Soil Erosion Status, Priority Treatment Areas and Conservation Measures for Different Districts of Meghalaya

ICAR- Indian Institute of Soil and Water Conservation
218, Kaulagarh Road, Dehradun-248 195

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Citation

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FOREWORD

भारतीय कृषि अनुसंधान परिषद
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उप महानिदेशक (प्राकृतिक संसाधन प्रबंधन)
Dr. Suresh Kumar Chaudhari
Deputy Director General (Natural Resources Management)

28.08.2023

Message

Meghalaya, being the most rainfall-rich state in the country, contends with challenges of land degradation due to water erosion and soil acidity. The issue of acidic soils is exacerbated by water erosion, particularly in regions where a significant portion of cultivated land is dedicated to *Jhum* cultivation (shifting cultivation). Notably, water erosion stands as the primary driver of land degradation in areas encompassing Shillong, the eastern parts of Nongstain, the southern Jaintia hills, and the Khasi hills. It is, therefore, crucial to address these challenges strategically and promptly to prevent significant environmental issues, including the reduction of vegetative cover, escalation of soil erosion, depletion of natural springs, and a decline in biodiversity.

I am pleased that the ICAR-Indian Institute of Soil and Water Conservation, Dehradun has prepared a technical document addressing the status of soil erosion, identifying priority treatment areas, and proposing conservation measures for various districts within Meghalaya. This document primarily addresses the severity of soil erosion across different districts, featuring the state's soil erosion risk map categorized into distinct priority classes. It also covers the extent of erosion, specific challenges, soil and water conservation techniques, along with district-level strategies for agronomy, vegetation, and agroforestry. The information in this report has been presented in user's friendly mode for the various stakeholders namely land managers, state government officials, and policymakers.

I extend my congratulations to whole team of ICAR-IISWC, Dehradun involved in this endeavour of compiling the valuable information.

(S.K. Chaudhari)

PREFACE

The ICAR-Indian Institute of Soil and Water conservation (IISWC), Dehradun is one of the national Institute of Natural Resource Management Division (NRM) of the Indian Council of Agricultural Research, Ministry of Agriculture and Farmer's Welfare, Government of India. The Institute along with its eight research centres is constantly working for development of site-specific cost-effective soil and water conservation technologies, and it offers officers and graduate assistants of various state governments' specialised training in watershed management and soil conservation.

Meghalaya is a wettest Indian state situated in North East India. Soil erosion through water is a serious problem in major part of the state as nearly 34.46% area has soil erosion of 25-35 t ha^{-1} yr^{-1}. Overall, 56% of state's total geographical area (TGA) is affected by water erosion with soil erosion rates ranging from 0 to 35 t ha^{-1} yr^{-1} as majority of the areas have high slope, low soil depth (<1.5 m) and high drainage density, and therefore susceptible to higher soil erosion risks. Based on the priority classification, 34.47% was found to be most vulnerable under priority classes 1 and 2. *Jhum* cultivation prevalent in this North Western State coupled with indiscriminate deforestation has led to accelerated erosion for which proper vegetation cover needs to be established on very steep slopes.

The document aims at identifying critical areas based on the permissible soil erosion rate and existing erosion rate at a given location in each districts of the State. The document contains soil erosion status and erosion induced losses including production and monitory losses at national level as well as for Meghalaya. District specific agronomic, vegetative and engineering measures have been included to accelerate the adoption and implementation of SWC measures and facilitate various stake holders. The list of location specific soil, water and conservation measures for each district have been compiled as ready reckoner for policy makers, researchers, planners, NGOs and extension functionaries to address the various issues of land degradation.

We sincerely acknowledge Director, ICAR-IISWC, Dehradun for providing all the necessary facilities and guidance to accomplish this endeavour successfully well on the time. We are equally thankful to subject matter experts for their valuable guidance and cooperation.

(Authors)

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1.0 INTRODUCTION

Soil erosion is one of the most serious environmental concerns affecting all natural and human-managed ecosystems. Soil erosion, besides having significant impact on productivity of cultivated land also adversely affects chemical, physical and biological functions of soil leading to soil degradation and depletion of multiple soil functions. Although soil erosion is a global phenomenon, it has intensified in recent years due to population pressures, developmental activities, and unscientific land use and land management practices. The risk of soil erosion in Indian Himalayan states like Meghalaya is more serious as the land can no longer be sustained for production, mainly due to high intensity of rainfall, deforestation, overgrazing, forest-fires and faulty land use practices thus leading to their abandonment. About 56.0 % of total geographical area (TGA) of Meghalaya state experiences moderate or moderate to severe soil erosion loss (Mandal *et al.,* 2020). Further, the average production loss of cereal and millets, oilseed and pulse crops were estimated to be 20%, 23% and 22%, respectively and consequently average loss considering cereals, oil seeds and pulses together is about 20% (Sharda and Dogra, 2013). In an agrarian country like India, assessment of soil erosion risk is of paramount importance to preserve soil's productive potential and ensure sustainable land use (Mandal and Giri, 2021, Sharda and Mandal, 2018). Land managers and policy makers need to have adequate knowledge of intensity and distribution of soil erosion risk areas to check land degradation, and efficiently plan and execute various cost-effective land-based interventions to achieve the targets of land degradation neutrality (LDN) (UNCCD, 2013). Hence, it is imperative to quantify the risks associated with overuse of soil functions, which lead to land degradation and consequently impact the eco-system services.

This report provides a thorough review of Meghalaya's district-level soil erosion problems along with appropriate soil and water conservation measures as suggested solution to arrest the problem. Land managers and farmers can quickly consult this report as a ready reckoner when addressing soil erosion issues in their region.

2.0 LAND DEGRADATION THROUGH SOIL EROSION AND ITS IMPACTS

2.1 Land Degradation

In India, about 121.7 M ha area, which includes arable and non-arable lands, is subjected to various forms of land degradation (ICAR 2010), with maximum (82.6 M ha, 68.4%) contributed by water erosion (49% area accounts for soil loss >10.0 t ha^{-1} yr^{-1}). The soil erosion and other associated losses is presented in Fig.2.1

2.2 Gross Erosion Rate

The gross annual soil erosion of our country is 5.11 billion tonnes out of which 34.1% deposited in the reservoirs, 22.9% is discharged outside the country (mainly to oceans), and 43.0% is displaced within the mainland (Sharda and Ojasvi, 2016). Average annual reduction in water storage capacity of dams by 1.2% from 4937 big dams and average life span reduction of dams by 25 years (Range 8-53 years).

2.3 Production Loss and Monetary Loss

The annual production and monetary losses due to water erosion were estimated for 27 major rainfed cereals, oilseeds and pulses crops, to be 13.4 M t (Sharda *et al.,* 2010) valued at Rs 29200 crore during 2015-16 (Sharda and Dogra, 2013).

2.4 Nutrients Loss

A significant amount (8 to 11 Mt of NPK) of nutrients gets transported with runoff and eroded soil leading to net loss of ecosystem services. Soil loss resulting in loss of 5.37 to 8.40 M t of nutrients in India (Sharda and Ojasvi, 2016) estimated total monetary loss of Rs 38,54 to 45,41 crores annually (2020 price). Further the estimated erosion linked loss of N, P, K, and S nutrient displacement as 4.41 to 9.61, 0.387 to 2.31, 4.43 and 1.27-1.65 million tonnes amounting to the corresponding monetary loss of Rs 13500- 29300, Rs 1850-8320, Rs 17300 and Rs 5890-7790 crore rupees (2020 price), respectively.

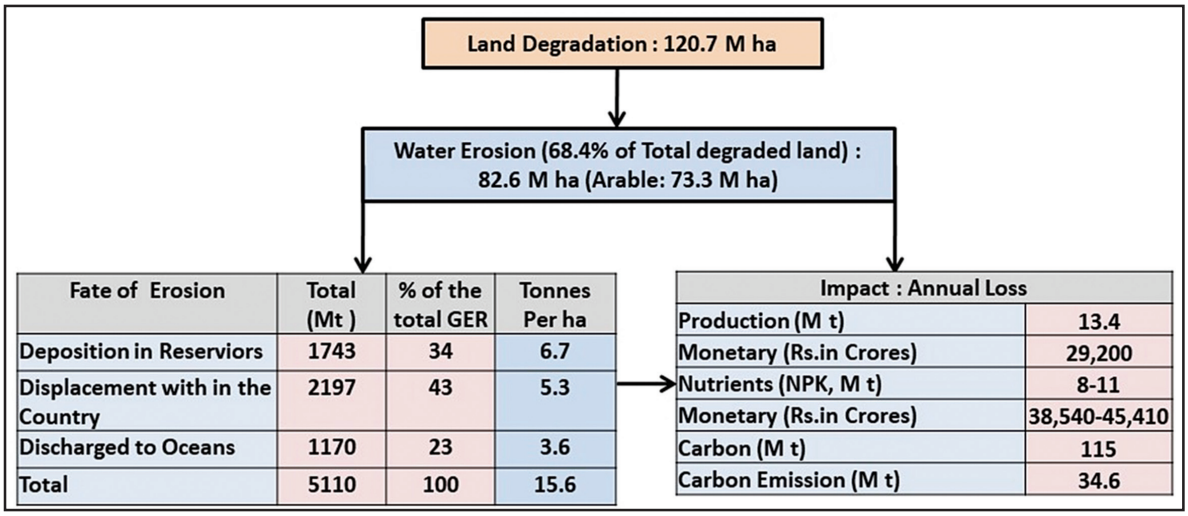
2.5 Carbon Loss

Release of extra carbon dioxide into the atmosphere by organic matter dislodgement followed by decomposition has serious implications on climate change. The soil pool loses of 1100 Mt C into the atmosphere as a result of soil erosion and another 300-800 Mt C annually to the ocean (Lal,

2011). Quantity of organic C displacement due to water erosion in India is about 115 Mt yr^{-1} which consequently emits about 34.6 Mt of C to the atmosphere; adoption of appropriate soil and water conservation measures for erosion control can reduce C emission by 19.0 – 27.0 Mt yr^{-1} (Mandal *et al.,* 2020).

2.6 Loss in Reservoir Capacity

The total sediment trapped in the reservoirs with a total gross capacity of 299.5 $Gm^3$was estimated at 1679 M m^3yr^{-1}, as a result of which the average annual capacity loss of the reservoirs was calculated as 1.04% with a range of 0.47 to 3.05% (Sharda and Ojasvi,2016). Loss of gross storage capacity in the range of 0.50 % to 0.80 % per year is experienced in the case of larger dams with capacity varying from 51 to >1000 Mm^3. Smaller dams of 1 to 50 Mm^3capacity experience a reduction in storage capacity ranging from 0.80 % to > 2.00 % per year. The annual total storage loss and dead storage loss in Sardar Sarovar dam has been estimated to be 0.495% and 1.27% respectively resulting to annual capitalized loss of 1070 to 1137 million rupees for loss in power generation and irrigated area under different scenario of rainfall (Pande *et al*., 2014).



Fate of Erosion	Total (Mt)	% of the total GER	Tonnes Per ha
Deposition in Reserviors	1743	34	6.7
Displacement with in the Country	2197	43	5.3
Discharged to Oceans	1170	23	3.6
Total	5110	100	15.6

Impact : Annual Loss	
Production (M t)	13.4
Monetary (Rs.in Crores)	29,200
Nutrients (NPK, M t)	8-11
Monetary (Rs.in Crores)	38,540-45,410
Carbon (M t)	115
Carbon Emission (M t)	34.6

Fig. 2.1. Soil erosion and associated losses in India (GER- Gross erosion rate)

3.0 THE APPROACH

Soil erosion risk depends upon the balance between prevailing soil erosion rate and the permissible rate or soil loss tolerance limit. While prevailing soil erosion rate is a function of physiographic, edaphic and climatic factors at a given location, the assessment of site-specific soil loss tolerance limit of the location helps in understanding capacity of the soil to withstand the forces of soil erosion. For example, about 32% areas of Peninsular Plateau can only afford a soil loss ranging from 2.5 to 7.5 t ha^{-1} yr^{-1} (NAAS, 2017) while soil erosion rates in such area is more than 10 t ha^{-1} yr^{-1}. In this case, soil erosion rates are higher than the SLTL, indicating the necessity for soil erosion control.

The district wise prioritization/risk area was assessed from the data base on potential soil erosion rates and soil loss tolerance limits (T-value) for the state of Meghalaya. The potential soil erosion rate was compared with the value of soil loss tolerance limit, the differences in value of potential soil erosion and soil loss tolerance limit of a place was used for deciding priority class, higher the difference (Potential soil erosion rate – soil loss tolerance limit), higher the priority. Based on the difference of soil erosion and tolerance limits, five priority classes have been defined normalizing the difference values between 35 and 5 t ha^{-1} yr^{-1}(Class 1 > 35 t ha^{-1} yr^{-1}, Class 2: 25–35 t ha^{-1} yr^{-1}, Class 3: 15-25 t ha^{-1} yr^{-1}, Class 4: 5-15 t ha^{-1} yr^{-1} Class 5 < 5 t ha^{-1} yr^{-1}). In addition to the above difference, an area having T-value of 2.5 t ha^{-1} yr^{-1} is considered most sensitive due to shallow soil depth and poor quality, it is highly vulnerable to loss of crop productivity if soil erosion exceeds the T–value. This makes Meghalaya state an area of great concern from soil erosion point of view. For operational point of view the sum of priority class 1, 2 and 3 has been taken into consideration and the severity of soil erosion risk has been reclassified. According to this re-classification, severity class A, B and C were defined based on the cumulative area of < 50000 ha, 50000-100000 ha and > 100000 ha respectively (Kannan et al, 2021).

Soil erosion in a given priority class has to be brought within the permissible rate or T-value to achieve sustainability of production systems, and for carbon sequestration. The identification of critical areas in the priority classes based on the permissible soil erosion rate or T-value at a given location in each district of Meghalaya and the proposed conservation measures for each district are aimed to reduce soil erosion below the soil tolerance limit.

4.0 EROSION STATUS AND CONSERVATION PLANNING FOR THE STATE OF MEGHALAYA

4.1 About the State

The word Meghalaya literally means "the Abode of clouds". Meghalaya is a hilly strip in the eastern part of the country, about 300 km long (east-west 100 km wide), with a total area of about 22,429 sq km, out of which 42% is under forests. The state covers 3 agro-climatic zones viz., temperate sub-alpine zone, sub-tropical hill and plain zone, mild-tropical hill and plain zone. Topographically, the state has most of its land covered by hills interspersed with gorges and small valleys, with elevations ranging from 150 to 2000 m above sea level (asl). The total population of the state is 2,306,069 (Census, 2001), with a density of 103 persons per sq km. The state has a monsoon type of climate, which varies widely depending on altitude and the physiographic features of the land mass. While the Shillong plateau has a bracing climate verging towards the temperate type, the lower regions adjoining the Surma and Brahmaputra Valleys (100-300m) have a tropical climate. With average annual rainfall as high as 1200 cm in some areas, Meghalaya is the wettest state in India. The soils of the hills are majorly derived from a gneissic complex parent. Taxonomically, the soils of the state have been classified as Alfisoils, Inceptisols, Entisols, and Ultisols. The texture of soils varies from loamy to fine loamy. The soils of the alluvial plains adjacent to the northwest and southern plateau are very deep, dark brown to reddish-brown in colour and low in nitrogen supplying potential, deficient in available phosphorous and medium to low in available potassium. The reaction of the soils varies from acidic (pH 5.0 to 6.0) to strongly acidic (pH 4.5 to 5.0). Most of the soils occurring at higher altitudes under high rainfall belts are strongly acidic due to intense leaching. The base saturation of these soils is less than 35%. These soils are not suitable for intensive crop production. Areas around Shillong and east of Nongstain are affected by moderate to severe erosion covering about 56% of the TGA. In the southern Jainta hills and Khasi hills, erosion is very severe.

4.2 Soil Erosion Rate

A summary of the results for the state of Meghalaya is given in Table 4.1, which indicate that overall soil erosion through water is a serious problem in major part of the state as nearly 34.47% area falls under priority class of 25-35 t ha^{-1} yr^{-1}. Majority of these areas have high slope, low soil depth (<1.5 m) and high drainage density, and therefore higher soil erosion risks. Soil erosion is affecting 56% of state's TGA with erosion rates ranging from 0 to 35 t ha^{-1} yr^{-1}. Soil erosion is more prevalent in southern Jainta hills and Khasi hills in certain undulating pockets of the state where

high intensity rainfall and steepness of slope has contributed to higher erosion rates (Mandal *et al*., 2020).Analysis of the data revealed that 34.53% areas in the state falls under the very severe erosion category whereas the percentage of very slight, slight moderate and severe erosion classes is 14.62 23.19, 17.68 and 9.98%, respectively. Although the soils in the state indicated better resistance to soil erosion due to high organic carbon content, the shallow soil depth and high slopes make the soil vulnerable to erosion. By comparing the potential erosion rates with permissible rates, it was observed that 34.47% area of the state is subjected to high erosion risk (Table4.1). However, there was practically no area which could be classified under priority class I with very high erosion risk. The analysis further revealed that 37.90% area is very stable and requires no conservation measure. Considering severe and very severe categories of erosion together 44.51% area is very critical. Owing to preponderance of forests, barren and uncultivated lands, cultivation has been extended to marginal lands through extensive deforestation resulting in high soil erosion rate (40 t ha^{-1} yr^{-1}) and low productivity. Most of the cultivated area falls under *Jhuming* (shifting cultivation) and rest under upland terraces, wetland terraces, valley lands and plains. Thus, such areas are most sensitive and require special care during cultivation. Jhum cultivation and indiscriminate deforestation lead to accelerated erosion for which proper vegetation cover need to be established on very steep slopes. The spatial distribution of erosion risk prone areas classified under various priority classes is presented in Fig. 4.1.

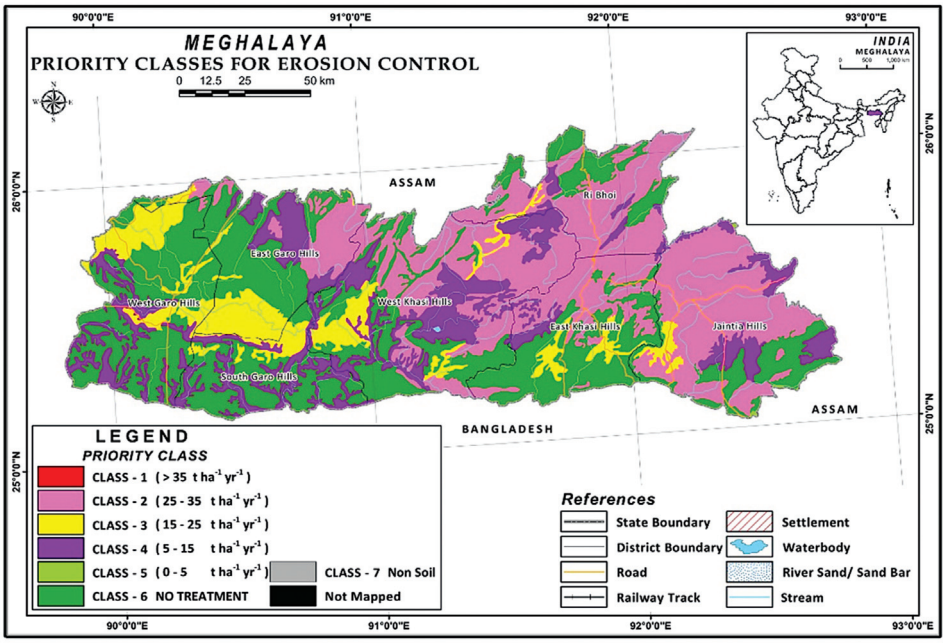


Fig. 4.1.Priority classes for erosion control in of Meghalaya State

Table 4.1: Area under different potential erosion rates, tolerance limits and priority classes in the state of Meghalaya

Area (m ha) Under different erosion categories	Erosion categories(t ha^{-1} yr^{-1})						
	<5 (Very slight)	5 to 10 (Slight)	10 to 20 (Moderate)	20 to 40 (Severe)	>40 (Very severe)	Others	
	0.33(14.62)	0.52(23.19)	0.40(17.68)	0.22(9.98)	0.77(34.53)		
Area (m ha)	T-values(t ha^{-1} yr^{-1})						
Under different T-values	2.5	5.0	7.5	10.0	12.5	Rock/ unreported	
	-	-	0.20(8.97)	2.02(90.58)	-	0.01(0.45)	
Area (m ha)	Priority Classes(t ha^{-1} yr^{-1})						
Under different priority classes	1	2	3	4	5	6	Others
	>35	25-35	15-25	5-15	0-5	<0	-
	-	0.77 (34.47)	0.22 (9.97)	0.28 (17.57)	0.003 (0.12)	0.85 (37.90)	-

4.3 Soil Loss Tolerance Limit (SLTL)

Data pertaining to soil loss/erosion tolerance limits indicated that soil loss tolerance limit (T-value) ofthe Meghalaya State are mostly varies between 7.5 and 10.0 t ha^{-1} yr^{-1}(Fig.4.2 and Table 4.1). T-values revealed that soils of the state have strong resistance capacity. Very high T-value (12.5 t ha^{-1} yr^{-1}) was not recorded as depth of soil is a limiting factor in the state.

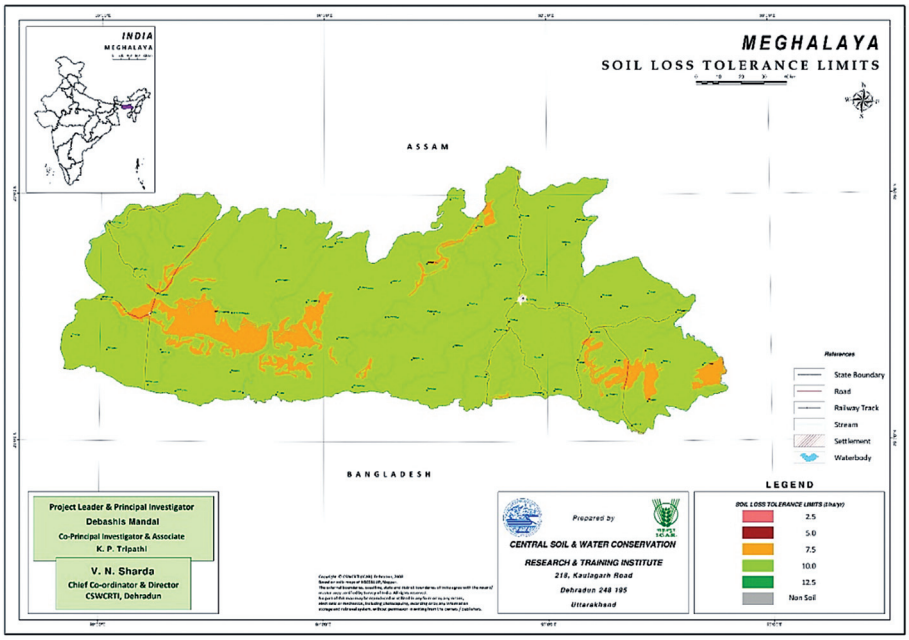


Fig. 4.2. Soil Loss Tolerance Limit map of Meghalaya State

4.4 Production and Monetary Loss from Rainfed Crops due to Soil Erosion

The average production loss of cereal and millets, oilseed and pulse crops were estimated to be 31%, 44% and 33%, respectively,and consequently, average loss considering cereals, oil seeds and pulses together is about 31%. Out of 0.05 million tonne total production losses, 91.6% is due to losses in cereals and millets, 4.6% in oilseeds and 3.9% in pulses (Fig. 4.3). In terms of monetary losses, 78.9% of the total loss of ₹ 925 million occurs in Meghalaya due to production losses in cerealsand millets, followed by 10.8% in oilseeds and 10.3% in pulses (Fig. 4.4). The largest contribution is from paddy (63%) followed by maize (13%), and other pulses (10%).

The productivity losses of cereal and millets, oilseed and pulse crops were estimated to be 500 kg ha^{-1}, 258 kg ha^{-1} and 436 kg ha^{-1}, respectively. The average productivity loss of all these crops together is477 kg ha^{-1} (Sharda and Dogra, 2013), which in monetary terms was ₹ 9735 ha^{-1} during 2018-19 (Fig 4.5). The Gross State Domestic Product (GSDP) of Meghalaya for 2018-19 at current prices was estimated to be ₹ 33,481 crore (PRS, 2019). Therefore, the State's loss due to soil erosion by rain water during the cultivation of rainfed cereal, oilseed and pulse crops is equal to 0.28% of its GSDP during 2018-19.

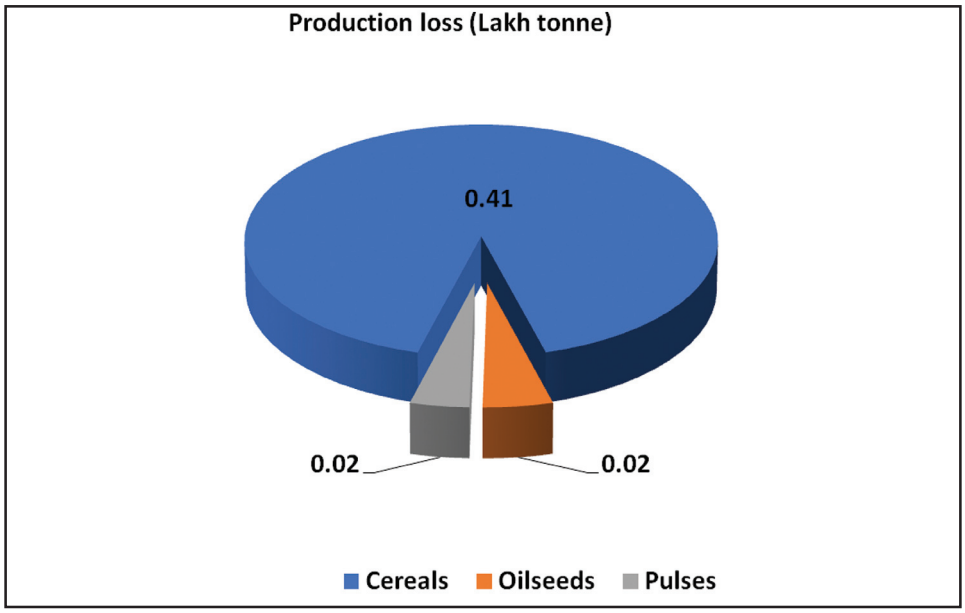


Fig. 4.3. Estimated total production loss of rainfed crops due to soil erosion in Meghalaya State

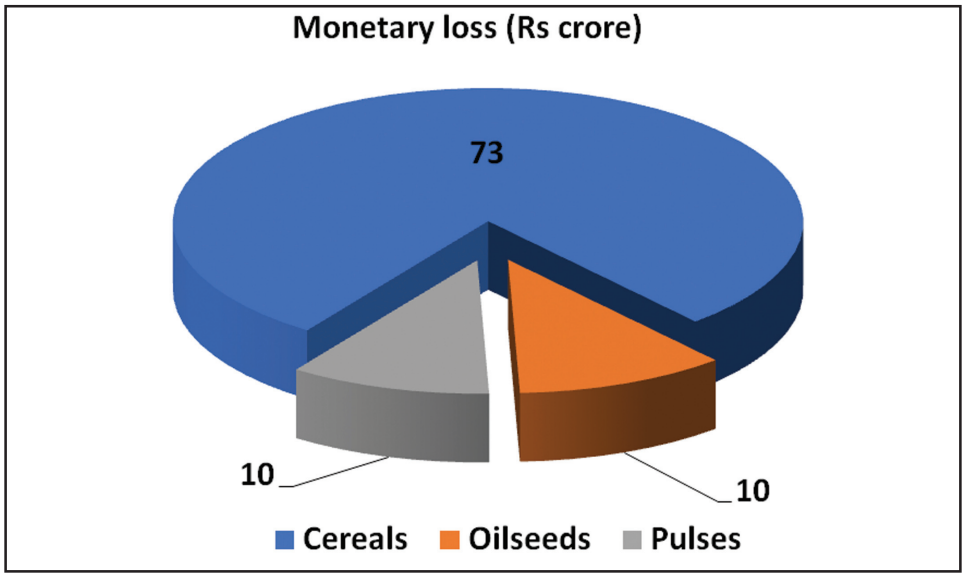


Fig. 4.4. Estimated total monetary loss (in ₹) of rainfed crops due to soil erosion in Meghalaya State

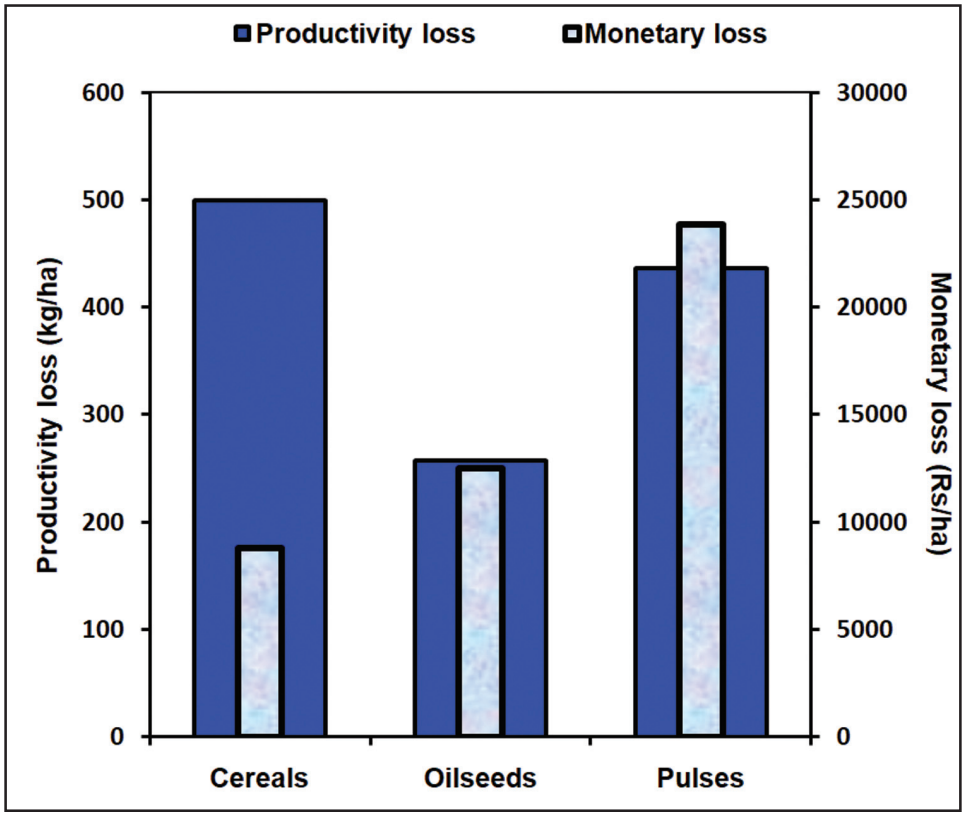


Fig. 4.5. Estimated productivity (kg ha^{-1}) and monetary loss (Rs. ha^{-1}) of rainfed crops due to soil erosion in Meghalaya State

4.5 Area under Risk and Treatment Measures

It is evident that only 62.10% of TGA of the state requires different degrees of soil erosion management and 37.89 % of TGA falls under no treatment category in view of the fact that soil loss is within permissible erosion limits. Majority of the area has a T-value of 10 t ha^{-1} y^{-1} while only 9 % of the TGA has a T-value of 7.5 t ha^{-1} y^{-1} (Table 4.1). Delineating critical land degradation areas through prioritization process is crucial for developing open-space plans that protect soil and water resources, and in turn the ecosystems. Detail account of district wise severity of erosion areas and critical problem with their possible solutions has been given in Table 4.2. The last column of Table 4.2 refers Table 4.3 which is given in the succeeding sections of the document. Table 4.3 presents soil and water conservation engineering measures, under different land situations, Table 4.4 presents district wise agronomic and vegetative measures and Table 4.5 presents district wise agroforestry measures.

Table 4.2. District wise severity of erosion areas and critical problem with their possible solutions in Meghalaya

S N	District	TGA (000'ha)	Area under risk (000'ha)	% Area of the district	Special erosion problem	Solutions measures
Severity of Risk-No risk						
-Nil-						
Severity of Risk-A						
1	South Garo Hills	192.32	22.34 (1: 0.0; 2: 0.00; 3: 22.34)	11.62	Shifting cultivation (Jhum), Very weak natural materials, Steep slope cuttings, Flash floods and drought, Unlined natural water channels, Landslide	Table 4.3-Sr No. 3.1.1, 3.1.3, 6.1.1, 6.1.5, 7.7
Severity of Risk-B						
2	West Garo Hills	331.97	68.47 (1: 0.0; 2:14.77; 3:67.37)	20.63	Shifting cultivation (Jhum), Flood inundation and soil erosion, Siltation, landslides, deforestation and watershed degradation,	Table 4.3- Sr No. 1.6, 3.1.1, 3.1.2, 3.2.1, 6.1.1, 6.1.5, 4.9, 7.7
Severity of Risk-C						
3	East Garo Hills	292.85	115.48 (1:0.0; 2: 61.70; 3: 53.77)	39.43	Shifting cultivation (Jhum), Steep slope cuttings, Heavy siltation, landslides, Unlined natural water channels, deforestation and watershed degradation	Table 4.3- Sr No. 1.6, 3.1.1, 3.1.2, 3.2.1, 6.1.1, 6.1.5, 4.9, 7.7
4	East Khasi Hills	280.53	125.56 (1:0.0; 2: 104.14; 3: 21.42)	44.76	Landslides, deforestation and watershed degradation, Flash flood inundation and soil erosion, Siltation, Shifting cultivation	Table 4.3-Sr No. 2.1, 3.1.1, 3.1.3, 3.2.1, 6.1.1, 6.1.5, 7.7
5	Ri Bhoi	242.13	160.61 (1:0.0; 2: 157.73; 3: 2.88)	66.33	Shifting cultivation (Jhum), Steep slope cuttings, Heavy siltation, landslides, deforestation and watershed degradation	Table 4.3- Sr No. 4.9, 1.6, 3.1.1, 3.1.2, 3.2.1, 7.7, 6.1.1, 6.1.5
6	Jaintia Hills	380.99	251.92 (1:0.0; 2: 240.39; 3: 11.53)	66.12	Very weak natural materials, Steep slope cuttings, Flash floods and drought, Unlined natural water channels, Landslide	Table 4.3- Sr No. 1.6, 3.1.1, 3.1.2, 3.2.1, 6.1.1, 6.1.5, 7.7, 4.9
7	West Khasi Hills	522.11	252.39 (1:0.0; 2: 207.96; 3: 44.43)	48.34	Shifting cultivation (Jhum), Very weak natural materials, Steep slope cuttings, Flash floods and drought, Unlined natural water channels, Landslide	Table 4.3- Sr No. 4.9, 3.1.1, 3.1.2, 3.2.1, 7.7, 6.1.1, 6.1.5, 1.6, 6.1.7
	Total	**2242.9**	**996.77**	**44.44**		

Note: A= < 50,000 ha area is critical; B= between 50,000-1,00000 ha area is critical; C= > 1,00000 ha area is critical in a district. Critical area is the sum of area under priority class 1, 2 and 3. Data in Parentheses shows area under different priority class based on difference between potential erosion (Er) and soil loss tolerance limit (T) i.e. (E_r – TL); 1: (E_r – TL) >35 t ha^{-1} yr^{-1}, 2: (E_r – TL) in the range of 25-35 t ha^{-1} yr^{-1}, 3: (E_r – TL) in the range of 15-25 t ha^{-1} yr^{-1}. Table 4.3 represents different soil and water conservation measures for different land situations and Table 4.4 represents district wise potential agroforestry systems (AFS).

Table-4.3: Soil and water conservation measures for different soil erosion priority classes

S No	Conservation Measures	Slope <10%		Slope-10-33%	
		Low priority class		High priority class	
		Arable land	Non-arable land	Arable land	Non-arable land
1.0	**Agronomic Measures (up to 6%, agronomic measures alone; >6% with other land management practices)**				
1.1	Contour cultivation/farming	√		√	
1.2	Inter or mixed cropping	√		√	
1.3	Green manuring & Recycling crop residues	√		√	
1.4	Crop rotation	√		√	
1.5	Mulching	√		√	
1.6	Conservation tillage/Conservation agriculture	√		√	
1.7	Cover crops/ strip cropping	√		√	
1.8	Fodder/ tea/ medicinal-aromatic crops on the terrace riser			√	
1.9	Ridge and furrow (Deep soils)	√			
1.10	Dead Furrow opening in between the crop lines (Deep soils)	√			
1.11	HorticulturSp.P: Cultivationof vegetables / spices	√		√	
1.12	Emplacement of Coir/jute geotextiles on contours	√		√	
2.0	**Vegetative measures (At lower slope-alone, at higher slope with other conservation measures**				
2.1	Vegetative barrier*	√	√	√	√
2.2	Agri-horticulture		√	√	√
2.3	Vegetally* guarded conservation trenches and ridges (VGCTR)		√		√
2.4	Afforestation/reforestation		√		√
2.5	Grassed waterways	√	√	√	√
2.6	Live vegetative check dam (Bamboo)		√		√
2.7	Stream bank stabilization with bamboo and other species		√		√
	*Species: Bajra Napier (BN) hybrid, guinea grass, Setaria, sorghum, maize, oat, cowpea, guar, *Melia azedarach, Morus alba,Ulmus wallichiana,Morus serrata,Bauhinia variegate*, *Leucaena leucocephala*				
3.0	**Mechanical/Engineering Measures**				
3.1	**Bunding**				
3.1.1	Contour/Field bunding/Trench-cum-bund	√	√	√	√
3.1.2	Graded bunding (uniformly and variable graded)-Black soils	√			
3.1.3	Stone bund (Where stones are available onsite)	√	√	√	√
3.1.4	Compartmental Bunding	√		√	
3.2	**Trenching**				
3.2.1	Contour trenching		√		√
3.2.2	Continuous contour trenching		√		√
3.2.3	Contour staggered trenching		√		√
3.2.4	Graded trenching		√		√

3.2.5	Water absorption trenches		√		√
3.2.6	Half-moon trenches/terraces	√	√	√	√
3.2.7	Recharge pit		√		√
3.3	**Terracing (Bench)**				
3.3.1	Leveled terrace	√		√	
3.3.2	Inward sloping	√		√	
3.3.3	Outward sloping	√		√	
3.3.4	Puertorican type/vegetative	√		√	
3.3.5	Half-moon terraces			√	√
3.3.6	Conservation bench terracing	√			
3.3.7	Narrow based terracing			√	
4.0	**Drainage Line Treatments (DLTs)**				
4.1	Earthen Check dam		√		
4.2	Sandbag check dam (Katta-carat)		√		
4.3	Brush wood check dam (BWCD)		√		√
4.4	Loose boulders check dam (LBCD)		√		√
4.5	Gabion check dam		√		√
4.6	RR check dam		√		√
4.7	Gabion terrace support wall		√		√
4.8	Retaining wall/ Revetment		√		√
4.9	Silt detention tank		√		√
5.0	**Water Harvesting**				
5.1	Community pond/Ooranies	√	√	√	
5.2	Embankment pond		√		
5.3	Pond renovation & Desilting	√	√	√	
5.4	Farm pond-Dugout	√		√	
5.5	Subsurface runoff collection wells			√	
5.5	Pond lining	√	√	√	
5.6	Roof top water harvesting	√		√	
5.7	Diversion Based water harvesting			√	√
	Special problem area				
6.0	**Mine spoil area/ Land Slide Prone Area**				
6.1	**Vegetative**				
6.1.1	Vegetative hedges		√		√
6.1.2	Brushwood check dam				√
6.1.3	Watling (live)				√
6.1.4	Double-row Brushwood dam / Log wood brush filled check dam				√
6.1.5	Grassed contour barrier		√		√
6.1.6	Bamboo plantation		√		√
6.1.7	Afforestation		√		√
6.1.8	Aerial seeding (very high slope or unapproachable area)				√

6.1.9	Turfing/Soding				√
6.1.10	Geo-textiles		√		√
6.2	**Mechanical/Engineering Measures**				
6.2.1	Contour bunds/Stone bund		√		√
6.2.2	Stone wall				√
6.2.3	Staggered trenches and planting		√		√
6.2.4	Loose Boulder check dam (locally available)				√
6.2.5	Diversion drain/ Interceptor drain				√
6.2.6	Nala bunds		√		
6.2.7	Gabion check dam				√
6.2.8	Gabion drop structures				√
6.2.9	Toe wall/toe drain				√
6.2.10	Retaining wall				√
6.2.11	Jute geo textiles for slope stabilization/ Coir Jeo textiles for stabilization of land slide areas				√
6.2.12	Stream Channelization (Retaining wall, Bank		√		√
	(Slope >33%) protection walls. Spurs with apron etc)				
7.0	**Gullied and Ravine Land**				
7.1	Bio fencing/social fencing		√		√
7.2	Peripheral bund		√		√
7.3	Peripheral bund supported by close plantation of bamboo		√		√
7.4	Safe disposal of water from gully head-Piped/ chute spillway-		√		√
7.5	Bamboo on ravine bed and grass on slope		√		√
7.6	Bamboo based live check dams		√		√
7.7	Alternate land use system/Agroforestry		√		√
7.8	Mechanical/Engineering measures		√		√
7.9	Earthen check dam		√		√
7.10	Boribund check dam		√		√
7.11	Silt retention tank		√		√
7.12	Staggered trenching + plantation		√		√

Note 1: District wise details of agronomic and vegetative measures for Meghalaya is referred in Table 4.4

Note 2: For concept, design and estimates of soil and water conservation measures, kindly refer, Mishra, P. K., Jual, G. P., Tripathi, K. P., Ojasvi, P. R., Shrimali, S. S., Sena, D. R., Kumar, A., Patra, S. 2017. Field manual on soil and water conservation structures, ICAR, New Delhi, ISBN: 978-81-7164-167-3

Note 3: For Agroforestry solution for soil water conservation in Mehghalaya kindly refer Table 4.5

Table 4.4. District wise area under various erosion risk and the proposed agronomic and vegetative soil and water conservation measures for Meghalaya

[District Details: Name of District, Total Geographical area, TGA (000, ha), area under erosion risk (A(Er)) ('000 ha), erosion risk area as a percentage of TGA (Er (%)), Special erosion problem (Sp.P)]				
S. N.	**Cropping System (Intercropping, mixed cropping, Conservation Agriculture, crop rotation, etc.)**	**Green manuring, Cover crops and Mulching**	**Protection-cum Productive Vegetative Barriers (Grasses/Fodder/Medicinal-Aromatic Crops /Tea/ etc.)**	**Special problem area: Grassed waterways/live check dams/Mine spoil area/ Land Slide Prone Area**
	Severity of Risk-A			
1.	**South Garo Hills, TGA:192.32, A(Er): 22.34, Er(%): 11.62%, Sp.P: Shifting cultivation, Landslide, Flash floods and drought**			
	• Ginger, Turmeric, Mustard cultivation with furrow system • Rice-Maize- Maize + Cowpea	•Green manuring with Cowpea •Leaf litter mulch for moisture conservation and to improve fertility	• *Citrus reticulata, Michelia oblonga, Pinus kesiya, Schima wallichii,* Banana, *Erythrina indica, Bambusa pallida, Terminalia myriocarpa*	• Culvert with sluice • Afforestation with the following species –*Grewia spp. Morus spp, Bamboo, Bauhinia variegate*
	Severity of Risk-B			
2.	**West Garo Hills, TGA: 331.97, A(Er): 68.47, Er(%): 20.62%, Sp.P : Shifting cultivation, Steep slopes, Deforestation, Siltation**			
	• Horti-pasture Peach/Plum/Apricot+ Rye grass/Tall fescue+ White clover • Rice, Maize, wheat, Millet, Potato, Chilli, Ginger, Paddy, Ginger, Colocasia, Chilli, Dioscoria, Pumpkin, Sweet potato, Maize, Bottle-gourd, Betel vine, Pineapple • Soil fertility management	• Green manuring with Cowpe, Cluster bean • Leaf litter mulch for moisture conservation and to improve fertility	• *Citrus reticulata, Michelia oblonga, Pinus kesiya, Schima wallichii,* Banana, *Erythrina indica, Bambusa pallida, Terminalia myriocarpa, Albizzia chinensis, Albizzia lebbeck, Morus alba* • *Dicanthiumannulatum, Chrysopogon fulvus, Lolium perenne, Setaria grass, Panicum maximum*	• Culvert with sluice • Afforestation with the following species – *Citrus reticulata, Michelia oblonga, Pinus kesiya, Schima wallichii,* Banana, *Erythrina indica, Bambusa pallida, Terminalia myriocarpa Albizzia spp., Bamboo,* Apricot, Peach, Plum
	Severity of Risk-C			
3.	**A:East Garo Hills, TGA: 292.57, A(Er): 115.48, Er(%): 39.43%, SP.P: Shifting cultivation, landslides, soil erosion and deforestation**			
	• Ginger, Turmeric, Mustard cultivation with furrow system • Horti-pasture Peach/Plum/Apricot+ Rye grass/Tall fescue+ White clover • Rice-Maize- Maize +Cowpea Maize (Baby corn)- Oats-Maize (Baby corn)	• Green manuring with Cowpea, Cluster bean • Leaf litter mulch for moisture conservation and to improve fertility	• *Citrus reticulata, Michelia oblonga, Pinus kesiya, Schima wallichii,* Banana, *Erythrina indica, Bambusa pallida, Terminalia myriocarpaleucocephala, Albizzia chinensis, Albizzia lebbeck, Bauhinia variegata* • *Dicanthiumannulatum, Chrysopogonmontanus, Lolium multiflorum, Chrysopogon fulvus, Festuca arundinacea, Dactylis glomerata, Phleum alpinum*	• Culvert with sluice • Afforestation with the following species–*Salix alba, Ulmus wallichiana, Albizzia spp., Morus serrata,* Apricot, Peach, Plum

4.	**A: East Khasi Hills, TGA: 280.53, A(Er): 125.56, Er(%): 44.76%, E : Shifting cultivation, deforestation, Flash flood inundation and soil erosion, deforestation and watershed degradation**			
	• Horti-pasturePlum/Litchi/Peach+ Guinea/Setaria+ S. hamata • Wheat+ Mentha intercropping •Soil fertility management	•Green manuring with Cowpea, Cluster bean •Leaf litter mulch for moisture conservation and to improve fertility	• *Grewia optiva, Celtis australis, Leucaena leucocephala,Melia azedarach, Albizzia chinensis, Albizzia lebbeck, Morus alba,* • *Dicanthiumannulatum, Chrysopogon fulvus, Lolium perenne, Setaria grass, Panicum maximum, Dactylis glomerata, Tall fescue*	• Culvert with sluice • Afforestation with the following species–*Grewia spp., Celtis australis, Morus spp., Bamboo, Leucaena leucocephala*
5.	**A: Ri Bhoi,TGA: 242.13, A(Er): 160.61, Er(%): 66.33%, E : Steep slope cuttings, Heavy siltation**			
	•Maize+Cowpea- Oat+Fodder Mustard- Sorghum + Cowpea BN Hybrid+	• Green manuring with Cowpea, Cluster bean • Leaf litter mulch for moisture conservation and to improve fertility	• Paddy, Ginger, Colocasia, Chilli, Dioscoria, Pumpkin, Sweet potato, Maize, Bottle-gourd, Betel vine, Pineapple *Albizzia chinensis, Albizzia lebbeck, Bauhinia variegata* • *Dicanthiumannulatum, Chrysopogonmontanus, Lolium multiflorum, Chrysopogon fulvus, Festuca arundinacea, Dactylis glomerata, Phleum alpinum*	• Culvert with sluice • Afforestation with the following species –*Ulmus wallichiana, Salix alba, Morus serrata, Leucaena leucocephala, Albizzia chinensis, Albizzia lebbeck, Bauhinia variegata*
6.	**A: Jaintia Hills,TGA: 380.99, A(Er): 251.92, Er(%): 66.12%, E : Shifting cultivation, Steep slope cuttings Flash floods and Landslide**			
	• Maize+Cowpea- Oat+Fodder Mustard- Sorghum + Cowpea BN Hybrid+	• Green manuring with Cowpea, Cluster bean • Leaf litter mulch for moisture conservation and to improve fertility	• *Pinus kesiya, Schima wallichii, Bambusa pallida, Psidium guajova, Citrus sp., Pyrus comminis, Prunus* • *Chrysopogonmontanus, Lolium multiflorum, Chrysopogon fulvus, Festuca arundinacea, Dactylis glomerata, Phleum alpinum, Stipa spp., Chrysopogongryllus*	• Culvert with sluice • Afforestation with the following species – *Salix alba, Morus serrata, Morus alba, Bauhinia variegata*
7.	**A: West Khasi Hills, TGA: 522.11, A(Er): 252.39, Er(%): 48.34%, E : Shifting cultivation, Steep slope cuttings Flash flood inundation and soil erosion, Siltation**			
	• Horti-pasture Khasi mandarin, Apricot/Peach+ Tall fescue /Orchard grass + White /Red Clover • Ginger cultivation with furrow system•Peach/Plum/Apricot+ Rye grass/Tall fescue+ White clover	Green manuring with Cowpea, Cluster bean • Leaf litter mulch for moisture conservation and to improve fertility	• *Pinus kesiya, Schima wallichii, Bambusa pallida, Psidium guajava, Citrus sp., Pyrus communis, Prunus, Melia azedarach, Albizzia chinensis, Albizzia lebbeck, Morus alba,* • *Dicanthiumannulatum, Chrysopogon fulvus, Lolium perenne, Setaria grass, Panicum maximum, Dactylis glomerata, Tall fescue*	• Culvert with sluice • Afforestation with the following species –*Celtis australis, Leucaena leucocephala, Melia azedarach, Albizzia spp., Morus alba, Apple, Apricot, Peach*

Source: Fodder Resources Development Plan for Meghalaya (2022). ICAR-Indian Grassland and Fodder Research Institute, Jhansi.

Note: Severity risk-No risk: Area under (Er-T) >15 t ha^{-1} yr^{-1} is nil however some area having more than 10 t ha^{-1} yr^{-1} need to be treated. Severity Risk A= < 50,000 ha area is critical; severity Risk B= between 50,000-1,00000 ha area is critical; Severity Risk C= > 1,00000 ha area is critical in a district. Critical area is the sum of area under priority class 1, 2 and 3. Data in Parentheses shows area under different priority class based on difference between potential erosion (Er) and soil loss tolerance limit (T) *i.e.* (E_r – TL); 1: (E_r – TL) >35 t ha^{-1} yr^{-1}, 2: (E_r – TL) in the range of 25-35 t ha^{-1} yr^{-1}, 3: (E_r – TL) in the range of 15-25 t ha^{-1} yr^{-1}. Table 4.4 represents different soil and water conservation measures for different land situations and Table 4.5 represents district wise potential agroforestry systems (AFS)

Table 4.5. Agroforestry solution for soil and water conservation in Meghalaya State

S. No.	Agro climatic zones	Districts	Agroforestry System	Crops
1	Temperate sub-alpine zone (1500-2000 m asl*)	South Garo Hills, East Khasi Hills, West Khasi Hills	*Pinus kesiya, Schima wallichii, Bambusa pallida, Psidium guajava, Citrus sp., Pyrus communis, Prunus sp.*	*Pinus* + ginger, cabbage, Cauliflower and Sweet potato, *Schima wallichi/ Pinus* + ginger, Sweet potato and been, Prunus + cabbage, maize, mustard leaf
2	Sub-tropical hill and plan zone (800-1500 m asl)	West Khasi Hills, Ri Bhoi, East Garo Hills,	*Citrus reticulata, Michelia oblonga, Pinus kesiya, Schima wallichii,* Banana, *Erythrina indica, Bambusa pallida, Terminalia myriocarpa*	Citrus + maize, bean, cauliflower, *Schima* + pineapple, maize, ginger
3	Mild-tropical hill and plain zone (200-800m asl)	Jaintia Hills, Ri Bhoi, West Khasi Hills	*Atrocarpushetrophyllus, Assam lemon, Citrus spp , Psidium guojava,* Banana and *Areca catechu*	Artocarpus /banana + pine apple; Arecanut + beetle vine, pineapple, black pepper
*asl: above sea level				

5.0 CONCLUSION

Water erosion is a major problem in Meghalaya as compared to other adjoining states; out of the total geographical area 77.2 % area is affected by water erosion and soil acidity. Out of the total degraded area, about 41% is degraded exclusively by water erosion, while 10% area in acid soils also suffers from water erosion. The remaining 49% is degraded exclusively due to soil acidity. Within the water-eroded area, the widespread practice of shifting cultivation largely contributes to the problems of soil erosion and loss of fertility. Areas around Shillong and east of Nongstain are affected by moderate to severe erosion, covering about 56% of TGA. In the southern Jaintia hills and Khasi hills, erosion is very severe. In the southern Jaintia and Khasi hills, erosion is very severe. About 56% of the total geographical area of the state has a potential erosion rate of more than the permissible rate of 10 t $ha^{-1}yr^{-1}$. There is a need for soil and water conservation (SWC) treatments.

In addition to soil erosion problems on arable and non-arable lands, associated special problems like mine spoil, landslide prone areas, open scrub, river water ingress, floods and water scarcity etc. make the land treatment more challenging. A wide range of soil and water conservation measures, including agronomic and vegetative measures for different land situations and agroforestry measures for different districts have been suggested. The suggested measures aim to reduce soil erosion below the soil loss tolerance limit of the area. The uniqueness of the present approach is that it integrates soil erosion risk areas with production losses of major crops, which would immensely benefit land use planners and policymakers in identifying and prioritizing the areas for execution of site-specific best management practices and bringing soil erosion rates within the permissible limits, thus saving on scarce financial resources.

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PHOTOGRAPHS

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