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Ravine lands in north-western states of India and their developmental potential

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ABSTRACT

Gully erosion has led to severe terrain deformation alongside some of major river systems of India. These ravine lands of some major river systems are economically and ecologically hyper-sensitive riparian landscapes which play a crucial role in flood and drought mitigation, aquatic and riparian biodiversity, micro-climate moderation and rural livelihood security. There has been lack of agreement on current status of ravine lands in India; reported ravine area by different institutions varies1 M ha to 10 M ha in India. This paper reports results of a study conducted by ICAR-IISWC for determining the extent of the problem, and to assess developmental potential of ravine lands in four north-western states of India. Total ravine area delineated in four states, *viz*., Uttar Pradesh, Madhya Pradesh, Rajasthan and Gujarat is 1.036 M ha which shows about 62% reduction in total ravine area statistics reported by National Commission on Agriculture in 1976. Nevertheless, under unprotected conditions, the average ingress rate increased from 0.43% to 1.26% over a period of 60 years. Partially or fully treated ravine clusters have shown negative ingress rates indicating reduction in ravine area and initiation of restoration of ravine lands. Implementation of ravine reclamation packages have demonstrated benefit:cost ratio (BCR) of 1:1.4 to 1:2.54. Post-project evaluation of ravine area development project after 5 and 10 years of its completion has shown about three and six fold increase in cultivated land and gross irrigated area, respectively and consistent improvement in cropping intensity from 65% to 175% resulting into 386% increase in total crop production. Additional collateral benefits recorded were reduced runoff, erosion rates, improved availability of drinking water and general improvement in social conditions. Current assessment suggests that scientific and judicious ravine land management would increase 10% to 50% of existing arable lands, develop irrigation capacity for its 30% to 60% arable lands, improve 9% to 28% cropping intensity and 20% to 66% of current yield levels with an overall 118% to 280% increase in net returns through increased crop production. Severely degraded non-arable lands can potentially be developed to strengthen several livelihood systems for local in habitants with an expected BCR of 1.49 to 2.46.

1. INTRODUCTION

The reliable periodical assessment of extent and severity of various forms of land degradation is an emerging priority in the backdrop of global initiatives for attaining land degradation neutrality (LDN) coordinated by United Nations Convention for Combating Desertification (UNCCD), which is endorsed by India with a commitment to restore 26 M ha of degraded lands by 2030 (India Today, 2019). There is an urgent need to identify hot-spots and prioritize restoration targets based on their ecological impacts and economical viability. Ravine lands are physically degraded and abandoned landscapes having very high ecological value and developmental potential.

Ravine lands or bad lands are networks of gullies consequential of incessant water induced erosion, which eventually leads to severe terrain deformation. A gully is an erosion channel, usually deeper than 0.3 m, developed by ephemeral streams with steep banks and a nearly vertical gully head. Very extensive degradation of land in the form of deep gullies has occurred along some of the major river systems of the country in various states. The largest is the Yamuna-Chambal ravine zone. The ravines flank along

Yamuna river for nearly 250 km and have attained a depth of more than 80 m in Agra and Etawah. The Chambal ravines flank the river Chambal in a 10 km wide belt, which extends 480 km southwards from the Yamuna confluence up to the Kota town in Rajasthan. Several Chambal tributaries, *e.g.* Mej, Morel, Kalisindh, etc. are infested with ravines. In Gujarat, ravine belt is spread over Tapti, Narmada, Watrak, Sabarmati and Mahi river basins. Besides, ravines are also found in Chhota Nagpur, Bihar, Mahanadi and upper Sone valley, Indo-Gangetic plains, Shivaliks and Bhabar tract, and Western Himalayas (Dhruva Narayana, 1993).

The National Commission on Agriculture reported 3.67 M ha of ravine lands in India, out of which 2.76 M ha (75%) are spread over north-western Indian provinces Uttar Pradesh, Madhya Pradesh, Rajasthan and Gujarat (NCA, 1976). Derived from detailed ground survey, these were the first authentic and reliable assessments of gully erosion problems at the national level. Subsequent periodical assessments by the National Remote Sensing Agency Centre (NRSA, 2000 and NRSC, 2010) and National Bureau of Soil Survey and Land Use Planning (Sehgal and Abrol, 1994) were based on indirect measurement, and due to the difference in their mapping approach, the estimates were not comparable. Also, ravine reclamation and ravine extension are continuing processes, therefore, incessant monitoring of the problem area is desirable.

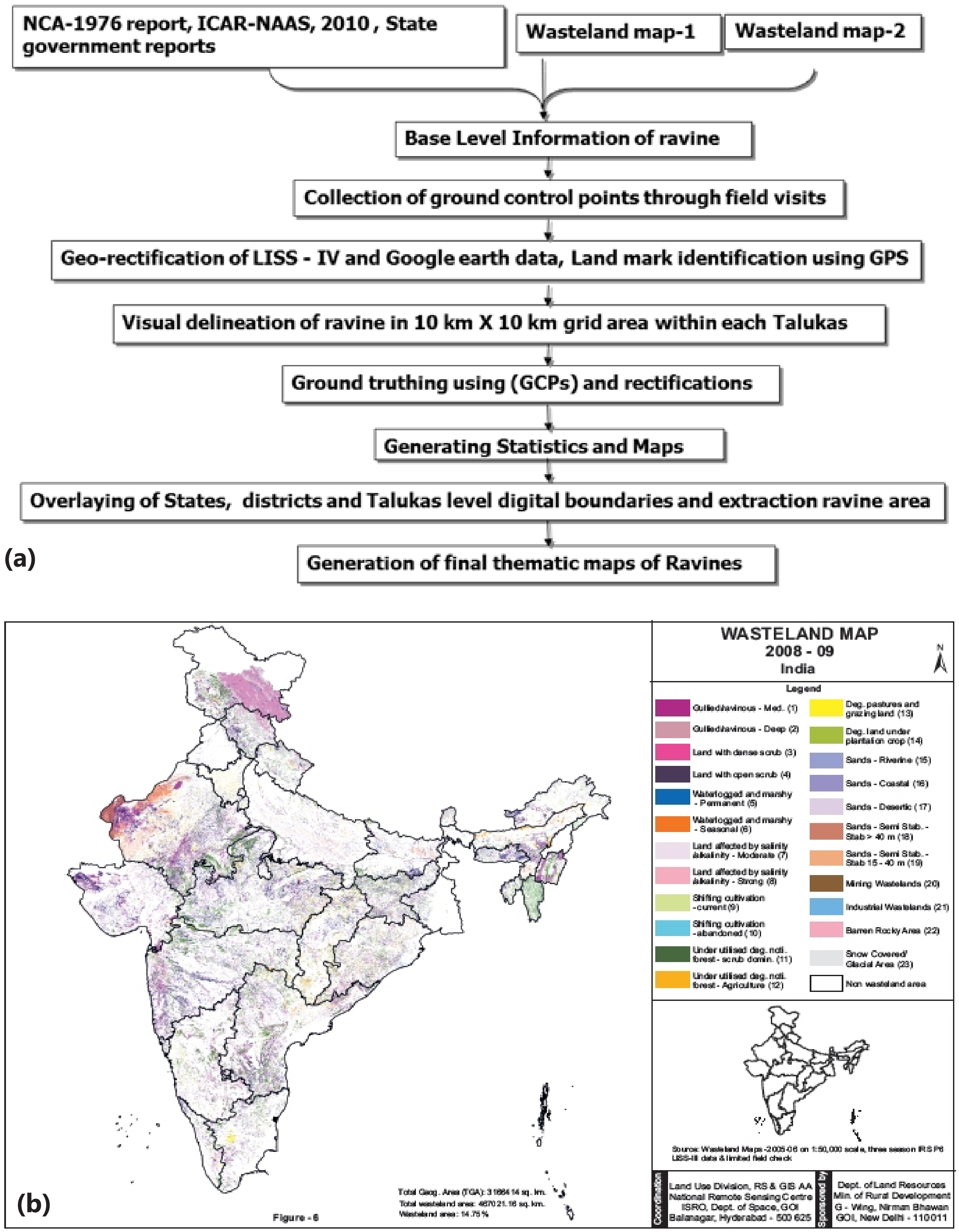
Recent advancements in mapping tools offer ample opportunities for categorization and delineation of ravine landswith a reasonable accuracy. High resolution satellite imageries, including hyper spectral and microwave, Unmanned Aerial Vehicle (UAV), Light Detection and Ranging (LiDAR) techniques, Digital Photogrammetry, etc. need to be explored for detailed characterization and developing topographic maps. Use of UAV for landfill surveys can help in quick data collection with high accuracy; however, it does not work very well in vegetated areas (Stallings, 2016). Relatively superior performance of LiDAR technique over other methods, including total Station and GPS, have been reported with respect to their relative precision, accuracy, resolution, ease of operation and other data quality parameters (Chekole, 2014). However, these new tools are yet to be tested for monitoring of alluvial ravine dynamics.

Ravine lands are ecologically hyper-sensitive riparian landscapes which are crucial to flood and drought management; aquatic and riparian biodiversity; micro-climate moderation; and rural livelihood security. Spread over deep alluvial soils alongwith major river systems, the ravine lands have a very high productivity potential. Outreach programmes of ICAR-IISWC undertaken in Chambal, Mahi and Yamuna ravine systems have evidenced high economic returns along with several collateral benefits, including increased productivity of non-arable lands and animal production systems, creation of additional livelihood opportunities, reduced erosional losses, and improved quality and availability of water (Singh *et al.,* 2018). Despite the mixed response of the past efforts and methodological difference in assessment, the application of different ravine reclamation technologies through multiple ravine reclamation programs resulted in a substantial reduction in ravine areas. The initial efforts were primarily targeted to shallow and medium ravines, and as a result, a substantial area under shallow and medium ravines was reclaimed/leveled and brought to cultivation. Conceding the renewed public interest for ravine lands restoration and prevailing conflicting estimate for extent of the problem, a concentrated effort is needed to turn these lands into productive ones. Up scaling of ravine reclamation technology for other parts of ravine areas which remain least attended till date is a complex and cost-intensive task, which requires a careful assessment of developmental potential of ravine lands based on systematic appraisal of extent and severity of the problem. This paper presents district and taluka-wise ravine lands in four north-western states of India *i.e*. Rajasthan, Uttar Pradesh, Gujarat and Madhya Pradesh alongwith spatial map, and developmental potential of these lands assessed using ex-post evaluation of previous ravine developmental projects, and *ex-ante* assessment of benchmark ravine clusters, which would guide developing state and national programs for ravine reclamation with realistic cost-benefit scenarios encompassing dominant ecosystem services.

2. MATERIALS AND METHODS

Delineation of Ravine Lands

For delineation purpose, the ravine area is defined as 'the gully network deeper than one metre developed on table lands in the vicinity of a river or its tributaries'. Usually these are continuous type of gullies; discontinuous gully developed on hilly terrain have been excluded in this delineation process. The delineation methodology includes visual delineation of the rugged land and modification of boundaries using remote sensing imageries. All preceding reports and maps (NCA, 1976; MoA, 1984; NRSC, 2000; NRSC, 2010, Kumar *et al*., 2018) were referred to identify ravine districts and dominant ravine area in four states of Uttar Pradesh, Madhya Pradesh, Rajasthan and Gujarat. High resolution LISS-IV and Google Earth imageries, for the period 2010-14, were used for delineating ravine lands. All spatial data were converted to Lambert Conformal Conic projection system with Everest as Datum. The digital boundary of Sates, districts and *taluka* delineated from 1:50000 scale toposheets were overlaid on the delineated ravine map for extracting ravine data. Some new districts and *talukas* could not be extracted because of non availability of the desired administrative map; so, there is scope of improvements. The flow chart depicting steps followed for identification and delineation of ravines and the wasteland atlases used as base map is presented in Fig. 1. To minimize visualization error while delineating, only one category of degraded land (ravine) was focused upon. The decision rule for marking ravine land in visual interpretation includes irregular boundary (regular boundary means attended or cultivated land), vegetation pattern near the boundary, association with streams or isolated hill, shadowing due to undulation, and relative elevation profile (specially near hills). Small patches of gullied land near minor streams which remained largely undetected on a coarse resolution imagery were also identified and mapped using 10 km x 10 km grid within each *taluka* boundary. Ground truthing on predetermined representative ground control points (156 GCPs) collected along Mahi, Yamuna and Chambal ravines were used for ground truthing.



(Source 1(B): https://dolr.gov.in/sites/default/files/Wastelands_Atlas_2011.pdf)

Fig. 1(a). Flow chart of methodological framework for delineation of ravines and (b) Wasteland atlas used as base map

Estimation of Ravine Ingress Rates

The ravine extension rates of over a period of 15 to 20 years were estimated for Chambal and Yamuna ravines. For estimating rate of gully extension or gully ingress rates, data obtained from village revenue maps, Survey of India toposheets and Google earth maps for different dates were compared. Data obtained from secondary sources were verified with actual ground surveys feedback from local inhabitants. The ravine ingress rate was computed using following equation:

$$A_n = A_o\,(1 + \frac{r}{100})^n \qquad ...(1)$$

Where, A_n is ravine area after n years, A_o is initial ravine area, r is compound rate of ravine ingress (%) and n is number of year.

Assessment of Developmental Potential of Ravine Lands

The developmental potential of ravine lands was assessed in this study by two types of economic appraisal approaches *i.e. ex-post* and *ex-ante* evaluation. The *ex-post* evaluation was based on long-term data collected for quantification of biophysical and socio-economic benefits experienced in response to ravine reclamation interventions implemented in Chambal ravine region. Considering that the treatment needs and cost:benefit analysis are closely linked to the highly variable landscape features and agro-climatic conditions, four benchmark ravine clusters were selected to represent site conditions of Chambal, Yamuna and Mahi ravine lands. The *ex-ante* evaluation of developmental potential of these benchmark ravine clusters was carried out after detailed survey and careful investigation of site specific treatment needs.

***Ex-Post* Evaluation**

The economic impact of various ravine restoration interventions over time was quantified for Badakhera Ravine watershed of Bundi district of Rajsthan using before and after project analysis approach. The Badakhera project was implemented during 1998-2003 to demonstrate technological packages for reclamation of ravinous wastelands through participatory approach and to monitor ecological and socio-economic benefits of implemented interventions. Developmental programme included crop demonstrations, construction of graded and peripheral bunds strengthened with grasses, land leveling in inter-bunded areas; and, construction of masonry, gabion or loose boulder spillways for safe disposal of excess runoff. Drainage lines were treated with straight drop masonry or gabion spillways constructed at gully heads, and with series of check dams, gully plugs and live hedge barriers to stabilize and flatten the gully beds. Two farm ponds of 1.6 ha m and 0.6 ha m capacity were constructed. Simultaneous monitoring on ecological and socio-economic parameters was carried out for impact evaluation of watershed project. In order to monitor the impact of soil and water conservation measures on surface runoff, 3 micro-watersheds, *viz.,* W1 (44.50 ha) treated with mechanical and vegetative measures; W2 (11.27 ha) treated with mechanical measures of soil and water conservation; and W3 (29.29 ha) without soil and water conservation treatments, were equipped with 3:1 triangular weirs and water stage level recorders for recording runoff and collecting runoff samples for soil loss estimation. The data collected at the time of project launch (1997-98) was taken as benchmark, which was followed by periodical survey of all the beneficiaries carried out during different years 1999-2000, 2007-08, and 2013-14.

***Ex-Ante* Assessment**

Ex-ante economic analysis of four ravine reclamation projects was done using data collected from sample development plans of four ravine clusters, namely Manikpura (district Agra, Uttar Pradesh), Bagli (district Bundi, Rajasthan), Bagheswari (district Morena, Madhya Pradesh) and Khorwad-Sili (district Anand, Gujarat). These four ravine clusters represented Yamuna, upper Chambal, lower Chambal, and Mahiand Kachchh ravine regions, respectively. The development plans envisaged reclaiming part of degraded arable land for agriculture, and creation of irrigation infrastructure without any major change in existing cropping pattern. Treatment of land with conservation measures in accordance with gully reclaimability classification and farmers' preferences; crop demonstrations for introducing improved cropping practices; restoration of community lands for optimum production of fodder, fuel or fiber; and, strengthening animal production and other livelihood support systems were key interventions of developmental plans. Budget provisions were also made for capacity building and institutional development for ensuring post-project sustenance of project benefits. Ravine reclamation benefits were derived from incremental crop production arising from crop area expansion; increased cropping intensity as a result of increased irrigation facilities; enhanced crop productivity on arable land; and, use of non-arable community land, river bed and other wasteland reclaimed for silvi-pasture, bamboo plantation and horticultural crops based on observed choices made by farmers and recommendation of subject matter experts as per their suitability in particular region of ravine area. To calculate the incremental benefits, the existing returns on arable and non-arable lands were deducted from proposed expected returns after the project implementation.

Input-output data used for estimation of costs and returns of different production systems for arable and non-arable lands was generated from research data register of ICAR-IISWC, discussion with farmers from selected representative ravine clusters sites, and opinion and experience of subject matter experts. The prices for input and output were taken for the year 2013-14, and projected for period of analysis assuming project life of 25 years. The inputs were valued at market prices and the outputs at farm harvest prices given by Directorate of Economics and Statistics, Government of India. A general inflation rate of 7% was considered for estimating the cash inflow and outflow at nominal price for the production horizon of 25 years. The cash inflow and outflow estimated at nominal price were converted into constant price using GDP price deflator available for the years 2010 through 2013 (OECD, 2014). A uniform discount rate of 10% was used in the present analysis to convert the cash inflow and outflow into present values. *Ex-ante* evaluation considered incremental benefits and costs that will arise with the proposed project interventions over the existing situation, as it would be without the project interventions for the analysis. The discounted measures of project worth or economic appraisal criterion (Gittinger, 1982) were as under:

$$\text{Benefit-Cost Ratio (BCR)} = \frac{\sum_{t=1}^{n} B_t (1+r)^t}{\sum_{t=1}^{n} C_t (1+r)^t} \quad ...(2)$$

$$\text{Net Present Worth (NPW)} = \sum_{t=1}^{n} \frac{(B_t - C_t)}{(1+r)^t} \quad ...(3)$$

Where, B_t = benefits in each year, t = 1, 2 ...n; C_t = costs in each year, t = 1, 2 ...n; n = number of years of analysis; r = interest (discount) rate.

3. RESULTS AND DISCUSSION

Ravines Area Distribution in India

For understanding the current trends and status of ravine lands in India, results of this study need to be examined with previous land degradation statistics available. There are hardly any pre-independence historic records documenting extent or distribution of ravine lands in India. The National Commission on Agriculture (NCA) of India estimated state wise ravine area (Table 1) and reported a total of 3.67 M ha of ravine lands in India which was expanding with an annual growth rate of about 8000 ha. In 1984, a working group on reclamation and development of ravines in Ministry of Agriculture, Government of India, reported 3.975 M ha ravine area based on land degradation statistics available for different states (MoA, 1984). During the period of 1985-2000, National Bureau of Soil Survey and Landuse Planning (NBBS&LUP), Nagpur and National Remote Sensing Agency (NRSA), Hyderabad separately developed soil degradation and wasteland maps of India using different approaches. Following process-based degradation mapping derived from 10 km grid soil profile studies supported with satellite data, NBSS&LUP estimated 10.37 M ha ravine land in the country which was classified as terrain deformation due to water erosion (Sehgal and Abrol, 1994). The NRSA followed remote sensing technology for identifying land use and physical features for mapping non-agricultural areas, and reported 2.06 M ha of gullied and ravine land (NRSA, 2000). The gross underestimation of ravine area by NRSA was primarily due to exclusion of agricultural land and difference in mapping approach. To tackle the issue of conflicting figures reported by different organizations, National Academy of Agricultural Sciences (NAAS), New Delhi took an initiative to harmonize and normalize the area statistics with scientific and logical reasoning through inter-institutional meetings (ICAR-NAAS, 2010). The harmonized statistics suggested a total of 10.37 M ha area under influence of gully erosion, which included 2.06 M ha ravine wastelands. Nevertheless, these estimates emerged from land degradation data previously reported by different organizations without any further ground verification. The harmonized data carried forward the inherent limitations of data collection procedures used previously. Therefore, it would be sensible to compare the area statistics obtained through the current ravine mapping with NCA.

Table: 1
State-wise area under ravines

S.No.	State	Ravine area (000' ha)
1.	Uttar Pradesh	1230
2.	Madhya Pradesha	683
3.	Rajasthan	452
4.	Gujarat	400
5.	Maharashtra	020
6.	Punjab	120
7.	Biharb	600
8.	Tamil Nadu	060
9.	West Bengal	104
	Total	3669

[a]Area included Chhattisgarh, [b]Area included Jharkhand

Ravine lands have shown their presence in almost all states of India, however, scope of this study was restricted to four major ravine states which include Uttar Pradesh, Madhya Pradesh, Rajasthan and Gujarat. Total ravine area delineated in four states Uttar Pradesh, Madhya Pradesh, Rajasthan and Gujarat is 1.036 M ha (Fig's 2 and 3). This delineated area comprises rugged land (terrain deformation) only; however, for treatment planning, additional peripheral table land (buffer zone) needs to be accounted. Despite the use of high resolution imageries and meticulous efforts in visual interpretation and delineation, the GCPs based ground truthing indicated the possibility of error of upto 5% for major ravine patches accounting about 70% of the ravine, and upto 20% error in rest 30% of the ravine area. The current ravine area mapping shows about 62% reduction in the total ravine area with reference to ravine area statistics reported by NCA. About 75% area in Uttar Pradesh and Gujarat, and about 50% area in Madhya Pradesh and Rajasthan has been reclaimed since 1976 (Table 2). District wise area statistics of four representative ravine regions namely, Mahi and Kachchh region, upper Chambal region, lower Chambal region and Yamuna river region (Fig. 4) is tabulated and presented accordingly in Table 3.

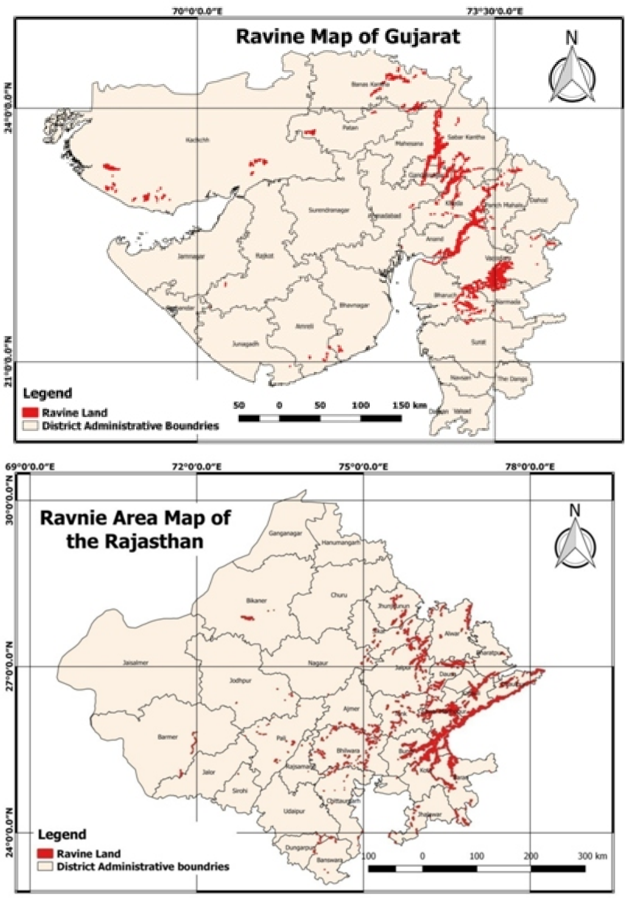


Fig. 2. Ravine area maps of Gujarat and Rajasthan (ravine land not true to scale)

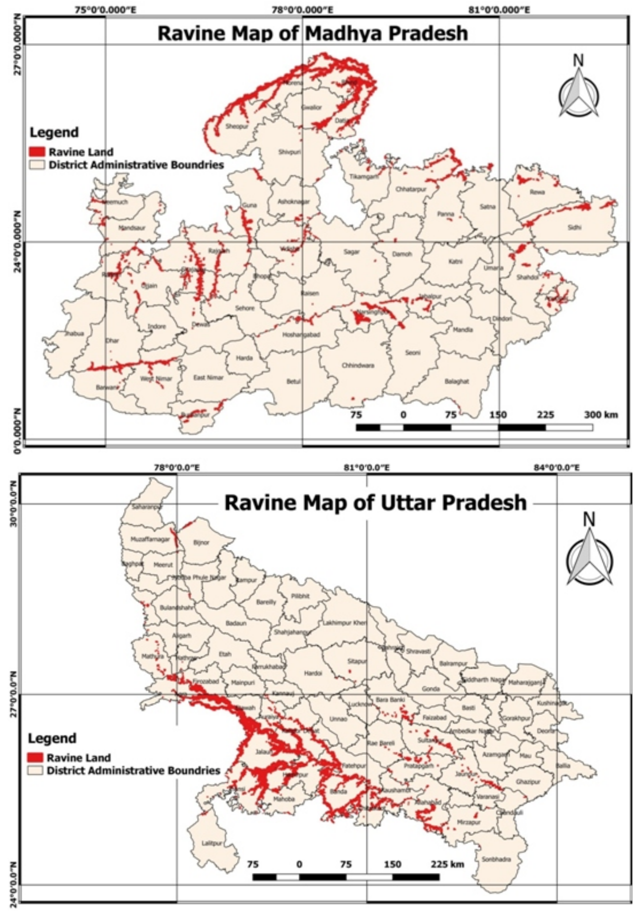


Fig. 3. Ravine area maps of Madhya Pradesh and Uttar Pradesh (ravine land not true to scale)

In Gujarat, ravines are concentrated in eastern and central parts of the state showing significant presence in ten districts. Ravines are mainly associated with Mahi, Sabarmati and Narmada river systems and spread over 0.11 M ha. Vadodara, Sabarkantha and Kheda districts account for more than 80% of total ravine area of Gujarat. In Rajasthan, ravine land is spread across the state showing significant presence in 18 districts. The total ravine land identified in Rajasthan is 0.279 M ha of which Sawai Madhopur, Kota, Dhaulpur, Jaipur and Bundi are major ravine districts. Tenurial status of the land governs the actual and potential land use, and therefore influences both land degradation and restoration processes. Land tenure situation in Rajasthan during 1962-68 (Table 4) suggests that despite minimal agronomic activities, panchayat and government owned lands had greater vulnerability to degradation processes compared to farmers' lands. The severity of gully erosion as expressed by depth of gully in some districts of Rajasthan and Madhya Pradesh (Tables 5 and 6) indicates that upper catchment of Mahi had abundance of shallow ravines (<1.5 mdepth), while average depth of Chambal ravines increased from upper catchment (Kota and Bundi) towards middle (Sawai Madhopur) and lower catchments (Dholpur, Morena and Bhind). In Rajasthan, apart from Chambal river system, ravines have also developed around Luni river and isolated hills in small patches.

Table: 2
Change in ravine area (M ha) distribution over time in north-western states of India

States	NCA (1976)	NRSA (2000)	ICAR-IISWC (2014)
Gujarat	0.40	0.101	0.110
Madhya Pradesh	0.683[a]	0.757	0.312
Rajasthan	0.452	0.495	0.274
Uttar Pradesh	1.230	0.281	0.340
Total	2.765	1.634	1.037

[a]*Area included Chhattisgarh*

In Uttar Pradesh, ravines are concentrated in southern parts of the state, mostly along Yamuna and Chambal river systems. Jalaun, Etawah, Hamirpur, Agra, Jhansi and Kanpur Dehat are major ravine districts in Uttar Pradesh. Total ravine area in Uttar Pradesh is estimated to be 0.340 M ha. In Madhya Pradesh, ravines are concentrated in northern part of the state and mainly associated with Chambal, Betwa, and Dhasan rivers. Part of area under ravines is also present in central part of Madhya Pradesh along Narmada river system. It is spread over an area of 0.312 M ha mostly in Morena, Bhind, Narsimhapur, Chhatarpur, Datia, Gwalior, Shahdol and West Nimar districts. The major drainage

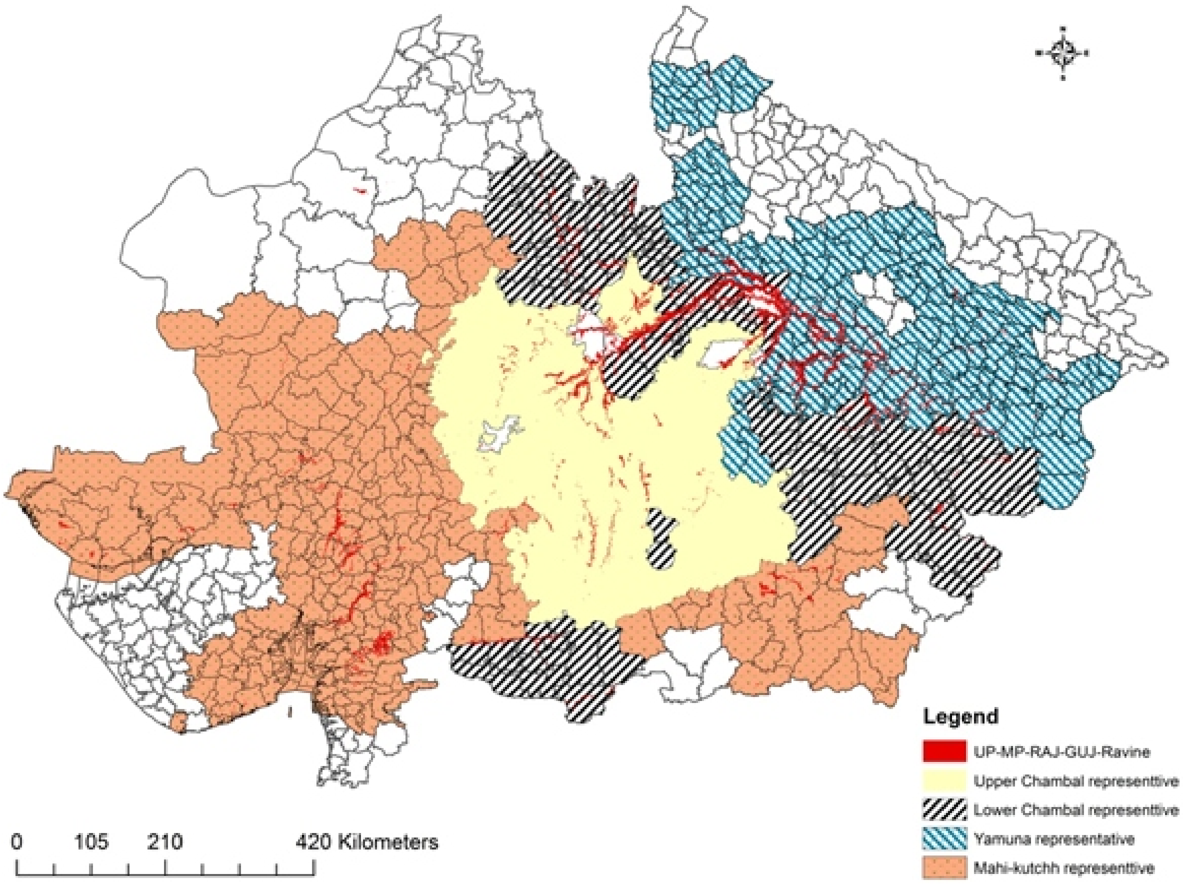


Fig. 4. The distribution of ravines in Uttar Pradesh, Madhya Pradesh, Rajasthan and Gujarat in four representative zones *viz.*, upper Chambal region, lower Chambal region, Yamuna river region, Mahi and Kachchh representative region (ravine land not true to scale)

system of Uttar Pradesh, Madhya Pradesh, Rajasthan and Gujarat is presented as Fig. 5. Ravines deeper than 5 m and 10 m are commonly observed in Morena, Bhind and Sheopur (Table 6).

It is clarified that present ravine area mapping has been done by delineating active gully systems, including rugged land (terrain deformation), and marginal lands located along the periphery of ravines have not been included. These lands are under immediate threat of gully erosion and should be included in ravine reclamation planning. Hence, treatable ravine area would be about 20% to 30% higher than what is reported here.

Rate of Gully Extension

The ravine extension rates of over a period of 15 to 20 years were estimated for Chambal and Yamuna ravines (Table 7). The estimated annual ingress rate for untreated Chambal catchments ranged from 0.133% to 1.264% with an overall average of 0.556%. This implies that 100 ha of ravine area would extend to 102.8 ha, 105.7 ha, and 111.73 ha after 5, 10 and 20 years, respectively in the absence of adequate conservation measures. Data in Table 7 depict the change in ingress rates of ravines over three time segments. The average ingress rate increased from 0.43% to 1.26% over a period of 60 years under unprotected conditions. Partially or fully treated ravine clusters have shown negative ingress rates indicating reduction in ravine area and initiation of restoration of ravine lands.

The biotic and abiotic factors have interactive effects on gully erosion, and therefore there is a regional influence on gully erosion which is manifested in characteristics of ravine lands of the region. Improper land use is the primary biotic factor in most cases. The removal of protective vegetation and cultivation of slopes without adequate conservation measures leads to rill and gully formation. Overgrazing, underground mining, road construction and livestock or vehicle trails also tend to induce gully erosion. Geology, geomorphology and soil of the region, seasonal rainfall pattern and other climatic conditions, shape and size of the catchment are major abiotic or physical factors. It has been suggested (Sharma, 1968; Sharma, 1976) that one of the primary causes for occurrence of ravine erosion in ecologically variable conditions is the lowering of base level of streams caused by upliftment of central highlands (830 m), Aravalli range (1160 m), Bundelkhand (1130 m), and Chhota Nagpur plateau (1160 m). Uniform skyline of

Table: 3
Distribution of ravine area in four major regions in India

Mahi and Kachchh Region		Upper Chambal Region		Lower Chambal Region		Yamuna River Region	
District Name	Area (ha)	District Name	Area (ha)	District Name	Area (ha)	District Name	Area (ha)
Rajasthan		Rajasthan		Rajasthan		Uttar Pradesh	
Nagaur	1495.2	Bundi	25483.4	Alwar	10063.9	Agra	37075.9
Barmer	1320.4	Kota	41884.9	Bharatpur	2907.4	Aligarh	19.5
Pali	1871.5	Jhalawar	5474.4	Dhaulpur	35761.9	Allahabad	10173
Sirohi	118.3	S. Madhopur	81987	Jaipur	34959.9	Banda	39600.5
Jalor	42.7	Chittorgarh	565.6	Jhunjhunun	6412.6	Bara Banki	2833.8
Udaipur	352.4	Bhilwara	3982.5	Sikar	7865.6	Bijnor	735.2
Dungarpur	813.2	Ajmer	2998.9	Uttar Pradesh		Bulandshahr	797.1
				Etawa (Half) Area)	24491.6		
Banswara	228.1	Tonk	7478.2	Madhya Pradesh		Etawa (Half) Area)	24491.6
Madhya Pradesh		Madhya Pradesh		Bhind	69400.9		
Ratlam	4188.3	Mandsaur	14a13.7	Bhopal	6.5	Faizabad	187.4
Dhar	3628.9	Shajapur	5921.6	Chhatarpur	13434.8	Farrukhabad	62.8
Hosangabad	477.4	Guna	7801.9	Damoh	451.5	Fatehpur	14318.7
Chindwara	328.6	Shivpuri	2336.8	East Nimar	7516.4	Firozabad	15677.2
Narsimpura	21999.1	Ujjain	3920.9	West Nimar	10128.2	Ghazipur	96.5
Jabalpur	4771.6	Dewas	831.1	Panna	2058.8	Hamirpur	42569.1
Balghat	112.2	Sehore	704.3	Rewa	6663.5	Hardoi	88.4
Seoni	1258.4	Indore	227	Shahdol	11187.3	Jalaun	52910.6
Gujarat		Gwalior	10889.5	Sidhi	5448	Jaunpur	1694.5
Ahmadabad	4124.8	Raisen	389.3	Tikamgarh	1442.6	Jhansi	29711.8
Amreli	437.4	Rajgarh	3156.9	Morena	92991.3	Kanpur Dehat	27887.5
Banas Kantha	9551.1	Sagar	155.7	Satna	1472.5	Kanpur Nagar	773.2
Bharuch	13050.2	Vidisha	1099.3			Lalitpur	188.1
Bhavnagar	340.7	Datia	14409.8			Lucknow	11.1
Gandhinagar	2293.3					Mainpuri	3.2
Junagadh	37.3					Mathura	1696.5
Kachchh	10129.6					Meerut	30.6
Kheda	15873.6					Mirzapur	2181.2
Mahesana	6413					Muzaffarnagar	2504.2
Panch Mahals	1597.8					Pratapgarh	3138
Rajkot	96.4					Rae Bareli	376.9
Sabar Kantha	17411					Sitapur	273.2
Surat	624.7					Sonbhadra	41.7
Vadodara	28145.4					Sultanpur	3475.5
						Varanasi	353.1
Total	153132.6		223112.7		344665.2		315977.6
Grand Total (four regions)							1036888.1

Table: 4
Tenurial status of ravine lands (ha) during 1962-68 in major ravine districts of Rajasthan

S.No.	Name of district	Government	Village panchayat	Private	Total
1.	Kota and Baran	23748	3002	14732	41482
2.	Bundi	9078	1847	11175	22100
3.	S. Madhopur	9489	1347	1615	12451
4.	Bharatpur	16188	2287	3146	21621
5.	Banswara	81	107	82	270
6.	Dungarpur	184	236	12	432

(Source: Report on survey of ravine lands in Rajasthan 1962-68, Forest Department, Government of Rajasthan)

Aravalli ranges and presence of hard formations like quartz conglomerate on hill slopes while phyllites and schist form the low lands in Chambal-Yamuna ravine area are supporting evidences to upliftment theory.

Characterization of Ravine Lands

Based on visual observations and detailed surveys of benchmark ravine clusters in different ravine regions, some variations in shape, size and branching patterns of gullies have been observed. The U-shaped gullies are generally prevalent in Mahi and Yamuna catchment indicating high erodibility of sub-surface soil horizons, whereas in upper Chambal catchment, where clay rich sub-surface soil has greater resistance against erosion than topsoil, V-shaped gullies are formed. In Chambal, Mahi and Yamuna ravine

Table: 5
Gully size distribution in Chambal and Mahi river systems

S.No.	River system	District	Percent of total ravine area in district			Total
			Shallow (≤0.91 m)	Medium deep (0.91-4.57 m)	Deep (>4.57 m)	
1.	Chambal	Kota	24	41	35	100
2.	Chambal	Bundi	24	51	25	100
3.	Chambal	Sawai Madhopur	18	23	59	100
4.	Chambal	Dholpur	7	14	79	100
5.	Mahi	Banswara	64	27	9	100
6.	Mahi	Dungarpur	21	61.5	17.5	100

(Source: Report on survey of ravine lands in Rajasthan 1962-68, Forest Department, Government of Rajasthan)

Table: 6
Gully size distribution in lower Chambal catchment of Madhya Pradesh

S.No.	Name of District	Area (ha) under gully depth classes				Total Area
		Shallow (0-1.5 m)	Medium (1.5-5 m)	Deep (5-10 m)	Very Deep (> 10 m)	
1.	Morena	7018 (20.0)	14037 (40.0)	8000 (22.8)	6039 (17.2)	35094
2.	Sheopur	2460 (19.2)	3957 (30.3)	6636 (50.8)	0 (0.0)	13053
3.	Bhind	3073 (14.9)	4097 (19.8)	9218 (44.6)	4298 (20.8)	20686
	Total	12551 (18.2)	22091 (32.1)	23854 (34.7)	10337 (15.0)	68833 (100.0)

Note: Figures in parentheses are percent of total area under gullies in a district (Source: State Land record data as communicated by Commissioner, Morena (Madhya Pradesh) in August 2014)

Table: 7
Ravine ingress rates in Chambal catchment of south-eastern Rajasthan

Time segment	Location	Land treatment	Study period	Observed changes in ravine area spread (ha)			Ingress rate (%)	Data source/ Reference
				Initial	Final	Difference		
I	Kachnavada cluster, dist. Kota,	Unprotected	1951-1970	165.80	182.50	16.70	0.481	Village revenue maps and Survey of India topo-sheets for respective years (Katiyar, 1992; Katiyar *et al.*, 1994, 1995)
	Badakhera cluster dist. Bundi,	Unprotected	1951-1970	730.40	831.00	100.60	0.647	
	Pipalda cluster, dist. Kota,	Unprotected	1955-1971	360.00	395.99	35.99	0.597	
	Khunetia cluster, dist. Kota	Unprotected	1955-1971	58.23	62.80	04.57	0.473	
	Baldeopura cluster, dist. Kota	Unprotected	1955-1971	25.10	27.30	02.20	0.526	
	Biraj cluster, dist. Bundi	Unprotected	1952-1971	2313.00	2375.00	62.00	0.133	
	Ajinda-Kapren cluster, dist. Bundi	Unprotected	1952-1971	2055.00	2185.00	132.00	0.312	
	Domgraja cluster (Sultanpur), dist. Kota	Unprotected	1952-1971	1606.00	1692.00	88.00	0.267	
II	Gokulpura cluster, dist. Kota,	Untreated	1962-1982	2016.00	2395.00	379.00	0.865	As above
III	Baglivillage, K. Patan, dist. Bundi	Unprotected	2003-2016	90.46	106.51	16.05	1.264	Google earth maps for respective years supported by field survey
	Lohli-Bagli cluster, Khatkar, dist. Bundi	Partially treated	2001-2018	317.62	229.53	- 88.09	-1.449	
	Badakhera, Lakheri, dist. Bundi	Treated ravine cluster	2006-2018	400.31	345.76	- 45.55	- 0.902	

(Source: https://www.mapsofindia.com/maps/india/india-river-map.htm)

Fig. 5. Major drainage lines of Gujarat, Rajasthan, Uttar Pradesh and Madhya Pradesh

region, generally a gully network is made up of many continuous gullies. A continuous gully has a main gully channel and many mature or immature branch gullies. Development of continuous gully channels is primarily a function of overland flow over loose alluvial deposits. The development of network of gully and its head ward advancement seems more related to the sharp slope and high soil erodibility than the runoff volume. As channel move downstream and catchment area increases, erosive power of flow increases exponentially with rising runoff volume. This type of gully channels become deeper down slope until it reaches local base-level. Discontinuous gullies may develop on hillsides after landslides. They are also called independent gullies. Torrents or other seasonal drainage channels developed in Shivaliks and outer Himalayas or other hilly terrains are discontinuous gullies. Discontinuous gully begin with an abrupt head cut and tend to become more shallow downslope, and often end as a mid slope alluvial fan. These types of gully require a different approach of land treatment than continuous type of gully network found on alluvial plains of Chambal, Yamuna, Mahi and other river catchments, and therefore, these independent discontinuous gullies are not delineated as ravine lands of the country. However, in alluvial plains of India, a discontinuous gully may develop and evolve into continuous type by coalescence, and therefore it is possible to find channels which are hybrid of two types.

Land degradation through gully erosion is a gradual process during initial stages. With advancement of gully erosion process, terrain roughness and topographic features alter rapidly. To examine the size distribution patterns of gullies in a ravine system, three ravine clusters representing different stages of ravine development were surveyed in Baraderra, Badakhera and Papri villages of Bundi (Rajasthan). These ravine clusters are located along Mej, which is a tributary of Chambal river. During early stages, a network of sparsely distributed very shallow (<1.5 m) gullies, with gentler side slopes (<7%) and bed slopes (1.1%), may occupy less than 20% of leveled cultivated lands. Under unprotected conditions, average gully depth increased down to 3.7 m and with steeper side slopes (20%) and bed gradient (3.8%). Gullied area engulfed about 80% of good land (Table 8). Relatively deeper (>10 m) ravine systems found in lower Chambal catchment of Dholpur, Bhind and Morena districts suggest that size, shape and depth of gullies are also associated with soil texture and elevation difference between table land and drainage channel.

Developmental Potential of Ravine Lands

Implementation of soil and water conservation treatments and installation of gully control structures sharply reduced runoff and soil loss in Badakhera project area. Four years data (Table 9) indicate that micro-watersheds treated with mechanical and mechanical plus vegetative measures recorded 47.4% and 78.5% less runoff, respectively than untreated watershed. Although runoff at the outlet of watershed was not measured, it is estimated that as a whole the runoff from watershed was about 30% during the initial years which reduced to less than 10% in response to conservation measures. The reduced runoff promoted soil profile recharge and improved 22% to 56% soil water content in the root zone of arable lands. The conservation measures prevented loss of about 28 tonnes of fertile soil per ha annually, which had a favorable impact on soil fertility status. Despite unfavorable monsoon conditions experienced during 6 years of project period and decline in cropped area for *kharif* season, area under *rabi* cropping increased by 19.74% (Table 10). With a marginal increase in cropping intensity (3.9 percentage points), total crop production from project area increased by 43.7% during project period (Table 10). Post project evaluation at 5 and 10 years after completion of Badakhera project in 2003 recorded self propelled rise in project benefits (Fig. 6). About three and six fold increase in cultivated land and gross irrigated area, and consistent improvement in cropping intensity from 65% to 175% led to 386% increase in total crop production from the project area (Singh *et al*., 2018). Detailed analysis of project data show that treatment cost was recovered through improved crop productivity of treated area within ensuing 3-5 years (Singh *et al*., 2005). The Badakhera ravine development project realized a BCR of 1.54 despite adverse rainfall pattern during project period (Singh *et al*., 2004). Furthermore, ravine area restoration has strong climate change impact mitigation value through increased C-sequestration rates (Pande *et al*., 2016), and

Table: 8
Topographic features of ravine lands during different stages of gully erosion in Bundi district (Rajasthan)

Topographic features	Gully development stages		
	Early	Intermediary	Advanced
Location (village)	Baraderra	Badakhera	Papri
Type of gully	Very Shallow	Shallow	Medium deep
Average depth (m)	1.5	2.5	3.7
Average side slope (%)	6.4	9.5	20.0
Average bed width (m)	6.0	3.5	4.0
Average bed slope (%)	1.1	3.2	3.8
Main channel length (m)	365	255	185
Table land : Ravine land ratio	3.89	0.33	0.20
Percent table land	79.6	24.8	16.67

Table: 9
Year-wise runoff and soil loss under treated and untreated micro-watersheds in Badakhera ravine development project area

Year	Rainfall (mm)	Runoff % of rainfall			Soil loss (t ha^{-1})		
		W1*	W2*	W3*	W1*	W2*	W3*
1999	180.5	10.5	16.2	32.4	20.8	26.0	46.5
2000	150.8	3.5	14.6	14.7	12.9	23.2	36.4
2001	209.8	4.9	16.9	40.8	10.6	13.1	56.6
2002	78.0	6.1	11.8	20.4	NR	NR	NR
Average	154.8	6.3	15.5	29.4	14.8	20.8	46.5

**W1: Treated with mechanical and vegetative measures (44.5 ha); *W2: Treated with mechanical measures (11.3 ha); *W3: No soil and water conservation treatments (29.3 ha); NR - Not Recorded*

Table: 10
Impact of ravine reclamation project on total crop production

Productivity parameters	Pre-Project	Post-Project
Crop area (ha)		
Kharif	123.3	108.62
Rabi	122.8	147.05
Total	246.1	255.67
Cropping intensity (%)*	64.95	67.47
No. of crops grown		
Kharif	5	5
Rabi	7	5
Total production		
SGE*q ha^{-1}	13	19
SGE q (from project area)	3212	4615

**Sorghum Grain Equivalent*

positive hydrological influences. Hydrological monitoring of surface and groundwater suggested that 83% to 90% of accumulated runoffs in water harvesting structures contributed to artificial recharge into aquifer (Ali *et al.*, 2015).

The *ex-ante* assessment developmental potential of ravine lands provides current scenario for return on investment for restoration ravine lands (Table 11). The results indicated economic viability of ravine restoration activities. The proposed ravine development projects in four ravine clusters projected positive net present values (NPV) which varied from ₹ 35.6 million (Manikpura cluster) to ₹ 107.6 million (Bagli cluster). The internal rate of return (IRR) varied from 24% to 33.4%. The variation in IRR under different clusters reflected the variation in response pattern by ravine clusters over time. The BCR was maximum (2.46) in Bageshwari cluster while it was minimum in Manikpura (1.49). In addition, a number of other benefits are expected over and above direct or tangible benefits considered in economic analysis of the sample developmental plans. The improved land quality may lead to increased land value due to increased productivity. Several intangible benefits of ravine restoration projects experienced are reduced erosional loss, flood mitigation, positive impact on stream and groundwater hydrology, improved water quality, enhanced carbon sequestration, improvement in riparian habitat and environmental quality, and overall improvement in life quality of local inhabitants. The *ex-ante* assessment of current developmental potential of Chambal, Mahi and Yamuna ravine lands suggest that scientific and judicious management of these lands would increase 10% to 50% of existing cultivable lands, develop irrigation capacity for its 30% to 60% arable lands, improve 9% to 28% of cropping intensity, and 20% to 66% of current yield levels with an overall 118% to 280% increase in net returns through increased crop production. The non-arable lands, which are under severely degraded state, can be developed to support several other livelihood activities. The estimated average treatment cost is about ₹ 1,20,000 ha^{-1} with a BCR of 1.87.

4. CONCLUSIONS

Ravine reclamation technology disseminated through various outreach programmes of ICAR-IISWC is estimated to have reached about 1.7 M ha as indicated by 62.5% reduction in ravine lands of four major ravine states of Uttar Pradesh, Madhya Pradesh, Rajasthan and Gujarat. Nevertheless, only

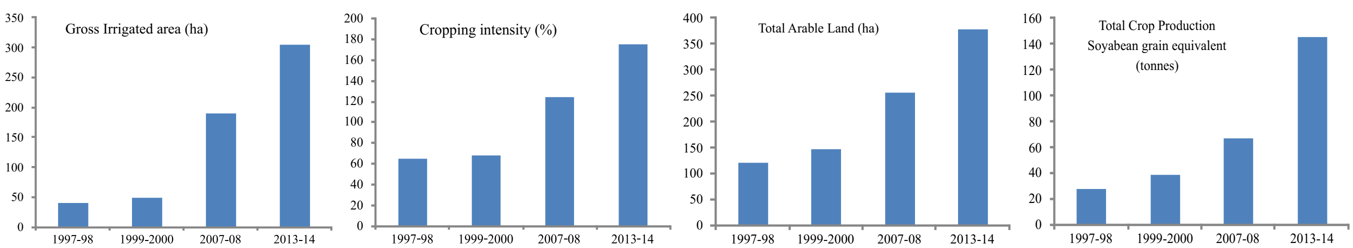


Fig. 6. Impact of ravine reclamation measures in Badakhera project (682.5 ha) of Bundi district (Rajasthan)

Table: 11
***Ex-ante* assessment of developmental potential of four benchmark ravine clusters**

Project description / Interventions	Manikpura (Yamuna catchment)	Bagheshwari (lower Chambal catchment)	Bagli (upper Chambal catchment)	Khorwad Shili (Mahi catchment)
Project Size				
Total area of ravine cluster (ha)	201	200	473	303
Arable land (ha)	65	86	322.8	93
Non arable (ha)	136	114	150.2	210
Project Cost Distribution				
Arable land treatments (conservation measures, crop improvement)	53,50,000	52,84,009	2,92,15,000	68,24,840
Non-arable land treatments (conservation measures, silvi-pasture, vegetation improvement)	88,16,830	1,10,72,260	98,40,000	1,90,39,600
Water harvesting structures	-	6,00,000	-	-
Drainage line treatment cost (₹) (spillways, check dams, bamboo plantation, etc.)	29,90,000	12,91,980	1,73,48,000	1,05,18,000
Irrigation facilitation cost (₹)	8,00,000	41,05,000	22,50,000	14,00,000
Livelihood activities (₹)	5,08,000	3,48,000	3,48,000	3,48,000
Planning, execution and capacity building (₹)	12,02,306	12,29,656	32,32,886	21,11,297
Total project cost (₹)	1,95,67,146	2,33,30,905	6,22,33,886	4,00,41,737
Economic Viability				
Unit area cost (₹ ha^{-1})	97,349	1,16,655	1,31,573	1,32,151
Net Present Value (₹ million)	35.65	67.05	107.63	85.31
Benefit:Cost ratio	1.49	2.46	1.84	2.10
Internal Rate of Return (%)	27.6	31.5	33.4	24.0

shallow and easy-to-reclaim sites have been reclaimed so far and vast stretches of relatively difficult sites with severe physical degradation remain unattended. In the backdrop of rapidly shrinking per capita land availability, reclamation of all forms of wastelands is a national priority. Extensive ravine areas await developmental initiatives because of exorbitantly escalated land value and availability of well demonstrated technological solutions with multiple and far reaching economic and ecological benefits. The ravine reclamation packages recommended by ICAR-IISWC can transform these waste lands to productive ecological parks having high potential for silt and carbon entrapment, and water harvesting. There is a need to take a fresh initiative at regional and national level in this regard. The ravine areas development is also a climate change impact mitigation activity, and therefore, international funding needs to be explored for such a cost intensive programme.

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