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Policy Paper on

Reclamation of Ravine and Gullied Land through Conservation Measures for Doubling Farmers' Income




ICAR-INDIAN INSTITUTE OF SOIL AND WATER CONSERVATION (IISWC)
Research Centre, Vasad-388-306, Anand, Gujarat
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LIST OF ACRONYMS AND SYMBOLS

S. No.	Acronyms and Symbols	Expansion
1.	M ha	Million hectare
2.	et al.	And others
3.	%	Percentage
4.	km	Kilometre
5.	m	Meter
6.	ha	Hectare
7.	km^2	Square kilometre
8.	e.g.	Example
9.	t $acre^{-1}$	Tonnes per acre
10.	GoI	Government of India
11.	UNDF	United Nation Development Fund
12.	EEC	Elevated economic corridor
13.	NABARD	National Bank for Agricultural and Rural Development
14.	ICAR	Indian Council of Agricultural Research
15.	<	Less than
16.	>	Greater than
17.	m^2	Square metre
18.	cm	Centimetre
19.	t/ha	Tonnes per hectare
20.	Kg/ha	Kilogram per hectare
21.	Kg/m^2	Kilogram per square metre
22.	g/l	Grams per litre
23.	IISWC	Indian Institute of Soil and Water Conservation
24.	cu. m./ha./year	Cubic meter per hectare per year
25.	:	Ratio
26.	×	Multiplication
27.	d/s	Downward slope
28.	u/s	Upward slope
29.	m^3/s	Cubic meter per second
30.	mm/hr	Millimetre per hour
31.	₹	Indian rupees
32.	&	and
33.	TFP	Total factor productivity
34.	CBO	Community based organizations
35.	PRI	Panchayati Raj Institutions
36.	GIS	Geographical information
37.	IT	Information technology
38.	NPV	Net present value
39.	B:C ratio	Benefit cost ratio
40.	IRR	Internal rate of return
41.	DPR	Detailed project report
42.	ERC	Energy resource conservation
43.	VFMC	Village forest management committee
44.	SHG	Self-help groups
45.	PPP	Public private partnership
46.	COP	Conference of the parties

Policy Paper

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1. INTRODUCTION

Soil erosion due to water in semi-arid climate has led to the development of ravine lands, which is considered as the most severe form of land degradation on earth. Ravine lands are formed when soil is not fully covered by the vegetation throughout the year and sporadic vegetation is not able to bind the soil particles from being washed away by rainfall (Dagar and Singh, 2018). Throughout the globe, ravine lands have severe limitations for their rehabilitation and sustainable utilization as a consequence of their unique topographical features (Singh *et al.*, 1966). Although ravines and gullies occur all over India, the largest incidence is found in Madhya Pradesh, Uttar Pradesh, Rajasthan and part of Gujarat. Ravines spread over an estimated area about 4.30 M ha in India. The Yamuna, Chambal, Mahi, and Sabarmati river systems constitute majority (around 72%) of these ravines (Soni *et al.*, 2018). There are several major areas of severe ravine erosion in India as shown in Fig. 1 and Fig. 2. The largest is the Yamuna-Chambal ravine zone. The ravines flank the Yamuna River for nearly 250 km and in Agra and Etawah may attain a depth of more than 80 m. Nearly 389,000 ha area is affected along the flank of Yamuna River in Southern Uttar Pradesh (Sharma, 1980). The Chambal ravine flanks along theRiver Chambal in a 10 km wide belt, which extends southwards from the Yamuna confluence to 480 km to the town of Kota in Rajasthan (Dagar, 2018a). Ravine affect basins of several Chambal tributaries, *e.g.,* Mej, Morel, Kalisindh, *etc.* altogether, about 5,000 km^2 area is affected (Dagar, 2018a). In Gujarat, ravine belt covers 500,000 ha and extends from the southern bank of the Tapti, banks of the Narmada, Watrak, Sabarmati and Mahi River basins. Besides these river basins, ravines are also found in Chhota Nagpur, Bihar, Mahanadi and upper Sone Valley, Indo-Gangetic plains, Shiwalik and Bhabar tract and Western Himalayas even up to the Kashmir Valley (Dhruvanarayana, 1993). Ravine lands have been reported to be losing in excess of 18 t $acre^{-1}$ soil loss (Singh *et al.*, 1992).

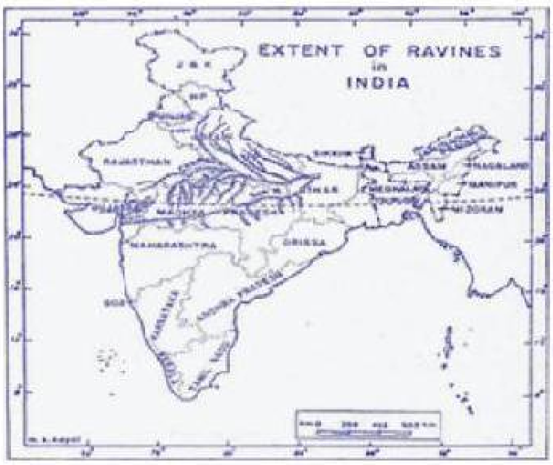

Fig. 1 Spatial extent of ravine in India

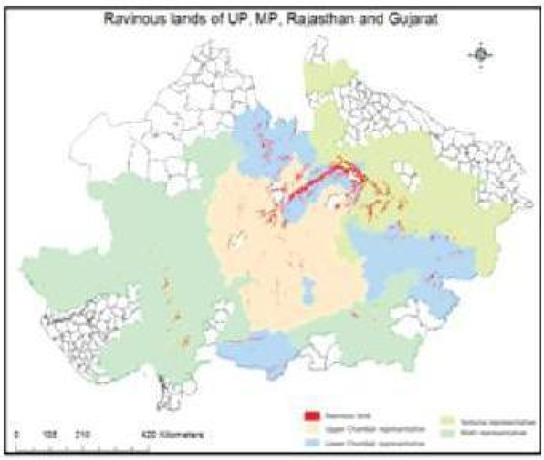

Fig. 2 Ravine lands of U.P., M.P., Rajasthan and Gujarat.

Sikka *et al.,* (2018) reported that the average annual loss of nutrients from ravine lands due to soil erosion was 5.37 - 8.4 million tons resulting into loss of production.

The rapid expansion of the erosion induced land degradation globally and the inadequacy of the effectiveand regional specific soil conservation practicescauses a continuous increase in area under such lands,which is affecting the socio-economic dimension ofthe regional population (Pena *et al.,* 2020). The socio-economic conditions, policy and unsustainable land management practices have largely been identified as the major causes for degradation of agricultural land resources (Meadows and Hoffman, 2002). However, at the micro level, important cause of natural resource degradation is lack of economic power to invest in conservation technologies. The land degradation caused due to extension of ravines needs special attention, as these marginal lands are susceptible to climatic aberrations like droughts and floods. These lands required a comprehensive and long term strategic plan to address the issue, not only for resource sustainability but also for environmental remediation (Dagar, 2018b). The poor productivity of lands, despite several land improvement programmes as given in Table 1, calls for further intensification of soil and water conservation programmes, apart from the other development schemes in the region. If left untreated the ravines tend to ingress the adjacent marginal and fertile table lands thus engulfing fields and at times, the habitations. It has been estimated that unattended ravines increase in area at the rate of 0.846% per annum (Dagar (2018a); Singh *et al.,* 2020). The resource poor small and marginal farmers of the ravine regions are mostly dependent on subsistence level of agriculture or allied agricultural activities emanating from these lands (Singh *et al.,* 2021). The extending ravines tend to deprive the local farmers of their occupations forcing them to work as landless labourers (Singh *et al.,* 2021). Thus, it is rightly said that extending ravines are the footprint of death for the cultivators. Therefore, considering the above context, the technologies developed and evaluated for reclamation of ravines in Western India by ICAR-Indian Institute of Soil and Water Conservation, Research Centre –Vasad are deliberated below in this paper.

Table 1. Important ravine reclamation initiatives in India

S. No.	Year	Nature of Initiative
1.	1884	• Afforestation in 1200 ha of ravine area of district Etawah (Uttar Pradesh) by District Collector and Zamindars.
2.	1919	• King of Gwalior (Madhya Pradesh) setup 'Kanwar Commission' to seek advice for arresting gully erosion and enhance food, fodder and fuel availability.
3.	1945	• GoI invited American Experts for formulation of ravine reclamation strategy and action plan.
4.	1952-1957	• GoI set up three 'Soil Conservation Research, Demonstration and Training Centres' at Agra, Kota and Vasad for Yamuna, Chambal and Mahi ravines, respectively.
5.	1955-1973	• State soil conservation scheme of Madhya Pradesh reclaimed 1219 ha ravine lands.
6.	1960-1970	• State Government of Uttar Pradesh, Madhya Pradesh, Rajasthan and Gujarat, with the assistance of GoI, implemented a project for delineation and characterization of ravines and mapped 1.38 M ha. • Central Ravines reclamation Board was setup and a National Ravine Reclamation Policy was formulated. • Centrally sponsored scheme implemented in 36670 ha for protection of table lands and stabilization of ravine lands.
7.	1977-1987	• Ravine erosion control schemes of Madhya Pradesh reclaimed 13500 ha of ravine lands.
8.	1987-1995	• Ravine reclamation in Decoit Prone Areas of Uttar Pradesh, Madhya Pradesh, Rajasthan and Gujarat implemented and reclaimed 1270 ha. • UNDP supported Project for ravines rehabilitation in Kota (Rajasthan). • EEC supported project in Yamuna ravines of Agra, Firozabad and Etawahdistricts of Uttar Pradesh • NABARD funded project in some districts of Uttar Pradesh.
9.	2002-2005	• Government of Uttar Pradesh Ravine Stabilization Project targeted 7000 ha ravine lands.
10.	2007-2014	• Forest department of Madhya Pradesh reclaimed 1200 ha of very deep ravines in lower Chambal catchment area.
11.	2009-2010	• World Bank funded pilot project of Ravine Reclamation executed by Uttar Pradesh Bhumi Sudhar Nigam in Fatehpur and Kanpur district of Uttar Pradesh targeted 62000 ha ravine land.

2. MECHANICAL MEASURES FOR RECLAMATION OF RAVINE LAND

Based on the topographical survey to represent various gullied/ravine lands of Western India condition a comprehensive gully classification scheme evolved by ICAR-Indian Institute of Soil and Water Conservation, Research Centre Vasad to classify the gully network into size categories based on gully dimensions, soil characteristics, seasonal submergence and climate is given in Table 2. (Dhruv Narayana, 2017). With progressively increasing terrain deformation from class 1 to class 8, there is a corresponding increase in erosion hazards and land use restrictions as given in Table 3. Among the ravine classes shallow ravines up to 1 m depth are recommended to be reclaimed for cultivation by land levelling, bunding and terracing. The runoff is channelized by installing marginal bunds supported with appropriate type of spillways. The reclaimed land is cultivated by applying the principles of conservation agronomy. There is also an ample scope of installing lift irrigation networks in these lands by lifting water from adjoining river or harvested runoff in deep ravines.

Table 2. Ravine land capability classification system developed by ICAR-IISWC,RC.Vasad

Class and colour code	Soil texture	Bed width (m)	Gully depth (m)	Side slope	Climate
Class-I (Light green yellow)	Silty clay, Clay, Loam, Sandy loam, Silty loam, Sandy clay	>18 / <6 (W_3) (W_1)	< 1.5 (Gd_1)	< 5% (S_1)	Humid climate with well distributed rainfall or having perennial irrigation.
Class-II (Yellow)	Silty clay, Clay, Sandy loam, Silty loam, Sandy clay	6-18 (W_2)	1.5-3.0 (Gd_2)	5-10% (S_2)	Humid climate with occasional dry spells or dry-cum-wet irrigation.
Class-III (Red)	Sandy clay, Silty clay, Clay, Loamy sand	> 18 (W_3)	3-6 (Gd_3)	10-15% (S_3)	Sub-humid climate or situated a tail end of an irrigation system. Where water is occasionally not adequately available.
Class-IV (Blue)	Any texture Excluding sand and with gravel	Any width	6-9 (Gd_4)	10-15%(S_3)	Semi-arid climate (without irrigation) with enough rainfall to sustain hardy horticultural plants.
Reclaimable classes decrease in priority for reclamation for agriculture from Class-I to Class-III. Class-III and Class-IV may be put under horticulture.					
Class-V (Dark Green)	Reclaimable classes 1 to 4 having the following hazards.	-	-	-	-
a. Water logging / salinity has developed due to irrigation system. b. Back flow and flooding from a nearby stream or river. Hence, the gully need not be reclaimed for agriculture. It may be put under any suitable grass or tree species.					
Class-VI (Orange)	Any texture including gravelly etc.	Any width	>9 (Gd_5)	15% irregular (S_4)	Semi-arid and arid with long dry spells.
Gully humps may also be included in this class					
Class-VII (Brown)	Any texture including gravelly etc.	Any width	>9 (Gd_6)	>15% irregular (S_5)	Semi-arid and arid with long dry spells.
Class-VII (Purple)	Any texture with rocks on surface.	Any width	>9 (Gd_5)	>15% irregular (S_5)	Semi-arid and arid with long dry spells.

3. MECHANICAL MEASURES FOR RECLAMATION OF SHALLOW RAVINES

3.1. Peripheral Earthen Bunds

About one third of the ravine lands in the country are shallow ravines (less than 1 m deep) and can be easily reclaimed with simple earth moving machinery for cultivation of crops. The management of shallow ravines instigates with designing and instituting a peripheral bund along the gully head to check the runoff generated from the adjoining marginal lands as shown in Fig. 3. The land levelling operations across the slope and smoothening on the upstream side of the peripheral bund increases the infiltration opportunity time for the runoff generated from the crop field. The in-situ soil moisture conservation increases the water and nutrient use efficiency of the cropping systems.

Fig. 3. Peripheral bund for reclamation of shallow ravines

3.2. Contour Earthen Bund With Grass Sodding

The management of shallow ravine by contour and peripheral bund has shown improvement in value of land and crop yield due to soil moisture retention within the field, prevention of soil and nutrient losses from the crop field. The different cross sections of contour and peripheral bunds were tested in ravine lands of Western India as shown in Fig. 4 (Tejwani *et al.*,1975). The design cross sections of the bunds were fixed on the basis of the area of the catchment, slope of the land and its location. The bunds were designed on the basis of the vertical interval or horizontal spacing as given in Table 4(a&b) (Tejwani *et al.*,1975). Usually one bund could only be located in each field approximately on contour, so that it can also serve as peripheral control of gully heads. These bunds were sodded with *Dichanthiumannulatum* and *Cenchrusciliaris* grasses. In ravine lands, an average cross section of 0.90 to 1.3 m^2 spaced at 0.90 to 1.20 m vertical interval was found best (Tejwani *et al.*,1975). Grass ramps and pipe outlets were provided in the bunds for the safe disposal of excess runoff water. It is further stated that the effectiveness of the bunds would be for a longer period, as with passage of time the rate of reduction of bund height is expected to be slow and can be maintained indefinitely with good stabilized grasses (Singh and Verma, 1971). It is also found that the area lost under bunds could fetch revenue from grasses, which is sufficient as compared to production in rainfed area (Singh and Verma, 1971).

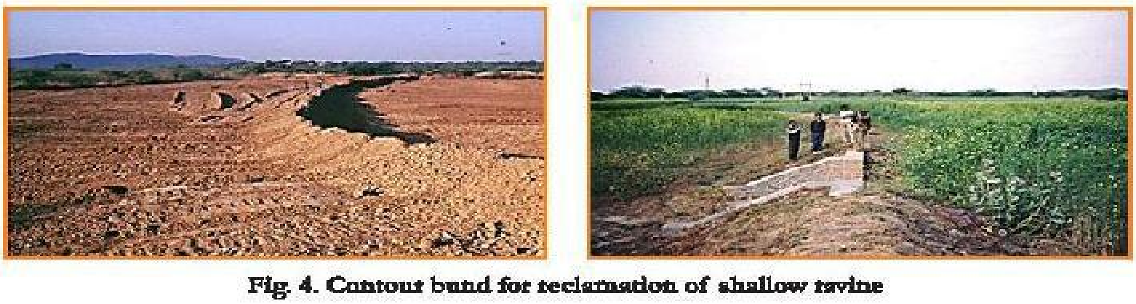

Fig. 4. Contour bund for reclamation of shallow ravine

3.3. Vegetative Barriers

Vegetative barriers are used either for supplementing or substituting the earthen bunds. The *Dichanthiumannulatum, Cenchrusciliaris, Vetiveriazizanioides, Eulaliopsisbinata, Saccharummunja*and*Aloe vera (L.) Burm.f.* vegetative barriers were evaluated for their effectiveness in reducing runoff, soil and nutrients losses from 2% slope of marginal shallow ravines. Vegetative barriers were grown across the slope at 45 m horizontal interval, in paired rows of 10 cm slip to slip spacing. The cultivation of pigeon pea (BDN-2) was done at 120 × 30 cm spacing in all plots. These vegetative barriers reduced the annual runoff by 19.7 to 50.1% and soil loss by 51.1-80.3% over the control plot (Kurothe *et al.*, 2013).

The Napier, Guinea and Para fodder grasses strips of 1 m and 2 m were grown as vegetative barrier in 2% slope in shallow ravines as shown in Fig. 5 and given in Table 7. The lowest sediment yield was observed in 2 m width of Napier grass strip (1.43 t/ha) followed by 2 m width of Guinea and Para grass strips as compared to control (4.07 t/ha), respectively.The 2 m width of Napier grass strips had lowest nutrient loss of (N-5.64 kg/ha, P-3.1 kg/ha, K-5.4 kg/ha) followed by Guinea and Para grasses which were found almost equally efficient in reducing nutrient losses from crop field which is 28 to 30% of nutrient losses from control (N-20.01 kg/ha, P-8.3 kg/ha, K-17.00 kg/ha).The equivalent yield of 2 m width of Napier grass strip and cotton crop (1293.5 kg/ha) had higher yield than control. The economic analysis shows that Napier grass strips of 2 m width was found best in reducing runoff, soil loss, nutrient losses and net return from crop field(Singh *et al.*, 2020).

Fig. 5. Vegetative barriers for reclamation of shallow ravine

3.4. Grassed Waterway

Grassed waterways are important for preventing the scouring of channel bed in shallow ravines. The *Para* grass strips in waterways were optimized for grass cover to check runoff velocity and reduce sediment concentration in downstream water bodies as shown in Fig. 6 and given in Table 7 . The different *Para* grass covers (0-100%) in waterways were studied at 2% slope. The different grass covers are 100%, 75%, 50%, 25% and no grass cover. These *Para* grass strips were able to produce green grass yield of 14.5 kg/m^2. The *Para* grass strip in waterways is able to reduce the outflow up to 22% with 100% grass cover. The grass filter strips is able to reduce the sediment concentration in runoff water by 5 times (from 3.6 to 0.72 g/l). The *Para* grass filter in waterways is able to reduce the flow velocity of runoff water by converting the super critical flows into sub critical flows (Kurothe *et al.*, 2013).

Fig. 6. Grassed waterway for reclamation of shallow ravine

4. RECLAMATION MEASURES FOR MEDIUM AND DEEP RAVINES

Medium-deep and deep ravines (more than 3m) can be reclaimed for horticultural or silvi-pastoral land uses. To stabilize gully head, gully beds and side slopes, various types of gully control measures have been evaluated by ICAR-IISWC and design specifications to different site conditions are recommended. During initial years these structures act as water harvesting and silt retention structures, and promote ground water recharge. A systematically treated gully network eventually gets transformed from silt producing site to silt entrapment site. Bio-engineering measures are planned for stabilization of steep side slope of deep gullies and river banks. Gradually, the terrain roughness is diminished giving rise to levelled and fertile gully beds. Suitable fruit, fuel and fodder species which have been identified for different ravine systems are given in Table 7. Regulating the biotic interferences is a key for successful vegetation establishment and productive utilization of ravine lands which can be achieved through empowering local beneficiaries to develop a social mechanism.

About two third of the ravine lands in the country are deep ravines having greater than 3-9 m depth with varying width and slope and these cannot be easily reclaimed with simple earth moving machinery for cultivation of crops. The management of deep ravines instigates with designing and instituting a series of composite check dams in the gully bed as given in Table 5 and Table 6. The construction of gully plug at regular interval with provision for safe disposal of runoff assists in stabilization of gully bed, which can be alternatively utilized for raising forage crops like *Napier* grass, *Guinea* grass, *Para* grass, Cow Pea (GFC-1,2,3,4), Jowar (GFS-3), Sorghum (AS-16, GFSH-1), *Marvel* grass, *Anjan* grass tolerant to water logging (Dhruv Narayana, 2017). The easing of gully is required in deep gully head to prevent caving action against steep slope due to runoff and to protect the adjoining marginal land from collapsing inside the gully due to unstable slope. The medium and deep gully can be reclaimed by terracing and or trenching for conservation of runoff, soil loss, associated nutrients and stabilize the steep slopes with time.

4.1. Composite Check Dam

A large number of earth cum brick masonry check dams were constructed in Mahi ravines of Western India for reclamation of medium and deep gullies in ravine (Kurothe *et al.*, 2013). These check dams were found to be very effective to check erosion, detaining the sediment and runoff water behind the structure which ultimately resulted in ground water recharge as shown in Fig 7.The deposition of sediment against the check dams was measured by fixing a series of angle iron poles on concrete level of the structure. The average sedimentation from these ravine sub-catchments having agricultural crop in table lands as well as in gully beds was 24.51 cu. m./ha/year during year 1961 to 1963 (Kurothe *et al.*, 2013). The average sediment deposition from watershed having agricultural crop in table lands and natural regeneration in gully beds was 4.20 cu. m./ha/year during year 1964 to 1977 (Kurothe *et al.*, 2013). After the siltation of these composite check dams the level terraces formed in the gully beds were stabilized and were put under cultivation but they were found to be poor in production. Therefore these reclaimed cultivated deep gully beds were subsequently planted with forest trees (Kurothe *et al.*, 2013).

Fig. 7. Composite check dam on gully for reclamation of medium and deep ravine

4.2. Gully Plugs

Gully plugs protect the gully beds by reducing the runoff velocity, distributing the water spread, increasing infiltration opportunity time and improving the soil moisture regime to support the vegetation cover as shown in Fig. 8. Gully plugs made of various materials i.e. brush wood, live hedges, earth, sandbags, brick masonry, loose boulder were evaluated in Western India (Kurothe *et al.*, 2013). The size and materials for the gully plug depends on the width, length and bed slope of the gully and anticipated runoff. In narrow gullies, whose width did not exceed 3 m, live hedges consisting of *Euphorbia* species were planted across the gully beds in three rows spaced 90 cm apart and the stems at 90 cm in each row staggered alternatively(Tejwani *et al.*, 1975).It was found that all types of gully plugs were effective either in retaining or retarding the runoff. The earthen gully plugs were found to be the cheapest. Brick masonry gully plugs are constructed at the confluence of gully branches in a compound gully.

The gullies where no runoff is expected from the top, earthen gully plugs of 1.1 m^2 cross section with a grassed ramp of 22.5 cm below the top level and spaced at 45-60 m horizontal interval were found suitable. However, for gullies in which excess runoff from the top was expected an earthen gully plugs of 2.2 m^2 cross section with a pipe outlet was found appropriate. The earthen gully plugs are required to be constructed for a life expectancy of 10 years. During these periods it is estimated that the vegetative growth of forest species will be sufficient to take care of soil erosion as well as their root system will be sufficiently developed to extract the moisture from deep soil layers (Tejwani *et al.*, 1975).


Fig. 8. Gully plugs for reclamation of medium and deep ravine

4.3. Gully Slope Easing

Deep and vertical gully heads in association with the phenomena of under cutting or caving extending at an alarming rate endanger buildings, roads, bridges, abutments, railway tracks and costly cultivated lands. The measures which can be economically and immediately adopted to stop further progress of the gully head or caving in the bottom of gully and then ease the gully for the remaining one third top portion of the vertical face. The newly formed slope of about 3:1 is stabilized by sodding with *Dichanthium annulatum* or *Cenchru ssiliaris* grasses (Tejwani *et al.*, 1975). The eased gully heads were found out to be in existence and working satisfactory even after 22 years of management. The comparison of eased gully with nearby gully under similar condition reveals that there is good vegetation on the eased gully head in comparisons to the unease gullies which are still exposed and covered with sparse annual vegetation (Kurothe *et al.*, 2013).

4.4. Bench Terracing

The impact of bench terracing on runoff, soil loss, and soil properties along with Sapota (*Achras zapota*) growth, fruit yield, biomass, and carbon stock in a degraded ravine land developed along the course of *Mahi* River in Western India were evaluated in a degraded ravine land developed along the course of Mahi River in Western India Table 7. The bench terracing in deep ravines with uniform slope of 15% resulted in significant decrease in runoff (34%) and soil erosion (25%), and enhanced tree growth, biomass and carbon stock. The cultivation of crops in between the tree plantation may induce significant soil loss (18% higher) due to tillage operations even though the runoff is not significantly affected. The findings suggested that bench terracing is the best soil and water conservation measure for restoring highly degraded ravines as shown in Fig. 9 (Kumar *et al.*, 2020).

Fig. 9. Bench terracing for reclamation of medium and deep ravine

4.5. Trenching

The impact of trenching in deep ravines was evaluated in ravines developed along the Mahi River in Western India. The staggered contour trenches were designed to harvest water based on maximum daily rainfall as shown in Fig. 10. The trenching density on the ravine slopes was kept to retain 30, 50 and 80% of runoff generated from the ravine catchment. A substantial reduction in runoff was observed for treatments with higher trench densities (50% and 80%) as compared to 30%. The sediment yield in different trench densities also followed the similar trend. These results are in conformity with the results reported for different trenching densities in horti-pastoral land uses by Ali *et al.* (2017) from Chambal ravines. The soil moisture was more or less similar in different trench densities just followed by the monsoon. However, soil moisture in the 80% trench density was highest and also remains for a longer period in the lower reaches of the ravine slopes (Parandiyal, 2020). The survival of Neem (*Azadirachtaindica*) saplings planted at a spacing of 6 m × 6 m was also found highest in 80% trench density as given in Table 7. In another study, the trenching of size 2 m × 0.5 m × 0.5 m at 14% uniform slope with Sapota plantation resulted in decrease in runoff by 16% and soil loss by 15% along with enhanced tree growth, biomass and carbon stock in the deep ravine slopes as given in (Table 7) (Singh *et al.*, 2020).

Fig. 10. Trenching for reclamation of medium and deep ravine

4.6. Bamboo Based Bio-engineering Measures

The bamboo based bio-engineering measures were found as an effective means for natural resource conservation in ravines (Wang, 1995). The soil erosion in bamboo plantations (178 kg ha^{-1}) was found to be comparatively less compared with other forest plantation (Ben-Zhi *et al.*, 2005). Bamboo also acts as a vegetative barrier and filter for silt laden runoff flowing in gullies. The bamboo induces silt deposition and reduces the velocity of flowing water along bare river banks and deforested areas in ravines as shown in Fig.11. *Dendrocalamus strictus* which occupies major area covered under bamboo plantation in India was found best for economic utilization of ravines as given in Table 7. It is reported that annually about 4000 culms of bamboo per hectare can be harvested from ravine lands (Rao *et al.*, 2012). The benefit-cost ratio of 1.98 from bamboo plantation in ravines is profitable having an economic return of 19.3% over a period of 20 years (Pande *et al.*, 2012). The intangible benefits of carbon sequestration and prevention of soil erosion are supplementary as given in Table 8. The ravine lands under the bamboo plantation increased the soil ph and organic carbon along with reduced runoff (Singh *et al.*,2014).

Fig. 11. Bamboo based bio-engineering measures for reclamation of medium and deep ravine

Table 3. Zone wise ravine land treatment measures

Site Characteristics	Land ownership	Recommended land treatnentmeasures
Zone I : Levelled (< 1% slope) marginal lands along the ravine area and vulnerable to gully head extension if left unattended	Private	Conservation agronomy, contour or graded bunding, peripheral bunds with masonry spillways.
	Community lands	Peripheral bunds with masonry spillways, In-situ moisture conservation measures with mini bunds, Silvi-pastoral system with recommended tree and grass species.
	Forest lands	Peripheral bunds with masonry spillways, Afforestation and other moisture conservation measures for overall habitat improvement and support for fuel and fodder need with mini bunds.
Zone II: Flat or mildly sloping lands or shallow and small gullies located between Zone I and deep gully system. (Ravine land capability class I, II and III)	Private	Gully head stabilization, Land levelling to form inward sloping terraces with proper outlets, Conservation bench terracing, Gully plugs.
	Community lands	Gully head stabilization, Half-moon terracing or staggered trenching, Silvi pastoral systems, Gully plugs.
	Forest lands	Gully head stabilization, Half-moon terracing or staggered trenching, Afforestation and other moisture conservation measures for overall habitat improvement and support for fuel and fodder needs, Gully plugs.
Zone III:Severely degraded medium deep to very deep ravines which cannot be economically reclaimed for cultivation. (Ravine land capability class IV and VI)	Private lands	Narrow horticulture terraces with halfmoon terracing or staggered trenching and side slope stabilization measures, Gully bed stabilisation, Micro irrigation system.
	Community lands	Silvi-pastoral system with half -moon terracing or staggered trenching and side slope stabilization measures, Gully bed stabilisation measures.
	Forest lands	Afforestation and vegetation modification interventions with suitable moisture conservation measures for overall habitat improvement and fuel and fodder needs. Gully bed stabilisation measures.
Zone IV: This back flow zone is situated between Zone III and river stream.	All types	Stream bank and side slope stabilization measures, Earthen check dams for embankment type water harvesting structures ,Pisciculture, wild life centuries, lifesaving irrigation systems, Gully bed stabilisation measures.

Table 4 (a). Earthen bund design dimensions for reclamation of shallow ravines

Soil type	TW(m)	BW(m)	H (m)	SS(d/s)/ (u/s)	CS(m^2)
Gravelly soils	0.3	1.215	0.6	0.75:1/1:1	0.45-0.54
Sandy loam or clay	0.3	2.1	0.6	1.5:1	0.72
Very shallow soils	0.45	1.95	0.75	1:1	0.9
Shallow soils	0.45	2.4	0.75	1.3:1	1.06
Medium soils	0.6	3.33	0.68	2:1 /1.5:1	1.31-1.44
Medium deep soils	0.3	4.43	0.75	1.5:1/4:1	1.77

TW: Top width (m), BW: Base width (m), Height (m), SS: Side slope, CS: Area of cross section (sq. m.).

Table 4 (b). Earthen bund design dimensions for varying slope conditions of ravines

Slope(%)	VI (m)	HI(m)	L(m)/ha
0-2	0.9	78	134-224
2-3	1.2	62.5	168-253
3-6	1.8	62.5	168-336
6-10	3.0	47	224-336

VI: Vertical interval (m), HI: Horizontal interval (m), L: Length of bund (m) per ha.

Table 5. Recommended drainage line treatment measures formedium and deep ravines

Stream order	Catchment	Peak flow* (m^3/s)	Suitable mechanical measures
1st order	< 2 ha	<0.25	Loose boulder check dam, Sand bag check dam, Brushwood check dam
2nd order	2-20 ha	0.25-2.5	Gabion, Rock fill earthen dam
3rd order	> 20 ha	>2.5	Masonry check dam

*Peak flow estimated for 150 mm/ hr rainfall intensity

Table 6. Tentative budget required of ravine reclamation works in different ravine zones based on price of 2011-12 for cost estimation

Ravine zone	Earth work for reclamation*		Cost of conservation measures (in lakhs)	Total cost (in lakhs)
	Volume (m^3/ha)	Cost □ per ha (in lakhs)		
Very shallow	1000	0.50	0.30	0.80
Shallow	3937.5	1.97	0.79	2.76
	4500	2.25	0.90	3.15
Medium deep	7875	3.94	1.56	5.50
	10125	5.06	1.60	6.66
	12150	6.08	1.60	7.68
Deep	14175	7.09	1.60	8.69
	16200	8.10	1.60	9.70
	14175	7.09	2.00	9.09
Very deep	16200	8.10	2.00	10.10
	18225	9.11	2.00	11.11

5. CROPPING PATTERN AND LAND HOLDING SIZE IN RAVINE REGION

The per capita land holding of farmers along ravines is small and farms were fragmented. Most of the families are marginal in land holdings, with average land holding size of less than 2.0 ha. Out of this, only 60% is arable land, the remaining being non-arable. About one fourth of the total cultivators are tenants and the majority of them belong to medium farmer's category (Pande *et al.*, 2011) and similar findings were reported from Chambal ravine region by Meena *et al.* (2021). As the holding-size increases, the proportion of ravine land also increases in different classes of land holdings. Pearl millet based cropping system is the most prevalent cropping systems across all the categories of farms. Farmers with irrigation facility also cultivate irrigated crops like Tobacco, Wheat and summer Pearl millet. It has been observed that some of the farmers, particularly medium, lease-in some better parcels of levelled land and grow remunerative crops like Tobacco, Castorand Banana.

6. AGROFORESTRY SYSTEM FOR RECLAMATION OF RAVINE LAND

Agroforestry based land use system is a profitable as well as sustainable alternative for rehabilitation of ravine lands. In this context, ICAR-IISWC, Research Centre, Vasad has evaluated a Silvi-Pasture system of *Melia dubia* and Lemon grass with microsite modified planting techniques for establishment under ravine lands of Mahi River Fig. 12. This agroforestrysystem require lesser input and results in better growth and biomass yield. Therefore, this system could be better alternative for improving the livelihood of small and marginal farmers along with soil and moisture conservation (Jinger *et al.*, 2021). *Melia dubia* grows very fast and produce good quality material for plywood industry in short span and therefore known as money spinning tree. However, since the *Melia dubia* takes some years to reach the harvesting stage, mean while Lemon grass provides intermittent income throughout the year as it is being harvested thrice in a year and sold at rupees 10 per kg (Jinger *et al.*, 2020).

Fig. 12. ***Melia dubia*** **and Neem based agroforestry system for reclamation of medium and deep ravine**

Similarly, horti-silviculture system of Dragon fruit and *Melia dubia* along with *in-situ* soil moisture conservation measures developed in gully beds of Mahi ravine by the institute for reviving the ravine lands and augmenting the income of the farmers Fig. 13. Dragon fruit yield and its fruit quality obtained in ravine lands even without application of irrigation and nutrients has given excellent performance, showing it suitability for degraded lands. The Dragon fruit is also known as super fruit due to its antioxidant properties and less sugar content making it suitable for diabetes patient (Kakade *et al.*, 2020). Therefore, Dragon fruit based horti-silviculture system could be an alternative technology for reclamation and sustainable productive utilization of gullied lands.


Fig. 13. Dragon fruit and Sapota based agroforestry system for reclamation of medium and deep ravine

Further, crop based agro-forestry system of Castor, Cowpea and Sapota has been developed by the institute for reclamation of gullied and ravine lands Fig. 13. Bench terracing and trenching has not only reduced the soil loss and runoff but also produced higher system productivity under agroforestry system (Jinger *et al.*, 2022; Kumar *et al.*, 2021). This system is energy efficient and economicaly viable for small and marginal farmers of Central Gujarat.

Table 7. Site suitability and production potential of suitable tree and grass species for ravines

Name of Species	PD	PL	RP	BP	UP
Acacia nilotica	3 × 3	Hump top, slope, and ravine beds	15-20	20-25	Fodder, fuel, small timber
Acacia tortilis	3 × 3	Hump top, slope and ravine beds	15-20	40 to 60	Fuel, fodder
Azadirachtaindica	8 × 8	Marginal lands, hump top and beds	30-40	40-60	Fodder, fuel and timber
Balanitesaegyptiaca	1 × 1	Hump top and slopes	15-20	30	Fuel wood, MFP
Prosopisjuliflora	1×1 to 3×3	Hump top, slope and ravine beds	20-25	60-90	Charcoal, Fuel wood&fencing materials
Tamarixdioica	3 × 3	Swampy areas on gully bottom	15-20	20	Reclamation of saline soils, Fuel
Soymidafebrifuga	3 × 3	Marginal lands and hump top	20-25	20	Fodder, fuel and light timber
Eucalyptus tereticornis	2×2 to 3×3	Marginal lands, swampy areas on gully bottom	10 to 12	26 to 37	Poles & fuel wood
Albizzialebbek	6 × 6	Marginal lands, hump - top	25-30	85-90	Fodder and fuel

PD: Planting density in meters,
PL: Planting location in ravines,
RP: Rotation period in years,
BP: Biomass Production in t/ha,
UP: Useful product.

7. DEVELOPMENTAL PROGRAM IN MAJOR RAVINE REGION

Ravine reclamation works under taken by the institute in various outreach programmes in Chambal, Mahi and Yamuna ravine systems had evidenced benefit: cost ratio of 1.4 to 2.54. Post project evaluation of Badakhera ravine watershed in Bundi district of Rajasthan after 5 and 10 years of project completion recorded about three and six fold increase in cultivated land and gross irrigated area; and consistent improvement in cropping intensity from 65 to 175 % facilitating 386 % increase in total crop production. This amounts to nearly ₹40000/ per ha of additional income due to watershed interventions Fig.14. Added collateral benefits observed were increased productivity of non-arable lands, animal production systems and other livelihood activities. Intangible environmental and social benefits included reduced soil loss and runoff and improved quality and availability of drinking water as given in Table 8. Erosion control measures in Badakhera reduced runoff and soil loss by 78 and 68 % and facilitated conservation of nearly 90 % of rain water and prevented loss of about 28 tonnes of fertile soil per hectare annually. Hydrological monitoring of surface and groundwater suggested that 83 to 90 % of accumulated runoff in water harvesting structures contributed to groundwater recharge into aquifer (Ali *et al*.,2015). Ravine area restoration has strong climate change impact mitigation value through increased C-sequestration rates (Pande *et al*., 2016).

Fig. 14. Mechanical measures for reclamation of ravines

8. CONSERVATION MEASURES AND INVESTMENT ON FARM IN RAVINE LAND

Though the marginal agricultural lands in ravines perceive occurrence of high runoff and soil loss affecting crop production, the individual efforts to adopt conservation measures were found lacking. Survey in Mahi ravines revealed that the majority of farms (more than 60%) in the three categories (marginal, small and medium), in fact, got conservation measures (field bund) done initially through the state agency and these beneficiaries of government programs realized positive benefits and also purchased table lands to grow cash crops.This helped them to earn profit, part of which was invested on maintenance of conservation measures. The average investment on maintenance varied from ₹40 per meter to ₹135 per meter of earthen field bund (at 2011-12 prices). Further, the farms without state assistance were observed to be incurring losses in crop production Fig. 15.

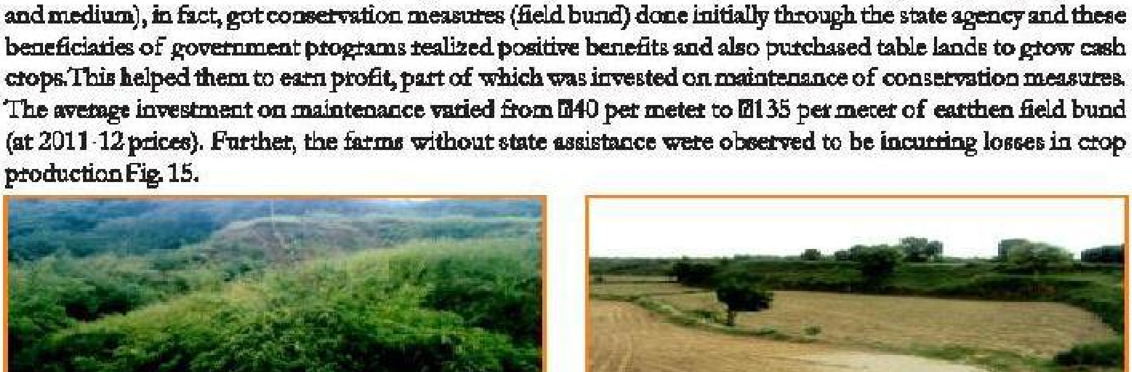

Fig. 15. Conservation measures for development of ravine land

The costs and returns distribution on farms revealed farms with state assistance to be better off than those without assistance. In fact, this explained the differential pattern of small investment on farm among different land classes. The latter groups of farms were observed to be lacking in economic incentive to invest on land. Benefit cost analysis of crop production, done with 10 % discount rate and 30 years period of analysis considering private opportunity cost analysis, revealed that farms with state assistance realized positive present value of net benefits but those farms with no assistance realized negative net benefits. In other words, the latter group of farms would hardly have any incentive to invest on land in future. Further, the net benefit realized by even farms with state assistance, particularly marginal farms, was too small to induce them to invest on land. The marginal, small and medium farms realized a net present value of annual net benefit ranging from ₹ 131 ha^{-1}, ₹ 997 ha^{-1} and ₹ 1624 ha^{-1} on marginal, small and medium farms, respectively at 2011 12 prices. This explains the lack of economic power to invest on maintenance of conservation measure despite perception about runoff and soil loss. Also it strengthens the argument that holistic development of farm and addressing the issue of farm profitability could, to some extent, pave the way for required levels of investment on conservation measures. The ratio of farm harvest price for pearl millet and the consumer price index for agricultural labour was examined to study the real domestic price realized by pearl millet growers in the region. The ratio, which reflected the average purchasing power of a rupee earned from this major crop, was not found favourable to farmers. In such a scenario, price incentive in pearl millet would not induce farm profitability, as revealed in the private opportunity cost analysis and, hence, had little incentive effect for farmers to invest on land. Incentive to invest on land examination of investment behaviour of small and marginal farms identified factors such as cash crop and credit worthiness of a farmer to be significantly affecting the decision to invest on land in general and conservation in particular. Income received from cash crop affected investment decision. Only those small and marginal farmers which had received state help in the past were able to lease-in parcel of table land and grow cash crop on such levelled land. Income from cash crop enabled them to invest on land levelling and bunding on other land parcels near ravines. The marginal farmers in the ravines, being vulnerable to low productivity and profitability, are unable to make investment on land. Initial state help in terms of conservation programme is essential to break the vicious circle of poor productivity, low farm returns and absence of investment on land. Credit worthiness of farmers was another factor affecting investment decision. Policies can be framed to offer loan for land development on small/ marginal farms at easier terms and conditions. Or else, programmes can be designed to make these groups of farmers inclusive in the financial plan of banking and non-banking institutions to address the problem of improving production on farm. This would help them arrest the process of land degradation in the long-run. Land tenure variable turned out to be weak in the study area, implying that tenure security itself had little impact on marginal farms. This is contrary to the established fact about effects of land tenure security on the incentives for farmers to make investments on land improvements, including investments in soil conservation practices (Feder and Nishio, 1998). In fact, the small scattered holdings in ravines probably holds little scope for land tenure security and, hence, as incentive for investment decision on farm in this region. In addition, the irregular slopes of these lands, lying adjacent to the ravines leave little room for improvement and thus, enhancing farm profitability. Thus, this policy variable is likely have a little role in adoption of conservation measures.

Table 8. Expected intangible benefits and its valuation techniques from various reclamation interventions in ravines land

Expected benefits	Variables	Valuation techniques
Prevention of soil erosion	Agriculture land protected from liable to loss	Land valuation
	Additional area brought under cultivation	Additional income
	Riverbed widening and depletion of carrying capacity	Damage function
	Appreciation in land value	Willingness to pay method
	Nutrient loss saved	Value of soil dredging cost
	Improvement in quality of land	Irreversible loss technique

Environmental	Ground water recharge (volume)	Nominal value or TFP approach
	Carbon sequestration	Hedonic pricing
	Recreation value	Hedonic or bidding game
	Flood protection	Damage function
	Drought mitigation	Risk approach
Livestock	Dung saved	Economic value
	Checking of migration	Travel cost
	Diseases incidences	Damage function
	Availability of fodder	Gain in production trails
Bio-diversity	Succession of economically important species	Economic value
Social benefits	Education	Literacy rate
	Social status	Assets value
	Equity	Index
	Women empowerment	Representation in CBO/PRI
	Migration	Income

The problem of land degradation in general and adoption of conservation measures in particular must find a place in the holistic development of small and marginal farms. Accordingly, the incentives mechanisms to motivate land tiller must be designed addressing the holistic farm development in view. It is further argued that in the present cost and price scenario, returns on farm make the marginal farms susceptible to a vicious poverty circle. The input and output prices prevailing in the region do not favour pearl millet based farming enterprise. Thus, price policy would have little impact on farm profitability and thereby, the incentive to adopt conservation on farm. Such farms need an initial dose of state help to break poverty circle. The facts gathered during field surveys have clearly brought out that the farms benefiting from past conservation programme of the state government have done better than those who were deprived of it. The farms with state assistance have been able to lease-in better piece of land and take cash crop to raise their profit level. Land tenure has not turned out be a significant variable affecting decision to invest on farm. This has been explained in terms of the size and bio-physical nature of such marginal land holdings in the ravine region. Credit worthiness, however, has shown a positive and significant relation with on-farm conservation decision. Financial help from banking institutions could improve their credit worthiness, thus, helping them invest on their land. The scope of present policy of financial inclusion could, thus, be broadened to resolve the issue of poor farm productivity and address the problem of land degradation in this region.

9. ECONOMIC VIABILITY OF THE RAVINE RECLAMATION PROGRAM

Ravine reclamation technology disseminated though various outreach programmes of ICAR-IISWC institution so far has extended about 1.7 M ha as indicated by 62.5 % reduction in ravine lands of four major ravine states namely Uttar Pradesh, Madhya Pradesh, Rajasthan and Gujarat. Nevertheless, only 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 year 2014, ICAR-IISWC submitted a consultancy report to National Bamboo Mission, Government of India, on 'Reclamation of ravine lands for productive utilization' which involved delineation of ravine area in Uttar Pradesh, Madhya Pradesh, Rajasthan and Gujarat; assessment of developmental potential of these lands; and preparation of detailed plan for ravines area development. The tentative estimated average treatment cost is about ₹1, 30,000 per ha. Economic viability and cost distribution of proposed project is given below in Table 9 and Table 10, respectively. For reclaiming about one million hectare of identified ravine land in four states the project cost would be about ₹13,000 crores. The ravine area development is also a climate change impact mitigation activity and therefore, international funding needs to be explored for such a cost intensive programme.

Some collateral research, developmental and policy initiatives are required to ensure scientific and sustainable development of these fragile and complex ecosystems as given in Table 11. To facilitate scientific planning at micro level there is a need to establish centralised repository of high resolution digital maps of ravine regions and initiate collaborative research for developing decision support system and planning tools. Up-scaling of ravine technologies can further be achieved through establishing benchmark model ravine development projects in representative agro-ecological zones and applying GIS modeling, IT and web technologies. There is also a need to create a national level nodal unit to expedite and coordinate ravine reclamation programme and address policy gaps. Restoration of ravine lands would be a crucial step forward for safeguarding our natural resources and shall be a national priority in the backdrop of Hon'ble Prime Minister's drive for doubling farmers' income.

Table 9. Economic viability of benchmark ravine restoration projects

Name of ravine cluster	NPV(□ in millions)	B:C ratio	IRR (%)
1. Manikpura (Yamuna)	35.65	1.49	27.6
2. Bagheshwari (Lower Chambal)	67.05	2.46	31.5
3. Bagli (Upper Chambal)	107.63	1.84	33.4
4. Khorwadshilli (Mahi)	85.31	2.10	24.0
Discount rate: 10%; Project life: 25 Years			

Table 10.Tentative percent cost distribution of ravine restoration project components

Various budget component	Per cent of total
1. Administrative costs	2.0
2. Monitoring, Evaluation	0.5
3. Institution and Capacity Building	1.0
4. Detailed Project Report (DPR).	1.0
5. Soil & water conservation measures	75.0
6. Installation of lift irrigation system	10.0
7. Plantation in non-arable lands	8.0
8. Other Livelihood activities	2.0
9. Consolidation phase	0.5
Total	100

It can be concluded that in order to promote the interest of ravine area farmers for sustainable development, their capacity building by training needs should be addressed. Economically viable technological solutions developed by ICAR-IISWC are very well demonstrated through various outreach programmes and have reached about 1.7 M ha of ravine land in Uttar Pradesh, Madhya Pradesh, Rajasthan and Gujarat since 1976. The resource poor farmers of the ravine areas can be empowered by giving exposure on the improved technologies of production systems and soil and water conservation through organizing appropriate trainings. The well-designed training curriculum on relevant aspects will provide adequate knowledge and skills in adopting soil and water conservation measures on private and community land. This will help in conserving most scarce natural resources and enhancing productivity of the ravine areas.

Table11. Core issues and proposed strategies for ravine reclamation planning

S. No.	Core Issues	Proposed Strategies
1.	**Highly Fragile & Complex Ecosystem** ▪ Severe terrain deformation ▪ Very low soil productivity ▪ Highly erodible soils ▪ Frequent back flow ▪ Unstable slopes ▪ Pot hole and cracking behaviour ▪ Excessive biotic pressure ▪ High risk of failure for conservation measures ▪ High variability in bio-physical conditions	**Facilitating Scientific Planning** ▪ Capacity building of field functionaries. ▪ Careful analysis of terrain conditions and hydrological behaviour of the project area. ▪ Selection of time tested, location specific and cost effective conservation measures. ▪ Provide sufficient planning time ▪ Ecosystem monitoring at benchmark project sites. ▪ Provision for mid-term evaluation and quality control mechanism. ▪ Reduce biotic pressure through fuel and fodder alternatives, habitat improvement in degraded ravines and formation of ERC or VFMC etc. ▪ Selection of project areas in phased manner
2.	**Need for Cost Intensive Management** ▪ Preference for cultivation ▪ Climatic uncertainties	**Ensure Economic Viability of Production System** ▪ Priority to reclaim private lands for cultivation. ▪ Provision for micro irrigation system. ▪ Manage biotic and abiotic risks ▪ Increase cropping intensity and consider high value crops. ▪ Introduce improved packages for crop and animal production systems. ▪ Provision for flexible developmental cost
3.	**Resource Constraint Community** ▪ Extreme poverty ▪ Small holding size ▪ Low & unstable crop yields ▪ In adequate alternate livelihood support systems	**Strengthening Livelihood Support** ▪ Increased crop production and house hold income. ▪ Establishment of SHG and alternateself-employment opportunities. ▪ Introduction of improved animal based production systems ▪ Skill development for livelihood activities.
4.	**Social Resistance to Change** ▪ Lack of awareness and initiatives ▪ Disintegrated communities ▪ Unequal distribution of benefits ▪ Lack of effective village institutions ▪ Illegal land occupancy	**Community Empowerment** ▪ Sensitization and awareness generation camps ▪ Training modules and exposure visits for beneficiary house hold ▪ Ensure gender and social equity ▪ Ensure effective community participation in planning and execution processes ▪ Maintain complete transparency ▪ Establish and strengthen village level Institutions
5.	**Inadequate Policy and Political Support** ▪ Lack of political will ▪ Low priority areas ▪ Weak law enforcement ▪ Inadequate market support ▪ Lack of policy framework ▪ Lack of budget provisions	**Policy Framework** ▪ Realistic problem assessment framework ▪ Develop functional linkages between research and developmental agencies ▪ Land use policies with suitable tenure provisions ▪ Exploring possibility for employing PPP model ▪ Provision for effective law enforcement ▪ Establish market support for specific products
6.	**Project Unsustainability** ▪ Dependence for external support ▪ Lack of effective village institutions	**Post Project Sustenance Mechanism**

10. THE WAY FORWARD FOR RECLAMATION OF RAVINE

Land is a finite resource and demographic pressure is ever increasing. For sustainability of our fragile ecosystem on one hand and fulfilling all the developmental aspirations of present as well as future generation on other hand we have to cultivate and utilize every inch of our land in most scientific and productive manner. The India is one of the first countries to commit United Nation Convention to Combat Desertification Sustainable Development Goal to achieve the land degradation neutrality by 2030 during COP-14 held at New Delhi in September, 2019. India will restore an additional 5 M ha of degraded land by 2030, raising the land to be restored in India to 26 M ha. Arable lands along the major ravine zones are marginal lands which needs greater scientific management and developmental interventions so that they can be cultivated in a sustainable manner. Poor soil fertility, imbalance fertilization, soil moisture deficit or excess, mono-cropping, outbreak of major insect-pest and diseases, lack of choices of crops due to wild life damage are major agronomical issues which needs attention for higher production and profit from these marginal lands. These lands are threatened by excess water during some part of the year and are also devoid of proper soil moisture for supporting two or more crops for the rest period of the year. Safe disposal of excess rain water during rainy season and conserving or storing it for raising post-monsoon season crops can bring revolution in these marginal lands. The marginal arable land along the ravine systems are lacking proper drainage network due to varied reasons which results in complete submergence of the field crops at the time of heavy downpour.Developing such type of drainage network and linking it to a water storage structure in a cluster manner can solve the dual problem of excess water during monsoon and raising post monsoon crops. This harvested rain water can be judiciously utilized for crop production by means of micro irrigation systems. This will increase the farm productivity as well as cropping intensity of the marginal lands along the ravine system. Round the year availability of quality irrigation water in the perennial rivers along the ravine is a major opportunity for agriculture development of these regions. This water can be utilized for crop cultivation, animal husbandry as well as drinking purposes by means of lift irrigation. Installation and successful operation of these type of irrigation systems is a need of the hour. Farmers of these regions are doing subsistence farming which can be converted into integrated farming through scientific intervention by integration of livestock, poultry, apiary, fishery, etc. for round the year employment, higher profit as well as complementarity of enterprises. This can be made possible through exposure visits to the fields of progressive farmers and capacity development of the target group. Another major issue is the damage to field crops by wild life, which possess a major threat for higher production as well as restricting choice of growing high value crops in these areas. This type of menace can be tackled by means of community efforts by installing various type of fencings at large scale. Various type of suitable bio-fencing plants are available which can be planted along the farm boundaries for checking wildlife damage. Integration of suitable forestry and horticulture plantation by means of agroforestry and agri-horti systems in the marginal arable lands can enhance farm productivity as well as minimization the risk of wild life damage. There are various research, developmental, extension and policy issues which need greater attention in a more holistic way to utilize these lands in profitable manner while conserving it for future generation. Though various potential technologies are available for higher production but their lack of site suitability and scale neutrality is a major hindrance. A better framework of technology development, refinement and application in the field for scientific crop production from these fragile systems is needed for sustainable development of these marginal lands. In addition to this there exists an inter-temporal trade off in the decision making of farmers with respect to conservation investment. The investments often have long pay back periods and reduce short term household incomes. The critical question is whether long term benefits would be sufficient to compensate farmers' immediate costs.Therefore, ravine ecosystem can become an important milestone in achieving the food and nutritional security in coming decades through reclamation of ravine land with different site specific interventions as discussed above. There is a great opportunity for providing sustainable livelihood to the resource poor people of these regions though reclamation of the ravine with people's participation. An integrated approach with production system for bio-process industry will also generate employment opportunities for local people. In addition to this ravine reclamation is expected to mitigate climate change through carbon dioxide sequestration. Therefore, ravine reclamation should need to be on priority for the policy makers to achieve the future sustainability goals.

11. REFERENCES

Ali, S., Sethy, B. K., Singh, R. K., Parandiyal, A. K., & Kumar, A. (2017). Quantification of hydrologic response of staggered contour trenching for horti-pastoral land use system in small ravine watersheds: A paired watershed approach. *Land Degradation & Development, 28*(4), 1237 1252.

Ali, S., Singh, R.K., Sethy, B.K. (2015). Field application of a dynamic potential groundwater recharge simulation model for small recharge ponds. *Applied Engineering in Agriculture*, ASABE, 31(2): 267-279. DOI 10 13031/aea.31.10516.

Ben-Zhi, Z., Mao-Yi, F., Jin-Zhong, X., Xiao-Sheng, Y., Zheng-Cai, L. (2005). Ecological functions of bamboo forest: research and application. *Journal of Forestry Research, 16*(2), 143-147.

Dagar, J. C. (2018a). Ravines: formation, extent, classification, evolution and measures of prevention and control. In *Ravine lands: greening for livelihood and environmental security* (p. 19-67). Springer, Singapore.

Dagar, J. C. (2018b). Perspectives of vegetation ecology and biodiversity for management of ravine lands. In *Ravine lands: greening for livelihood and environmental security* (p. 69-118). Springer, Singapore.

Dagar, J. C. & Singh, A. K. (2018). Greening Ravine Lands: Policy Issues and the Way Forward. In *Ravine Lands: Greening for Livelihood and Environmental Security* (p. 601 615). Springer, Singapore.

Dhruva Narayan, V.V. (2017). Soil and water conservation research in India (Third edition). Agronomic measures in soil and water conservation. p. 153-174, Indian Council of Agricultural Research, New Delhi.

Dhruva Narayana, V.V. (1993). Soil and Water Conservation Research in India, ICAR, New Delhi, p. 449.

Feder, G. and Nishio, A. (1998). The benefits of land registration and titling: Economic and social perspectives. Land Use Policy, 15: 25-43.https:// doi. org/ 10. 1016/j. geode rma. 2019. 114093.

Jinger, D., Kakade, V.D., Kaushal, R., Dinesh, D., Bhatnagar, P.R., Singhal, V. (2021). Rehabilitation of degraded lands through different planting techniques in Meliadubia Cav. *Food and Scientific Reports*2(1): 7-9.

Jinger, D., Kakade, V.D., Singhal, V., Dinesh, D. (2020). Lemon grass: A Lucrative Crop for Degraded Lands of Central Gujarat. *Agriculture & Environment E-newsletter* 1(3): 26-29.

Jinger, D., Kumar, R., Kakade, V., Dinesh, D.,Singh, G., Pande, V.C., Bhatnagar, P.R., Rao, B.K., Vishwakarma, A.K., Kumar, D., Singhal, V. (2022). Agroforestry system for controlling soil erosion and enhancing system productivity in ravine lands of Western India under climate change scenarios. *Environmental Monitoring and Assessment*. https://doi.org/10.1007/s10661-022-09910-z.

Kakade, V.D.,Jinger, D., Dayal V., Charan, S., Nangare, D.D., Wakchaure, G.C., Dinesh, D. (2020). Dragon fruit: wholesome and remunerative fruit crop for India. *Food and Scientific Reports*1(12): 44-48.

Kumar, R., Bhardwaj, A.K., Rao, B.K., Vishavkarma, A.K., Bhatnagar, P.R., Patra, S., Kumar, G., Kakade, V., Dinesh, D., Pande, V.C., Singh, G., Dobhal, S., Sharma, N.K. (2020). Development of degraded ravine lands of Western India via Sapota (*Achraszapota*) plantation with terracing vs. trenching on slope based conservation measures. *Land Degradation & Development, 32*(1), 101-111. *Land Degradation & Development*. DOI: https://doi.org/10.1002/ldr.3691.

Kurothe, R.S., Singh, H.B., Tiwari, S.P., Pande, V.C., Bagdi, G.L., Sena, D.R., Vishvakarma A.K., Kumar, G. (2013). Fifty years of research in soil and water conservation. CSWCRTI, Research Centre, Vasad, India, p. 10-100.

Meadows, M. E. and Hoffman, M. T. (2002). The nature, extent and causes of land degradation in South Africa: Legacy of the past, lessons for the future? Area, 34(4): 428 437.

Meena, D. C., Parandiyal, A. K., Kumar, D., & Dogra, P. (2021). Evaluation of farming systems of degraded lands of Yamuna ravines in Central India for income generation and sustainable livelihoods. *Indian Journal of Soil Conservation, 49*(1), 50-58.

National Commission on Agriculture (1976) Part V Resource Development. Government of India, Ministry of Agriculture and Irrigation, New Delhi, 189-196.

Pande, V.C., Kurothe, R.S., Kumar, G., Singh, H.B., Tiwari, S.P. (2016). Economic assessment of agri-horticulture production systems on reclaimed ravine lands in Western India. Agroforestry Systems, DOI 10.1007/s10457-016-0025-x.

Pande, V.C., Kurothe, R.S., Rao, B.K., Kumar, G., Parandiyal, A.K., Singh, A.K., Kumar, A. (2012). Economic analysis of bamboo plantation in three major ravine systems of India. Agricultural Economics Research Review 25(1): 49 59.

Pande, V.C., Kurothe, R.S., Singh, H.B., Tiwari, S.P. (2011). Incentives for Soil and Water Conservation on Farm in Ravines of Gujarat: Policy Implications for Future Adoption. Agricultural Economics Research Review, 24(1): 109-118.

Parandiyal, A. K., Sethy, B. K., Somasundaram, J., Ali, S., &Meena, H. R. (2020). Potential of Agroforestry for the Rehabilitation of Degraded Ravine Lands. In *Agroforestry for Degraded Landscapes* (pp. 229-251). Springer, Singapore.

Pena, S.B., Abreu, M.M., Magalhaes, M.R., Cortez, N.(2020). Water erosion aspects of land degradation neutralityto landscape planning tools at national scale. Geoderma.

Rao, B.K., Kurothe, R.S., Singh, A.K., Parandiyal, A.K., Pande, V.C., Kumar, G. (2012). Bamboo plantation based technological interventions for reclamation and productive utilization of ravine lands. CSWCRTI. *Technical Bulletin No*, 30.

Sharma, H.S. (1980). Ravine erosion in India. Concept Publication, New Delhi,p. 96.

Sikka, A. K., Mishra, P. K., Singh, R. K., Krishna Rao, B., & Islam, A. (2018). Technological interventions for managing Ravine lands for livelihood and environmental security. In *Ravine lands: greening for livelihood and environmental security* (p. 217-236). Springer, Singapore.

Singh G., Mishra,P.R. and Bullian, S. 1966. Ravine ravage must be controlled. Indian Farming, XVI (3): 21-22.

Singh, A.K., Kala, S., Dubey, S.K., Rao, B.K., Gaur, M.L., Mohapatra, K.P., Prasad, B. (2014). Evaluation of bamboo based conservation measures for rehabilitation of degraded Yamuna ravines. *Indian Journal of Soil Conservation, 42*(1), 80-84.

Singh, B. and Verma, B. (1971). A comparative study of the economics of various soil conservation-cum-grass land improvement practices for rejuvenating forage production in ravine lands, (Forage production). *Indian Forester*, 97 (6): 315-321.

Singh, G., Babu, R., Narain, P., Bhushan, L.S. and Abrol, I.P. (1992). Soil erosion rates in India. Journal of Soil and Water Conservation 47 (1): 97 99.

Singh, G., Kumar, R., Jinger, D., Dhakshanamoorthy, D. (2020). Ecological Engineering Measures for Ravine Slope Stabilization and Its Sustainable Productive Utilization. In (Ed.), Slope Engineering. IntechOpen. https://doi.org/10.5772/intechopen.94136.

Singh, R.K., Kurothe, R.S., Kumar, A., Ali, S., Singh, A.K., Mishra, P.K. (2021) Ravine Land Management. DKMA Publication, ICAR, New Delhi.

Soni, M.L., Subbulakshmi, V., Renjith, P.S., Dagar, J.C., Yadava, N.D. (2018). Reclamation of ravine lands for higher production. In: Dagar, J.C., & Singh, A.K. (Eds). Ravine lands: Greening for livelihood and environmental security. Springer Nature Singapore, p. 279–307. https://doi.org/10. 1007/ 978- 981- 10-8043-2_12.

Tejwani, K.G., Gupta S.K., Mathur, H.N. (1975). Soil and water conservation research in India. (1956-71) I.C.A.R. Publication, New Delhi, India, p. 254-310.

Wang, Y., and Liu, Y. (1995). Hydrological characteristics of a moso-bamboo (Phyllostachyspubescens) forest in south china. *Hydrological Processes, 9*(7), 797-808.

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