ISBN-978-93-94687-21-9

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






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

ISO 9001:2015

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Citation

Singh, R. J., Mandal, D., Dogra, P., Kumar, G., Kaushal, R., Roy, T., Islam, S., Madhu, M. (2023) Soil erosion status, priority treatment areas and conservation measures for different districts of Uttarakhand, ISBN-ISBN-978-93-94687-21-9

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Published by

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FOREWORD

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Dr. Suresh Kumar Chaudhari
Deputy Director General (Natural Resources Management)

30.01.2023

Foreword

Soil and water are two vital natural resources essential for improving agro eco-system productivity and sustainability. Adoption of inappropriate and unscientific land use and management practices for short-term gains has resulted in degradation of land resources in Uttarakhand affecting long term sustainability and environmental security in the region. The situation is getting compounded further with the adverse impacts of climate change.

Good quality soil is fundamental to sustainable crop production and its loss by erosion has serious consequences on soil and crop productivity. Over the years, Uttarakhand has lost its top surface fertile soil and water retention capacity due to to washing of clay and organic matter which occurs when water flows above the surface of the soil creating several rils. These rils widens leading to more gully erosion. Overall, the soil erosion through water is a serious problem in major part of the state but yet about 44% of the area has soil erosion rate more than 10 t ha^{-1} yr^{-1} and need various kinds of soil and water conservation treatment.

ICAR-Indian Institute of Soil and Water Conservation (IISWC), Dehradun has developed location specific, eco- friendly and cost-effective conservation measures in farmers' participatory mode for promotion in North-Western Himalayan states namely J&K, Ladakh, Himachal and Uttarakhand adopting watershed approach. In this context, the technical brief on "Soil Erosion Status and Conservation Measures" for Uttarakhand by ICAR-IISWC, Dehradun will be very useful to all the stakeholders involved in natural resource management in the state.

(S.K. Chaudhari)

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PREFACE

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, unscientific land use and land management practices. The risk of soil erosion in Indian Himalayan states is more serious as many lands can no longer be sustained for production, mainly due to high intensity rainfall, deforestation, overgrazing, forest-fires and faulty land use practices thus leading to their abandonment. About 44% of total geographical area (TGA) of Uttarakhand state experiences moderate or moderate to severe soil erosion loss.

In this context, the current technical brief on "Soil Erosion Status, Priority Treatment Areas and Conservation Measures for Different Districts of Uttarakhand" can serve the purpose of ready-reckoner for the policy-planners. This technical brief broadly divided into six chapters. The compiled information is mainly adapted from the previous work of the ICAR-IISWC and other similar institutes working in the field of soil erosion control in North-western Himalayan states. We sincerely acknowledge Director, ICAR-IISWC, Dehradun for providing all the necessary facilities and guidance to accomplish this endeavor successfully well on the time. We are equally thankful to subject matter experts for their valuable guidance and cooperation. We are also thankful to other faculty members of Division of Soil Science and Agronomy for their help to complete this task successfully.

We not only hope but also believe that this technical brief will be very useful for the stakeholders working on soil and water conservation. Mistakes and corrections are vital part of the any document, so comments and suggestions are always welcomed from the readers.

(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, unscientific land use and land management practices. The risk of soil erosion in Indian Himalayan states is more serious as many lands can no longer be sustained for production, mainly due to high intensity rainfall, deforestation, overgrazing, forest-fires and faulty land use practices thus leading to their abandonment (Mandal and Sharda, 2013). About 44% of total geographical area (TGA) of Uttarakhand state experiences moderate or moderate to severe soil erosion loss (Mandal et al., 2020). Further, the erosion induced 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 impacting on eco-system services. This report is a compilation of the detailed erosion problems of the North Western Himalayan State of Uttarakhand and offers a vivid guideline to the management of the erosion problems district wise based on their severity.

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%) contribution 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

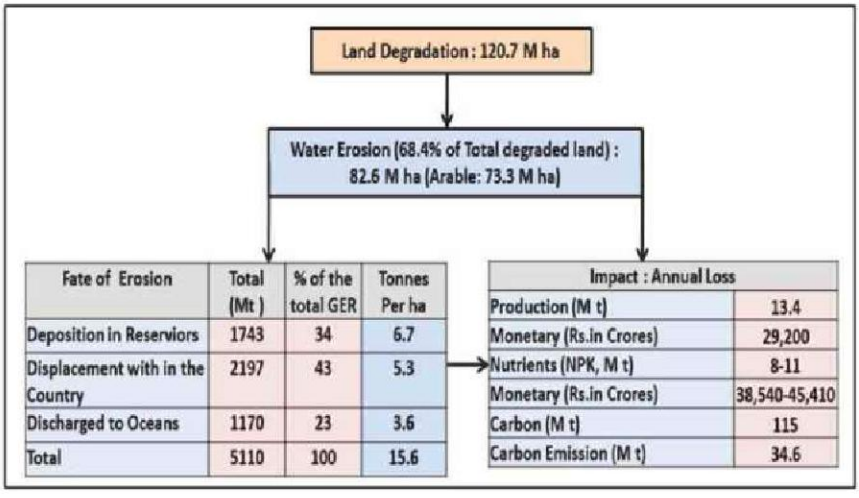
2.2 Gross Erosion Rate: The gross annual soil erosion of our country is 5.11 billion tonnes out of which 34.1% deposited in the reservoirs, 22.9% is discharged outside the country (mainly to oceans), and 43.0% is displaced within the mainland (Sharda and Ojasvi, 2016). Average annual reduction in water 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 & 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 Mt (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 Mt of nutrients in India (Sharda and Ojasvi, 2016) estimated total monetary loss of Rs. 38,540 to 45,410 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, 1850-8320,17300 and 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; 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 M m^3. Smaller dams of 1 to 50 M €m^3 capacity 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 Reservoirs	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.

The district wise prioritization/risk area was assessed from the data base on potential soil erosion rates and soil loss tolerance limits for the state of Uttarakhand. 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 Uttarakhand 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 (Naik 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 Uttarakhand 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 UTTARAKHAND

4.1 About the State

Uttarakhand is located at the central part of the Indian Himalaya. The state is wedged between Himachal on the west, and Nepal, on the east. Geographically, Uttarakhand can be divided into two distinct climatic regions, *viz.*, Kumaoun (rugged and cool mountainous terrain), and Garhwal (sharp edged and slopping terrains). With 70-80 rainy days per year, Uttarakhand has a sub-humid tropical climate influenced by seasonal heavy rains of southwest monsoon. The annual average rainfall of the state is 1163 mm, out of which 80% received only in 20-30 rainy days. Soils are generally shallow and occasionally moderately deep in plain areas with rock outcrops in some areas.

4.2 Soil Erosion Rate

Overall soil erosion through water is a serious problem in major part of the state as nearly 28.3% area has soil erosion 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 53% of state's TGA with erosion rates of 0-35 t ha^{-1} yr^{-1}, of which only 4% area is very severely affected (>35 t ha^{-1} yr^{-1}). Soil erosion is more prevalent in Northern districts and 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).

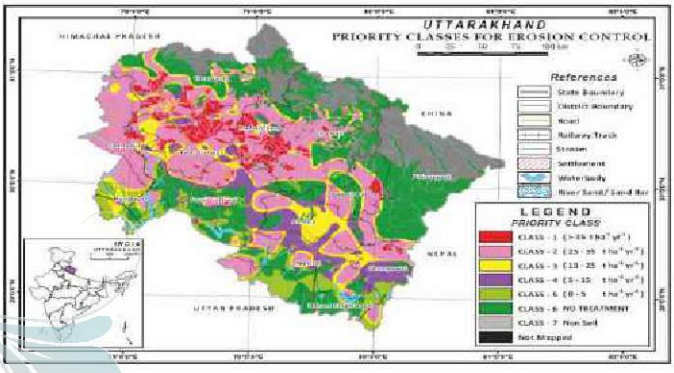


Fig 4.1. Soil erosion priority class map for Uttarakhand State

4.3 Soil Loss Tolerance Limit (SLTL)

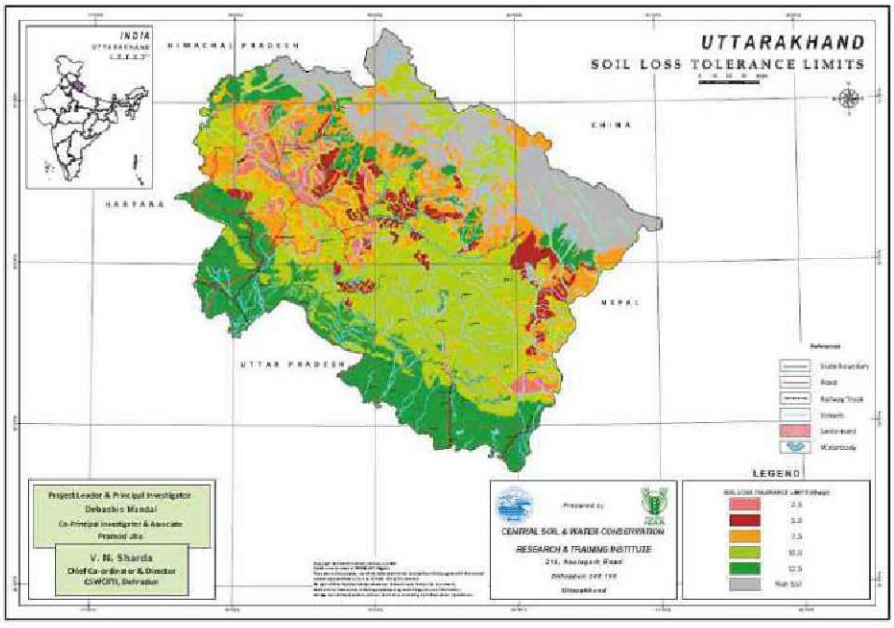


Fig. 4.2. Soil Loss Tolerance Limit map of Uttarakhand state

The tolerance limits in the state ranged from 2.5-12.5 t ha^{-1} yr^{-1} indicating a wide variation in soil function against the impact of water erosion on crop productivity (Jha and Mandal, 2010). Soils of Tarai and alluvial plains encompassing Dehradun, Haridwar, Udham Singh Nagar and broad valley regions of Tehri Garhwal, Pithoragarh, Bageshwar, Almora, and Nainital were good in terms of soil quality with higher tolerance value of 12.5 t ha^{-1} yr^{-1} than the soils of higher slope regions in Lesser and Greater Himalayas. The SLTL-values for the soils of Greater Himalaya covering the districts of Uttarkashi, Tehri Garhwal, Rudraprayag, and Champawat, were in the range of 2.5 to 5.0 t ha^{-1} yr^{-1}. The variations in soil groups and SLTL-values were due to differences in values of most sensitive indicators, *viz*; bulk density, organic carbon and soil depth. Wide variation in soil loss tolerance value (2.5 to 12.5 t ha^{-1} yr^{-1}) was observed under the soils of Lesser Himalaya (Jha and Mandal, 2010). Shallow soil depth (<50 cm soil depth) with low permeability, low organic carbon content and low soil pH contributed to lower SLTL-values.

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 20%, 23% and 22%, respectively, and consequently average loss considering cereals, oil seeds and pulses together is about 20%. Out of 0.16 million tonne total production losses, 93.1% is due to losses in cereals and millets, 2.0% in oilseeds and 4.9% in pulses (Fig. 4.3). In terms of monetary losses, 86.2% of the total loss of Rs. 4009 million occurs in Uttarakhand due to production losses in cereals and millets, followed by 10.7% in pulses and 3.1% in oilseeds (Fig. 4.4). The largest contribution is from fingermillet (28%) followed by wheat (24%), and other cereals (22%).

The productivity losses of cereal and millets, oilseed and pulse crops were estimated to be 286 kg ha^{-1}, 144 kg ha^{-1} and 149 kg ha^{-1}, respectively. The average productivity loss of all these crops together was 269 kg ha^{-1} (Sharda and Dogra, 2013), which in monetary terms was Rs. 6425 ha^{-1} during 2018-19 (Fig 4.5). The Gross State Domestic Product (GSDP) of Uttarakhand for 2018-19 at current prices was estimated to be Rs. 2,37,147 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 0.17% of its GSDP during 2018-19.

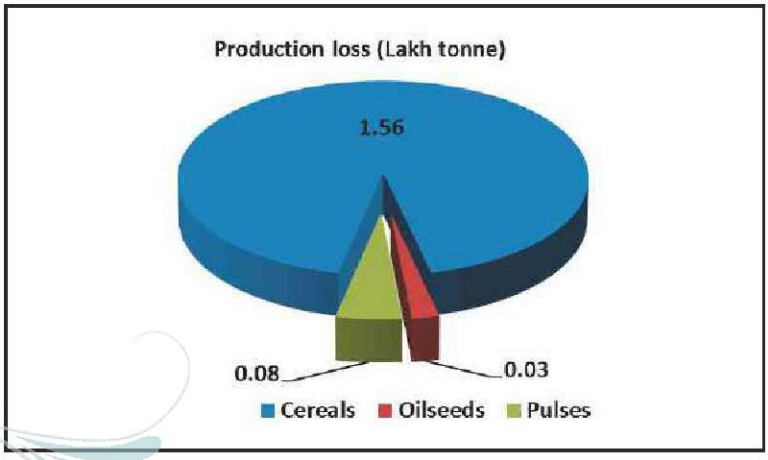


Fig. 4.3. Estimated total production loss of rainfed crops due to soil erosion in Uttarakhand State

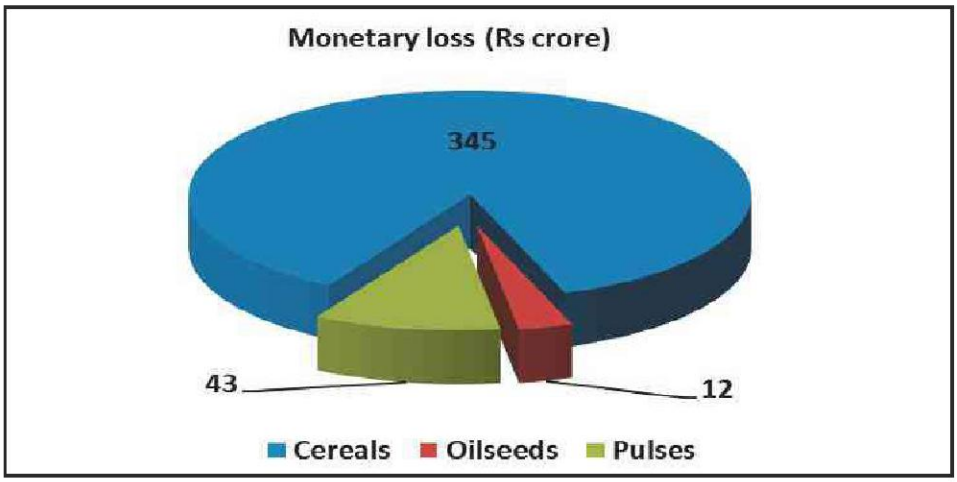


Fig. 4.4. Estimated total monetary loss of rainfed crops due to soil erosion in Uttarakhand State

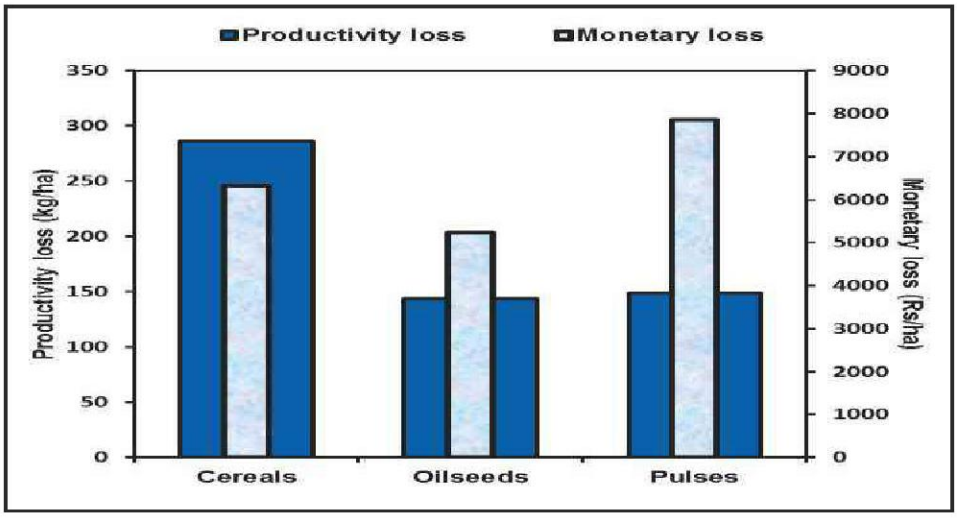


Fig. 4.5. Estimated productivity (kg ha^{-1}) and monetary loss (Rs. ha^{-1}) of rainfed crops due to soil erosion in Uttarakhand State

4.5 Area under Risk and Treatment Measures

The district wise details of erosion affected area and their classification in to priority classes A, B and C has been provided in Table 4.1 along with the possible soil and water conservation measures. The list of agronomic and vegetative measures is enlisted under Table 4.3 while the district wise agroforestry solutions for soil and water conservation are presented in Table 4.4.

Table 4.1. District wise severity of erosion areas and critical problem with their possible solutions in Uttarakhand

District	TGA (oooha)	Area under risk (oooha)	% Area of the district	Special erosion problem	Solutions
Severity of Risk-No risk					
-Nil-					
Severity of Risk-A					
Pithoragarh	724.1	40.0 (1: 0.8;2: 25.8; 3: 13.4)	5.53	Very weak natural materials, Steep slope cuttings, Flash floods, Unlined natural water channels, Loading of weak slopes by heavy constructions	Table 4.2 -Sr No. 3.1.1, 3.1.3, 6.1.1, 3.3.1, 6.2.4
Severity of Risk-B					
Udham Singh Nagar	272.0	70.40 (1:0; 2: 52.5; 3: 17.9)	25.9	Soil Piping, sand mining. loose slopes with high intensity rainfall, Gully erosion, Susceptible for flash floods, light soil texture	Table 4.2 -Sr No. 3.1.3, 3.1.2, 7.3, 6.1.6, 6.1.7, 3.2.3, 5.4, 6.2.10, 6.2.4, 4.6
Champawat	178.0	70.45 (1: 4.9;2: 45.6; 3: 20.0)	39.6	Very weak natural materials, Steep slope cuttings, Flash floods, Unlined natural water channels, Loading of weak slopes by heavy constructions	Table 4.2 -Sr No. 3.1.3, 3.2.1, 3.3.2, 4.6, 4.4, 3.1.1, 6.2.3, 4.8 Table 3 - Sr, No 19,20

District	TGA (oooha)	Area under risk (oooha)	% Area of the district	Special erosion problem	Solutions
Severity of Risk-C					
Haridwar	239.0	112.1 (2: 70.8; 3: 41.3)	46.9	Soil Piping, sand mining. loose slopes in riverside embankments and fragile hill slopes with high intensity rainfall, Gully erosion, Susceptible for flash floods, light soil texture	Table 4.2 -Sr No. 3.1.3, 3.2.1, 3.3.2, 4.6, 4.4, 3.1.1, 6.2.3, 4.8 Table 3 - Sr, No 19, 20
Bageshwar	222.5	120.4 (1: 9.3;2: 88.2; 3: 22.8)	54.1	Lime stone mining, Magnesite mining, very weak natural materials, Steep slope cuttings, Flash floods, Unlined natural water channels, Loading of weak slopes by heavy roadside constructions	Table 4.2 -Sr No. 3.2.1, 6.2.3, 6.2.4
Nanital	398.1	144.6 (1:0; 2: 89.1; 3: 55.5)	36.3	Very weak natural materials, Steep slope cuttings, Flash floods, Unlined natural water channels, Loading of weak slopes by heavy road side constructions	Table 4.2 -Sr No. 3.2.1, 6.2.3, 6.2.4

District	TGA (oooha)	Area under risk (oooha)	% Area of the district	Special erosion problem	Solutions
Rudraprayag	198.2	160.6 (1: 47.2;2: 97.0; 3: 16.3)	81.0	Very weak natural materials, Steep slope cuttings, Flash floods, Unlined natural water channels, Loading of weak slopes by heavy road side, constructions	Table 4.2 -Sr No. 3.2.1, 6.2.3, 6.2.4, 7.5, 6.1.6, 6.2.4, 4.6
Pauri Garhwal	524.8	165.2 (1: 7.8;2: 117.0; 3: 40.4)	31.5	Very weak natural materials, Steep slope cuttings, Flash floods, Unlined natural water channels, Loading of weak slopes by heavy constructions	Table 4.2 -Sr No 3.2.1, 3.1.1, 3.3.1, 6.1.1, 3.2.3, 3.2.1, 6.2.3, 4.6, 4.4.
Almora	312.7	188.2 (1:0; 2: 85.3; 3: 103.0)	60.2	Very weak natural materials, Steep slope cuttings, Flash floods, Unlined natural water channels, Loading of weak slopes by heavy constructions	Table 4.2 -Sr No. 3.1.3, 3.2.1, 3.3.2, 4.6, 4.4, 3.1.1, 6.2.3, 4.8
Dehradun	308.4	288.4 (1: 7.3;2: 247.5; 3: 33.5)	93.5	Very weak natural materials, Steep slope cuttings, Flash floods, Unlined natural water channels, Loading of weak slopes by heavy constructions	Table 4.2 -Sr No. 3.1.3, 3.2.1, 3.3.2, 4.6, 4.4, 3.1.1, 6.2.3, 4.8

District	TGA (oooha)	Area under risk (oooha)	% Area of the district	Special erosion problem	Solutions
Chamoli	780.5	300.0 (1: 36.9;2: 227.6; 3: 35.5)	38.4	Very weak natural materials, Steep slope cuttings, Flash floods, Unlined natural water channels, Loading of weak slopes by heavy constructions	Table 4.2 -Sr No. 3.1.3, 3.2.1, 3.3.2, 4.6, 4.4, 3.1.1, 6.2.3, 4.8
Uttarkashi	800.3	324.4 (1: 55.0;2: 198.7; 3: 70.6)	40.5	Very weak natural materials, Steep slope cuttings, Flash floods, Unlined natural water channels, Loading of weak slopes by heavy constructions	Table 4.2 -Sr No. 3.1.3, 3.2.1, 3.3.2, 4.6, 4.4, 3.1.1, 6.2.3, 4.8
Tehri Garhwal	389.7	348.4 (1: 62.7;2: 222.6; 3: 63.1)	89.4	Very weak natural materials, Steep slope cuttings, Flash floods, Unlined natural water channels, Loading of weak slopes by heavy constructions	Table 4.2 -Sr No. 3.1.3, 3.2.1, 3.3.2, 4.6, 4.4, 3.1.1, 6.2.3, 4.8
Total	5348.3	2333.2	43.6		

Note 1: District wise details of agronomic and vegetative measures for Uttarakhand is referred in Table 4.3

Note 2: 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 4.2 represents different soil and water conservation measures for different land situations, Table 4.3 presents the different agronomic and vegetative measures and Table 4.4 represents district wise potential agroforestry systems (AFS).

Table-4.2: 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 (upto 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	√		√	
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	Fascines of *Arundo donax* grass, paddy straw and maize stover	√		√	
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*/Mixed vegetative barriers*	√	√	√	√

2.2	Vegetative strips*		√	√	√
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: Hybrid napier (*Pennisetum purpureum*), Panicum, Palmarosa (*Cymbopogon martinii*), Vetivera grass (*Vetiveria zinanoides*) ; Guatemala grass (*Tripsacum laxum*); Weeping love grass *Eragrostis curvula);* Lemon grass (*Cymbopogon citrates);* Malabar (*C. flexuosus* Agave (*Agave Americana & Agave sisalana);* Geranium (*Pelargonium graveolens);* Mulberry (*Morus alba); Pigeon pea (Cajanus cajan)*				
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 (Slope >33%)				√
6.2.12	Stream Channelization (Retaining wall, Bank 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 Uttarakhand is referred in Table 4.3

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., Shrimal i, 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 Uttarakhand kindly refer Table 4.4

Table 4.3. District wise severity of erosion areas and critical problem with the possible agronomicand vegetative solutions in Uttarakhand

[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	Pithoragarh, TGA: 724.1, A(Er):40.0; Er (%): 5.53, Sp.P : Mining, Flash floods			
	• Paddy – green manuring crops • Ginger cultivation with furrow system • Bheemal with lemon grass • Multi-storey Beemal agro forestry system with lemon grass and other tree spices	• Green manuring with *Dhaincha* • Leaf litter mulch for moisture conservation and to improve fertility • Crop residue incorporation in Bheemal and lemon grass plantation	• Turfing with geo textiles • Vegetative hedge with Palmarosa, lemon grass and napier grass	• Culvert with sluice. Bioengineering measures such as live fascines, live stakes, wattling, crib structures on areas prone to landslide. • Community plantation (kachnar, subabul, banj) with Staggered trenches on degraded lands.
	TGA ('000ha):724, Area affected by erosion in severity Class A (A(Er)) ('000 ha): 40.0; % of TGA under risk (Er (%)):5.53%			

	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-B			
2	Udhamsingh Nagar, TGA: 272.0, A(Er): 70.40, Er (%): 25.9, Sp.P: Sand mining, Urbanization, Deforestation			
	• Paddy – green manuring crops • Ginger/Turmeric cultivation with agroforestry system • Poplar cultivation on field bunds • Wheat+ Mentha intercropping • Soil fertility management	• Green manuring with *Dhaincha* • Leaf litter mulch for moisture conservation and to improve fertility • Crop residue incorporation in sugarcane and paddy fields	• Turfing with geo textiles • Vegetative hedge with Palmarosa, lemon grass and napier grass	• Culvert with sluice • Protection and social fencing • Plantation of , *Syzygium cumini, Trewia nudiflora,* • *Terminalia arjuna on waterlogged soils*

3	Champawat, TGA : 178.0, A(Er) : 70.45, Er(%) : 39.6, Sp.P : Mining, Open Scrub			
	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
	• Paddy – green manuring crops • Ginger cultivation with furrow system • Bheemal with lemon grass • Multi-storey Beemal agro forestry system with lemon grass and other tree spices	• Green manuring with *Dhaincha* • Leaf litter mulch for moisture conservation and to improve fertility • Crop residue incorporation in Bheemal and lemon grass plantation	• Mixed vegetative barrier with napier and quick growing grasses in upland crops • Napier and lemon grass along the stream • Planting grasses along contour bund	• Protection and social fencing • Prevention of forest fire • Community plantation (kachnar, subabul, banj) with Staggered trenches on the lands devoid of vegetation.
	TGA ('000 ha): 450; Area affected by erosion in severity Class B (A(Er)) ('000 ha): 140.85; % of TGA under risk (Er (%)): 31.3 %			
	Severity of Risk-C			

	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
4	Haridwar, TGA: 239.0, A(Er) : 112.1, Er(%) : 46.9, Sp.P: Sand mining, Urbanization, Deforestation			
	• Paddy – green manuring crops • Ginger/Turmeric cultivation with agroforestry system • Poplar cultivation on field bunds • Wheat+ Mentha intercropping • Soil fertility management	• Green manuring with *Dhaincha* • Leaf litter mulch for moisture conservation and to improve fertility •Crop residue incorporation in sugarcane and paddy fields	• Turfing with geo textiles • Vegetative hedge with Palmarosa, lemon grass and napier grass	• Culvert with sluice • Plantation of , *Eucalyptus, Syzygium cumini, Trewia nudiflora,* • *Terminalia arjuna on waterlogged soils near canals*
5	Bageshwar, TGA : 222.5, A(Er): 120.4, Er(%) : 54.1, Sp.P: Mining, Flash floods			

	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
	• Paddy – green manuring crops • Ginger cultivation with furrow system • Bheemal with lemon grass • Multi-storey Beemal agro forestry system with lemon grass and other tree spices	• Green manuring with *Dhaincha* • Leaf litter mulch for moisture conservation and to improve fertility • Crop residue incorporation in Bheemal and lemon grass plantation	• Turfing with geo textiles • Vegetative hedge with Palmarosa, lemon grass and napier grass	• Culvert with sluice • Bioengineering measures such as live fascines, live stakes, wattling, crib structures on areas prone to landslide
6	Nainital, TGA: 398.1, A(Er): 144.6, Er(%) : 36.3, : Sp.P: Soil Piping, Mining. Steep slopes with high intensity rainfall, Gully erosion, Susceptible for Landslides			
	• Paddy – green manuring crops • Ginger cultivation with furrow system • Bheemal with lemon grass • Multi-storey Beemal agro forestry system with lemon grass and other tree spices	• Green manuring with *Dhaincha* • Leaf litter mulch for moisture conservation and to improve fertility • Crop residue incorporation in Bheemal and lemon grass plantation	• Turfing with geo textiles • Vegetative hedge with Palmarosa, lemon grass and napier grass	• Culvert with sluice • Afforestration of community lands (*Cinnamomum tamala, Pyrus pashia Bamboo, Cedrus deodara, Quercus* • *Leucotrichophora)* • Moisture conservation trenches for preventing forest fire

	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
7	Rudraprayag, TGA: 198.2, A(Er): 160.6, Er (%): 81.0, Sp.P : Soil Piping, Mining. Steep slopes with high intensity rainfall, Gully erosion, Susceptible for Landslides			
	• Paddy – green manuring crops • Ginger cultivation with furrow system • Bheemal with lemon grass • Multi-storey Beemal agro forestry system with lemon grass and other tree spices	• Green manuring with *Dhaincha* • Leaf litter mulch for moisture conservation and to improve fertility • Crop residue incorporation in Bheemal and lemon grass plantation	• Turfing with geo textiles • Vegetative hedge with Palmarosa, lemon grass and napier grass	• Culvert with sluice • Bioengineering measures such as live fascines, live stakes, wattling, crib structures on areas prone to landslide. • Channel stabilization measure like brushwood/live check dams in first order gullies. • Bioengineering measures for stabilization of river banks.

	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
8	Pauri Garhwal, TGA: 524.8, A(Er): 165.2, Er (%): 31.5, Sp.P: Soil Piping, Mining. Steep slopes with high intensity rainfall, Gully erosion, Susceptible for Landslides			
	• Paddy – green manuring crops • Ginger cultivation with furrow system • Bheemal with lemon grass • Multi-storey Beemal agro forestry system with lemon grass and other tree spices	• Green manuring with *Dhaincha* • Leaf litter mulch for moisture conservation and to improve fertility • Crop residue incorporation in Bheemal and lemon grass plantation	• Turfing with geo textiles • Vegetative hedge with Palmarosa, lemon grass and napier grass	• Culvert with sluice • Moisture conservation trenches for preventing forest fire and checking soil erosion. • Bioengineering measures for landslide control. • Brushwood check dams in first order gullies. • Silvipasture system on community lands

	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
9	Almora, TGA: 312.17, A(Er): 188.2, Er (%): 60.2, Sp. P: Mining, Open Scrub, smaller portion under steep slopes, Barren rocky, Susceptible for Landslide			
	• Paddy – green manuring crops • Ginger cultivation with furrow system • Bheemal with lemon grass • Multi-storey Beemal agro forestry system with lemon grass and other tree spices	• Green manuring with *Dhaincha* • Leaf litter mulch for moisture conservation and to improve fertility • Crop residue incorporation in Bheemal and lemon grass plantation	• Turfing with geo textiles • Vegetative hedge with Palmarosa, lemon grass and napier grass	• Culvert with sluice • Block plantation with *in-situ* soil conservation measures • Brushwood check dams in first order gullies. • Silvipasture system on community lands ,

	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
10	Dehradun, TGA : 308.4, A(Er) : 288.4, Er(%) : 93.5 , Sp.P : Sheet erosion, Mining and quarrying, Susceptible for Landslides, Soil Piping, Steep slopes with high intensity rainfall, Gully erosion			
	• Paddy – green manuring crops Maize+ in situ live green manuring • Ginger cultivation with furrow system • Bheemal with lemon grass • Multi-storey Beemal agro forestry system with lemon grass and other tree spices	• Green manuring with *Dhaincha* • Leaf litter mulch for moisture conservation and to improve fertility • Crop residue incorporation in Bheemal and lemon grass plantation	• Turfing with geo textiles • Vegetative hedge with Palmarosa, lemon grass and napier grass	• Culvert with sluice • Bioengineering measures for torrent control and bank stabilization. • Brushwood check dams in first order gullies.

	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
11	Chamoli, TGA: 780.5, A(Er) : 300.0 , Er(%) : 38.4, Sp.P: Mining, Open Scrub, Barren rocky, Degraded lands			
	• Paddy – green manuring crops • Ginger cultivation with furrow system • Bheemal with lemon grass • Multi-storey Beemal agro forestry system with lemon grass and other tree spices	• Green manuring with *Dhaincha* • Leaf litter mulch for moisture conservation and to improve fertility • Crop residue incorporation in Bheemal and lemon grass plantation	• Turfing with geo textiles • Vegetative hedge with Palmarosa, lemon grass and napier grass	• Culvert with sluice • Bioengineering measures such as live fascines, live stakes, wattling, crib structures on areas prone to landslide. • Channel stabilization measure like brushwood/live check dams in first order gullies. • Bioengineering measures for stabilization of river banks.

	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
12	Uttarakashi, TGA: 800.3, A(Er): 324.4, Er (%): 40.5, Sp.P : Urbanization, flash floods			
	• Paddy – green manuring crops • Ginger cultivation with furrow system • Bheemal with lemon grass • Multi-storey Bheemal agro forestry system with lemon grass and other tree spices	• Green manuring with *Dhaincha* • Leaf litter mulch for moisture conservation and to improve fertility • Crop residue incorporation in Bheemal and lemon grass plantation	• Turfing with geo textiles • Vegetative hedge with Palmarosa, lemon grass and napier grass	• Culvert with sluice • Bioengineering measures such as live fascines, live stakes, wattling, crib structures on areas prone to landslide. • Channel stabilization measure like brushwood/live check dams in first order gullies. • Bioengineering measures for stabilization of river banks and landslides.

	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
13	Tehri Garhwal, TGA: 389.7, A(Er): 348.4, Er (%): 89.4, Sp.P : Mining, Open Scrub			
	• Paddy – green manuring crops • Ginger cultivation with furrow system • Bheemal with lemon grass • Multi-storey Beemal agro forestry system with lemon grass and other tree spices	• Green manuring with *Dhaincha* • Leaf litter mulch for moisture conservation and to improve fertility •Crop residue incorporation in Bheemal and lemon grass plantation	• Turfing with geo textiles • Vegetative hedge with Palmarosa, lemon grass and napier grass	• Soil moisture conservation trenches for preventing forest fire and checking soil erosion. • Bioengineering measures for landslide control. • Brushwood check dams in first order gullies. • Silvipasture system on community lands
	TGA (000 ha): 4173.67, Area affected by erosion in severity Class C (A(Er)) (000 ha): 2152.3, % of TGA under risk (Er(%)): 51.5 %			

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 4.1 represents different soil and water conservation measures for different land situations and Table 4.4 represents district wise potential agroforestry systems (AFS).

Table 4.4. Agro-forestry interventions in different zones of Uttarakhand

S. N	Zone	Farming situation	Rainfall (mm/year)	Districts	Agroforestry trees	Crops	Grasses
1	Zone A (up to 1000 m AMSL)	Tarai irrigated	1400	U.S. Nagar, Haridwar	**MPTs:** *Eucalyptus hybrid* (safeda), *Poplulus deltoides* (Poplar) **Fruit:** *Mangifera indica* (Mango), *Litchi chinensis* (Litchi), *Psidium guajava* (Guava)	Paddy, wheat, Mentha, sugarcane, lentil, chickpea, rapeseed mustard, Turmeric, Medicinal plants, Cucurbits **Livestock**: Buffalo and cattle	*Pennisetum purpureum, Cenchrus ciliaris, Chrysopogon fulvus, Bothrichloa intermedia, Cynodon dactylon*
		Bhabar Irrigated	1400	Nainital, Dehradun and Pauri Garhwal	**MPTs**: *Eucalyptus hybrid* (safeda), *Poplulus deltoides* (Poplar) **Fruit:** *Mangifera indica* (Mango), *Litchi chinensis* (Litchi), *Psidium guajava* (Guava)	Paddy, wheat, sugarcane, rapeseed mustard, potato, Turmeric, lentil, Berseem **Livestock:** Buffalo and cattle	*Setaria, Panicum maximum, Sehima nervosum, Dicanthium annulatum, Chrysopogon fulvus, Pennisetum purpureum*
		Irrigated lower hills (600-1000 m AMSL)	2000-2400	Champawat, Pauri Garhwal, Dehradun, Nainital, Tehri Garhwal	**MPTs**: *Acacia catechu* (Khair), *Bauhinia variegata (Kachnar), Dalbergia sissoo* (shisham), *Dendrocalamus strictus* (baans), *Eucalyptus* (safeda), *Leuceana leucocephala (subabul), Morus alba (shehtut), Tectona grandis* (sagwan) **Fruit:** *Mangifera indica* (Mango), *Litchi chinensis* (Litchi), *Prunus persica* (peach)	Paddy, Wheat, onion, chilly, peas, potato, radish, cauliflower, pulses oilseeds, soybean, Turmeric, Ginger, Colocassia, Frenchbean **Livestock:** Buffalo and cattle, goat	*Setaria, Panicum maximum, Apluda mutica, Chrysopogon fulvus, Dicanthium annulatum, Pennisetum purpureum*

		Rain-fed lower hills (600-1000 m AMSL)	2000-2400	Champawat, Nainital, Pauri Garhwal, Dehradun, Tehri Garhwal, Bageshwar	**MPTs**: *Acacia catechu* (Khair), *Bombax ceiba* (Semal), *Bauhinia variegata* (Kachnar), *Dendrocalamus strictus* (baans), *Dalbergia sissoo* (Shisham), *Eucalyptus* (Safeda), *Grewia optiva* (bhimal), *Leuceana leucocephala* (subabul), *Toona ciliata* (tun), *Broussonetia papyrifera (paper mulberry), Kydia calycina* (pula), *Melia azaderach* (bakain) **Fruit:** *Artocarpus integrefolia* (kathal), *Ficus glomerata* (timla), *Ficus palmata, Mangifera indica* (Mango), *Prunus persica* (peach), *Pyrus communis* (pear)	Finger millet, Maize, Paddy, wheat, pulses, mango, Chilli, Frenchbean, Peas **Livestock:** Buffalo, cattle and goat	*Chloris gayana, Dicanthium annulatum, Pennisetum pedicellatum*
2	Zone B 1000-1500 m AMSL	Mid hills	1200-1300	Champawat, Nainital, Almora, Dehradun, Tehri Garhwal, Bageshwar	**MPTs**: *Albizia chinensis* (kala siris), *Bauhinia variegata* (kachnar), *Celtis australis* (khirak), *Grewia optiva* (bhimal), *Morus serrata* (*shehtut*), *Toona ciliata* (tun) **Fruit:** *Citrus aurantifolia* (kagzi nimbu), *Citrus sinensis (malta), Ficus glomerata* (timla), *Juglans regia* (akhrot), *Malus domestica* (apple) *Prunus armeniaca* (apricot), *Prunus domestica* (plum), *P*unica granatum (anaar), *Pyrus communis* (pear),	Paddy, finger millet, wheat, potato, tomato, peas, cole crops, pulses, French bean **Livestock:** Cattle, sheep & goat	*Digietaria , Chloris gayana, Chrysopogon gryllus, Setaria sphacelkata, Pennisetum* spp

3	Zone C 1500-2400 m AMSL	High hills	1200-2500	Pithoragarh, Almora, Chamoli, Bageshwar	**MPts:** *Aesculus indica* (pangar), *Morus serrata* (shetut), *Myrica esculenta* (kafal), Populus cilata (poplar), *Quercus leucotrichophora* (banj), *Qurecus dilata* (moru), Salix (beuns), **Fruit:** *Juglans regia* (akhrot), *Prunus armeniaca* (apricot), *Malus domestica (apple), Prunus persica (peach), Punica granatum (anaar), Pyrus communis* (pear), *Prunus cerasus* (cherry),	Amaranth, finger millet, French-beans, Cole crops, potato, **Livestock:** Cattle, sheep and goat	*Agropyron longearisatum, Festuca rubra, Lolium perenne, Andropogon tristis, Dactylis glomerata, Poa partensis, Poa alpine and Sporobolus* spp
4.	Zone D> 2400 m AMSL	Very High hills	1300	Pithoragarh, Chamoli and Uttarkashi	*Salix* spp, *Hippophae rhamonides (seebuckthorn), Malus domestica* (apple)	Amaranth, buckwheat, peas, Cole crops, and potato. **Livestock:** Sheep & goat	*Agrostis spp., Poa alpina, Phleum alpinum, Trisetum spicatum*

5.0 CONCLUSION

Water erosion is a major problem in Uttarakhand state as compared to other adjoining plain states. In Uttarakhand about 44% of the total geographical area need soil and water conservation (SWC) treatments. The rest about 56% have erosion rate lower than the tolerance limit therefore no priority treatment is warranted, however, field level agronomic and vegetative measures are recommended for these lands as well. Tehri-Garhwal district is having the highest area *i.e.* 348 thousand hectares of land in need of SWC interventions followed by Uttarkashi (324 thousand hectares) and Chamoli (300 thousand hectares). The Tehri-Garhwal district is also having 222 thousand hectares under high erosion risk (risk category 25-35 t ha^{-1}) followed by Chamoli (227 thousand hectares) and Uttarkashi (199 thousand hectares).

In addition to soil erosion problem of arable and non-arable lands, associated special problems like mine spoilt, landslides, open scrub, river water ingress, flood 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 of Uttarakhand have been suggested. The suggested measures aim at reducing 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 policy makers to identify and prioritize the areas for execution of site-specific best management practices and bring soil erosion rates within the permissible limits, thus saving on scarce financial resources.

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