POLICY PAPER 88

Mitigating Land Degradation due to Water Erosion

NATIONAL ACADEMY OF AGRICULTURAL SCIENCES, NEW DELHI
December 2017

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CITATION : NAAS 2017. Mitigating Land Degradation due to Water Erosion. Policy Paper No. 88 National Academy of Agricultural Sciences, New Delhi: 20 p.

Published by Dr Anil K. Bawa, Executive Director on behalf of
NATIONAL ACADEMY OF AGRICULTURAL SCIENCES
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Preface

India is projected to be the most populous country in the world with about 1.5 billion people by 2030. Hence, food security for all would be the most challenging task and land resource management would constitute an important step in achieving this goal. However, our country is confronted with a daunting challenge of managing large scale land degradation estimated to be spread in an area of over 120 million hectares, which is about 37% of our geographical area. Soil erosion due to water, being the most dominant cause of land degradation, results in loss of soil nutrients, reduction in crop productivity, occurrence of floods/droughts, reduction in reservoir's capacity and loss of biodiversity. Loss of crop productivity and water storage capacity has serious consequences for country's food, livelihood and environmental security. Land is essentially required for the development of all sectors of economy. It is thus imperative to strike a balance between developmental activities and sustainability of production systems through protection of natural resources, especially land. To achieve efficient management of land resources with sustainable agricultural growth in the country, there is an urgent need to evolve a land use policy that provides adequate safeguards against land degradation.

It is with these objectives in mind that the National Academy of Agricultural Sciences (NAAS) organized a brain storming session (BSS) on "Mitigating Land Degradation due to Water Erosion" on June 20, 2017 at NAAS Complex, New Delhi under the convenership of Dr V. N. Sharda. The BSS was attended by eminent scientists, ministry officials and experts in the relevant disciplines. The deliberations were enriched by in-depth interaction on the issues under consideration. The policy paper is an outcome of the dedicated efforts of all concerned and I especially compliment the Convener, the distinguished participants, and the editors of NAAS for bringing out this Policy Paper. I am sure that it will be useful to all Fellowship and stakeholders.

(Panjab Singh)
President

Mitigating Land Degradation due to Water Erosion

1. INTRODUCTION

Soil erosion is integrally linked to land degradation. The excessive soil loss resulting from poor land management has serious implications for crop productivity and food security, which calls for sustainable use of our soil resource. The processes of soil erosion, sediment delivery and sediment transport are key components and measures of the land degradation. Erosion and sediment redistribution processes are the primary drivers of landscape development and play an important role in soil development. Equally, the magnitudes of the sediment loads transported by rivers have important implications on the functioning of the system. Since erosion and sediment dynamics also have important implications on food production thus have a significant socio-economic dimension as well.

High sediment loads in rivers can result in major problems for water resource development, for example reservoir sedimentation and the siltation of water diversion and irrigation canals, tend to increase the cost of treating water abstracted from such rivers. Furthermore, high sediment loads can result in pollution and habitat degradation in river systems.

Land use and the hydrology of a river basin, erosion and sediment transport processes are sensitive to changes in climate, land cover and wide ranging human activities. These include forest cutting and land-clearance, the expansion of agriculture, land and crop management practices, mineral extraction, urbanization and infrastructural development, dam and reservoir construction, and programmes for soil conservation and sediment control (Walling, 2009).

Globally, about 24 billion tonnes of fertile soil is lost annually through water erosion (FAO, 2011). The soil pool loses 1100 Mt C into the atmosphere as a result of soil erosion and another 300-800 Mt C annually to the ocean through erosion-induced transportation (Lal, 2011). A harmonized national database on land degradation in India shows that 120.7 Mha or 36.7% of the total arable and non-arable land surface of the country suffers from various forms of degradation (NAAS, 2010) with water erosion, contributing a major part of about 83 Mha (68.4%). Other forms of land degradation such as wind erosion (12.4 Mha), chemical degradation due to salts (6.74 Mha) and acidity (17.94 Mha), and physical degradation due to mining and water logging (1.07 Mha) also have significant impact on productivity of land resources. Water erosion also results in loss of soil organic carbon, nutrient imbalance, compaction, decline in soil biodiversity, and contamination with heavy metals and pesticides. Soil loss rate in our country is about 1535 t $km^{-2}yr^{-1}$ (Sharda and

Ojasvi, 2016), resulting in loss of 5.37 to 8.4 Mt of nutrients, reduction in crop productivity, occurrence of floods/droughts, reduction in reservoirs capacity (1% to 2% annually), and loss of biodiversity. Loss of crop productivity, one of many negative impacts of soil erosion by water, has serious consequences for country's food, livelihood and environmental security. Major rainfed crops in India suffer an annual production loss of 13.4 Mt due to water erosion which amounts to a loss of Rs. 205.32 billion in monetary terms (Sharda and Dogra, 2013). Similarly, the crop production loss due to salinity and alkalinity at the national level has been estimated at 5.66 and 11.18 Mt, respectively which is equivalent to monetary loss of Rs. 80 and Rs. 150 billion, considering MSP of the year 2014-15 (ICAR-CSSRI, 2016 a, b). Thus production and monetary losses would be 2-3 times higher if all forms of land degradation are accounted for.

Against this background, controlling soil erosion and sediment transport through the rivers can have important repercussions for our soil resource and its sustainable use for food production. Changes in land–ocean sediment transfer will result in changes in country's biogeochemical cycles, particularly in the carbon cycle. For example, reduced sediment loads can result in the scouring of river channels and the erosion of delta and coastal areas as well as causing reduced nutrient inputs into aquatic and riparian ecosystems, particularly lakes, deltas and coastal seas. Therefore, though the entire land surface is exposed to some degree of erosion, not every piece of land is required to be treated. An analysis of erosion risk based on the soil loss tolerance limits Sharda and Mandal (2011) revealed that only about 50% of the Total Geographical Area (TGA) of India falls under five priority erosion risk classes, requiring different degrees of erosion management.

This Policy Paper attempts to give a brief review of existing knowledge regarding the sediment dynamics, erosion risk and impact of erosion on crop productivity and to identify key uncertainties and future research needs. The recommendations are an outcome of BSS held on 20th June, 2017 at NAAS, New Delhi under the convenership of Dr V.N. Sharda.

2. EXISTING UNDERSTANDING OF SOIL EROSION AND ITS IMPACT

2.1 Soil erosion due to rainfall erosivity

The gross erosion rates (t km^{-2} yr^{-1}) from the mainland of India were estimated (Maji, 2007; NAAS, 2010) by employing Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978). The erosion rates are best analysed on a watershed, catchment or river basin scale. The percentage of area under category-wise gross erosion rates (PER) in 23 river basins covering the main land of the country is presented in Fig. 1a. It is evident that a significant portion of the total area (24%) falls under high (2000–4000 t km^{-2} yr^{-1}) and very high (> 4000 t km^{-2} yr^{-1}) erosion categories. Maximum percentage of area (26%) falls in the moderate (1000–2000 t km^{-2} yr^{-1}) erosion category while 43% of the total area is covered under low (500–1000 t km^{-2} yr^{-1}) and very low (< 500 t km^{-2} yr^{-1}) erosion categories. As per area statistics, the Ganges is the largest river basin of the country covering 25.7% of the total land area, followed by the Indus (14.2%), the Godavari (9.5%), the Krishna (7.9%), and the Brahmaputra (7.4%) rivers. The annual gross erosion (Mt yr^{-1}) in different river basins is presented in Fig. 1b. It shows that 68% of the total gross erosion is registered from the basins in the northern region, while southern region basins contribute only 32%. Besides differences in other climatic and physiographic characteristics, this low erosion is attributed to more stable geological formations in the southern plateau region. Three basins, the Brahmaputra, the Ganges and the Indus, which drain the northern Himalayan region, together contribute 50% of the total gross erosion in the country. The area weighted average PER in different river basins is found to vary from 603 t km^{-2} yr^{-1} to 3000 t km^{-2} yr^{-1} with highest PER in a small area of north Ladakh not draining into the Indus.

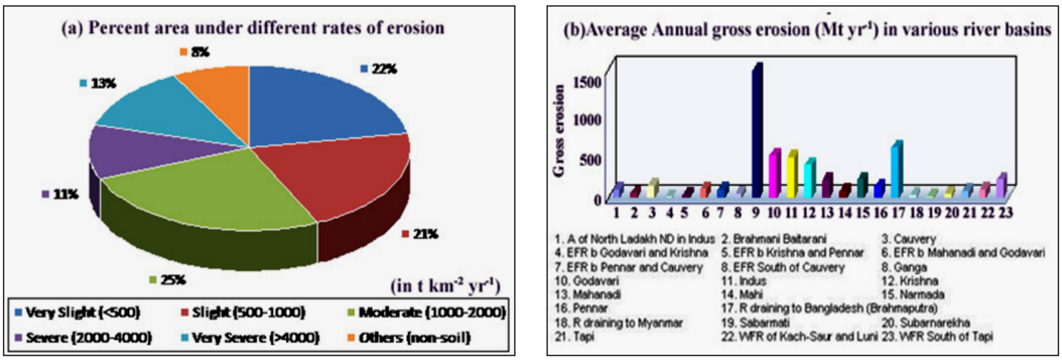


Fig. 1. (a) Percent of geographical area of India under different rates of erosion, (b) Average annual gross erosion in 23 river basins of India

2.2 Key drivers of erosion

2.2.1 Land clearance and catchment disturbance

The precise magnitude of the increase in erosion caused by land clearance and disturbance depends on the nature of the disturbance, the proportion of the catchment affected, the degree of development of the river basin, the catchment characteristics, and the climatic conditions. It is generally accepted that poor vegetation cover and unsustainable land use of these degraded lands results in higher erosion rates. However, a time-varied estimation of gross erosion is essentially required to fully understand and quantify land use derived changes in the erosion rates. It is thus important to quantify the impact of various developmental programmes being undertaken in the country.

2.2.2 Dam construction

In India, about 4937 large dams (having height 15 m or more) have been constructed in the past 60 years to harness the water resources of the country for various purposes (CWC, 2009). The total sediment trapped in the reservoirs with a total gross capacity of 299.5 G m^3 was estimated at 1679 M m^3 yr^{-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).

The annual rate of loss of gross storage capacity of all reservoirs due to sedimentation was estimated and the frequency of different categories of reservoirs is shown in Fig. 2a (Sharda and Ojasvi, 2016). Loss of gross storage capacity in the range of 0.5% to 0.8% 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 0.8% to >2% per year.

Another parameter of interest is the useful life of the reservoirs, which was estimated as the time taken to bring about 25% reduction in gross storage (dead storage + live storage) capacity as per estimated sedimentation rates. The average life of all reservoirs is estimated to be 24.8 years with a range of 8 to 53 years (Sharda and Ojasvi, 2016). Fig. 2b shows that the life of reservoirs may vary from 8 to 40 years for smaller dams, whereas for larger dams, with a capacity of more than 50 M m^3, it may be 40 to more than 50 years. Interestingly, the contribution of 4485 smaller dams to total storage capacity (299.3 G m^3) in all the river basins is only 8.9%. However, their widespread spatial distribution caters to the domestic, agricultural, and industrial needs of a large number of people. Hence, to prevent high siltation rate in these reservoirs, effective land protection measures in their catchments are essentially required.

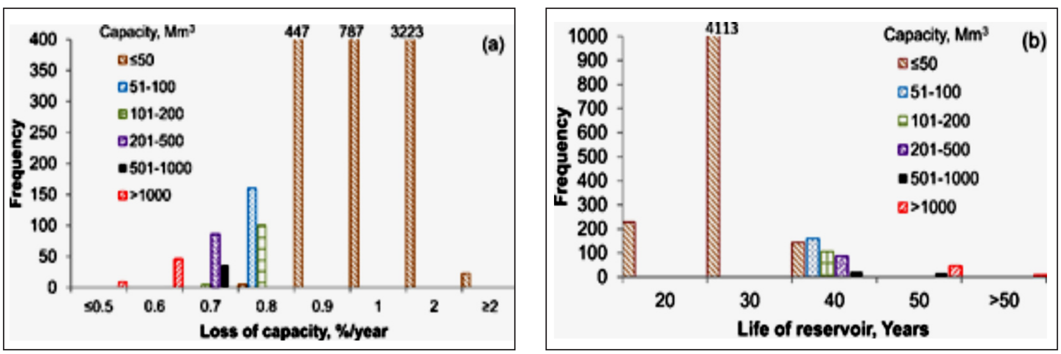


Fig. 2. (a) Loss of reservoir capacity (% of gross storage per year) and (b) Life of reservoirs estimated on the basis of 25% loss in gross storage capacity

2.2.3 Soil conservation and sediment control

Active implementation of soil and water conservation (SWC) and sediment control programmes in river basins can result in reduced erosion and sediment loads in water bodies. Although the literature provides many examples of plot and small catchment experiments that clearly demonstrate the success of soil and water conservation measures and improved management practices in reducing local soil loss, there is currently limited quantitative evidence of the impact of such measures in reducing the sediment fluxes from larger catchments or river basins.

Uri and Lewis (1999) reported that as a result of the widespread implementation of soil conservation measures and other financial incentives introduced by the Food Security Act of 1985, the total erosion from U.S. cropland was reduced from 3.4 Gt per year in the early 1980s to 2.0 Gt per year in the latter half of the 1990s. In China, the results of applying soil conservation and sediment control measures over an area of 752,500 km^2 basin of the Yellow river revealed about 40% reduction in sediment load attributed to the implementation of soil conservation and sediment control measures.

The impact assessment of SWC measures on larger catchments is often constrained by the lack of information on their geo-spatial distribution. Montgomery (2007) reported higher erosion rates from upland agricultural fields as compared to that from native vegetation and geologic erosion. However, Sharda and Ojasvi (2016) showed that gross erosion in river basins is most prominently influenced by land-use factors and erosion rate across the basins. The statistical relations between erosion rates and environmental variables throw some light on the effectiveness of land protection measures and impact of reservoir construction on the overall sediment fluxes in large river basins. However, lack of spatially distributed information on conservation practices and sediment depositions within the catchments, limit the presentation of a holistic picture of sediment control by SWC measures and watershed management, especially on a regional scale.

2.2.4 Climate change

Climate change has increased risk and unpredictability for farmers (especially of small and marginal categories). Projections of monsoon rainfall pattern over the Indian subcontinent indicate that by 2050, a 10% increase in the quantity and 10% increase in the intensity of rainfall are very likely due to climate change, leading to increase in erosive power of rainfall. Based on the results of Sharda and Ojasvi (2006), it is projected that a 1% increase in rainfall intensity may increase the rainfall erosivity by 2.0%. Another study on interrill erosion by Ojasvi *et al.* (2006) indicates that 1% increase in rainfall intensity may increase soil loss from croplands by 1.5%.

By 2050, the erosion rates of water erosion class 500-1000 t km^{-2} yr^{-1} are expected to increase to more than 1000 t km^{-2} yr^{-1}, which is presently considered as the land degrading soil erosion rate. Hence, about 66 Mha area in our country under the erosion class of 500-1000 t km^{-2} yr^{-1} that covers mostly croplands will be additionally affected by higher rates of erosion due to climate induced changes in rainfall. This will result in significant increase in water erosion affected land degradation area from the current levels unless ameliorative measures are taken. These projections also suggest that a comprehensive knowledge-base on land degradation scenario due to various driving forces in our country should also be developed and updated for the benefit of various stakeholders.

2.3 Indicators for identification of hot spots and bright spots

2.3.1 Soil erosion risk areas

The critical permissible limit of soil erosion beyond which crop productivity is adversely affected is considered as 1000 t km^{-2} yr^{-1}. The soil loss map (Fig. 3) shows that more than 60% of the Total Geographical Area (TGA) of north eastern states - Nagaland, Meghalaya, Arunachal Pradesh, Assam, Chhattisgarh and Jharkhand - have erosion rates above the critical permissible limits. Further, more than 40% area in the states of Uttar Pradesh, Uttarakhand, Madhya Pradesh and Manipur also suffer from potential erosion rates above the critical limit. On the whole, 49 Mha in the country is subjected to potential erosion rate above the critical limit, of which 11% falls in the severe category with erosion rate of more than 40 t ha^{-1} yr^{-1}.

Soil susceptibility can be determined by soil loss tolerance values (T-values). Of all the physiographic regions, the great plains of India are better placed with higher soil loss tolerance value (12.5 t $ha^{-1}yr^{-1}$) followed by coastal plains. The areas of utmost concern are Peninsular India and Peninsular plateau where a considerable area can only afford soil loss ranging from 2.5 to 5.0 t $ha^{-1}yr^{-1}$. Analysis of tolerance limits data revealed that about 42.8% of TGA can tolerate a soil loss of more than default T- value of 12.5 t $ha^{-1}yr^{-1}$. Remaining about 57.2% area had T- value ranging between 2.5 and 10.0 t $ha^{-1}yr^{-1}$ including about 7.4% area with T- value of 2.5 t $ha^{-1}yr^{-1}$. The area with T value of 2.5 t $ha^{-1}yr^{-1}$ is most sensitive from conservation point of view as due to shallow soil depth and poor quality, it is highly vulnerable to loss of crop productivity if erosion exceeds the T –value. Annual crops grown in rainfed shallow soils are highly susceptible to droughts, the frequency of which has increased in the recent years.

The difference in extent of soil erosion and soil tolerance limit can be used to prioritize areas for undertaking soil and water conservation measures. Soil erosion in a given priority class has to be brought within the permissible rate or T-value to prevent loss of productivity and achieve sustainability of production systems. Therefore, critical areas in the priority classes

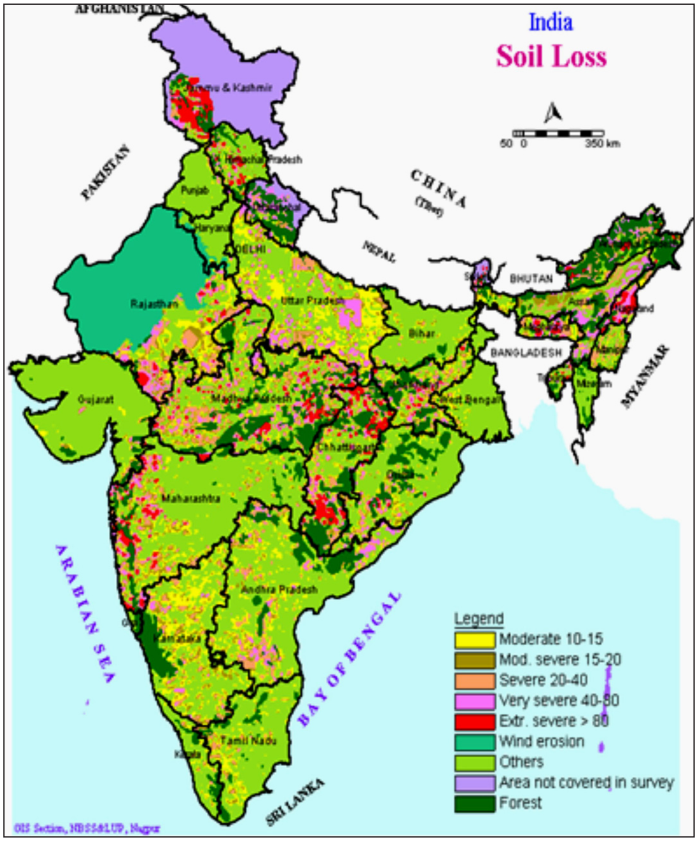


Fig. 3. Average annual gross erosion rate in different States of India

were identified based on the targeted erosion rate or T-value at a given location in each state. Priority area with a target value of 2.5 t $ha^{-1}yr^{-1}$ is considered as most critical, requiring immediate attention for adoption of appropriate conservation strategies. Based on the soil erosion risk analysis, out of the total priority area of 162 Mha under 5 erosion risk classes in all the states, about 11% (17.80 Mha) area is found to be most critical with a target value of only 2.5 t $ha^{-1}yr^{-1}$. Similarly, under the five priority classes, 11.97 Mha (7.4%), 35.23 Mha (21.8%), 47.41 Mha (29.3%) and 49.22 Mha (30.4%) areas are critical in decreasing order of magnitude with target value of 5.0, 7.5, 10.0 and 12.5 t $ha^{-1}yr^{-1}$, respectively. Among the states, Maharashtra has maximum critical area (47.7%) with a target value of 2.5 t $ha^{-1}yr^{-1}$ followed by Rajasthan (31.6%), Karnataka (13.5%) and Gujarat (12.3%). Identification and execution of site specific best management practices is essentially required in these areas to bring the prevailing erosion rates within the permissible limits which may otherwise adversely affect crop productivity.

Considering priority Classes 1 and 2 together, major part of the respective TGA in the states of Nagaland (68.6 %TGA), Arunachal Pradesh (42.5%TGA), Meghalaya (34.6%TGA) and Uttarakhand (33.6%TGA) requires adoption of appropriate conservation measures for erosion control. In the states of Assam, Chhattisgarh, Sikkim, Uttar Pradesh and Jharkhand, nearly 20-30% of their TGA falls in priority Classes 1 and 2. A modest level of erosion risk with 10-20% of TGA under priority Classes 1 and 2 is observed in the states of Andhra Pradesh, Madhya Pradesh, Tripura, Himachal Pradesh, Maharashtra, Karnataka and Rajasthan. The erosion risk is low in the states of Jammu and Kashmir, Orissa, Tamil Nadu, Gujarat, Delhi, Punjab and West Bengal with only 1 to 10% of TGA falling in priority Classes 1 and 2. Overall, about 50% of the TGA of India falls under five priority erosion risk classes, requiring different degrees of erosion management. These findings can immensely help land use planners and policy makers to identify and execute site specific best management practices to bring erosion rates within the permissible limits following watershed approach.

2.3.2 Production and economic losses in rainfed crops

Annual loss in production in India was estimated to vary from 7.2 Mt to 13.5 Mt (Brandon *et al.*, 1995) which by considering 11 major crops varied from 1.7% to 4.1% of total production valued at Rs. 52 to 84 billion. TERI (1998) reported annual loss due to all forms of soil degradation ranging from Rs. 89 to 232 billion, out of which erosion by water and wind alone accounted for Rs. 61 billion (69%) to Rs. 216 billion (94%). However, the reported findings were either based on poor data base of limited number of studies conducted in the Indian sub-continent, Africa and North America or on gross assumptions regarding effect of soil degradation on crop productivity. Experimentally determined region specific and crop specific yield reduction factors were not utilized in the estimations. As a result, the estimates of production loss due to water erosion by various agencies varied widely.

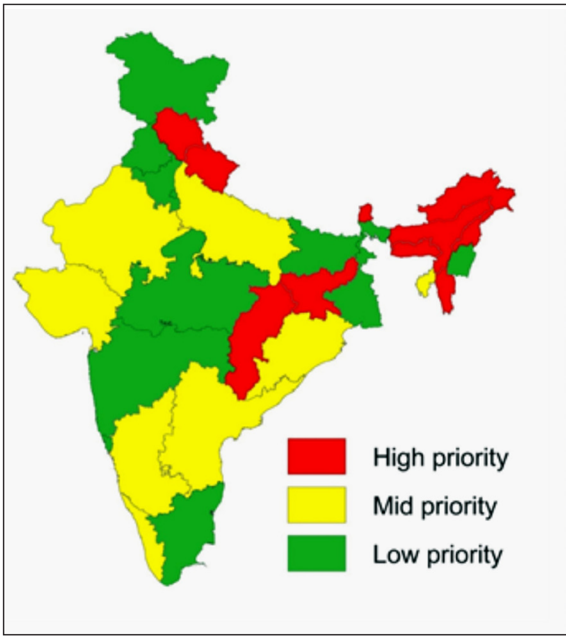
Following a systematic approach, production and monetary losses due to water erosion were computed for 27 major cereal, oilseed and pulse (COP) crops cultivated in the rainfed areas of Indian states (Sharda *et al.*, 2010a; Sharda *et al.*, 2010b; Sharda and Dogra, 2013). The estimations were based on crop and agro-climatic region specific productivity loss factors evolved by utilizing experimental data, which were extrapolated for five erosion categories ranging from less than 500 t $km^{-2}yr^{-1}$ to more than 4000 t $km^{-2}yr^{-1}$. These were then integrated with respective crop's erosion category-wise potentially eroded rainfed area under each of the three major soil groups (alluvial, black and red) in a given state. The on-site production and economic losses estimated separately for major rainfed COP crops in each state were then cumulated to obtain total losses at national level. The computed production loss of a crop was valued with its government support price.

The production loss of considered COP crops together ranged from 1.4% in Punjab and Haryana states located in low productivity loss prone alluvial Indo-Gangetic Plains to 41% in erosion prone north-eastern Himalayan state of Nagaland. The country as a whole loses 15.7% of its total production of COP crops (Sharda *et al.,* 2010a; Sharda *et al.,* 2010b), which is equivalent to Rs. 292.03 billion in monetary terms as per latest 2015-16 prices. Out of the total production and monetary losses at national level, the cereals are the major contributors (66% and 44%, respectively), followed by oilseeds (21% and 32%, respectively) and pulses (13% and 24%, respectively). Paddy is most affected among all the crops in terms of production loss (4.3 Mt) followed by maize, soybean, groundnut, sorghum and 'other pulses'. However, in monetary terms, paddy (Rs. 60.7 billion) is followed by groundnut, soybean, maize and 'other pulses', which together account for about 62% of the total monetary loss of COP crops in India.

Productivity loss in rainfed cereals at state level ranges 0.2-10.9 quintal (q) ha^{-1}, for oilseeds 0.1-6.3 q ha^{-1}, and for pulses 0.04-4.4 q ha^{-1}. These losses in the states having relatively smaller areas under these crops and are low ranked in terms of total production loss, such as north-eastern states, Goa, Kerala and Uttarakhand, are 2 to 5 times higher than the national average and are placed in top 8 to 10 ranks of affected states, thus justifying the need to estimate productivity losses rather than the production losses. The north-eastern states, though account for only 4% of rainfed area under considered crops, are the leading states in terms of productivity losses. India as a whole suffers a loss of 1.63 q/ha in productivity of rainfed crops (Sharda and Dogra, 2013), which is valued at Rs. 3533/ha as per latest 2015-16 MSP.

2.3.3 Prioritizing states by combining erosion risk and production losses

As a corollary to findings of previous sections, it is evident that crop production losses would be more in higher erosion risk areas. Therefore, to prioritize the states where more attention is required for taking land degradation control measures, the two criteria can be combined to simplify the decision-making. The findings are presented in Fig. 4, which shows that 9 states should be given high priority, 8 states moderate priority and remaining states low priority for taking land degradation control measures. The analysis highlights the urgency to minimize the production losses due to water erosion in rainfed areas of the country. The assessment is a major step forward in understanding the losses suffered by the country due to land degradation by water erosion across major crops, states, zones and the country as a whole. The risk of crop failure will be further compounded due to weather aberrations under land degraded production systems. This would sensitize the policy makers, planners, conservationists and environmentalists to develop appropriate strategies to prevent huge losses in production of major rainfed crops due to water erosion in different states and zones.



HIGH PRIORITY STATES	
1	Nagaland
2	Sikkim
3	Arunachal Pradesh
4	Uttarakhand
5	Meghalaya
6	Chhattisgarh
7	Assam
8	Himachal Pradesh
9	Jharkhand
10	Mizoram
MID PRIORITY STATES	
1	Rajasthan
2	Gujarat
3	Uttar Pradesh
4	Kerala
5	Karnataka
6	Odisha
7	Tripura
8	Andhra Pradesh
LOW PRIORITY STATES	
1	Bihar
2	Delhi
3	Goa
4	Haryana
5	Jammu & Kashmir
6	Madhya Pradesh
7	Maharashtra
8	Manipur
9	Punjab
10	Tamil Nadu
11	West Bengal

Fig. 4. Prioritization of states for erosion control considering both erosion risk areas and productivity losses

2.3.4 Environmental benefits of soil conservation and watershed management

For mitigating land degradation in the country, watershed development programmes of central and state governments are being implemented during the past two decades, and they are now well recognized as growth engines for sustainable agricultural development as well as overall development to achieve food security. Case in point is Fakot watershed located in Tehri Garhwal district of Uttarakhand state. The watershed is one of the four model watersheds developed by ICAR-IISWC (formerly CSWCRTI) for the first time in India and hence is known as mother of watershed development programme in the country. It was demonstrated that the total food and milk production within the watershed increased by more than 3 and 2 times during the implementation phase (IP), and by 6 and 7 times, respectively during financial withdrawal phase (FWP) over the pre-project phase (PP). Fruit production increased from negligible to 62 quintals, and after the IP, it increased rapidly by more than 34 times over the production achieved during IP. Significant increases in food production were achieved due to 156% increase over PP in net irrigated area during FWP. Quality of water available for meeting drinking needs improved. Improvement in the livestock quality improved FYM availability and simultaneously reduced forest dependency for fodder by 14% points during IP and 55% points during FWP. The project has become self-sustainable and the values of all the positive attributes have continued to increase and the values of detrimental factors (dependency on forest, runoff, soil loss) are showing a declining trend even after the withdrawal of the project.

Under the Comprehensive Assessment of Watersheds in India, macro-level evaluation of 636 micro watersheds was done through meta-analysis by Joshi *et al*. (2008). The results of meta-analysis revealed that watershed program is providing multiple benefits in terms of augmenting income, generating rural employment (151 man days/ha^{-1}), increasing crop yields, increasing cropping intensity (35.5%), reducing run-off (45%) and soil loss (1.1 t ha^{-1}yr^{-1}), augmenting groundwater, building social capital and reducing poverty. In terms of economic efficiency, watersheds generated an average Benefit-Cost Ratio (BCR) of 2 and only 0.6% of watersheds failed to commensurate with the investment (<1 BCR). The mean internal rate of return (IRR) from the watersheds investment was 27.4%. Thirty two per cent of watersheds showed a mean BCR of >2 and 27% of watersheds yielded an IRR >30% which showed immense potential to upgrade watershed programme in the country.

2.3.5 Evaluation of watershed management projects

To be able to verify to what extent the activities in the implementation phase contribute towards the objectives, clearly defined indicators need to be established for these objectives. Since objectives often relate to both physical factors, such as erosion and hydrological status, and socio-economic and sustainability factors, including local institution development, capacity building, participation rates, financial performance and resource leveraging, a wide range of direct or proxy indicators need to be established. Further, continuing improvement in project performance requires identification of even more effective indicators to take the informed decisions (Sharda *et al*., 2012).

Some indicators have been evolved and used at the global level, mainly for assessing the bio-physical impacts in the watersheds. However, many of these indicators cannot be easily understood or employed by the agencies implementing watershed development programmes in India. Careful selection of key indicators for monitoring and impact assessment is cost-effective as it is not possible to monitor every aspect of a project. The main challenge in identifying indicators is to select those that are sufficiently representative and at the same time easy to understand and measure on a routine basis. The classic mantra for monitoring and evaluation has been to develop simple, measurable, achievable, relevant and time-sensitive (SMART) indicators.

Sharda *et al*. (2005 and 2012) evolved several indicators for assessing some of the bio-physical as well as socio-economic impacts of the watershed development projects in the country. A need was felt to identify some more useful and practicable indicators to reasonably monitor and assess the impacts of watershed interventions on biophysical, socio-economic and sustainability attributes. Efforts were made to evolve and present those indicators which can be easily employed by the implementing agencies to scientifically and systematically analyse the impacts of various interventions in watershed development programmes. These indicators relate only to the tangible impacts, though watershed development projects also yield many intangible benefits, which are often difficult to quantify and valuate.

Some of the indicators evolved were used in pre-project and post-project scenarios to evaluate the overall impact of the watershed development interventions in six model watersheds developed under Integrated Wastelands Development Programme (IWDP) of Ministry of Rural Development (MoRD) in different agro-ecological regions of the country, namely Eastern Ghats, Western Ghats (Nilgiris), Shivaliks (Himalayan foot-hills), Bundelkhand region, Western Coast Gujarat Plain and Chambal Ravines, having diverse physiographic, climatic and socio-economic conditions to demonstrate participatory watershed management concept as enshrined in the Guidelines of Govt. of India in 1994 (Sharda *et al*., 2005).

Keen interest was shown by the farmers of these watersheds in improving their land through levelling, terracing and bunding, which reduced the general slope of their fields, as indicated by the Land Levelling Index (LLI), which improved from 0.37 to 0.65. This along with other interventions helped in reducing runoff from the watersheds by 9% to 24% and soil loss ranging from 0.4 to 40 t $ha^{-1}yr^{-1}$ down to 0.04 to 10 t $ha^{-1}yr^{-1}$, with an average decrease of 72%. As a result, the overall Crop Productivity Index (CPI) increased by 12% to 45% with overall increase of 28 % in the crop productivity. Crop Diversification Index (CDI) also increased by 6% to 79% in the watersheds with an average increase of 22%. Cultivated Land Utilization Index (CLUI) also improved significantly (2% to 81%) with an average value of 27%. The Induced Watershed Eco-Index (IWEI) also showed improvement indicating that 12 % additional watershed area was rehabilitated through green bio-mass. These projects were found to be economically viable with Benefit-Cost Ratio (BCR) of more than 1.0 and varying from 1.14 (Salaiyur) to 1.69 (Kokriguda). In addition to the bio-physical indicators, several socio-economic and sustainability indicators were also evaluated. Intangible benefits from the watershed programmes which can override the tangible benefits also need to be assessed at macro-scale.

A set of indicators evolved to analyse the impact of watershed and sustainability attributes would provide a sound and scientific basis to critically evaluate the impact of agronomical, biological and engineering measures on improving the productivity of arable and non-arable lands, socio-economic status of the watershed community and ensure environmental stability in the long run. They would also help in economically justifying the expenditure on various activities in the watershed development programmes involving huge investments in the country. The evaluation of such programmes through the developed indicators would also bring greater transparency and accountability towards the people and also inculcate better confidence among the implementing agencies. The indicators would also facilitate comparison of various watershed development projects executed by different developmental agencies in terms of performance and impact more scientifically and systematically across the watersheds within the state, in the region and the country as a whole. Inclusion of these indicators may be made mandatory in all the ongoing watershed development programmes by the Government of India as an integral component of Common Guidelines for Watershed Development Projects for effective monitoring and evaluation. The indicators need to be adopted and evaluated on a wider scale representing different climatic, physiographic, edaphic and socio-economic conditions in the country to realistically assess the performance of watershed development programmes and their inter-comparisons.

3. STRATEGIES FOR ACHIEVING LAND DEGRADATION NEUTRALITY

Due to financial constraints, it is neither desirable nor feasible to treat the entire watershed area to achieve the intended objectives. The importance of the concept of prioritization of erosion risk areas/ critical areas was validated in two watersheds namely, Sukhomajri and Fakot representing lower and middle Himalayan regions of India.

It was noticed that out of 4207 ha catchment area of Sukhna lake, only about 80 ha area covering Sukhomajri watershed was critical area contributing significantly to sediment yield. Therefore, by treating about 50% of the critical area, the soil loss reduced drastically by about 80% from 150 t ha^{-1} to 20 t ha^{-1}. Interestingly, the soil erosion in the entire catchment could be brought down within the permissible/targeted soil loss value (ranging between 7.5 and 10.0 t $ha^{-1}yr^{-1}$) by treating only 69% of the critical area thus saving on both time and cost. Similarly, the impact of critical area/partial area treatment on reduction of soil loss was studied by analysing the time series data of a middle Himalayan watershed located at Fakot village in Uttarakhand state of India (Dhyani *et al.*, 1997). It is also evident that the impact was more pronounced in this watershed as only by treating 20 to 55% of the watershed area by appropriate bio-engineering measures, the soil erosion could be brought below the specified target value of 2.5 to 7.5 t $ha^{-1}yr^{-1}$ (Jha and Mandal, 2010).

Thus even a partial area treatment has the potential to achieve the desired impact through biological and landscape regeneration processes without treating the entire watershed area up to saturation level. Similar findings have been reported by Islam *et al.* (2014) for Nilgiri hill region of India.

3.1 Emerging issues and options

A key issue in natural resource management is the robust monitoring to chart the success or otherwise of specific conservation measures. Such information is required so that governments or other donors of schemes, and farmers, can be informed on whether or not the measures are being successful and deliver value for money or whether changes in policy or practice are required. At the local scale, monitoring tools do exist although they are rarely applied. Current methods for monitoring at regional scale have limitations; advances in satellite-derived information and new tracer technology offer potential for quantifying erosion, but further development is needed before they can be used with confidence. The major need in practice is the provision of evidence to farmers and policy makers that controlling soil erosion leads to better crop yields and a more secure food supply, either directly or indirectly and in both the short- or longer-term.

In the past 30 years, the net sown area has remained static at around 140±2 Mha, though gross cropped area has steadily increased from 165.79 Mha (1970-71) to 195.25 Mha (2011-12). While the land utilization pattern has stabilized, particularly in the past decade, the pressure on the finite land resource has swelled. Per capita land availability has declined from 0.91 ha in 1951 to 0.27 ha in 2007-08 (GoI, 2013) and is estimated to fall to 0.19 ha capita^{-1} by 2050 due to increasing human population. The decline is more pronounced in case of arable land, which has dropped from 0.34 ha capita^{-1} to 0.12 ha capita^{-1} during 1961-2013 (World Bank, 2016). This is below the prescribed threshold limit of 2.0 ha of unirrigated land or 1.0 ha of irrigated land required for a family of five to six members (ADB, 2007). To ensure food security, the average productivity of all food grains needs to be doubled from current 1.75 t ha^{-1} to 3.3 t ha^{-1} to produce the estimated 310 Mt of food grains from the net sown area of 150 Mha in 2050 (AFC, 2003).

SWC technologies have the potential not only to reduce land degradation but also to address concerns of water scarcity, agriculture drought, climate change, and biodiversity conservation. Central and State governments have set an ambitious target to construct lakhs of farm ponds and wells in rainwater-scarce areas of the country through various programs like PMKSY, MGNREGA and watershed development. However, lack of geo-spatially distributed information on rainwater harvesting (RWH) and conservation practices limit the presentation of a holistic picture on the effectiveness of land protection measures, impact of construction of water bodies and watershed management.

Interventions to control land degradation through watershed development are being undertaken by various agencies, but we need to have instruments to assess the impact of these interventions. To verify to what extent these interventions contribute towards the development objectives, clearly defined benchmarks and indicators need to be established for these objectives. Continuous improvement in project performance requires identification of effective and measurable indicators to take the informed decisions (Sharda *et al*., 2012).

The production losses, which can be enormous on cumulative basis thereby significantly affecting the agrarian economy of the country need to be minimized and brought within permissible limits through efficient management of our finite arable land resource. The issue of land degradation can be addressed following the concept of participatory integrated watershed management (Sharda and Juyal, 2006), which needs to be undertaken in a science-based programme mode to achieve sustained productivity for achieving the envisioned agricultural and economic growth rates and environmental security in future. Though watershed development is the engine for agricultural growth in the country, the impact of these capital intensive multi-dimensional projects need to be objectively assessed through data-driven and measurable indicators for realizing the potential of watershed development programmes. Crop specific and region/area specific targeted approach is warranted in the rainfed areas of the country which have the potential to usher in next agricultural revolution.

4. RECOMMENDATIONS

Nations need to protect their soil resources from excessive erosion which may otherwise threaten the productivity of agriculture sector, reduce the availability of existing water resources and in turn endanger food and environmental security. Following recommendations are made to support the land use planners and policy makers to identify the priority programmes and develop the best manageable policy framework for controlling land degradation.

Policy Issues

- A comprehensive geo-spatially distributed knowledge-base on land degradation scenario due to various driving forces such as land use changes, construction of water bodies and climate change should be developed and periodically updated to present an holistic picture on the effectiveness of land protection measures and soil and water conservation technologies for the benefit of stakeholders. High resolution remote sensing data in an advanced GIS environment to assess land degradation and identify hotspots in different states/ regions can be potentially employed at macro and micro scales to achieve this objective.
- In view of limited financial resources for developmental and environmental programmes, the concept of partial area/ critical area treatment may be invariably adopted after identifying the priority erosion risk areas for maximizing returns with least investment and achieve the target of bringing soil loss within the permissible limits.

- Estimated life of majority of our reservoirs is less than 25 years with a range of 8 to 40 years. These reservoirs cater to the domestic, agricultural, and industrial needs of a large number of people. Hence, to protect and to preserve the existing available water resource, effective land protection measures in their catchments are essentially required.
- The catchment areas of our river basins urgently need integrated soil and water conservation measures following watershed approach by identifying site-specific best management practices to prevent irreversible loss of soil to oceans.
- To economically justify the huge expenditure on soil conservation and watershed development programmes by Central and State Governments and ensure greater accountability and transparency towards public investments, a clearly defined set of indicators is needed. Implementation of these indicators should be made mandatory as an integral component of Common Guidelines for Watershed Development Projects by Govt. of India.
- Several government policies and programmes such as RVPs, FPRP and IWMP, being implemented over the years to check land degradation due to water erosion at micro and macro scales need to be continued and strengthened with a renewed vigour without diluting its intended purpose after merger with PMKSY and should rather complement and supplement this flagship programme after convergence.
- The Ministry of Agriculture and Farmers Welfare and Department of Land Resources, Ministry of Rural Development may allocate funds and plan their investments following priority erosion risk area approach as envisaged in the Policy Paper to economize on both cost and time. A road map need to be prepared by the implementing Ministries to complete the task of treating the degraded lands starting with highest priority class downwards in a phased manner within the stipulated time frame.
- Scientific land use planning is the ultimate way forward for mitigating land degradation by identifying and delineating the niche areas for specific crops and commodities based on biophysical, ecological, social and economic attributes. This would pave the way for National Land Use Policy for optimal use of limited land resources.

Researchable Issues

- There is a need to analyse the impact of climate change scenarios on land degradation and quantify the resulting loss of carbon and nutrients. Carbon sequestration potential of rehabilitated degraded lands needs to be assessed for achieving the National Development Council (NDC) goals on Green House Gas (CHG) emissions.
- Productivity and monetary losses in rainfed crops due to other forms of land degradation such as wind erosion, salinity, alkalinity, acidity, water logging etc. need also to be scientifically and systematically estimated and integrated with losses due to

water erosion to present a comprehensive picture on the impacts of all forms of land degradation on crop productivity and develop crop/ area specific strategic plans to contain these losses.

- Methodology need to be developed to assess not only tangible but also intangible benefits of rehabilitating degraded lands due to water erosion which may include quantification of loss of nutrients, soil organic carbon and microbial diversity under different land use systems in various ecological regions.

Developmental issues

- Sensitization and capacity building workshops/meetings for various stakeholders need to be organized by Ministry of Agriculture and Farmers Welfare and MoRD for mainstreaming crop/ area specific best management practices for checking land degradation through various developmental programmes such as NMSA, RKVY, PMKSY, MGNREGA.
- Incentivise farmers to adopt soil and water conservation technologies in a participatory mode as they initially require high investment and yield dividends are noted only in the long run by ensuring sustainability of production system besides enhancing crop productivity. This can be achieved through Direct Benefit Transfer (DBT) scheme of Government of India for farmers who adopt asset generating engineering measures and soil and water conservation technologies.

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