


Figure 2.5: Schematic Drawing of Design Type III, (a) Cross Sectional View; and (b) Plan View (Redrawn from HILIP, 2017)

The recommended construction sequence is given below:

(i) Preparing 1:1.1.5 slope with 1 m wide berm at mid-level
(ii) Filling 250 mm thick earth
(iii) Compacting slope manually with 10 kg rammer
(iv) Placing of 1m height continuous tow wall along the slope with 75 mm CC work, 375 mm and 250 mm brick work
(v) Placing geo-jute on the prepared slope
(vi) Placing of 450mm×450mm×75 mm centered 150 mm dia hole CC block

(vii) Placing Vetiver in the block hole @450mm c/c both way (as shown in Figure 2.5)
-Tree plantation with Hizol and Koros @ 2.5 m c/c and 5 m from row to row (if land is available)

Type IV: Slope Protection by RCC Poles based Palisading

The required materials for this design type are 150mm×125mm RCC poles, Vetiver grass, soil, brick, sand, cement and geo-jute.

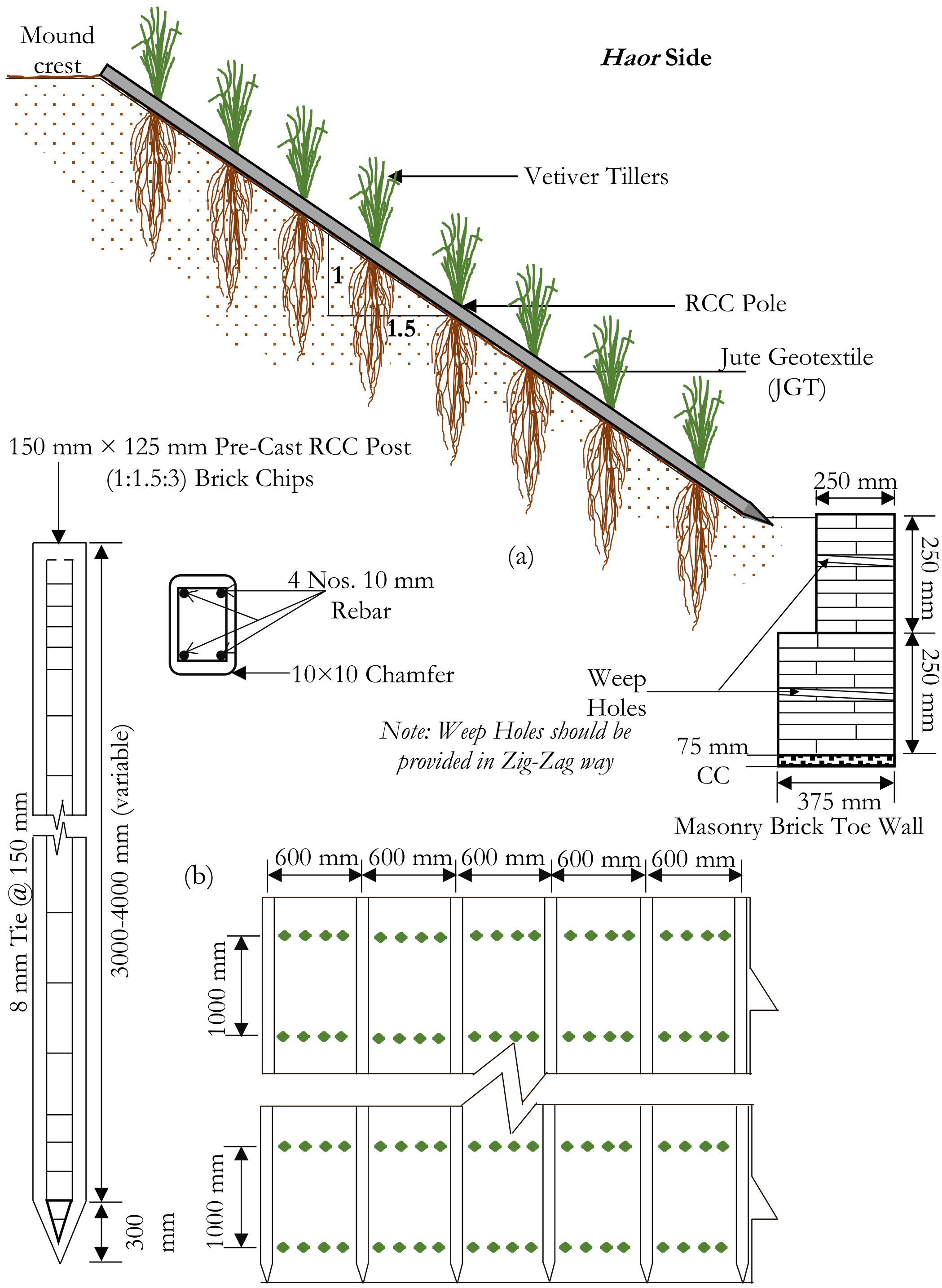


Figure 2.6: Schematic Drawing of Design Type IV, (a) Cross Sectional View; and (b) Plan View (Redrawn from HILIP, 2017)

The mode of implementation is conducted by LCS labor. This type is recommended for moderate to deep *haor* area with severe erosion record. The recommended construction sequence is given below:

(i) Preparing 1:1.1.5 slope with 1 m wide berm at mid-level
(ii) Filling 250 mm thick earth
(iii) Compacting slope manually with 10 kg rammer
(iv) Placing of 1m height continuous tow wall along the slope with 75 mm CC work, 375 mm and 250 mm brick work
(v) Placing geo-jute on the prepared slope
(vi) Placing 150mm×125mm RCC 3 to 4m long poles as palisades @ 600 mm c/c on the prepared slope
(vii) Placing Vetiver grass @ 100 mm c/c between poles and 1000 mm c/c between two rows (as shown in Figure 2.6)
- Care taking by LCS for the first two seasons
-Tree plantation with Hizol and Koros @ 2.5 m c/c and 5 m from row to row (if land is available)

2.5 Implementation at Field

Five *haor* districts were selected as study area under the implementation of LGED, according to the depth and effect of wave action of the *haor*s. The sites of have been selected on the basis of topographical, ecological and socio economic parameters. Collected data included growth measurement, performance of vetiver, growth of other vegetation alongside, soil type, amount of water in soil and soil characteristics, vegetation sample collection, performance of slope (whether erosion has occurred or not, if occurred, how much).

Effectiveness of the proposed methods was determined by observing performance of proposed measures against forces/natural disasters such as heavy rain, flood, wave action, etc. Evidence of distress was recorded regularly and photographs of the sites were taken regularly. Local people/users within the project influence area were interviewed for qualitative performance evaluation of the protection measures. From periodic monitoring, the level distress was evaluated (parameters: length of distress, settlement of existing protection measures etc.). Meteorological data was collected from internet, Institute of Water and Flood Management (IWFM), Bangladesh Meteorological Department (BMD) etc. The study locations according to the *haor* type are summarized in Table 2.3.

From field study, three types of protection work was done by observing the necessity of protecting *haor* area, they are: (i) Road Slope Protection; (ii) Village Island Protection; and (iii) Killa Protection.

Table 2.3: Field Study Locations

Haor Type	District	Name of Monitored Upazilas	Number of Monitored Upazilas
Shallow *haor*	Brahmanbaria	Sarail, Ashuganj, Brahmanbaria Sadar, Bancharampur	4
Mid-depth *haor*	Habiganj	Azmiriganj, Lakhai, Baniachong	3
Deep *haor*	Kishoreganj	Itna, Nikli	2
	Netrokona	Kalmakanda, Khaliajuri	2
	Sunamganj	Derai	1
		Total	**11**

Table 2.4 shows the location of the monitored road slope, village islands and killa with GPS data and design type applied in that particular location.

Table 2.4: Location Details of Monitored *Haor* Infrastructures

Type of Work	Districts	Upazila	Location	GPS	Design Type
Road Slope (10)	Brahmanbaria	Sarail	Kalikaccha UP – Bariura Bazar Road	N24.055556, E91.147500	Type III
		Ashuganj	Modhupur Temohoni to Lalpur R&H via Lalpur UP Road	N24.008831, E90.990644	Type III
			UP Office (Bhabanipur) – Dogarishwar Bazar Road	N24.001667, E91.010556	Type III
		Brahmanbaria Sadar	Panchabaty R&H to Akhaura Bazar Road (Part 1 & 2)	N23.879444, E91.141281	Type III
			Panchabaty R&H to Akhaura Bazar Road	N23.877222, E91.155556	Type III
		Bancharampur	North West Side Bridge Approach R&H Road	N23.735278, E90.829722	Type II
	Habiganj	Azmiriganj	Paschimbag – Azmiriganj Road	N24.513056, E91.311111	Type III
	Kishoreganj	Itna	Chowganga – Chandrapur Road	N24.521111, E90.955278	Type III
			Itna-Ajmiriganj GC Road	N24.561472, E91.202389	Type III
	Netrokona	Kalmakanda	Guturabazar	N25.039833, E90.902917	Type III
Village Island (11)	Brahmanbaria	Sarail	East Noagaon	N24.090833, E91.134722	Type III
	Habiganj	Baniachong	Vatipara	N24.456944, E91.372500	Type III
		Lakhai	Chikonpur	N24.282500, E91.219167	Type III
	Kishoreganj	Nikli	Kamalpur	N24.339411, E90.949547	Type III
			Daulotpur-Aglapara	N24.261111, E90.942667	Type III
	Netrokona	Kalmakanda	Janjailpara	N25.024122, E90.925208	Type III
		Khaliajuri	Mujibnagar	N24.684783, E91.165303	Type III
			Hayatpur	N24.652808, E91.189019	Type III
	Sunamganj	Derai	Meghna Barghor	N24.838888, E91.280278	Different Scheme
			Meghna Notunpara	N24.843597, E91.290200	Type III
			Kochua	N24.778594, E91.383638	Type III
Killa (1)	Habiganj	Baniachong	Bogir *Killa*, Kagapasha Union	N24.575278, E91.399167	Type II

2.6 Monitoring Procedure

Monitoring has been conducted on the basis of the following parameters:

(a) Socio-economic profile: Hard solutions for infrastructure protection are not feasible for all the locations of the project areas. Also there is a possibility of negative impact on bio-diversity if such solutions are to be applied. In this context, soft solutions i.e. bio-engineering were applied.

(b) Improvement over existing technology: The existing technology for infrastructure protection has been monitored in this project and its performance was evaluated. Analyzing the collected data, scope for improvement over the existing technology has also been investigated.

A monitoring log was designed to collect data from the selected sites. A sample monitoring log is shown in Appendix A. At the time of data collection, photographs from different angles of the existing site, growth characteristics of vetiver root and shoot had been taken. Comparative performance evaluation of existing technologies has been done. Vetiver and soil samples were collected for classification, characterization and nutrient analyses.

2.7 Soil Tests

Soil samples has been collected from the seven sites of Brahmanbaria, four sites of Habiganj, four sites of Kishoreganj, four sites of Netrokona and three sites of Sunamganj for soil index property test and nutrient test. Collected samples have been tested at the Geotechnical Engineering Laboratory of BUET, and nutrient contents are being tested at Soil Resource Development Institute (SRDI). Soil characteristics data are useful to determine the growth and performance of vetiver in different soils. The list of laboratory tests conducted is given in Table 2.5 with appropriate standards.

2.8 Model Study

To determine the sustainability in submergence and against wave action according to the condition of *haor* region, small scale models were fabricated at BUET premises.

2.8.1 Submergence Model

A model study had been conducted on the rooftop premises of Department of Civil Engineering, BUET to replicate the situation of wet season of *haor* basin. Based on these activities an undergraduate thesis has been published (Latif, 2019). Four glass models was constructed (size 30.5cm×30.5cm×122cm, thickness=10 mm) to investigate the root growth and performance of vetiver in submergible condition.

Among these four models, two models were fabricated with JGT and remaining two without JGT. The soil was dredged fill sand collected from Chankharpul, Dhaka. The vetiver tillers were collected from Pubail, Gazipur. All vetiver tillers were planted at 10 cm c/c spacing. The photograph of the formulated model study is shown in Figure 2.7 (a).

After about 130 days all four models were filled with water for checking the sustainability under continuous submergence. Thus it would be continued until they are alive and in this way their sustainability will be observed under flash flood in *haor* region. Remaining two models with and without geo jute were representative of frequent rise and fall of water in *haor* region. Figure 2.7 (b) shows the procedure and models of the vetiver tillers in submerged condition.

Table 2.5: Soil Properties Test Scheme

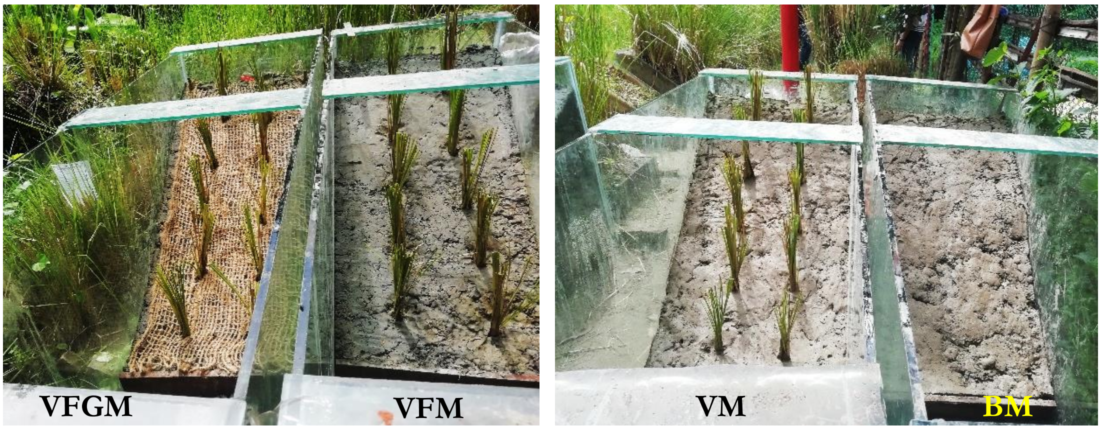
Properties	Name of the Test		Standards/ Methods	Parameters	Institute
Index Properties	Grain Size Analysis		ASTM C136, ASTM D422	F.M., % Fines	Geotechnical Laboratory, BUET
	Natural Moisture Content		ASTM D2974	ω_u	
	Specific Gravity Test		ASTM D854	G_s	
Engineering Properties	Falling Head Permeability Test		ASTM D5084	k	
	Direct Shear Test (CD)		ASTM D3080	ϕ	
Chemical Properties	Nutrient Test	pH	ASTM D4972	pH	SRDI
		Organic Matter	ASTM D2974	OM	
		Total Nitrogen	Potassium Chloride Extraction	N	
		Potassium	Bray Extraction	K	
		Phosphorus	Ammonium Acetate Extraction	P	
		Sulphur	Barium Sulphate Precipitation Method	S	
		Boron	Extraction with DTPA	B	
		Zinc	Hot Water Extraction	Z	

(a) (b)

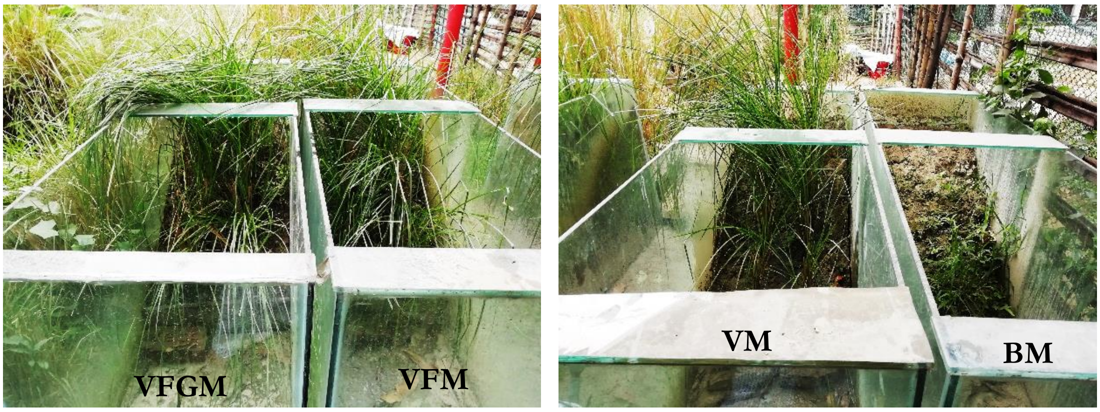
Figure 2.7: Photographs of (a) Models Constructed on Rooftop of CE Building, BUET; and (b) Submerged Vetiver Tillers under Water

2.8.2 Wave Tolerance Model

To evaluate the growth performance and propagation of the vegetation against wave action, four glass models (size 190cm×60cm×95cm) were fabricated. Half of the models were filled up at 8th August 2019 by compacted *haor* soils with a slope ratio of 1:1.5 (V:H). The soil was brought from Ramrail Upazila, Brahmanbaria with the cooperation of LGED officials. Vetiver tillers were collected from Pubail, Gazipur (GPS: N23°56'18.3", E90°28'02.8"). Among the four glass models, the first one (BM) was constructed with *haor* soils. The second model (VM) was also filled up with *haor* soil and covered with vetiver @20 cm c/c spacing. The soil of the third model (VFM) and fourth model (VFGM) was mixed and compacted with 8.5% fly ash (w/w) as stabilizer, and covered with vetiver @20 cm c/c spacing. The fourth model (VFGM) was covered with geo-jute of 600 gsm after soil compaction and slope preparation. After final slope preparation, a small wooden plank of 15 cm was installed at the toe of the soil slopes for each model, as a temporary guide wall. 5 (five) vetiver tillers per point were sown. Figure 2.8 (a) shows the photograph after the completion of vetiver plantation within all four models. Figure 2.8 (b) shows the condition of the growth of tillers after 160 days of plantation.



(a)



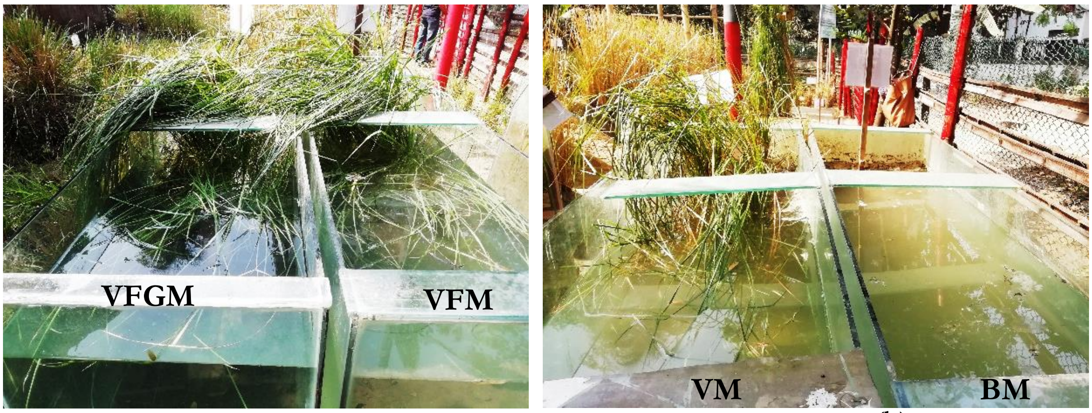
(b)

Figure 2.8: Photographs of (a) Models at the Day of Vetiver Plantation (24th August 2019); and (b) after 160 Days of Vetiver Plantation (30th January 2020)

From the day of plantation, proper care was taken of the tillers by watering, nursing, cleaning weeds and monitoring the models. After 172 days, all four models were filled up with water up to a height of 70 cm to create the submerged condition. Figure 2.9 shows the model condition after submergence. All models were kept under submerged condition for 5 days.

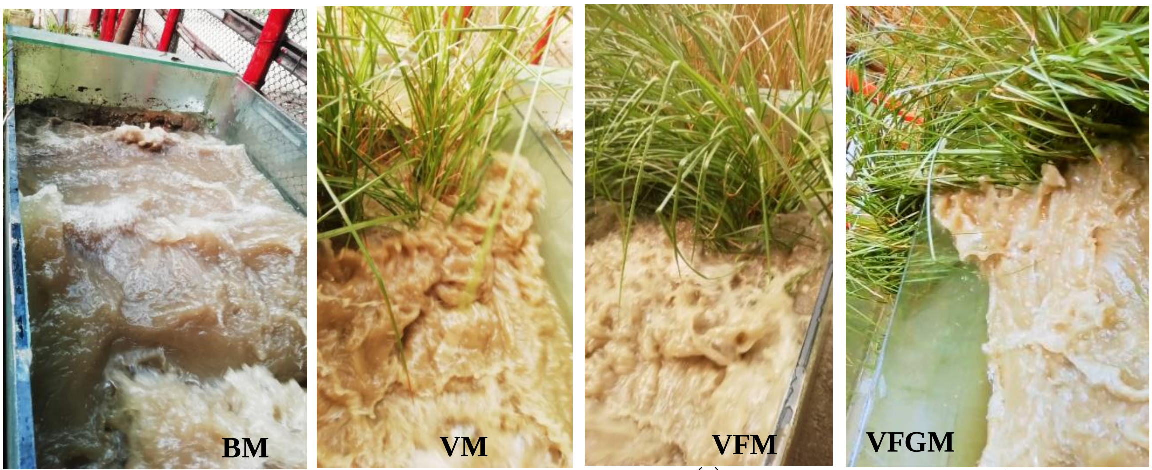
Wave action was produced after 5 days of submergence, after 177 days of growth of the tillers. The waves acted as strong dynamic forces along the slope without and with vegetation. The water depth, wave height, wavelength, amplitude, time period of wave and time required to break down the slope with losing the slope soil were calculated for each models. Figure 2.10 shows wave action propagation on the models BM, VM, VFM and VFGM. After wave propagation of all four models, slope breakdown time, mass of soil loss and turbidity of each model were estimated.

The tillers were allowed to grow up to 177 days (about 6 months) before wave action application. After wave action generation, from the each three models one vetiver tiller was uprooted carefully to measure the shoot and root length and diameter. One post graduate thesis (Islam, 2020), two undergraduate theses and one conference paper (Islam et al., 2020b) have been published based on these activities of the research project.



(a) (b)

Figure 2.9: Four Submerged Models at 173th Day of Plantation: (a) VFGM and VFM, and (b) VM and BM



(a) (b) (c) (d)

Figure 2.10: Photographs of Wave Action on the Models: (a) BM, (b) VM, (c) VFM and (d) VFGM

CHAPTER THREE

OUTCOMES OF THE RESEARCH

CHAPTER THREE: OUTCOMES OF THE RESEARCH

3.1 Introduction

This research was conducted to investigate the effectiveness of vetiver grass to protect the infrastructures of the *haor* by ecological revetment system using bio-engineering system. The findings obtained from the field, model studies and laboratory investigations are presented in this chapter. Sub-soil characteristics of this region, and cost comparison with applied design types and traditional practices are also briefed in this chapter.

3.2 Soil Properties of the *Haor* Region

3.2.1 Index Properties

Table 3.1 summarizes the soil type, Fineness Modulus (FM) and specific gravity (G_s) of the soils collected from field study areas. Figure 3.1 shows the photographs of all collected soils from five *haor* districts.

Table 3.1: Index Properties of *Haor* Soils

District	Site Name	Soil Type*	F.M.	G_s
Brahmanbaria	Kalikaccha, Sarail	Grey Sandy Silt	0.66	2.67
	East Noagaon, Sarail	Brown Silty Sand	1.29	2.62
	Modhupur, Ashuganj	Brown Silty Sand	0.93	2.61
	Dogarishwarbazar, Ashuganj	Brown Silty Sand	1.06	2.56
	Panchabaty (1&2), B. Baria Sadar	Brown Silty Sand	1.22	2.48
	Panchabaty, B. Baria Sadar	Brown Sandy Silt	0.73	2.60
	Salimabad, Bancharampur	Brown Silty Sand	1.10	2.72
	Ramrail	Brown Silty Sand	1.49	2.68
Habiganj	Vatipara, Baniachong	Brown Silty Sand	2.02	2.74
	Bogir Killa, Baniachong	Brown Sandy Silt	0.18	2.68
	Paschimbag, Azmiriganj	Grey Sandy Silt	0.69	2.68
	Chikonpur, Lakhai	Brown Sandy Silt	0.51	2.60
Kishoreganj	Chowganga, Itna	Brown Silty Sand	1.46	2.51
	Itna-GC Road, Itna	Grey Sandy Silt	0.97	2.66
	Kamalpur, Nikli	Brown Silty Sand	0.55	2.54
	Daulotpur, Nikli	Brown Silty Sand	0.38	2.65
Netrokona	Guturabazar, Kalmakanda	Grey Sandy Silt	0.85	2.75
	Janjailpara, Kalmakanda	Brown Silty Sand	1.40	2.49
	Mujibnagar, Khaliajuri	Brown Sandy Silt	0.58	2.72
	Hayatpur, Khaliajuri	Brown Silty Sand	1.47	2.68
Sunamganj	Meghna Barghor, Derai	Brown Silty Sand	1.10	2.56
	Meghna Notunpara, Derai	Brown Silty Sand	1.57	2.68
	Kochua, Derai	Grey Silty Sand	1.51	2.62

**Classification based on ASTM D422*

Figure 3.2 shows a sample of grain size analysis curves of *haor* areas. From all the graphs and tables, it indicates the variety and non-uniformity of soil type in this region. It shows that almost all of the soil types are silty sand/sandy silt, i.e., non-plastic, are fine in nature.

Figure 3.1: Visual Photographs of *Haor* Soils

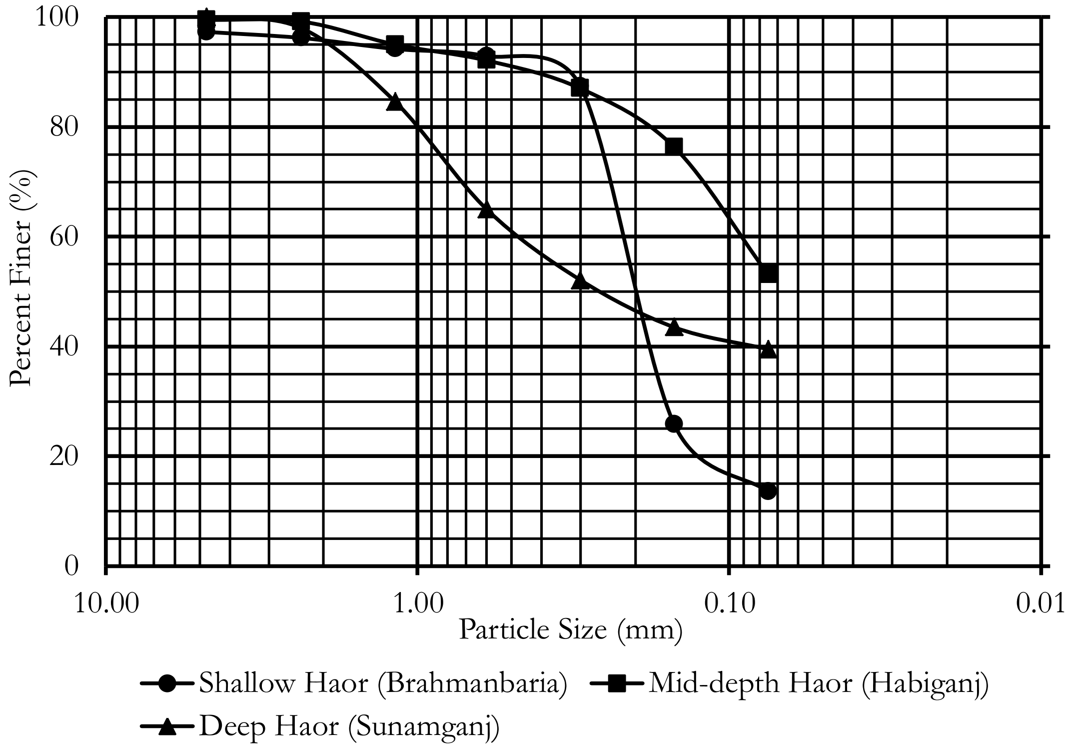


Figure 3.2: Grain Size Distribution of the *Haor* Soils

3.2.2 Engineering Properties

Permeability test and direct shear tests (CD) were conducted of *haor* soils to determine the infiltration capacity and shear strength parameters. The results are summarized in Table 3.2 along with the natural moisture content of soil. It is found that, most of the *haor* soils obtain a low degree of permeability (Lambe, 2014). Soils of Sunamganj are the most impermeable soil, where soils of Habiganj are the most permeable soil among all *haor* districts.

Table 3.2: Permeability Characteristics of *Haor* Soils

Location	Natural Moisture Content, ω_u (%)	State of the soil	Permeability at 20°C, k (cm/sec)	Degree of Permeability	Void Ratio, e
Kalikaccha, Sarail, Brahmanbaria	11.35	Loose	1.091×10^{-3}	Low	1.57
		Medium Dense	8.535×10^{-4}	Low	1.36
		Dense	3.966×10^{-4}	Low	1.15
Ramrail, Brahmanbaria	15.65	Loose	6.571×10^{-5}	Very Low	2.09
		Medium Dense	6.405×10^{-5}	Very Low	1.56
Paschimbag, Azmiriganj, Habiganj	9.36	Loose	1.155×10^{-3}	Low	1.44
		Medium Dense	1.075×10^{-3}	Low	1.30
		Dense	7.786×10^{-4}	Low	1.17
Chowganga, Itna, Kishoreganj	14.19	Loose	2.380×10^{-4}	Low	1.51
Guturabazar, Kalmakanda, Netrokona	16.22	Loose	5.275×10^{-4}	Low	1.52
		Medium Dense	4.144×10^{-4}	Low	1.48
		Dense	1.483×10^{-4}	Low	1.37
Kochua, Derai, Sunamganj	11.52	Loose	8.046×10^{-5}	Very Low	1.49

Table 3.3: Shear Strength Parameters of *Haor* Soils

Location	Moisture Content, ω (%)	Dry Density, γ (kN/m³)	Normal Stress, σ_n (kPa)	Shear Stress, τ_{max} (kPa)	Cohesion, c (kPa)	Angle of Friction, Φ (°)
Kalikaccha, Sarail, Brahmanbaria	48.1	10.6	30.97	12.52	–	31
	44.0	10.4	61.93	35.47		
	43.2	10.3	123.83	75.01		
Ramrail, Brahmanbaria	43.7	10.9	30.97	14.82	–	26
	35.2	11.2	61.93	30.37		
	28.5	11.3	123.83	59.70		
Paschimbag, Azmiriganj, Habiganj	36.2	11.9	30.97	12.78	–	28
	35.2	11.5	61.93	31.39		
	35.2	11.4	123.83	66.59		
Chowganga, Itna, Kishoreganj	38.2	12.1	30.97	12.52	–	27
	36.7	12.3	61.93	30.12		
	34.4	12.3	123.83	64.80		
Guturabazar, Kalmakanda, Netrokona	36.8	12.8	30.97	25.19	–	30
	30.4	11.5	61.93	28.91		
	32.4	13.0	123.83	30.81		
Kochua, Derai, Sunamganj	31.2	14.2	30.97	42.71	5.8	36
	32.3	14.1	61.93	38.92		
	30.4	14.5	123.83	37.68		

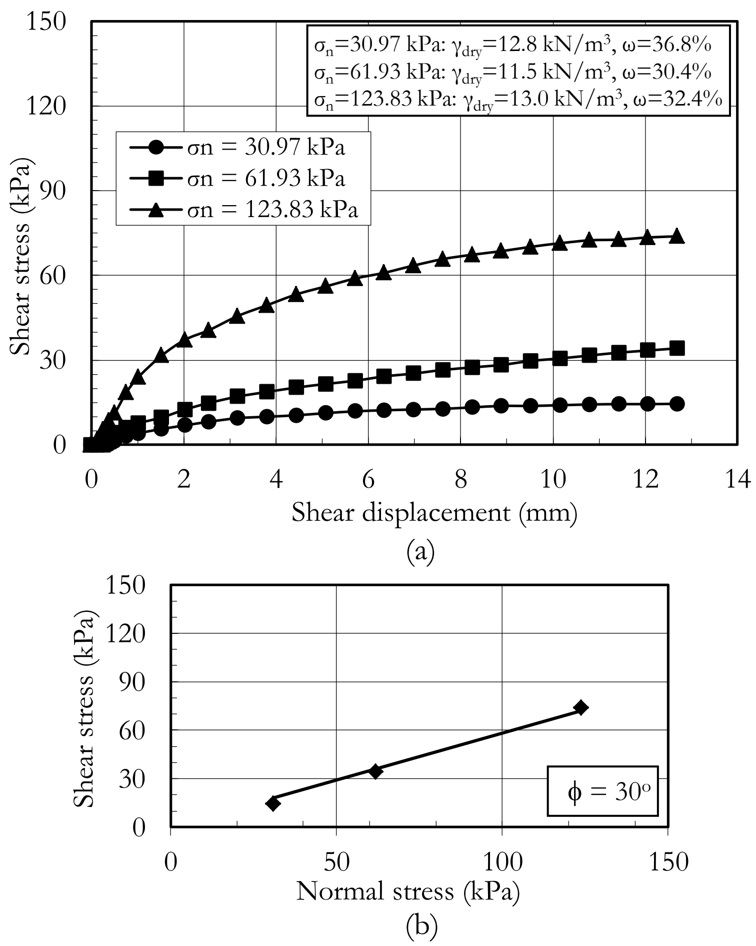


Figure 3.3: Graphs of (a) Shear Stress vs. Shear Displacement; and (b) Shear Stress vs. Normal Stress for Soil from Guturabazar, Kalmakanda, Netrokona

All strength parameters from the graphs of the *haor* soils are summarized in Table 3.3. Figure 3.3 shows the shear stress vs. shear displacement curves and shear stress vs. normal stress graphs of a typical *haor* soil. From Table 3.3 and Figure 3.3, it is found that the *haor* soils are loose in consistency of soil.

3.2.3 Chemical Properties

The soil samples from Brahmanbaria, Habiganj, Kishoreganj, Netrokona districts were sent to Soil Resource Development Institute (SRDI) to measure the essential elements of soil for proper growth of vegetation, i.e. available Nitrogen, Phosphorus, Potassium, Sulphur, Zinc, Boron, pH of the soil. These results are shown in Table 3.4.

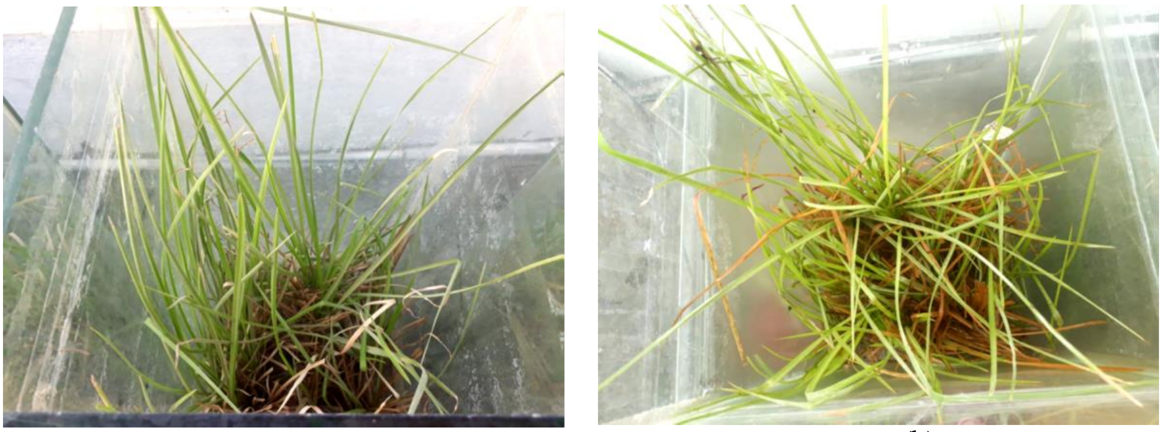
Table 3.4: *Haor* Soil Nutrients with Necessary Adjustments

Elements	Chemical content of *Haor* Soil	State of *Haor* Soil	Required amount	Requirements to reach optimum level
pH	4.0-7.8	Acidic-Alkaline	6.0-7.5	Lime addition to reduce acidity
N (%)	0.015-0.365	Low	3.0	Organic compost using vegetables coffee grounds
P (ppm)	1.2-104.96	Very Low - High	16	Lime addition
K (meq/100g)	0.09-2.75	Very Low - Very High	0.32	(a) Fruit addition to compost. (b) Gathering the potassium-rich ashes by burning wood once the fire is out (c) Dig 6 to 8 inches beneath the surface of the ground or plant container, then mix coffee grounds into the soil
S (ppm)	0.46-93.56	Low -Very High	10-50	Elemental sulfur addition, also known as "flowers of sulfur," or aluminum sulfate
Zn (ppm)	0.72-10.81	Low	50	Compost or organic manure addition
B (ppm)	0.07-3.01	Low	6	Small amount of boric acid addition (1/2 tsp. per gallon of water) as a foliar spray will do the job, and water the area to move boron into the root zone. Wearing protective clothing, including safety eyewear is recommended.
Organic Matter (%)	0.7-2.0	Low	2-4	Perennial pasture growing and addition of organic fertilizers.

3.3 Model Study Outcomes

3.3.1 Submergence Model

The vetiver tillers of four models were allowed to grow for 130 days before applying full submergence. After seven days of submergence the water was allowed to pass. It has been observed that, the shoots become greener than earlier with some newly grown shoots. Some shoots became yellow/brown in color fully or partially, but there was no bad odor which indicates no sapling were rotten. Figure 3.4 shows the difference between the conditions of vetiver before and after submergence. A sub-root can be observed due to submergence, which usually decreases the efficiency of root strength due to the hollow condition of root matrix. After submergence, shoot and root length, shoot and root matrix diameter, number of new shoots etc. were measured which are tabulated in Table 3.5. From the overall observation, it can be concluded that vetiver is sustainable under seven days of flash flood.



(a) (b)

Figure 3.4: Condition of Vetiver (a) before Submergence; and (b) after 7 Days Submergence

Table 3.5: Growth Performance of Vetiver under Submergence after 137 Days

Parts of vetiver	Parameters	Value/Condition	
		Vetiver only	Vetiver + JGT
Shoot	Length (cm)	28-82	22-64
	Width (cm)	1	1
	Diameter of the bush (cm)	8	10.5
	Color	Green	Green
Root	Length (cm)	60-75	60-70
	Single root diameter (cm)	0.2	0.2
	Root matrix diameter (cm)	8	13
Leaf	Color	Green, yellowish brown	Green, yellowish brown
Tiller	Inflorescence	Yes (After 240 Days)	Yes (After 240 Days)
	No. of tillers grown in one point	31	64

3.3.2 Wave Tolerance Model

After submergence creation of the four models, the condition of vetiver tillers was similar as before. Figure 3.5 shows the slope condition of the four models after wave action propagation. The amount of soil loss by wave action generation is tabulated in Table 3.6. The wave action propagation was continued up to breaking of the slope. From Table 3.6, it is visible that the model without any type of protection (BM) broke so quickly with a huge soil loss. The model with vetiver (VM) broke 15 times later with 23% less soil loss. The model with *haor* soil, 8.5% fly ash and vetiver tiller (VFM) broke 2 times later with 12% less soil loss than that of VM. The fourth model (VFGM) with *haor* soil, 8.5% fly ash, JGT, and vetiver tiller broke 1.6 times later with 54% less soil loss than that of VFM. Turbidity was also measured for the four models by turbidity meter. 10 ml soil with water mixture from the four models was diluted with 40 ml distilled water to measure the turbidity shown in Table 3.6.

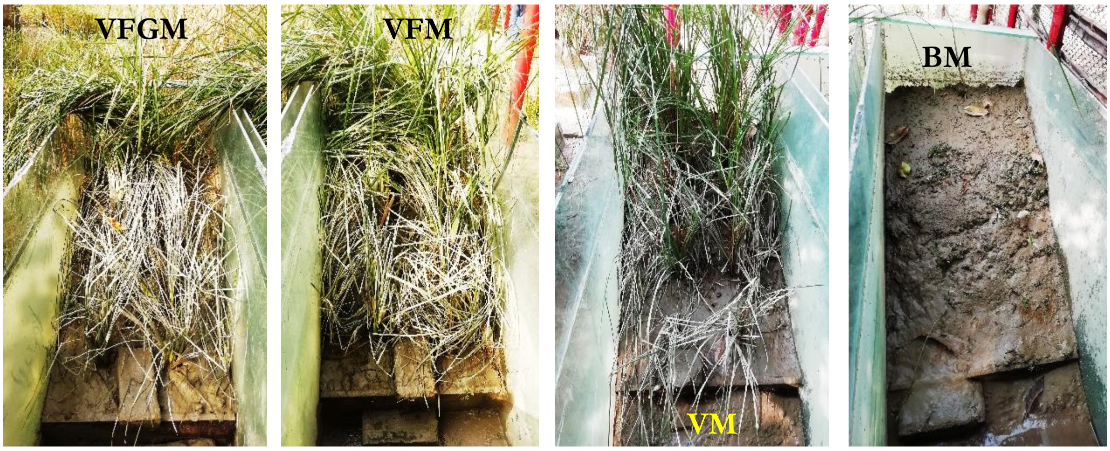


Figure 3.5: Slope Condition after Wave Action Generation

Table 3.6: Performance of Wave Tolerance Models

Model Name	Wave Height (cm)	Wave Velocity (m/s)	Slope Breakdown Initiation Time (sec)	Total Soil Loss (kg)	Actual Turbidity (NTU)	Damage Type
BM	5-20	0.2-0.3	33	24.50	2620	Major
VM			483	19.84	1935	Medium
VFM			907	17.44	1370	Minor
VFGM			1429	8.02	1060	Minor

After 177 days of plantation, measurements were taken of shoot and root length of the vetiver tillers, which is tabulated in Table 3.7 Figure 3.6 shows taking measurements of vetiver tillers of six month age for the three wave tolerance models.

Table 3.7: Growth Performance of Vetiver of Wave Tolerance Models after 177 Days

Parts of vetiver	Parameters	Value/Condition		
		VM	VFM	VFGM
Shoot	Length (cm)	25-130	18-147	18-170
	Width (cm)	1	1.2	1
	Diameter of the bush (cm)	7.6	13.0	11.0
	Color	Green	Green	Green
Root	Length (cm)	7.6-71	10-61	13-74
	Single root diameter (cm)	0.2	0.3	0.3
	Root matrix diameter (cm)	6.4	9.0	12.0
Leaf	Color	Green	Green	Green
Tiller	Inflorescence	No	No	No
	No. of tillers grown in one point	13	31	28

At the time of plantation only 5 tillers were sown in one point, which increased to 13, 31 and 31 tillers for VM, VFM, and VFGM, subsequently. The root of the tillers reached up to the bottom of the models, and it also formed a matrix with the other tillers.

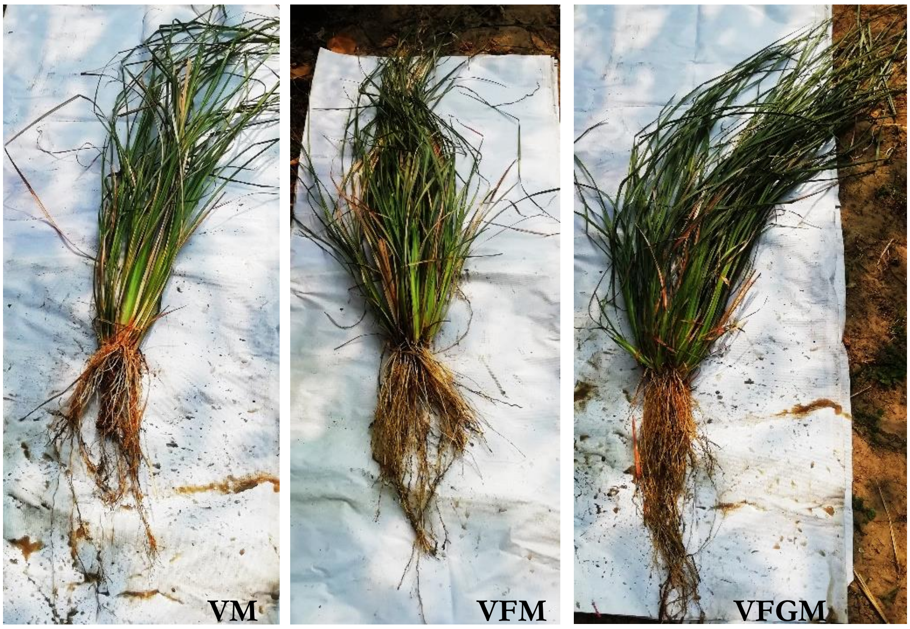


Figure 3.6: Vetiver Tillers of Three Models (VM, VFM and VFGM)

Soil loss was found less where the root matrix was in a large scale. The shoot matrix also helped to protect the soil from washing away against erosion. By means of all data, VFGM can be stated as the most compatible and stabilized revetment model comparing with others. It is found that the degree of increasing protection measures increased positive impact on slope protection. Based on this model study, vetiver protection were found both submergence and wave tolerant, as no tillers were uprooted and washed away due to wave action.

3.4 Performance of the Pilot Studies

The consultant team observed the performance of bio-engineering technology for the protection of *haor* infrastructures in village islands, road slope and *killa* against wave action, submergence and soil erosion. Topographical and climatic condition were observed also. Some typical pilot studies are presented in this article.

3.4.1 Road Embankment

The road slope protection works are important for proper communication system of *haor* people, on which the economic condition depends. 10 (ten) road slope protection works were monitored for the purpose of field study in the *haor* districts.

Shallow *Haor*

Among all *haor* districts, Brahmanbaria is categorized as shallow *haor* according to depth. The visited six road embankment sites are tabulated in the previous chapter.

Figure 3.7 shows the condition of slope protection works in Kalikaccha UP- Bariura Bazar Road in Sarail Upazila of Brahmanbaria district. This site faced submergence by four monsoon periods. The slope seemed to be steep (1:1, V:H), and design type III as implemented. After about two years, it is seen that around 200 vetiver tillers have been grown from two planted tillers. Figure 3.7 (b) shows the broken CC blocks along with the slopes where no vetiver tillers were found, which occurred due to lack of bondage with soil. It indicates that the growth of vetiver is very good, but as maximum tillers were uprooted by local people, and for poor maintenance of the site, garbage disposal the overall performance of slope protection was not satisfactory enough.

(a)

(b)

Figure 3.7: Photographs of (a) Slope Condition at 14th January 2019; and (b) Loosened CC Blocks along Slope

Slope protection work at Modhupur Temohoni to Lalpur R&H via Lalpur UP & GC Road, Ashuganj, Brahmanbaria is situated beside a branch of the river *Meghna*. The applied design scheme was Type III (CC block with hole) with earthen pavement here. Figure 3.8 (a) shows the photographs of slope condition and vetiver growth at 14th January 2019, where Figure 3.8 (b) is stating the slope condition at 16th November 2019. The performance of vetiver growth was quite well along 100 m strip in this site, so the road slope is well protected against rainfall, submergence and wave action for three monsoon periods.

Figure 3.8: (a) Slope Condition after Facing Two Monsoons; and (b) Slope Condition after Facing Three Monsoons

Improvement of slope protection wok at North West Side Bridge Approach R&H Road under Salimabad UP to Faridabad union, Bancharampur, Brahmanbaria is situated alongside a river named '*Titas*" and a swamp named '*Kaizzor beel*'. The slope improvement of the approach road in south side is conducted by LGED, where the design scheme was Type II, vetiver tillers were planted on both slope and shoulder of the road. Figure 3.9 (a) shows the road geometry after facing three monsoon periods with rainfall, submergence and wave action, where vetiver tillers were burnt down and new tillers were not grown yet. Vetiver tillers were burnt by local people for abundance of rodent residents and robbery nuisances. Figure 3.9 (b) shows the road condition after facing four monsoon periods. New vetiver tillers were grown within this interval from burnt shoots.

(a) (b)

Figure 3.9: Site Condition of Salimabad, Bancharampur, Brahmanbaria at (a) 15th January 2019; and (b) 16th November 2019

Mid-depth *Haor*

Habiganj is mid-depth *haor* according to depth among all *haor* districts. The slope ratio of road slope protection on Pashchimbag-Azmiriganj Road, Azmiriganj, Habiganj was found as 1:1 (V:H). In this site, design Type III was applied. The plantation area of this site is rural populated area, so numerous disturbances were observed. Figure 3.10 (a) shows state of the slope at 26th January 2019, whereas Figure 3.10 (b) is the slope condition at 18th November 2019, after facing rainfall and submergence. The growth of vetiver was good, but due to poor maintenance, maximum hole of CC blocks became blank which expedited slope failure during monsoon.

(a) (b)

Figure 3.10: (a) Slope Condition of the Paschimbag, Azmiriganj, Habiganj after Facing Two Monsoons; and (b) Slope Condition of the Site after Facing Three Monsoons

Deep *Haor*

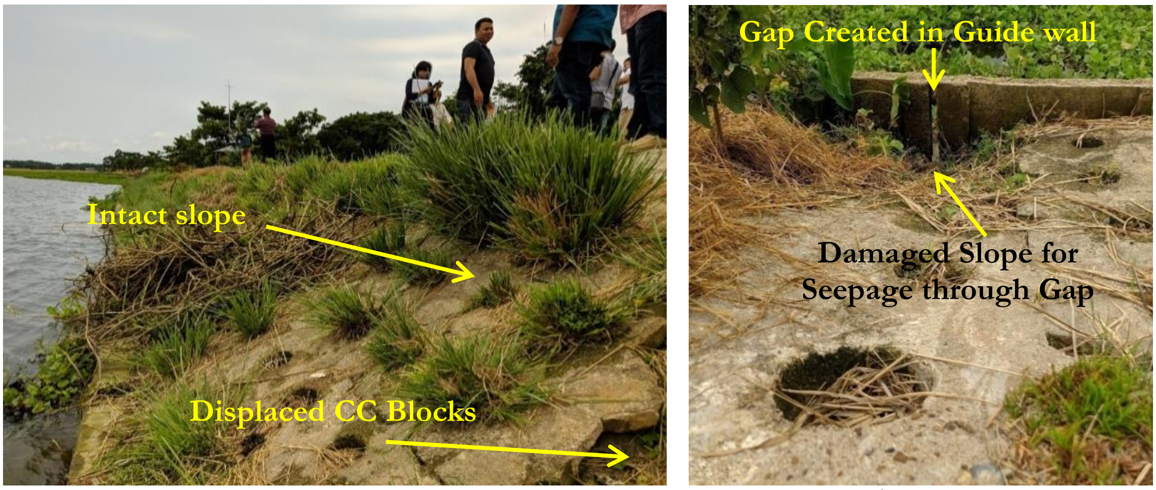
Kishoreganj is categorized as deep *haor* by depth of the surrounding *haor*s. The road slope protection work at Chowganga- Chandrapurhat road slope protection wall, Chowganga Union of Itna Upazila, Kishoreganj district, is situated beside a river named *Amader Nadi*.

The slope ratio was found as 1:1 (V:H), and toe wall was provided beneath the slope. Figure 3.11 (a) and (b) shows the slope conditions after facing rainfall, submergence and wave action by two monsoons. The slope was found intact for the excellent growth of vetiver. Figure 3.11 (b) shows the slope condition at the same Upazila constructed by solid CC blocks. After facing similar climatic conditions, design Type III sustained very well, where the solid blocks broke easily for the lack of bondage with soil, which made the slope condition vulnerable. Figure 3.11 (c) shows the slope condition after facing two monsoon periods, where the vetiver tillers were trimmed, so even though after facing one more flood, the slope condition was satisfactory. At this site, it was found that children were collecting trimmed vetiver shoots as a source of income, by selling the tillers as fuel and fodder.

(a) (b) (c)

Figure 3.11: Slope Condition at Chowganga, Itna, Kishoreganj: (a) at 8th March 2019; (b) by Protection with Solid Blocks; and (c) at 8th February 2020

Netrokona is also a deep *haor* district, and the road slope protection site visit was conducted at Borkhapon UP office-Guturabazar road slope protection of Kalmakanda Upazila on 23rd May 2019. This site is situated beside the *Meda beel* at the south side of the road. The slope ratio was found as 1:2 (V:H). In monsoon, this road slope fully submerges under water. The slope tends to break easily against wave action as proper compaction of soil was not done during slope preparation. Figure 3.12 (a) shows the overall slope condition constructed by design Type III.



(a) (b)

Figure 3.12: (a) and (b) Slope Condition of the Site at Guturabazar, Kalmakanda, Netrokona after facing two monsoons

The growth performance of vetiver at this site was excellent, but some blocks were replaced from slope against wave action and surface runoff, as no vetiver tillers were found within those blocks. A grade beam was constructed underneath the slope at this site, and a guide wall was constructed at the toe of the slope shown in the Figure 3.12 (b). As gaps were created within the guide wall, it allowed seepage which washed away the slope soil, accelerating the failure of the slope.

3.4.2 Village Island

The village areas of *haor* districts turn into detached islands in monsoon due to heavy rainfall, submergence and wave action. So, the distresses of the livelihood become immense which stimulates the need of appropriate protection for these villages. Total 11 (Eleven) village island protection works were monitored in the five *haor* districts for pilot study.

Shallow *Haor*

In Brahmanbaria, a village protection work at East Noagaon Village near Noagaon GPS, Sarail was conducted, where the slope ratio was found as 1:2.4 (V:H).

Figure 3.13: Village Protection work at East Noagaon, Sarail at 14th January 2019

At this site, Type III design scheme was implemented. Figure 3.13 shows the slope condition of village protection work behind East Noagaon Primary School, East Noagaon, Sarail after facing rainfall and submergence by four monsoons. The growth performance of vetiver was poor because of scarcity of sunlight in that place, poor maintenance and garbage disposal. Despite of the poor growth of vetiver tillers, the slope condition was moderate as other vegetation (Kansh, *Saccharum spontaneum*) was grown here very well.

Mid-depth *Haor*

The village island protection work in Habiganj was conducted in Vatipara village, Baniachong which is situated beside *Ratna beel* and *Barak* River. The slope was mild at the beginning as the ratio is 1:2 (V:H), but after a separating bridge towards north-west side the slope the ratio was found 2.4:1 (V:H) which indicates a very steep slope. The slope was constructed with interlocking hollow blocks, but the thickness was found to be inadequate to provide enough protection against erosion.

The first plantation of vetiver took place on 10th April 2018, but the overall area was inundated at monsoon. So replantation was done on 2nd January 2019. Figure 3.14 (a) shows the slope condition on 26th January 2019, after 24 days of the plantation. Figure 3.14 (b) shows the condition on 18th November 2019, after facing a flood. As the plantation was done in dry season, the tillers grew properly and when rainfall and flood occurred, the tillers protected the overall slope by preventing washing away the CC blocks and soils. At this location, swamp trees named "Koroch" are found, which are highly water resistant that can survive long duration of inundation during the rainy season.

(a) (b)

Figure 3.14: Photographs of Slope Condition at Vatipara, Baniachong, Habiganj: (a) 24 Days after Plantation; and (b) After Facing One Flood

Deep *Haor*

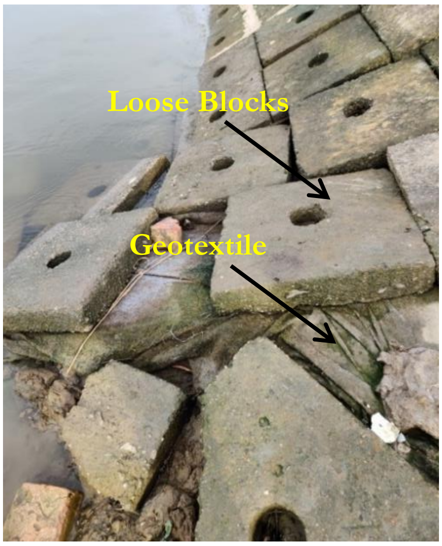
In Netrokona, village protection work in Hayatpur was conducted in Khaliajuri Upazila at 9th February 2020, which faced three monsoon periods with full submergence and wave action. The slope ratio was found as 1:1.5 (V:H) as per design schedule, and design type III was applied on this site. Block holes were found as sealed off by mortar and the slope surface was filled by sandy soil at this site. So the slope failed by loosening the blocks as shown as Figure 3.15 (a), since there was no interaction within the protection system and the soil. Some vetiver tillers were found at the toe of the slopes at the site. A vetiver source was found at the same village and the growth of the tillers was found excellent after facing three monsoons, as shown as Figure 3.15 (b). Although this site was also surrounded by deep *haor*, the condition of the road of vetiver source was found good due to proper protection, which indicates the submergence tolerance of vetiver tillers.

(a) (b)

Figure 3.15: (a) Broken Slope by Sealed Block; and (b) Vetiver Source at Hayatpur, Khaliajuri, Netrkona

At Sunamganj, village island protection work was conducted at Meghna Notunpara village under Rafinagar union and Kochua village of Derai Upazila. Meghna Notunpara village is situated beside the *Kaliergota haor*, and Kochua village is situated beside the *Safety haor*, which are vulnerable during monsoon period. The slope ratio was found as 1:1.6 (V:H) and 1:1.4 (V:H), respectively at Meghna Notunpara village and Kochua village.

(a)



(b)

Figure 3.16: Photographs of (a) Slope Condition at Meghna Notunpara, Derai, Sunamganj; and (b) Slope Condition at Kochua, Derai, Sunamganj

Figure 3.16 shows the difference between the two sites. In Figure 3.16 (a), excellent growth of vetiver tillers and good slope condition was observed after facing two monsoons. Figure 3.16 (b) shows the slope condition of Kochua village. At Meghna Notunpara, stairs were provided in the slope, so no interruption occurred and the tillers and slope of the village island was found intact. No interlocking block was provided in this protection system. But in Kochua village, CC hollow blocks were placed on slope in April 2019, and flood occurred before plantation of vetiver tillers. Consequently, blocks got unattached to soil due to no plantation of tillers after one flood. In the both village islands, inundation usually occurs up to 1.8 m height from the toe of the slope, and wave action occurs from south-east direction during monsoon. Nevertheless, the slope condition was excellent in Meghna Notunpara and erosion did not occur, as vetiver tillers were planted and maintained properly.

3.4.3 Killa (Raised Land)

Killa is a comparatively raised fallow land in *haor* which is usually used during flash flood or early flood to save crops and other wealth. Size of a *killa* is generally 60 m×30 m. People very often use the *killa* land for crop harvesting purposes before the monsoon flood.

1 (one) *killa* was monitored for the purpose of field study, at Bogir *Haor* under Kagapasha Union, Baniachong Upazila of Habiganj. Figure 3.17 (a) shows the submersible road condition on the way to the killa. The condition of road on the way of the killa was very poor. Due to surface runoff and flood by facing three monsoons, the slope was damaged at a greater value.

Only three vetiver samples were found in this site shown in Figure 3.17 (b). In place of vetiver tillers, a species of shrub named "Dholkolmi" was planted after the flood in this area.

But the overall condition of the site seemed worn-out due to poor maintenance.

(a)

(b)

Figure 3.17: Photographs of Bogir *Killa*, Habiganj: (a) Submergible Road Condition; and (b) Very Few Vetiver Tillers Found at the Site

3.4.4 *Bee*l Bank and Model Village

A beel is a lake-like wetland. Throughout the rainy season, *haor, beels* and all wetlands combines up and create vast stretch turbulent water that it is thought of as a sea. So it is difficult to differentiate between the protection of *haor* infrastructures and beel bank protection.

A model village means somewhat ideal condition of village, where transportation, communication and protection measures are applied properly as per design to observe the performance against similar climatic and topographical condition with all other *haor* infrastructures. A model village island was supposed to be constructed in Mithamoin, Kishoreganj. As it is not constructed yet, the model village was not possible to visit.

3.4.5 Growth performance of Vetiver

Growth of vetiver tillers was found excellent in all districts, by terms of survival of the grasses, condition of slope and shoot and root length of the tillers. Figure 3.18 represents the growth data of vetiver tillers in the five *haor* districts.

The roots of the vetiver tillers could not be uprooted properly, so actual measurement of root was not possible. In Brahmanbaria, the range of maximum shoot and root length of vetiver were found as 15.2-177.8 cm and 16.0-35.6 cm. The age of the tillers was 730-1430 days.

In Habiganj, the range of maximum of shoot and root length of vetiver were found as 30.5-137.8 cm and 7.6-33.0 cm, and in Kishoreganj, the range of maximum of shoot and root length of vetiver were found as 16.5-132.1 cm and 15.2- 22.9 cm. The age of the tillers was 24-1035 days and for Habiganj and 335-1430 days for Kishoreganj.

In Netrokona, the range of maximum of shoot and root length of vetiver were found as 58.4-132.1 cm and 12.7-20.3 cm. In Sunamganj, the range of maximum of shoot and root length of vetiver were found as 82.0-89.0 cm and 17.8-27.9 cm. The age of the tillers was 737-1035 days for Netrokona and 515-1245 days for Sunamganj.

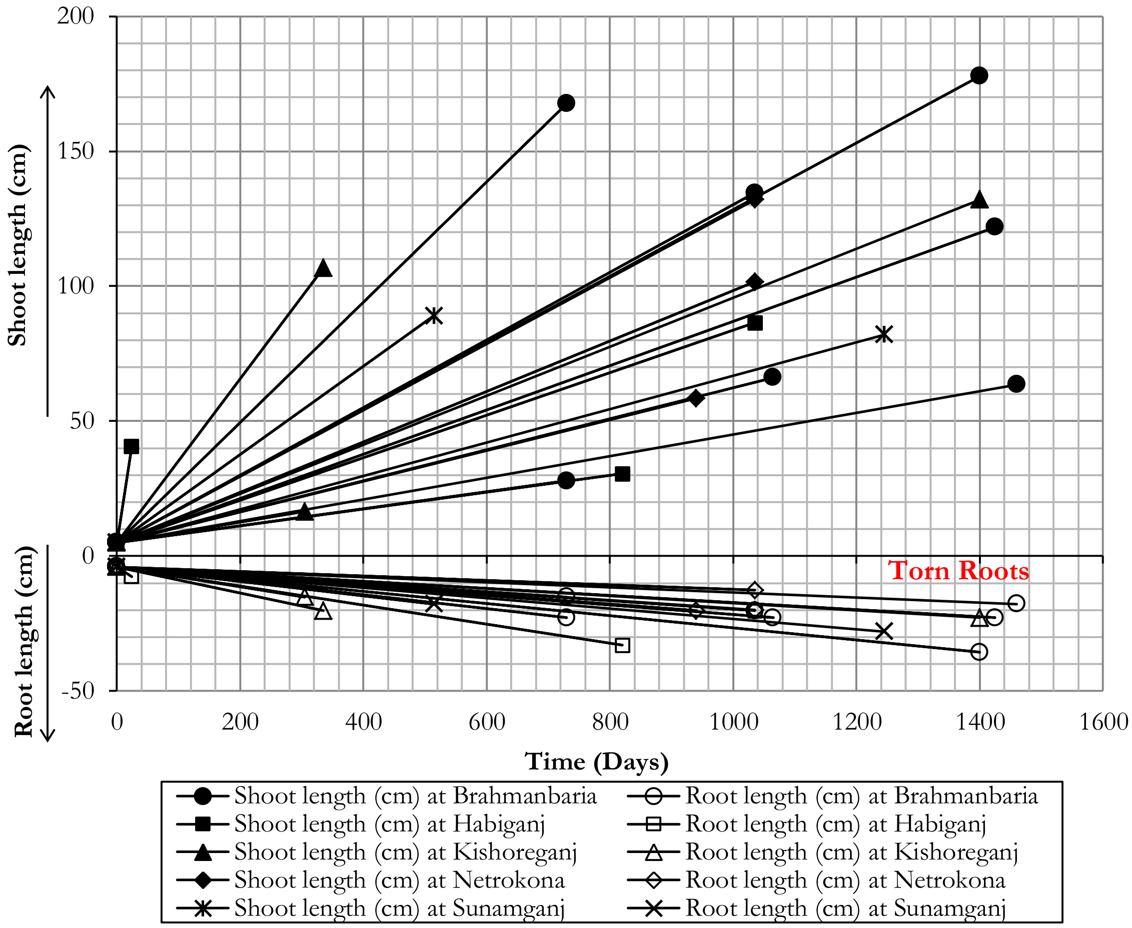


Figure 3.18: Growth of Vetiver in *Haor* Region

3.4.6 Available Vegetation in *Haor*

The following plants were found to grow surrounding vetiver grasses at the sites in *haor* basin of Brahmanbaria, Habiganj, Kishoreganj, Netrokona and Sunamganj.

Herbs:

1. Durba (*Cynodon dactylon*): A creeping grass working as a turf on the road shoulder.
2. Malankuri (*Eleusine indica*): A small tufted grass, scattered here and there on road shoulder, and holding the ground.
3. Moida/Moujja/Ikhar (*Sclerostachya fusca*): A robust, largely tufted, rhizomatous grass protecting the toes of the slopes.
4. Kuksim (*Vernonia patula*): A delicate erect, short herb scantily growing in the intervening spaces among the slabs as well as on the road shoulders.
5. Kansh (*Saccharum spontaneum*): A perennial grass of more than 1 m tall with fibrous roots was found to grow in some holes and intervening spaces of slabs, anchoring very firmly to the ground and resisting water logging.
6. Bherenda/Bhenna (*Ricinus communis*): Tall robust shrubs of this species were found to grow at one side side of the slope, and more or less stabilizing the soil.
7. Notey (*Amaranthus viridis*): A delicate, short herb growing in the intervening spaces of slabs, hardly imparting any protecting effect on slopes
8. Fern: A few ferns were found to grow in the intervening spaces of slabs holding the soil.
9. Malankuri (*Eleusine indica*): A small tufted grass, scattered here and there on road shoulder, and holding the ground.

10. Kuksim (*Vernonia patula*): A delicate erect, short herb scantily growing in the intervening spaces among the slabs as well as on the road shoulders.
11. Makur-Jali (*Digitaria ciliaris*). A delicate annual grass growing on the Killa.
12. Fola Ghash (*Echinochloa crusgalli*): This grass was cultivated near the slopes. It is a partially aquatic grass.
13. Dhani Ghash (*Panicum repens*): A creeping perennial grass with long horizontal rhizomes growing on the margins of slopes. It stabilizes the soil very strongly and can withstand inundation.

Shrubs:

1. Chhitki/Khoi/Khoibabla (*Pithecellobium dulce*): A stout, branching shrub found to grow scattered in the intervening spaces among the slabs, and firmly holding the slope.
2. Kudura/Dumur/Kakdumur (*Ficus hispida*): An erect, stout shrub of about 1 m tall growing in the intervening spaces of the slabs, and firmly holding the slope.
3. Bherenda/Bhenna (*Ricinus communis)*: Tall robust shrubs found to grow scantily on the upper sides of the slope, and more or less stabilizing the soil.
4. Rongon (*Ixora coccinea*): A dwarf, stout shrub scantily growing in a few intervening spaces of slabs, and strongly protecting the slope.
5. Dhutura (*Datura stramonium*): A bushy, soft solitary shrub, found to grow at one end of the slope, and moderately holding the earth.
6. Berela/Bola (*Sida cordifolia*): A dwarf, coarse, solitary shrub found to grow in the intervening space of slabs, fixing the soil.
7. Ghagra (*Xanthium indicum*): A short, coarse shrub found here and there in the intervening spaces of slabs, and holding the soil.
8. Bhat (*Clerodendrum inerme*): An erect small shrub growing profusely along the road shoulders on top of slopes, and firmly stabilizing the ground.
9. Borohalkasunda (*Cassia occidentalis*): A shrub of about 1 m tall found to grow scantily in the holes of slabs upon the slope.
10. Agrajit (*Clitoria ternetea*): A small bushy shrub about 2 ft tall growing in the intervening spaces of the slabs, and holding the soil.
11. Dholkolmi (*Ipomoea fistulosa*): A large gregariously growing shrub stabilizing the margins and slopes of Killa. It can withstand considerable period of inundation.
12. Bishkatali (*Polygonum orientale*): A bushy small shrub growing scattered on the Killa slopes.
13. Muktapati (*Clinogyne dichotoma*): A stout, erect, clump forming shurb very strongly holding the habitat with long inundation surviving efficiency.

Climbers:

1. Telakucha/Gutum (*Coccinea cordifolia*): A delicate climber straggling over the Vetiver clumps, but hardly retarding their growth.
2. Assamlata (*Eupatorium odoratum*): A gregarious climber straggling over Vetiver tufts and other vegetation, and seriously retarding their growth.

Trees:

1. Assheora/Sheora (*Streblus asper*): A few small trees of about 1 m tall with strong roots were found to grow in the intervening spaces among the slabs, and strongly holding the slope.
2. Norcha/Naricha/Jiban (*Trema orientalis*): A small tree of more than 2 m tall standing erect in some holes of slabs as well as in their intervening spaces. It is capable of surviving inundation of flood water as well as in firmly holding the slopes.
3. Kul (*Zizyphus mauritiana*): Small trees were found to grow very scantily along the road shoulders above the slopes, and stabilizing the earth.

4. Rendikoroi/Raintree Koroi (*Samanea saman*): Large trees growing along the road shoulders and playing an important role in the stability of slope protection.
5. Banana (*Musa paradisiaca*). Clumps of banana trees were found to grow at one end of the slope, and substantially holding the earth.
6. Rendikoroi/Raintree Koroi (*Samanea saman*): A few medium sized trees growing along top margins of the slopes, and fixing the ground.
7. Bhatam/Lattu (*Trewia polycarpa*): A few small trees found in the toes of slopes, capable of protecting the slope.
8. Jarul (*Lagerstroemia speciosa*): A medium sized tree growing along the road shoulders as well as on slopes, capable of resisting flood water inundation.
9. Koroi (*Albizia procera*): A couple of large trees growing along the margins of roads up the slopes, and playing an important role in the stability of slope protection.
10. Mehogini (*Swietenia mahagoni*): A few of this large tree were found to grow along the margins of the road up the slopes, and providing support to earth stabilization.
11. Barun (*Crataeva nurvala*): Saplings of a medium sized tall tree of this species were found to grow in numbers along the toes of the slopes. This plant can resist long duration of inundation, and is effective in the protection of slopes.
12. Koroch (*Pongamia pinnata*): It is a medium to large sized tree growing in the toes of slopes. It is a highly water resistant plant that can survive long duration of inundation during the rainy season.
13. Mera/Meragoda (*Trewa polycarpa*): The only tree found at one end of the slope. It is a water resistant plant.
14. Hijal (*Barringtonia acutangula*): A low tree that can stand water logging and work as slope stabiliser.
15. Kodom (*Anthocephalus chinensis*): A large tree found to grow on the road margins.
16. Jiga (*Lannea coromandelica*): A small sized tree usually grows along margins of slopes near water. It is a water resistant plant which can overcome long duration of inundation.

Here, trees like Bonnya (*Crataeva nurvula*), Koroch (*Pongamia pinnata*), Hijal (*Barringtonia acutangula*), Pitali (*Trewa polycarpa*) can be planted on the *killa s*lopes for soil stabilization.

3.5 Workshop Outcomes

One of the scopes of the overall monitoring work was to undertake one national and five district workshops to share the outcomes with LGED Officials and Field Engineers and getting their feedback and suggestions. BUET Team have conducted workshops at Brahmanbaria, Habiganj, Kishoreganj, Netrokona and Sunamganj during the period January to August 2019. On the workshops held on Habiganj, Kishoreganj and Netrokona, questionnaires were provided to inquire and record about the responses of the LGED personnel, Field Engineers and progressive farmers. The responses varied to place to place.

Figure 3.19 represents the response of people of Habiganj, Kishoreganj and Netrokona about the most effective design types against wave action and other parameters in *haor* region. As Type I (Bamboo + Chailya grass) and Type IV (Vetiver + RC pole) were not implemented in any area, all the responses were based on design Type II (Vetiver only) and Type III (Vetiver + CC block). Most of the people think that in case of village island, *killa* and road slope protection, Type III is the better solution that Type II. People also suppose that for strong wave action, only hard solution will work. As a very short time for overall slope construction is available, vetiver tillers do not get adequate time to grow properly. As a result, the tillers wash away and people think that only vetiver tillers are not susceptible against wave action.

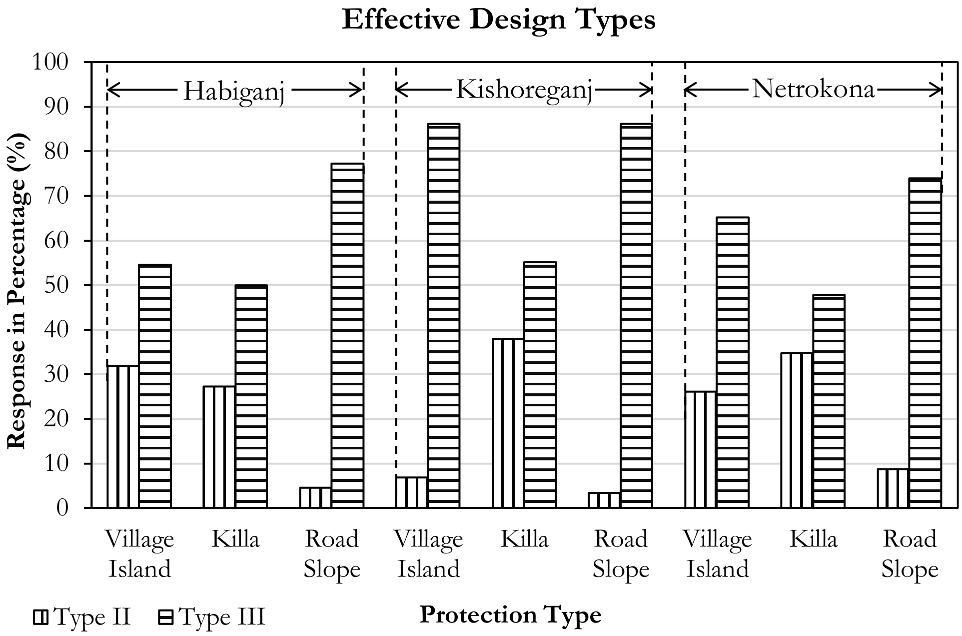


Figure 3.19: Most Effective Design Type in *Haor* according to *Haor* People

According to most of the people from *haor* area and Engineers of Habiganj, Kishoreganj and Netrokona, the main reason of infrastructure protection failure is occurred by floor and *afal,* shown in Figure 3.20.

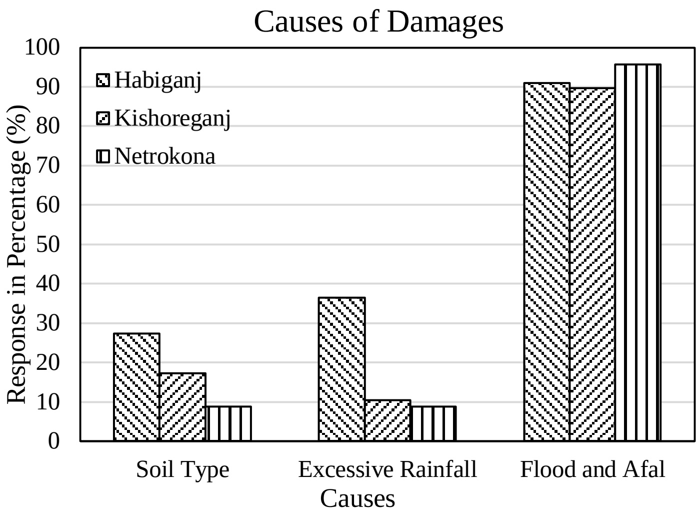


Figure 3.20: Main Reasons of Damaging Infrastructures and Protection Systems of *Haor*

In *haor* areas, the following problems are arisen to protect the revetments:

(a) Scarcity of soil, so the slope has to be filled with dredge filled sand
(b) Difficult to maintain slope ratio for scarcity of land
(c) Not compacting the soil properly before slope preparation
(d) Huge wave action
(e) Time lacking to construct the complete revetment
(f) No drainage system and stairs
(g) Difficulties in case of transporting materials
(h) Short wages of labors
(i) Holes made by reptiles

To protect the revetments from wave action and damages, the following steps can be taken:

(a) CC Block with Vetiver
(b) Brick toe wall/guide wall
(c) RCC retaining wall
(d) CC Block with Vetiver and wire mesh
(e) CC Block with Vetiver and geotextile
(f) Vetiver only
(g) Proper compaction and slope maintenance
(h) Bamboo
(i) Filtering material
(j) Other vegetation (Hijol, Koroch)

Figure 3.21 presents the main collection sources of vetiver in *haor* districts. From the workshops, it can be decided that the proper time of vetiver plantation in *haor* districts is either April-May, or September-October (Figure 3.22). It will depend on the flood and inundation schedule every year of the respective area.

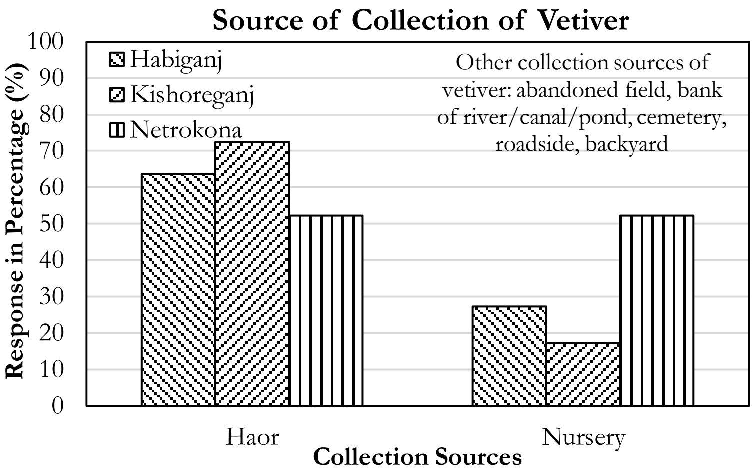


Figure 3.21: Collection Sources of Vetiver in *Haor*

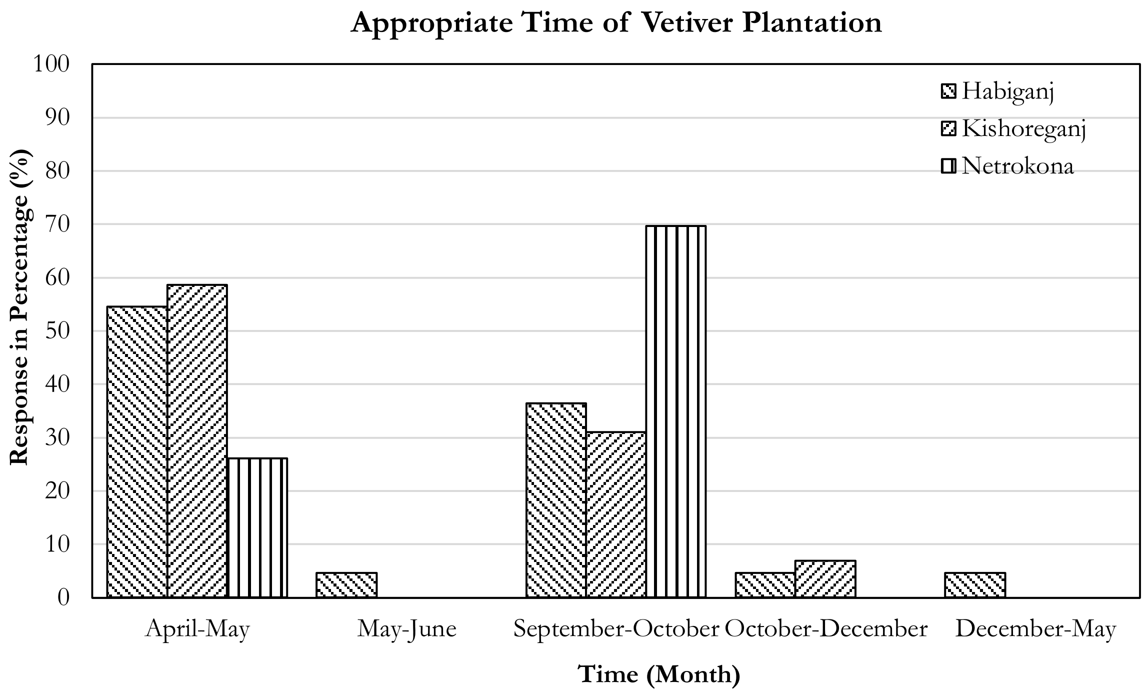


Figure 3.22: Appropriate Time of Vetiver Plantation

It is recommended to keep the slope ratio as 1:1.5 (V:H) as per design. But as in *haor* region land scarcity is a big problem, this slope ratio cannot be attained, though for clayey and sandy soil, the slope ratio should be 1:2 and 1:3, respectively. From Figure 3.23, it can be observed that *haor* people think that 1:2 is the proper sustainable slope ratio.

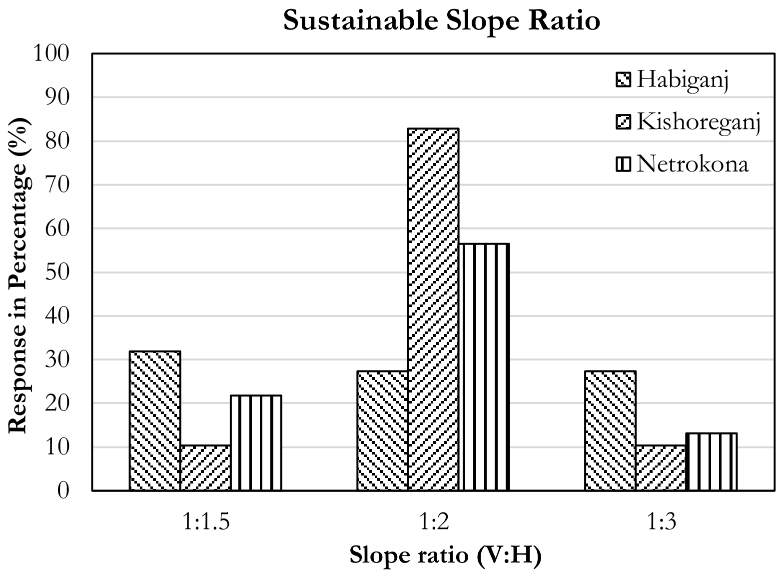


Figure 3.23: Proper Slope Ratio to be maintained for *Haor* Infrastructures

Mix ratio is an important parameter in case of CC block construction. In most of the cases in field, a mix ratio of 1:2:4 is used. In case of shallow *haor*, a mix ratio of 1:1.5:3 also can be used to minimize the cost (Figure 3.24a). The thickness of *haor* should be designed as per stability analysis and cost effectiveness. In case of deep *haors,* thickness of CC block should be greater than that of shallow *haor*. From Figure 3.24(b) it can be seen that *haor* people of Habiganj and Netrokona, the accepted thickness of CC block is 100 mm, where in Kishoreganj, it is 150 mm.

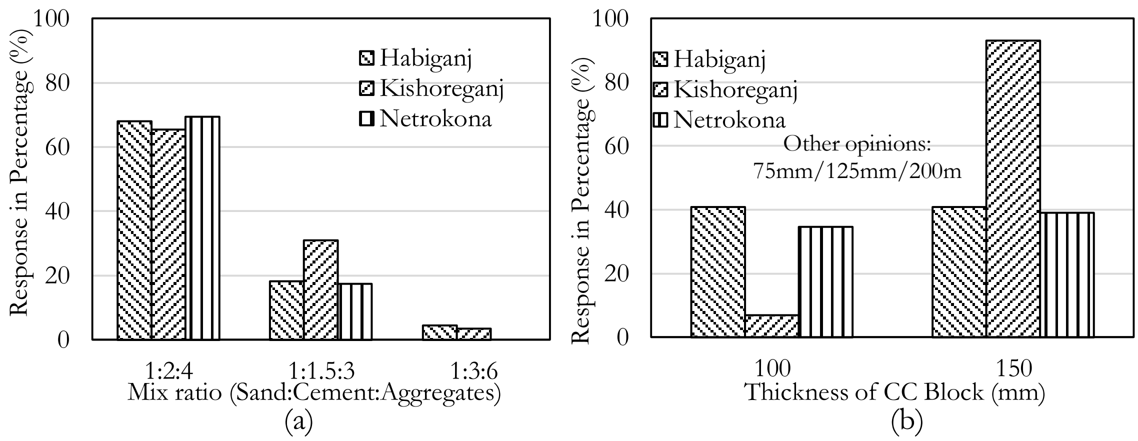


Figure 3.24: (a) Adequate Mix Ratio of CC Block; and (b) Adequate Thickness of CC Block

3.6 Cost Analyses

Total cost estimation was done according to the rate schedules of LGED for Cumilla, Sylhet, Narayanganj and Mymensingh zones (LGED, 2019). Figure 3.25 shows the total construction cost, including material, labor and maintenance cost. From field study, Type II and Type III were found as more feasible in case of sustainable, environmental friendly and compatible solution. In case of cost benefit analysis, both Type II and Type III are found efficacious also than traditional practices of slope protection by solid blocks.

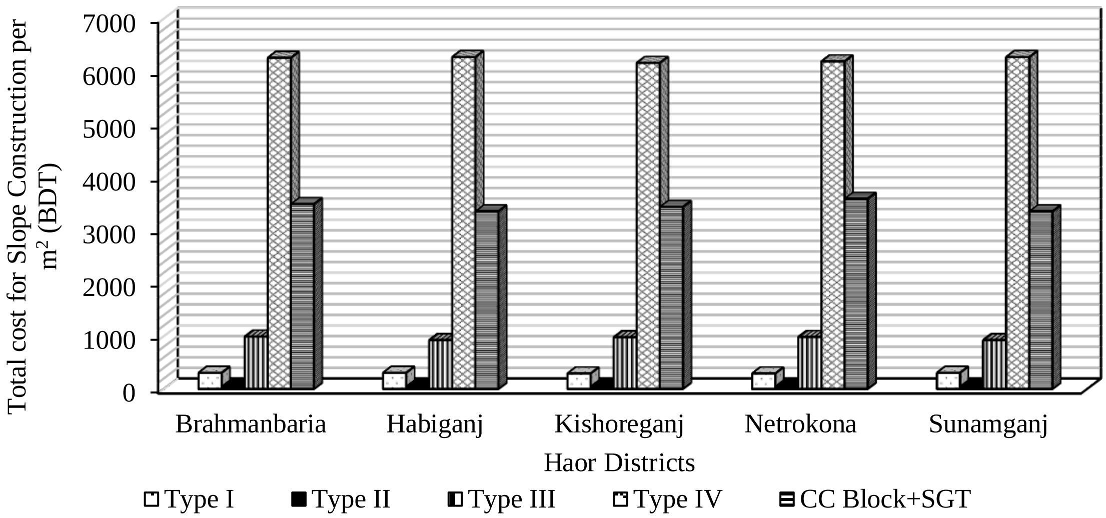


Figure 3.25: Comparison of Total Cost of Different Protection Methods per m^2

3.7 Summary

Finings obtained from the monitoring of village island, *killa* and road slope at the five *haor* districts are summarized below:

(i) *Haor* soils are found mostly in grey or brown in color. The soil type is classified as silty sand/sandy silt, and acidic to alkaline in nature. It has been found that the specific gravity (G_s) of *haor* soil ranged within 2.48-2.74 and F.M. of the soils are found as 0.55-1.57. The shear strength and permeability characteristics indicated the loose consistency and very low to low degree of permeability of *haor* soils. By nutrient tests, it was estimated that *haor* soils lack of maximum essential nutrients, i.e., nitrogen, organic matter content, boron, and zinc.

(ii) From model studies, vetiver tillers were found as both submergence and wave tolerant. By increasing the protection measures like fly ash and JGT, the slope becomes more stabilized.

(iii) Soil should be compacted properly before the slope construction, and before slope preparation, maintaining proper slope ratio according to the soil type is required. Mix ratio of CC blocks needs to be increased to at least 1:2:4 and thickness of the CC hollow blocks can be 100-150 mm depending on the depth and wave action of *haor*. Punched jute geo-textile (JGT) is recommended to use instead of synthetic geo-textile for appropriate propagate the roots of vegetation within soil. Precast block is preferred than in-situ blocks and interlocking blocks based on cost effectiveness and easy construction procedure. Construction of stair system is important at suitable interval of the slope to ensure movement of human, cattle, etc. Sufficient shoulder width should be provided so that the heavy traffic load does not cause damage to the slope.

(iv) Growth of vetiver tillers is found excellent in *haor* districts, by observing survival of the grasses, condition of slope and root length of the tillers. Plantation of vetiver at field site should be completed as soon as possible as the tillers die after 2-3 days of collecting from source location. So, vetiver should be collected from local nursery developed by local people.

(v) It is very important to ensure replantation of tillers where the planted grasses did not survive instead of filling the holes with soil or mortar. To repair the overall slope condition, trimming and replantation of vetiver tillers are needed, at the same time new CC blocks should be placed. Trimming and nursing of vetiver tillers in a regular basis is required. Besides, ensuring of proper sunlight, maintenance and watering of the site is very important.

(vi) Koroch, Dholkolmi etc. are not deep rooted grasses, but these species can help to protect the soil from rain induced erosion along with vetiver. So besides vetiver, different types of vegetation can be planted for holistic approach. However, after the fully propagation of vetiver tillers, the other plants should be removed. Garbage disposal and some harmful climber named 'Assamlata' needs to be eliminated, as these obstruct the growth of vegetation.

CHAPTER FOUR
INSTALLATION GUIDELINE

CHAPTER FOUR: INSTALLATION GUIDELINE

4.1 Introduction

The monitoring and visiting of the project areas from five *haor* districts included total ten (10) road slope protections, eleven (11) village protections and one (1) *killa* protection work, which was conducted during January 2019 to February 2020. Based on the field observations; five district workshops meeting with LGED officials, Field Engineers and local people; and model tests conducted in BUET; and long-term field and laboratory experience of the Team Leader in Bangladesh perspective, a guideline is developed for protecting *haor* infrastructure by bio-engineering method using vetiver. This chapter presents the guideline and steps for vetiver based bio-engineering method.

4.2 Key Features

The overall guideline for a proper slope protection system in *haor* basin can be categorized into two types depending on the plantation time, (1) Post monsoon plantation and (2) Pre monsoon plantation.

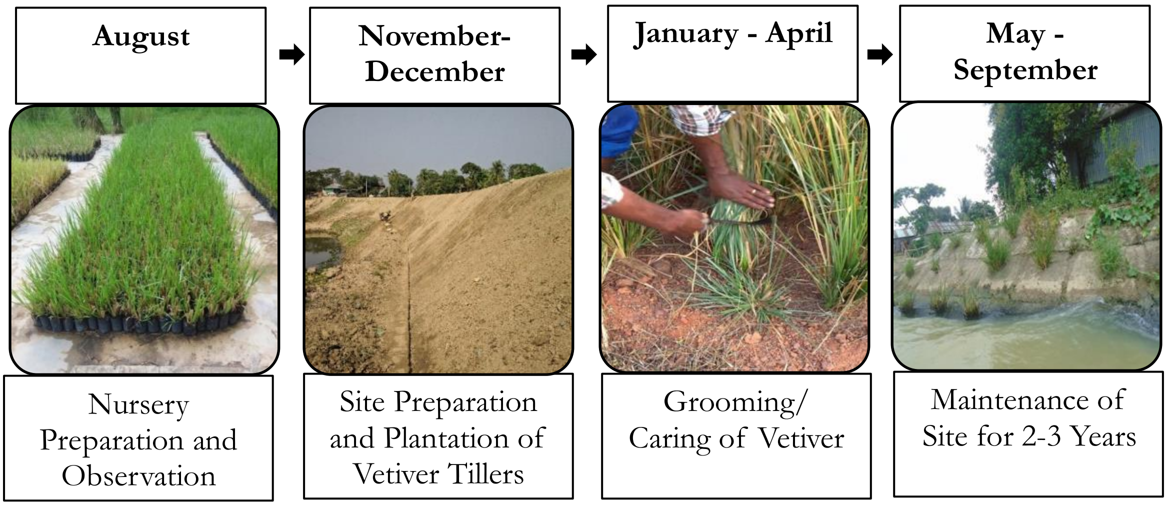


Figure 4.1: Steps of Post Monsoon Vetiver Plantation

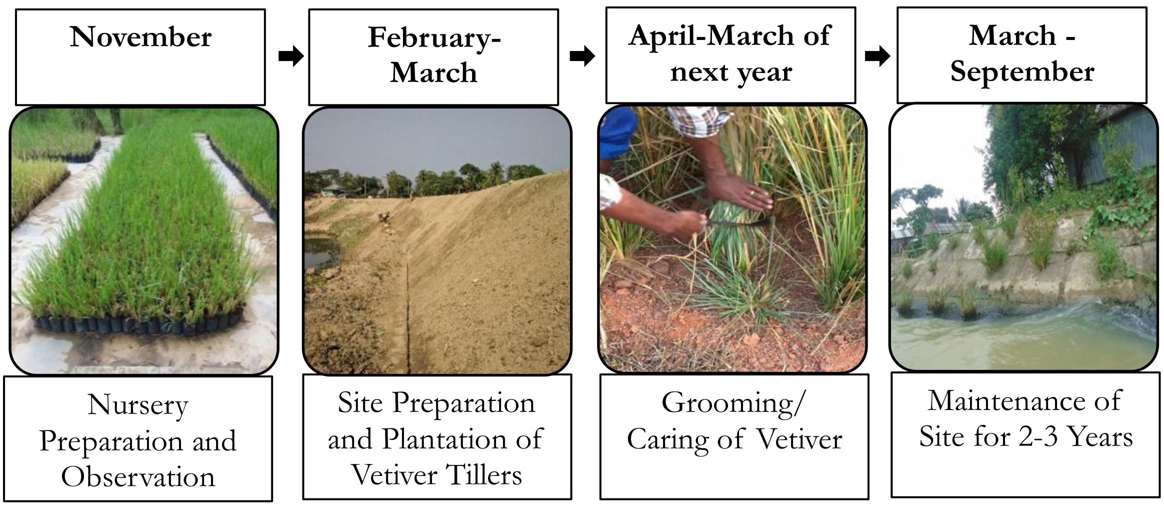


Figure 4.2: Steps of Pre Monsoon Vetiver Plantation

Figure 4.1 and Figure 4.2 show the steps of post monsoon plantation and pre monsoon plantation, respectively. The steps are described in details in guideline. As monsoon period usually ends in October, in case of post monsoon plantation vetiver plantation at the site initiates from November. Before site preparation, a nursery needs to be prepared at least 90 days prior to the plantation at site. In case of nursery, the tillers need to be protected from excessive rainfall, and no watering is needed.

For pre monsoon plantation, the tillers need to be planted prior to the monsoon period which starts from April. As the nursery is prepared in dry season, watering is necessary. During monsoon, regular site maintenance is not fully possible. So the tillers are allowed to grow up to the dry season of the following year.

4.3 Guideline

An installation guideline of vetiver by bio-engineering method for the protection of *haor* infrastructures can be stated as the following steps.

(1) Nursery Preparation

For nursery site, an open raised land with sufficient sunlight is preferable with nearby water source (canal, pond, reservoir, *beel* etc.). Otherwise, water will be needed to be supplied by mechanical system (pump and hose pipe). In case of land selection for nursery, comparatively elevated land should be chosen for the lower possibility of water logging. Distance from the nursery and the actual plantation site should to be considered while selecting the nursery site for that specific purpose.

Index and chemical properties of nursery soils should be determined before planation if possible for evaluating the necessity of fertilizers or additives. Mostly, ground plantation requires application of fertilizer to an extent (e.g. Di Ammonium Phosphate, cow dung shown in Figure 4.3a).

(a)

(b)

Figure 4.3: Photographs of (a) Application of Cow Dung Manure; and (b) Planation of Tillers at Nursery

Plantation can be done on ground in grid pattern with 23-30 cm c/c distance and 3 tillers per point, depending on the available space in the nursery plot as shown in Figure 4.3 (b). Watering is required twice in a day in case of lower water level or insufficient amount of rainfall, (Figure 4.4a). Otherwise, watering once in a day is adequate. Rain cover is required if nursery is constructed in the monsoon period (April to October) as presented in Figure 4.4 (b).

(a) (b)

Figure 4.4: Photographs of Nursery of (a) Watering for Pre Monsoon Plantation; and (b) Rain Cover Protection for Post Monsoon Plantation

(a) (b)

Figure 4.5: Photographs of (a) Site Protection by Bamboo Fencing; and (b)Vetiver Tillers Planted in Polybag at Nursery

(a) (b)

Figure 4.6: Photographs of (a) Vetiver Tillers Planting on Rafts; and (b) Hydroponics by Vetiver (www.slideshare.net/mik1999/vetiver-for-terracing-and-stabilizing-soil)

Vetiver planted in nursery requires at least 120 days for growing fully. Regular care and observation (e.g. trimming, weed separation etc.) have to be ensured within this duration. Construction of bamboo fence is required to prevent human and livestock disturbances as shown in Figure 4.5 (a). A strap of polymer nets can be provided around the fence for better protection. Proper maintenance and observation accelerates the exponential growth of the tillers, which can be 100-120 tillers per point.

If nursery bed soil is unsuitable for plantation and if the water table position is found as very low, plantation can be done in polybags (Figure 4.5b) with better-quality nursery soil (sandy soil/clayey soil mixed with cow dung, fly ash and peat moss). As *haor* region remain submerged for most of the time of the year, proper growth of vetiver becomes difficult. For these areas, vetiver cultivation by hydroponics can be an efficacious system. Hydroponics is a subset of hydroculture, which is a method of growing plants without soil, by instead of using mineral nutrient solutions in a water solvent, shown in Figure 4.6.

(2) Design Schemes

Three design schemes are developed for applying in *haor* region according to the topographic areas, climatic factors and depth of the surrounding *haor*s.

Scheme I: The main required materials for Scheme I is vetiver (Figure 4.7). This scheme is suitable for the protection of infrastructures situated within shallow depth *haor*s. The construction sequence of Scheme I is suggested below:

(i) Prepare slope with a slope ratio of 1:2 or 1:3 (V:H) depending on soil type.
(ii) Compact soil of the slope properly.
(iii) Plantation of vetiver tillers @15 cm c/c in both direction (as shown in Figure 4.7).
(iv) Provide fencing to protect vetiver from human and animal disturbances.
(v) Engage LCS for the first two-three seasons for taking care of newly planted vetiver.
(vi) Tree plantation with Hizol/Koroch/Bonnya after the full growth of vetiver, if land is available.

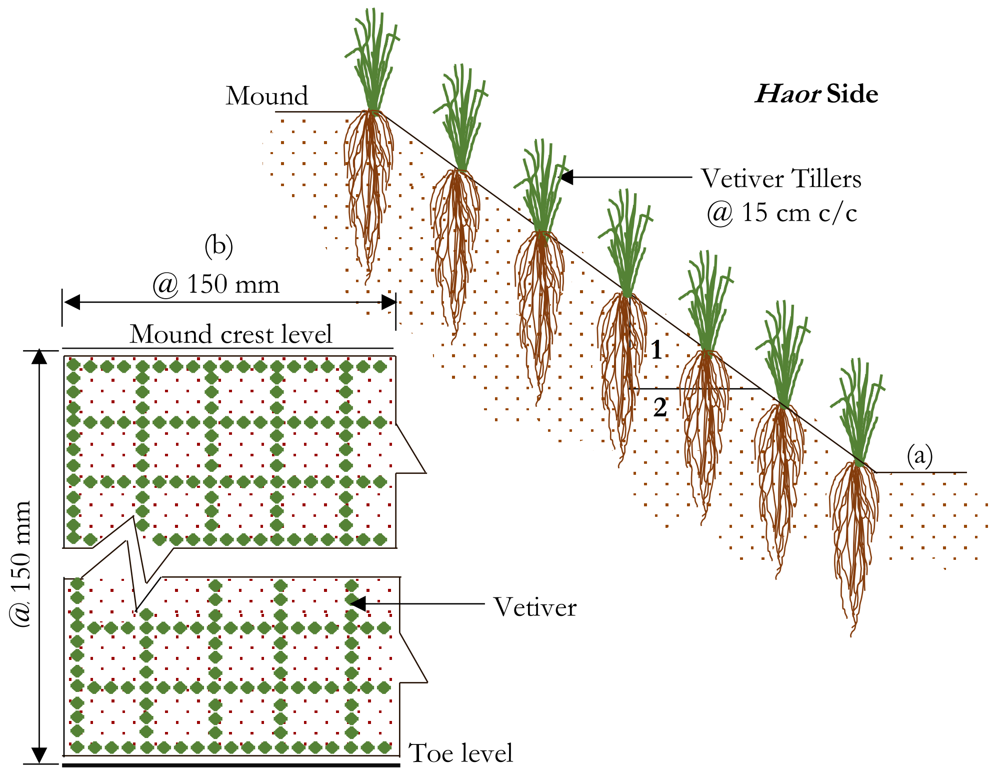


Figure 4.7: Diagrams of Scheme I: (a) Cross Sectional View; and (b) Plan View

Scheme II: The main required materials for Scheme II are vetiver and Jute Geotextile (JGT). This scheme is suitable for the protection of infrastructures situated within mid-depth *haor*s. The construction sequence is:

(i) Prepare slope with a slope ratio of 1:2 or 1:3 (V:H) depending on soil type.
(ii) Compact soil of the slope properly.
(iii) Placing JGT (500 gsm) on the prepared slope.
(iv) Plantation of vetiver tillers @22 cm c/c in both direction (as shown in Figure 4.8).
(vii) Provide fencing to protect vetiver from human and animal disturbances.
(viii) Engage LCS for the first two seasons for taking care of newly planted vetiver.
(ix) Tree plantation with Hizol/Koroch/Bonnya after the full growth of vetiver, if land is available.

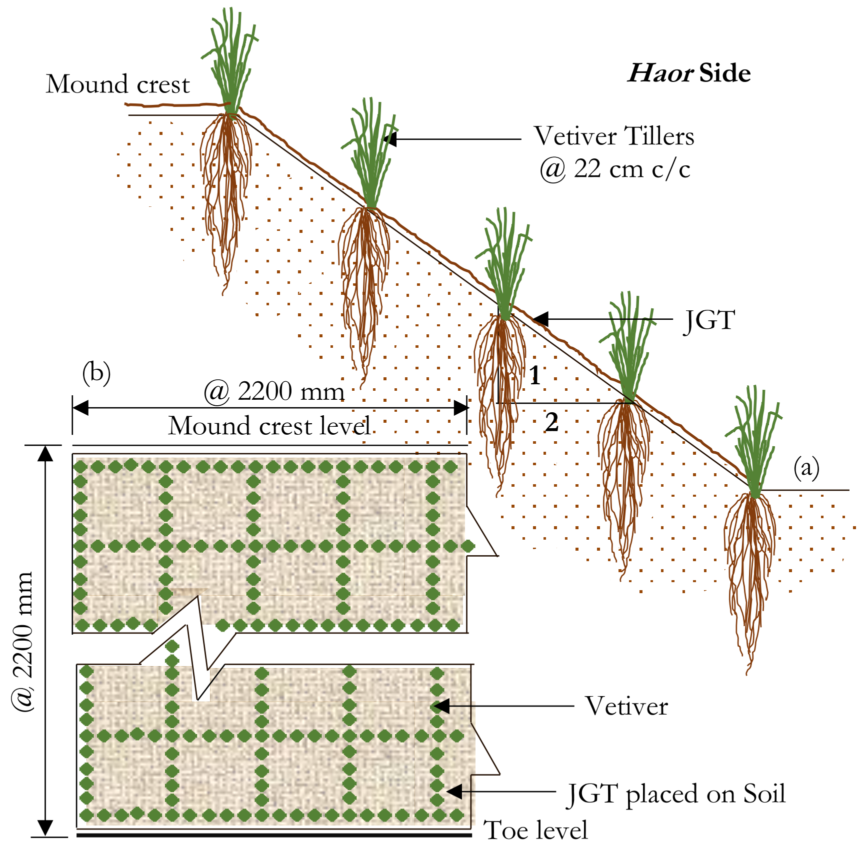


Figure 4.8: Diagrams of Scheme II: (a) Cross Sectional View; and (b) Plan View

Scheme III: The main required materials for Scheme III are vetiver, Jute Geotextile (JGT) and CC hollow blocks. This scheme is suitable for the protection of high embankments and infrastructures situated within deep *haor*s. The construction sequence of Scheme III is:

(i) Prepare slope with a slope ratio of 1:2 or 1:3 (V:H) depending on soil type.
(ii) Compact soil of the slope properly.
(iii) Construct continuous brick toe wall along the slope (Height h_1, h_2; width b_1, b_2 shown in Figure 4.9 will vary depending on embankment height, *haor* depth and soil type) with 75 mm CC work and weep holes with filtering system.
(iv) Placing JGT (500 gsm) on the prepared slope.

(v) Placing 450mm×450mm centered 150 mm diameter hole CC block with a mix ratio 1:2:4. Thickness of the CC blocks will vary within 100-150 mm depending on *haor* depth. Interlocking system or star shaped CC block should be avoided.

(vi) Planting vetiver in the block hole @450mm c/c both ways (as shown in Figure 4.9).

(vii) Provide fencing to protect vetiver from human and animal disturbances.

(viii) Engage LCS for the first two seasons for taking care of newly planted vetiver.

(ix) Tree plantation with Hizol/Koroch/Bonnya after the full growth of vetiver, if land is available.

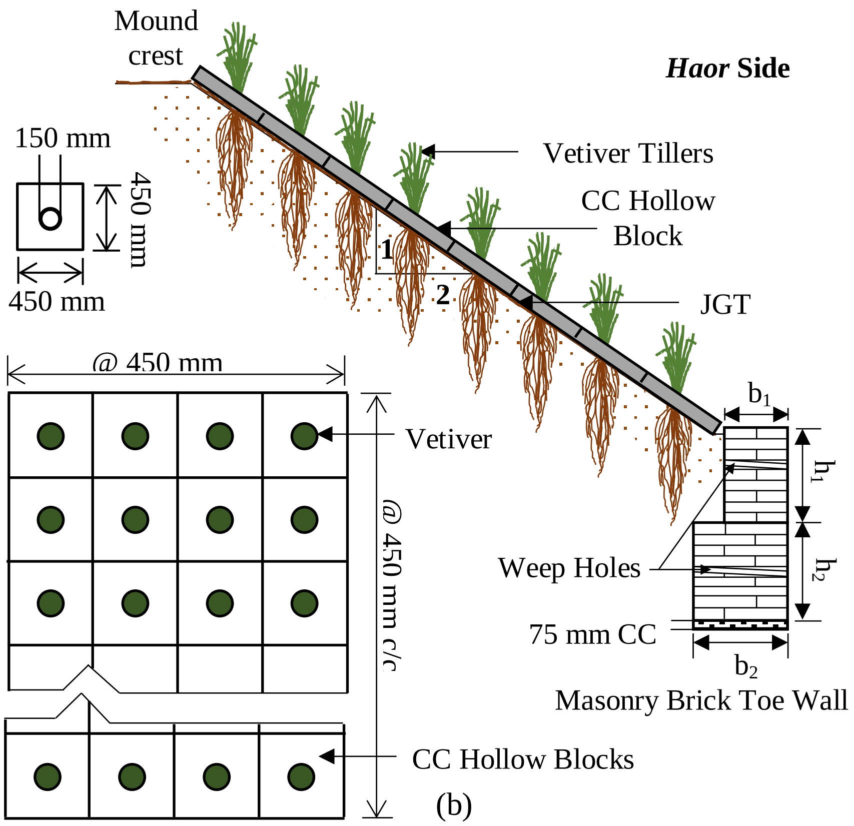


Figure 4.9: Diagrams of Scheme III: (a) Cross Sectional View; and (b) Plan View

(3) Site Preparation

At first, the area that requires protection is to be selected. Soil type, index and engineering properties of the particular slopes should be determined by laboratory tests prior to slope preparation and plantation (Specific gravity, grain size analysis, direct shear, unconfined compression test, consolidation and field density). Soil chemical properties (pH, N, P, K, S, B, Zn and Organic Matter) need to be determined to estimate the requirement of fertilizers or supplements in case of deficiency of the nutrients.

Appropriate design (Scheme I-Scheme III) for protection is to be selected or prepared on the basis of available land, topography, soil type and climatic factors. Slope of the site needs to be prepared prior to the plantation with slope ratio 1:2 and 1:3 for clayey and sandy soil respectively. Soil should be compacted layer by layer for improving the sub-soil characteristics. Adequate soil compaction needs to be achieved for both of proper root growth and prevention from bearing failure. In case of loose or soft soil, ground improvement (sand column) will be required. Vetiver Grass Ash (VGA) or Fly Ash (FA) can be mixed with soil for slope stabilization.

(a) (b)

Figure 4.10: Photographs of (a) Slope Preparation by LCS; and (b) JGT Placement on Prepared Slope

In mid-depth and deep *haor*s, JGT (minimum 500 gsm) should be applied on the slope surface prior to planation to prevent the early chance of top soil erosion. If Synthetic Geo-textile (SGT) is used instead of JGT, it should be punched in a sufficiently large dimension at regular interval, so that the vetiver root can propagate through the soil properly.

(4) Plantation Time

Vetiver tillers should be planted on bare slope (Scheme I), within JGT (Scheme II) or in between the holes of hollow CC blocks (Scheme III). Number of total required tillers is to be calculated as per requirement for collecting from nursery prior to the plantation. Plantation at site can be done on main site in Pre Monsoon (February-March) or in Post Monsoon (November-December) depending on the availability of tillers, labour and climatic factors.

Vetiver tillers, construction materials, equipment, fertilizer for plant etc. need to be prepared prior to plantation and construction if the time period for construction is insufficient. In case of short plantation period, contractor based procedure for minimum two years should be followed instead of LCS engagement.

(5) Fertilizer

Application of organic manure is necessary in some cases, i.e. nursery preparation, plantation of vetiver in dry season and in unfertile soil. In order to use fertilizer for vetiver, location specific soil analysis has to be done properly. Some examples of organic fertilizers for vetiver plantation (Figure 4.11) are: (1) Cow dung; (2) Rice husk; (3) Coconut dust; (4) Poultry droppings.

Surface application or application at 8-10 cm depth of soil is recommended for fertilizers. Fertilizer recommendation is not suggested when soil test values goes beyond optimum level (ranges between high and very high categories). The deficit nutrients can be filled up by the application of specific fertilizers as shown in Table 4.1.

Urea has to be applied to the soil after plantation in three phases; (1) After 15-20 days of plantation, (2) After 1-2 month of plantation, and (3) After 2-3 month of plantation. TSP and MOP are to be mixed/applied to soil immediately before planting but separately. Decomposed farmyard manures should be used instead of fresh cow dung to increase the soil capacity to hold more water and nutrients.

(a) (b) (c) (d)

Figure 4.11: Photographs of Organic Fertilizers; (a) Cow Dung, (b) Rice Husk, (c) Coconut Dust and (d) Poultry Droppings

Table 4.1: Fertilizer Recommendation for Vetiver Plantation (BARC, 2012)

Types of Soil	Soil Analysis Interpretation	Nutrients Recommendation (kg/10000 m^2/year)			Corresponding Fertilizer Recommendation (kg/10000 m^2/year)		
		N	P	K	Urea (N)	TSP (P)	MOP (K)
Sandy	Very Low	150	40	50	326	200	100
Silt	Low	120	30	35	260	150	70
Clay	Medium	70	20	25	152	100	50
Loam	Medium	65	20	20	141	100	40

Note: Nitrogen (N), Source: Urea; Phosphorus (P), Source: TSP (Triple Super Phosphate); Potassium (K), Source: MOP (Muriate of Potash)

(6) Post Maintenance of the Site

Watering is needed daily for first two weeks and on alternate days for next 2 weeks. If the soil type is sandy or the water level is very low, watering is required twice in a day for first two weeks. Sunlight needs to be ensured on the plantation site at the earlier stage of growth of tillers.

Fencing is required to prevent possible human or cattle disturbances. Furthermore, a strap of polymer nets can be provided around the fence for better protection in the earlier stage of growth of vetiver. Labor Contracting Society (LCS) should be engaged with proper wages for the regular maintenance, caring of tillers, trimming, watering of plants, and weed separation of planted vetiver tillers per 1000m of strip of slope.

Burning of vetiver shoots should not be practiced instead of trimming. The first trimming is required after the first flowering up to 3rd node (38 cm) from the base. Trimmed shoot can be used as fodder, production of brooms, household utensils, house construction material etc. (Figure 4.12a). Replantation is required if tillers don't survive at any point as shown in Figure 4.12(b).

(a)

(b)

Figure 4.12: Photographs of (a) Trimmed Vetiver for Multi-purpose Uses; and (b) Replantation Requirement Scenario

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

Guidelines for protection measures for *haor* infrastructures by bio-engineering method has been developed based on the performance of the methods obtained from field observations, records and model tests conducted at BUET. The overviews of the study based on the synopsis of performance monitoring conducted on the five *haor* districts are presented in this chapter.

5.2 Conclusions

The main observations from the overall project are listed below.

Growth of Tillers:

(1) The growth performance of tillers is satisfactory in each site. Proper maintenance and more awareness of local people can upgrade the road slope condition to a significant and successful barrier against wave action.

(2) It has been observed that the slope condition remains good and erosion does not happen if vetiver tillers are planted and maintained properly, whether there happens wave action with a long inundation height. If stairs are provided in the slope, no interruption occurs and the tillers and slope of the village island is found intact.

(3) Growing of shoot in an extensive manner caused problems for the locality i.e., obstruction of actual road space hampering vehicle movement, muggers often attacking pedestrian and vehicles using vetiver shoot for their cover. This indicates the necessity of trimming on a regular basis.

Condition of CC Blocks:

(1) Hole of the CC blocks was found to be variable at different sites; (75-125 mm). Less hole diameter can obstruct the growth of the tillers. It is necessary to keep uniform hole size and mix ratio of the blocks in all sites.

(2) In case of interlocking CC blocks, construction procedure was found to be more difficult and these types of blocks tend to break against wave action easily, creating a failure pattern along the V-notches.

Others:

Road shoulders in some places were found collapsed due to no covering on the road shoulder. So, surface runoff or water supply leakage caused flowing of water under the CC blocks, which finally causes failure of CC blocks and also tillers at some places.

5.3 Recommendations

The recommendations of the discussed study are provided below.

Vegetation:

(1) For a compatible solution, the two monitoring cycle is requisite to compare the performance of the design types at fields.

(2) Plantation of vetiver at field site should be completed as soon as possible. Vetiver plantation should be done in triangular pattern at 15-25 cm c/c spacing as shown in the guideline instead of 2m×1m grid pattern of design Type II, so that the canopy can protect the slope from erosion.

(3) Proper sunlight for the natural growth of the plant is necessary. It was observed that in one site the tillers didn't get enough sunlight for most of the time of a day; which eventually results faded green leaves and less number of tillers at one point indicating poor growth.

(4) Trimming of the shoot of vetiver should be done up to 30 cm height from the base, as regular trimming accelerates the growth of root. Burning of shoot instead of trimming should not be practiced at all. It can bring a fire hazard and can also affect the growth of the plant, as it has been observed that new leaves can grow out of the burnt shoot.

(5) *Koroch, Dholkolmi, Ikhar* found in *haor* region are not deep rooted grasses, but these species can help to protect the soil from rain induced erosion along with vetiver. So besides vetiver, different types of vegetation can be planted for holistic approach. However, after the fully propagation of vetiver tillers, the other plants should be removed.

(6) Regular watering, weed separation, proper sunlight etc. are very important for the growth of vetiver tillers. To engage the LCS and labors for maintaining the site properly is extremely needed and strongly suggested. Weeds and other plants declining the growth of vetiver (like Assamlata) should be uprooted and cleared on a regular.

Slope Condition:

(1) Stairs should be provided at appropriate intervals at the slope of the road to ease the accessibility so that people don't destroy the tillers to make a path for their own.

(2) Covering of the shoulder with concrete work or also planting of tillers on the shoulder is recommended.

CC Blocks:

(1) Interlocking CC hollow blocks are difficult to construct, so the construction of CC blocks should be done according to the design provided in the guideline.

(2) Increase of CC block thickness to at least 150 mm is required where the wave action is immense.

(3) Plantation of tillers is recommended instead of filling of holes with soil or mortar where plant has died mostly due to improper maintenance.

Contractive Method:

In harvesting seasons, finding and engaging labors in slope protection works is difficult. So, LCS should be more operative to motivate people by providing vocational training and increasing social awareness. The training period of LCS organizers is 6 months, which is not sufficient according to the LCS organizers. They suggested increasing the duration of training. The wages of labors also need to be increased according to the discussion. In case of emergency situation, when time is limited for construction and labors are difficult to find, contractors and specialists are required to engage before minimum 1 year.

From the field study of the research project, model study and cost analyses, it can be established that, bio-engineering method is suitable for the protection of *haor* infrastructures if they are maintained properly.

5.4 Future Outlooks

Studies in the future that can be conducted based on the project outcome are mentioned below:

(1) Field scenario of wave tolerance and submergence of vetiver can be studied by constructing a model slope in mid to deep *haor* using modern technologies i.e., Flow probe/Acoustic Doppler Velocimetry (ADP), Unmanned Aerial Vehicle (UAV), Udometer. Correlations can be established between laboratory model data and actual field data.

(2) Intensive comparative growth studies can be conducted by planting tillers from same source in different area of *haor* region (shallow, mid and deep *haor*).

(3) Growth of tillers is dependable on the level of availability of nutrients in the soil. Further studies can be conducted on the influence of specific nutrient element on vetiver tillers with respect to different *haor* region.

(4) The impact of surface runoff on slopes can be investigated for several monsoon periods after vetiver plantation. Further studies can be done and correlations can be established in between surface runoff and vegetation coverage area.

(5) Growth studies of vetiver can be conducted where alternate growing method of plants (Hydroponic Farming) can be opted for if land availability for nursery is limited.

(6) Impacts of rainfall intensity and propagation of waves on vetiver planted on a slope can be studied for a consecutive monsoon period. Relations can be established between rainfall intensity/impact of waves and percent erodible soil with and without vetiver on slope.

(7) Influence of vetiver root matrix on the filtration system in a revetment structure can be investigated.

REFERENCES

Bangladesh Agriculture Research Council (BARC), (2012), *Fertilizer Recommendation Guide (FRG)*, Dhaka, Bangladesh, pp. 274.

Chowdhury. M.E., (2019), *Effects of Vegetation on Soil Water Interaction*, BSc. Engg Thesis, Department of Civil Engineering, Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh.

Islam, M. S., Arifuzzaman, Shahin, M. H. and Nasrin, S., (2013), "*Effectiveness of Vetiver Root in Embankment Slope Protection: Bangladesh Perspective*", International Journal of Geotechnical Engineering, Vol. 7, pp. 136–148.

Islam, M. S., Hoque, M. S., Mallick, S., Parshi, F. N. and Islam, T., (2017), "*Performance Evaluation of Bio-Engineering in Slope Protection for Different Soils*", International Conference on Disaster Risk Mitigation, Dhaka.

Islam, M.A., Islam, M.S. and Elahi, T.E., (2020), "*Effectiveness of Vetiver Grass on Stabilizing Hill Slopes: A Numerical Approach*", Geo-Congress 2020, DOI: 10.1061/9780784482797.011.

Islam, M.S. and Badhon, F.F., (2020), "*A Mathematical Model for Shear Strength Prediction of Vetiver Rooted Soil*", Geo-Congress 2020, GSP 316, pp. 96-105.

Islam, M.S., Eva, E.J., Islam, T. and Mallick, S., (2020a), "*Embankment Protection in High Saline Zone Using Bioengineering Method*", Int. Conference on Earth and Environmental Sciences & Technology for Sustainable Development (ICEEST 2020), Dhaka, Bangladesh, pp. 200-201.

Islam, M.S., Haque, M.S., Rahman M.M., Parshi, F.N., Mallick, S. and Islam, T, (2020), *Final Report on Investigation of Climate Resilient Slope Protection of Embankments, Coastal Climate Resilient Infrastructure Project (CCRIP).*

Islam, M.S., Hoque, M.S., Mallick, (2018), "*Eco-Slope Protection and Intervention at North-West Flood Prone Region*", UNDP-Bangladesh.

Islam, M.S., Hoque, M.S., Mallick, S., Parshi, F.N. and Rahman, A.K.M.L., (2016), "*Climate resilient slope protection for coastal regions of Bangladesh using bio-engineering techniques*", 3rd International Conference on Advances in Civil Engineering, CUET, Chittagong, Bangladesh, pp. 221-226.

Islam, M.S., Islam, M.K., Rahman M.M., Islam, T. and Hossain, S., (2018) *Inception Report on Monitoring the Performance of Village Protection, Model Village, Upazila/Union Road, Slope Protection, HILIP.*

Islam, M.S., Islam, M.K., Rahman M.M., Islam, T. and Hossain, S., (2020), *Draft Annual Report on Monitoring the Performance of Village Protection, Model Village, Upazila/Union Road, Slope Protection, HILIP.*

Islam, M.S., Islam, T., Hossain, S., Bhuiyan, S.R. and Islam, M.Z., (2020b), "*Bioengineered Protection System for Haor Infrastructures*", Int. Conference on Earth and Environmental Sciences & Technology for Sustainable Development (ICEEST 2020), Dhaka, Bangladesh, pp. 204-205.

Islam, M.S., Latif, M.B. and Islam, T., (2020), "*Bioengineering Technique for Protecting Submersible Roads in Haor Districts of Bangladesh*", presented at 2nd Conference of the Arabian Journal of Geosciences (CAJG-2), Sousse, Tunisia, in press.

Islam. T., (2020), *Performance of Ecological Revetment in Haor Areas of Bangladesh*, MSc. Engg Thesis, Department of Civil Engineering, Bangladesh University of Engineering and Technology (BUET), Dhaka-1000, Bangladesh.

Lambe, T.W., (2014), *Soil Testing for Engineers*, Wiley Eastern Limited, New Delhi.

Latif. M.B., (2019), *Protection of Submerged Embankment using Bioengineering Technique*, BSc. Engg Thesis, Department of Civil Engineering, Bangladesh University of Engineering and Technology (BUET), Dhaka-1000, Bangladesh.

Yong, W. and Yu, T.X., (2014), "*Ecological Revetment Reconstruction of Huang Jia River in Licha*", Applied Mechanics and Materials, Vol. 641-642, pp. 156-161.

Website: www.slideshare.net/mik1999/vetiver-for-terracing-and-stabilizing-soil (last accessed on 13th April, 2020)

Appendix A
Sample Monitoring Log

Date: 14/01/2019

Monitoring Log

Project name		Haor Infrastructure and Livelihood Improvement Project (HILIP)	
Location		Sarail, Brahmanbaria	
Name of the site		Kalikaccha UP-Bariura Bazar Road, Part 1 and 2	
GPS		N24º3'20", E91º8'51"	
Date of plantation/Construction		March, 2015	
Nursery location of Vetiver tiller collection		Nasirnagar, HILIP, LGED	
Date of monitoring		14/01/2019	
Monitoring No.		02	
Monitoring conducting persons with designation	BUET	Dr. Mohammad Shariful Islam	√
		Dr. Md. Kabirul Islam	×
		Dr. M. Matiur Rahman	√
		Engr. Tanzila Islam	√
		Engr. Sadman Hossain	√
	LGED	Mr. Sadequr Rahman, Md. Rashedul Hossain, Md. Helal Khan, Md. Zakir Hossain	

Collected data:

Design Type	Type III, CC block (450×450mm) with hole (125mm dia) +stepped brickwall	
Investigation of Shoot	Sample minimum shoot length	35.6 cm
	Sample maximum shoot length	177.8 cm
	Overall range of shoot	35.6~177.8 cm
	Shoot/stem diameter	5 mm
	Diameter of the bush	71.1 cm
	No. of tillers grown in one point	11
Investigation of Root	Single root diameter	2 mm
	Sample maximum root length	35.6 cm
	Root matrix diameter	10.2 cm
	Sample minimum root length	5.1 cm
Investigation of Leaf	Inflorescence	Yes
	Shoot/stem color	Faded green
	Leaf color	Faded green
Other vegetation grown alongside		Mojjoa/Ikhor, Dholaguiya/Chikan, Telakucha, Kash, Durba, Kul/Boroi, Verenda
Length of the vetiver planted strip		180 m
Length of the strip in which vetiver has grown well		18 m
Reasons of poor growth of vetiver (if any); info will be collected by interviewing the LGED officials and local people		No trimming and watering, poor maintenance, disturbed growth for garbage disposal

Remarks:

- Slope Condition: Steep slope, broken shoulder, crack in CC block, uproot of tillers by local people
- Special Observation: Replantation needed
- Samples to Collect:
  - Soil for Nutrient Test √
  - Soil for Index Properties √
  - Soil for Engineering Properties ×
  - Vetiver Tiller √

Appendix B
Meeting photographs

Figure B-1: Meeting at LGED Office, Agargaon on 26th November 2018

Figure B-2: IFAD Mission Leader and BUET Team at Model Site on 28th October 2019

Figure B-3: Draft Annual Report Presentation at LGED Headquarter, Agargaon on 3rd March 2020

Appendix C
Workshop photographs

(a) (b) (c) (d) (e) (f)

Figure C-1: Workshop at LGED Headquarter, (a) Sunamganj, on 31st August, 2019, (b) Brahmanbaria, on 6th November 2019, (c) Discussion with Local People at Brahmanbaria Workshop; (d) Habiganj, on 7th November 2019, (e) Kishoreganj on 10th December 2019 and (f) Netrokona on 11th December 2019


BUET
গণপ্রজাতন্ত্রী বাংলাদেশ সরকার
LGED
IFAD
INTERNATIONAL FUND FOR AGRICULTURAL DEVELOPMENT