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Economic assessment of bamboo based soil conservation interventions for reclamation of degraded ravine lands in India: implications for policy intervention

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Abstract: The study attempted to assess the economic feasibility of bamboo plantation in general and its role as reinforcement to soil conservation measures in particular, with implications for reclamation of degraded lands in ravine ecologies in India. Biophysical data, both primary as well secondary, collected from Mahi ravines in Gujarat and supported with on farm research data were economically analyzed. The study suggested that the bamboo based soil conservation measures were financially as well as economically viable. The biophysical data collected from fields suggested the effectiveness of the bamboo based conservations measures in similar conditions elsewhere. The study recommends to replicate the interventions and give financial incentives to the group/ village community to meet the initial high cost of establishment. Such initiatives of ravine reclamation programme could be converged with land based schemes of central and state governments like MGNREGA, National Bamboo Mission, Green Climate Fund of NABARD or such similar schemes in India. The large-scale bamboo establishment costs could be partly met with assistance from such schemes and the remaining maintenance and protection costs of plantation could be met by the group/ village society towards environmental services provided by the locational bamboo ecosystems. The implications for large scale reclamation of degraded gullied lands in the country have been drawn based on the results.

Keywords: Bamboo, soil conservation, economic assessment, ravine land, policy intervention

INTRODUCTION

Soil provides basis for all vegetation sustenance and, therefore, reducing erosion for sustenance of vegetation is crucial. Soil erosion has drawn the attention of researchers, policy makers and practitioners alike. Maintaining vegetative cover as a panacea for maintenance of land cover, soil conservation and land productivity has been well documented (Tripathi and Khawlhring, 2010). Vegetation plays its role at multiple

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levels, viz., canopy cover, surface cover and sub–surface cover (Wischmeier, 1975; Grey and Leiser, 1982; Greenway, 1987; Meyers, 1993; Gray and Sotir, 1996). The implication of vegetation for reclamation is vital on degraded land (Guangyu *et al*., 2008) in general and gullied land across the river systems (Higaki *et al*., 2007) in particular. More so in latter because of the positive soil conservation effects of vegetation planted in gullies.

Ravines are a system of gullies formed along the course of river systems. These net works of gullies spread over river banks are fragile ecosystems that affect the production systems in the adjoining areas. These encroach upon the catchment area with the flow of river water during rains. Such active gully systems commonly develop in unconsolidated alluvial materials due to changing patterns of land use and associated change in catchments hydrology (Ahmad, 1960; Sharma, 1968 & 1979). Ravines, world over, are posing threat to local/ regional agro ecologies and need urgent attention. In India, ravines are largely spread in the states of Uttar Pradesh, Rajasthan and Gujarat of India. These three states cover 2.08 mha (56.7%), out of the 3.67 mha ravine area in the country. Nearly 389,000 ha area is affected along the Yamuna in southern Uttar Pradesh (Dhruva Narayana, 1993). The Chambal ravines are spread along the river Chambal in about 10 km wide belt. An area of 5000 km^2 along the Chambal tributaries is also affected by ravines (*ibid*). In Gujarat, ravine belt are spread in 0.5 mha extending from banks of river Tapi, Narmada, Watrak, Sabarmati and Mahi basins (*ibid*).

Bamboo, a versatile grass species, can help reclaim gullies as it can be grown on steep hillsides, gully beds and along river banks through its interlocking root system and leaf deposit which inhibit soil erosion (Austin *et al*., 1983). Bamboo plantation is useful for enhancing natural resource conservation (Lawler, 1993; YanHui *et al*., 1995). In addition, benefits of living biomass and soil organic matter content in bamboo stands have been well reported (Wu, 1983; Wen, 1990; Huang *et al*., 1993; Lan *et al*., 1999; Zheng *et al*., 1997; Lin *et al*., 2004; Tong, 2007; Zhou *et al*., 2005) as also low soil erosion in bamboo plantation as against other forest plantation. The biological characteristics of bamboo make it a perfect tool for solving many environmental problems such as erosion control and carbon sequestration. On account of extensive rhizome-root system and accumulation of leaf mulch, bamboo serves as an efficient agent in preventing soil erosion, conserving moisture reinforcement of embankments and drainage channels (Zhou *et al*., 2005). The increased permeability of the soil reduces surface run-off, evaporation loss, allows better water penetration into the soil and increases drainage capacity of the soil. Bamboo conserves soil moisture and mitigates the adverse drought effects on flora and fauna (Sharma *et al*., 1992). Further, bamboo based agroforestry models are reported to improve ecological parameters of a highly degraded basaltic land (Behari *et al*., 2000). Average ranges of annual interception and stem flow in bamboo plantations have been reported to be in the range of 13 - 15% and 4 - 6%, respectively (Lu, *et al*., 2007) which looks a bit higher than those under natural hard-wood forests, due to special canopy characteristics.

The effect of bamboo plantation as soil conservation measure, however, has little mention in the literature. Therefore, a study was initiated to examine the effect of bamboo plantation supported with soil conservation measures in the reclamation of the gullied lands. Economic analysis of the bamboo based interventions in gullied land reclamation has been attempted for large scale adoption by stakeholders at local, regional and national level. This will help policy makers, funding agencies and non government organization embarking upon ravine reclamation programmes.

MATERIALS AND METHODS

This study is based on data collected from a research study conducted in Mahi ravine system in the Gujarat state in Western India (Figure 1). Government of India set up a research centre to study Mahi ravine and its reclamation measures at Vasad, Gujarat towards the end of First Five Year Plan. The climate of Vasad region is semi-arid, with an average annual rainfall of 850 mm. Around 98% of this rainfall is received during June to September. The Mahi ravines are broad-based U-shape gullies (Dhruva Narayana, 1993) and the parent material at the bank of river Mahi is quite deep with clay to clay loam, light textured soil. The research center has carried out extensive studies on bamboo plantation and its reclamation potential in degraded ravine land. *Dendrocalamus strictus* has been found to be successful. Experiments were conducted with different bamboo based interventions at Research Farm of Vasad and village community land, Khorwad, both located in Mahi ravine land (Table 1).

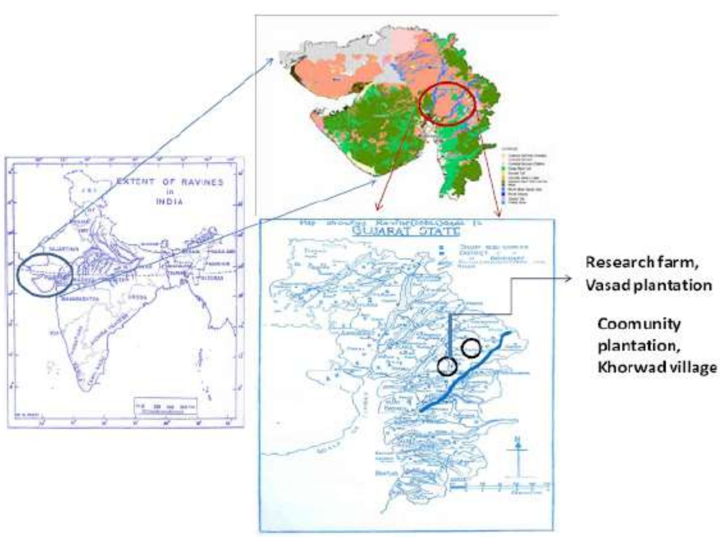

Figure 1. Study sites of Mahi ravines, Gujarat

Table 1. Details of the study sites at Mahi ravines

Details	Research farm, Vasad	Khorwad village[+]
Latitude, Longitude	$22^0$27'28"N 73^0 4' 43"E	$22^0$34'12"N $73^0$08'52" E
Altitude (m above sea level)	18.9	44.0
Rainfall (mm)	850	850
Temperature range (^{0}C)	10.7 – 39.0	11.0-39.0
Soil	Sandy loam to Sandy	Sandy loam to Sandy
Vegetation	Tropical Ravine Thorn Forest	Tropical Ravine Thorn Forest

[+] Community bamboo forest

Experiment details

The bamboo based interventions and the general plantation was done in the year 2008-09 under the National Bamboo Mission funded study. The two sites were selected for carrying out the experiment. The data included, conservation measures adopted prior to bamboo plantation, bamboo survival, growth, input and output details of bamboo plantation in ravines. The data pertained to the period 2009-10 through 2014-15. The bamboo pole harvest started in the year 2014-15.

Bamboo as reinforcement to soil conservation measures was tested in three different ways, viz., i) bamboo plantation with staggered contour trenches ii) bamboo plantation supported by bori bunds iii) bamboo plantation as Live check dams.

Bamboo plantation with staggered contour trenches

Staggered contour trenches of 0.5 m (width) X 0.5 m (depth) X 2.0 m (length) were dug out at 4.0 m X 4.0 m spacing in ravine beds across the slope (Fig. 2). The excavated soil was heaped on downstream side of the trench in the form of a bund for retention of moisture, prior to start of rains. Bamboo seedlings were planted besides the trench. Equal volume of soil along with 1 to 3 kg of FYM was refilled after planting and then firmly compacted.

Bamboo plantation with check dam made of sand bag (bori bund) supported supported by bamboo

Under this intervention, in degraded gullies, series of earthen check dams of woven (HDPE) polythene bags, locally available empty fertilizer or cement bags, filled with earth (*bori bund*) were constructed (Fig. 3). The earth filled polythene bags of 3 rows at bottom, 2 rows at middle and one row at top were kept to maintain the stable slope. After keeping these bags, soil was filled on top and sides and grass sodding/sowing was done for strengthening. At one end of the bund the top bags were removed and kept at up- and down-stream to serve as outlet. Along each *bori bund*, two rows, one each at upstream and downstream edge of bamboo saplings was planted with plant to plant spacing of 2 m. The bamboo plantation provided strength to the *bori bund*. In between the check dams general bamboo plantation were done with 4 m X 4 m spacing in staggered manner.

Bamboo plantation as live check dams

Under this intervention, bamboo saplings were planted in two staggered rows with 2 m X 2 m (plant to plant and row to row) spacing to act as live check dam (Fig. 4) without any soil and water conservation measures. The spacing between two live check dams was kept 10 m. In between the live check dams bamboo plantation were done at 4 m X 4 m spacing in staggered manner. After 4 to 5 years of plantation these staggered rows will act as live check dam and minimize runoff and soil loss.

Figure 2. Bamboo plantation with staggered contour trench

Figure 3. Check dam made of gunny bags filled with soil (*bori bund*) supported with bamboo

Figure 4. Bamboo planted at close spacing (2x2m) as live check dam

Data collection

The primary data of different treatments and bamboo plantation was regularly recorded over the period of experiment. The input data included field preparation, soil and water conservation measures, plantation, maintenance and harvest of bamboo poles (culms). The primary data of different treatments and bamboo plantation in Mahi is presented in Table 2.

Table 2. Basic data for working out cost of cultivation of bamboo in different bamboo based interventions (Base Year for the costs, 2014-15)

Description	Bamboo plantation
Plants (No./ ha)	625
Mortality Replacement (%)	20
Manure required (Kg per plant per year)	10
Fertilizer required (Kg per plant per year)	0.02
Cost of Fertilizer ($ / Kg)	0.35
Irrigation Cost ($/plant)	0.04
Irrigations (No./ year)	15
Seedling price ($ / No.)	0.15
Planting cost ($ / No.)	0.15
No. of harvestable plants per ha (%)*	30
Sale price per bamboo pole ($/pole)	0.78

* Harvesting done every alternate year during the production cycle, Rs 64 = $1
Source: Experimental data collected from field

The total cost of bamboo plantation in ravines is accounted for by: (1) land preparation (2) treatment cost (trench/ bori bund/ live checkdam) (3) plantation cost including planting material, (4) protection and maintenance, which included irrigation, cleaning of bamboo clump. Major expenditures in the first year included treatment, irrigation followed by establishment (site preparation and planting). The remaining expenditures were spread over the next four years, primarily for mortality replacement, irrigation and cleaning and thinning of clump from years 2 to 4. The cleaning and thinning of clumps every alternate year is critical to ensure the shape of the new culm, as this governs the price fetched by the bamboo pole. Similarly, bamboo harvest, which starts at 7th year in ravines, is done regularly (at 3 year felling cycle) to ensure higher culms per clump over the production cycle of bamboo in ravines (Duhruva Narayana, 1993). Capital cost of the bamboo based interventions was considered in the first year. The cost of bori bund (bund made of plastic bag filled with soil) supported with bamboo plantation was arrived at considering cost of bund, plantation and maintenance cost of bamboo at 1m X 1m spacing in two staggered rows in the up stream and down stream of the bori bund. Similarly, cost of bamboo as live check dam was estimated as two rows of staggered planting of bamboo at 2m X 2m spacing. Trenching cost was estimated based on the earth work rate prevailing in the area. The primary data on plantation was collected from the plantation sites at the selected representative gullies at the research farm, Vasad and the community bamboo plantation at Khorwad village in Anand district of Gujarat state. The costs were extrapolated on per hectare basis. The number of bamboo culms per clump harvested in the 7th year was, similarly, projected for one hectare in the three treatments.

The constant input and output prices for the year 2014-15 were considered to account for inflation. The harvest price of bamboo at farm gate was considered as these were realized at the research farm. This was justified on the ground that no organized market and identified marketing channel for bamboo sale existed in the ravines. The costs of the interventions viz., 'check dam made of sand bags (*bori bund*) supported with bamboo', 'trenching' and 'bamboo as live check dam' worked out to be 1264.5 \$ ha^{-1}, 776.4 \$ ha^{-1} and 1099.3 \$ ha^{-1}, respectively (Tables 3-5). The costs of bamboo plants, planting, irrigation and harvesting slightly varied depending upon the number of plants in different bamboo plantations. The present value of total cost including bamboo plantation at 4m X 4m spacing over a period of 20 years worked out to be 7424.5 \$ ha^{-1}, 5841.4 \$ ha^{-1}and 6997.9 \$ ha^{-1} in 'bori-bund supported with bamboo', 'trenching' and 'bamboo as live check dam' interventions, respectively. Out of which 24%, 27% and 28% is spent in the first year. Capital cost on treatment mainly accounts for the major share followed by the irrigation.

Table 3. Cost components ($/ha) in bamboo plantation with staggered contour trench (2014-15 prices)

S.No	Items	1 year	II year	III year	IV year	V to VII years
I	**Material**					
1	Planting material including 20% mortality replacement	94.8	18.9	18.9		
2	Manure and fertilizers (DAP)	3.5				
3	Plant protection chemical	9.3				
4	Irrigation, 15 Nos.	341.3	341.3	341.3	341.3	
II	**Labour**					
1	Land cleaning	156.2				
2	Cost of trenching	878.9				
3	Planting and staking	94.8	18.9	18.9		
4	Thinning and inter culture*				208.5	
5	Protection	46.8	46.8	46.8	46.8	46.8
6	Harvesting - 7th year onwards[@]					776.4

* Every alternate year from 4th year onwards during the production cycle

[@] Harvesting done every alternate year from 7th year onwards during the production cycle, Rs 64 = $1

Source: Authors' estimation from experimental data collected from field

Table 4. Cost components ($/ha) in bamboo plantation with check dam made of sand bags (bori bund) supported with bamboo (2014-15 prices)

S.No	Items	1 year	II year	III year	IV year	V to VII years
I	**Material**					
1	Planting material including 20% mortality replacement	79.8	15.9	15.9		
2	Manure and fertilizers (DAP)	3.5				
3	Plant protection	9.3				
4	Irrigation, 15 Nos.	351.5	351.5	351.5	351.5	
II	**Labour**					
1	Land cleaning	156.2				
2	Pitting	119.7	23.9	23.9		
3	Bori bund supported with bamboo plantation	991.9				
4	Planting and staking	79.8	15.9	15.9		
5	Thinning and inter culture*				210.0	
6	Protection	46.8	46.8	46.8	46.8	46.8
	Harvesting - 7th year onwards[@]					1264.5

* Every alternate year from 4th year onwards during the production cycle

[@] Harvesting done every alternate year from 7th year onwards during the production cycle, Rs 64 = $1

Source: Authors' estimation from experimental data collected from field

Table 5. Cost components ($/ha) in bamboo plantation with bamboo as live check dam (2014-15 prices)

S.No	Items	1 year	II year	III year	IV year	V to VII years
	Material					
1	Planting material including 20% mortality replacement	63.4	12.7	12.7		
2	Manure and fertilizers (DAP)	3.5				
3	Plant protection	9.3				
4	Irrigation, 15 Nos.	351.5	351.5	351.5		
	Labour					
1	Land preparation	156.2				
2	Live check dam of bamboo	1292.0				
3	Planting and staking	63.4	12.7	12.7		
4	Thinning and inter culture*				214.8	
5	Watch & Ward	46.8	46.8	46.8	46.8	46.8
6	Harvesting - 7th year onwards[@]					1099.3

* Every alternate year from 4th year onwards during the production cycle
[@] Harvesting done every alternate year from 7th year onwards during the production cycle, Rs 64 = $1
Source: Authors' estimation from experimental data collected from field

The output data included the bamboo poles harvested and the harvested poles per clump were 12, 7 and 11 in 'bori-bund supported by bamboo', 'trenching' and 'bamboo as live check dam' treatments, respectively. In case of 'bamboo as live check dam' and 'bori bund supported with bamboo' interventions, the area lost was accounted for while computing the harvested bamboo culms per hectare. Based on this, the available bamboo harvested for sale per hectare worked out to be 6225, 3822 and 5412 in 'bori-bund supported by bamboo', 'trenching' and 'bamboo as live check dam' treatments, respectively. Bamboo is observed to have a productive cycle of 40 years in ravine lands, the present analysis, however, was conducted for a period of 20 years. The market discount rate of 8% was used, though its sensitivity was analyzed using different discount rates. For economic analysis, a social discount rate of 5.9% was used (Atkinson *et al*, 2006) based on an estimate of a social discount rate for India.

Data analysis

Runoff and soil loss estimation

The bamboo based bio engineering measures were applied at three independent gullied lands. The runoff and soil loss were measured, for each rainfall event, at each gully outlet by constructing brick masonry hydraulic control structures and installing mechanical water stage recorders. The measurement was done for gullies put under bamboo based soil conservation measures as well as control (gully without measure). For each treatment, event based rainfall (depth, duration, and intensities), runoff (depth, duration, and rates) were measured. The runoff samples collected at the out let for each rainfall event were analyzed in the laboratory for assessing soil loss per unit volume of runoff.

Economic analysis

Discounted cash flow technique has been used to evaluate the bamboo based technological interventions in gullied land. The valuation approach in this analysis varies between individual and social perspectives of the inputs used in the technological interventions and the outputs accrued as well as discount rate used in the analysis. In the social perspectives inputs imported are valued at the international price realized at the project level. Similarly, social discount rate prevailing in the economy is used in the analysis. Bamboo plantation uses local inputs, hence, local prices prevailing in the region are used from both private and social perspectives. However, social discount rate for the country was used along with market rate for social and financial analysis, respectively.

Benefit-Cost Analysis

This has been widely used in the natural resources to help assess the economic efficiency, from society's point of view, of a production system. Discounted cash flow is used for this analysis. It attempts to identify and quantify costs and benefits to society/ individuals over a specified time period. This type of analysis is useful in the case of bamboo, where the objective is to develop and implement techniques for environmental soil and water conservation, soil improvement, and increase the area under plantation. In ravines bamboo not only provides the much needed timber but also can be used as soil conservation measure. The costs and benefits of those objectives are not only shared or consumed by specific individuals but by 'society' or groups within society.

There are three main criteria by which a single or set of techniques can be assessed and compared. These are:

(i) Benefit-Cost Ratio

This is simply the total of the present worth of expected benefits divided by the total of the present worth of expected costs. A production system with a ratio of greater than one is economically efficient in terms of resource use.

$$\text{Benefit-cost ratio} = \frac{\sum_{t=1}^{n} B_t (1+r)^t}{\sum_{t=1}^{n} C_t (1+r)^t}$$

ii) Net Present Worth

This is the difference between the present worth of the expected benefits and the present worth of the expected costs. Production systems which result in a positive net present worth are economically efficient in terms of resource use.

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

(iii) Internal Rate of Return

This is defined as the average earning power of the value of resources used in the production system. It is simply the discount rate used to estimate present worth cost and benefits at which net present worth becomes zero. A production system that give a rate of return higher than the existing market interest rate are resource efficient.

The formal mathematical statements of these criteria are given below:

Internal rate of return is that discount rate 'r' such that $\sum_{t=1}^{n} \frac{(B_t - C_t)}{(1+r)^t} = 0$

where, for t^{th} year

B_t = benefits in each year, t = 1, 2, ...n

C_t = costs in each year, t = 1, 2, ...n.

n = number of years.

r = discount rate.

Annual equivalent value

This gives the net present value in annual equivalent values distributed equally over the life span of the enterprise. This helps in the comparison of different production systems on annual basis over the time horizon (Godsey *et al*., 2009). When bamboo based intervention in ravines are compared on annual return basis Annual Equivalent Value (AEV) comparison is meaningful in arriving at the decision by the land owners, particularly the big farmers owning parcels of gullied land. In addition, this will also help the financing institutions in taking decisions about long term finance to group of such land owners and/or local management bodies such as tree cooperative societies and panchayat bodies.

$$AEV = NPV \left[\frac{r\,(1+r)^t}{(1+r)^t - 1}\right]$$

Where,

NPV = Net Present Value

r = Interest (discount) Rate

t = Time Period

Indirect benefits of soil conservation due to plantation

Indirect benefit was assessed in terms of sediment retained by the bamboo based soil conservation interventions. Soil erosion may affect downstream reservoir, commercial fish production pond, recreational lake down stream and the river, the ravines drain into. Erosion carries topsoil off fields, which reduces the land's productivity, besides affecting the dead storage of the reservoir down strem. Replacement cost approach was used to impute resource value to soil erosion avoided (Hufschmidt *et al.*, 1983; Dixon and Hufschmidt, 1986; Dixon *et al.*, 1994). The soil loss from degraded ravine lands moves to adjacent Mahi river. The cost of dredging the silt from dead storage of river was used to impute a value to the silt retained by the conservation measures. Average dredging cost of Rs 135/ CMT was used. This is the average of dredging cost spent by the Dredging Corporation of India in different dredging projects across the country from 2005 to 2015. The soil bulk density 1.44 gm/cc was used to change it to per tonne. The silt retained due to conservation interventions was analyzed for nutrient content. Assuming this silt to be uniformly distributed in the plantation site, the retained nutrients in the soil sample were valued at the annual marginal cost of their replacement artificially (Drechsel *et al.*, 2004). It assumed that the productivity of soil could be maintained if the lost nutrients and organic matter were replaced artificially. This justified use of Replacement Cost Approach. The basic premise of the replacement cost method is that the cost incurred in replacing productive assets damaged by an economic activity can be measured and interpreted as benefits if the damage were prevented.

The resource value of soil erosion can be given as under (Kumar, 2004);

$$B = \sum_{n=1}^{N} \frac{P_i D_i}{(1+r)^n}$$

Where,

$_iP$= Price of i[th] nutrient supplemented though a fertilizer

$_iD$= Quantity of i[th] nutrient lost through soil erosion

r= discount rate

n= number of years

RESULTS AND DISCUSSION

Bamboo production

The biological (vegetative) measure for soil and water conservation has been extensively used along side mechanical measures of erosion control, particularly in degraded lands. The advantage of former is, besides preventing the runoff and soil loss, there is addition of biomass into the soil thereby improving the soil properties. Deep and narrow gullies are recommended to be put under permanent vegetation of grasses and trees (Dhruvanarayana, 1993). The bamboo based soil conservation interventions were made during the rainy season and preparations for these interventions were completed prior to onset of monsoon. Bamboo plantation was done after soaking rains occurred and sufficient moisture was observed in the gullies. After execution of conservation interventions, the gullies were put under bamboo plantation at 4m X 4m spacing to examine the conservation effect on production. The impact of different bamboo based soil conservation interventions on bamboo growth parameters and runoff & soil loss in the gullies was systematically measured through regular monitoring and data collected on different parameters such as survival, growth, runoff and soil loss, bamboo pole harvest.

The bamboo plant survival data from various treatments in different ravine systems varied from 40 - 80%. From the data it is observed that highest survival (up to 80%) were recorded in gully beds treated with bamboo plantation with supportive staggered trenches followed by bamboo plantation with earthen check dams. The higher survival in these treatments is mainly due to prolonged moisture availability. The growth period of bamboo is 2-3 months after rains, during which time they attain their full height and diameter. The development of lateral branches takes place during the second season of growth. After the first season, solidification and hardening of culms take place. There is an initial short period of 14-18 days showing maximum rate of growth (22-33 cm/day) accounting for 25 to 56 per cent followed by moderate growth (11 to 16 cm/day) and subsequently slow growth (9 to 13 cm/day). During the day time, height increment is about 40 percent as against 60 percent during night. Maximum growth per day is 37 cm.

Bamboo saplings planted during 2008 were measured for different growth parameters in the year 2014-15. The average height was observed to be maximum under check dam made of sand bags supported with bamboo treatment (353 cm), followed by staggered trenches (330 cm) (Table 6). Similar trend was observed for clump diameter. Check dam made of sand bags supported with bamboo treatment recorded the maximum clump diameter (154 cm). This is followed by trench (151 cm) and live check dam (111 cm), respectively. The total bamboo poles (culms) per clump increased over the period and the average number of culms per clump increased from 16, 11 and 5 in bori bund, trench and bamboo as live check dam, respectively in 20011 to 37, 21 and 35, respectively in 2014. The yield from bamboo depends on annual rainfall and its distribution. The harvest of bamboo started in 2014-15 and the bamboo poles harvested varied from 3822 Nos. ha^{-1} in plantation with staggered contour trench to 6225 Nos. ha^{-1} in bamboo plantation with bori bund supported by bamboo. The good growth of bamboo in Mahi ravine lands is attributed to good soil depth and the moisture conserved through the interventions. Besides, the high stem flow amount and funneling ratio of bamboo plants in comparison to deciduous and coniferous plants makes better rainfall absorption and hydrologically best suited plantation in degraded ravine lands (Rao *et al.*, 2012).

Table 6. Bamboo plantation growth parameters under various bamboo based soil conservation interventions, Mahi ravines

Soil conservation interventions	Average height of clump (cm)	Average diameter of clump (cm)	Average collar diameter (cm)	Averaged number ofculms/ clump	Number of culms harvested per clump
Bamboo plantation supported with staggered contour trench	330.3	150.7	2.40	21	7
Bamboo plantation with check dam made of sand bags[#] supported with bamboo	353.0	154.1	2.72	37	12
Bamboo plantation with bamboo as Live Check dam	281.0	111.4	1.94	35	11

[#] Gunny bag filled with soil
Source: Experimental data collected from field

Runoff & soil loss

While mechanical measures have been recommended in gullies to prevent runoff and soil loss followed by tree plantation, bamboo based conservation measures with bamboo plantation have shown potential for productive and protective utilization of such degraded lands in addition to soil conservation benefit. In addition, the vegetative measures cost less than the mechanical measures (Kumar, 2004). Bamboo was observed to be quite promising both in terms of controlling runoff and soil loss in Mahi ravines. The gullied watershed with bamboo plantation retained more than 80% of rainfall that was either utilized by the plant or percolated deep, to recharge the ground water. Due to less runoff, soil loss was reported to reduce to less than 1t/ha/year from about 20 t/ha/year in degraded ravines as a result of bamboo plantation (Kurothe and Nambiar, 2001). Similar observation were taken under the three different interventions and it was observed that lowest runoff (67 mm) and soil loss (3.78 t/ha) was recorded in bamboo plantation with bori bund (earthen check dams made of sand bags filled with soil) followed by bamboo plantation with staggered trenches (runoff 104 mm, and soil loss 5.62 t/ha) in comparison to control watershed (runoff 183 mm, and soil loss 11.72 t/ha) (Fig 5).

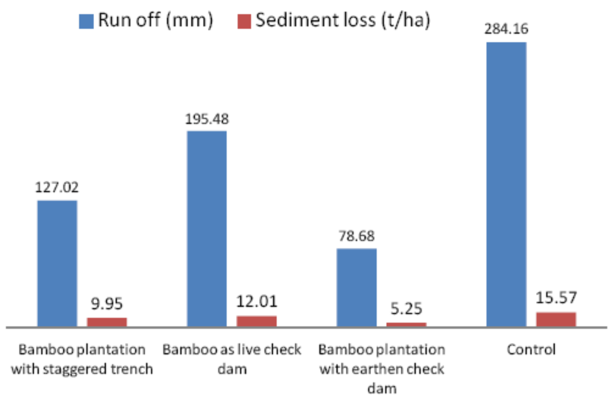

Figure 5. Runoff and soil loss in different bamboo based soilconservation interventions

Economic analysis of bamboo based interventions

The analysis was done both from the stand point of local farmers whose objective includes net returns from bamboo plantation and the community, whose objectives include environmental benefits apart from returns from the degraded ravine lands. This justified relevant policy interventions by local, regional and national governments. Both financial and economic analysis was done considering financial (interest rate) and social discount rates for the two analyses, respectively. No input required for the production system included imports, hence local prices were considered for social analysis.

After six years of plantation, one third of the culms per clump can be regularly harvested once in three year cycle (Dhruvanarayana, 1993) giving income to stakeholders. The remaining two third culms sustain the above and below ground environment by conserving soil and providing a sink to atmospheric carbon. The production benefit outweighed the soil conservation benefit which is true for all forest species including bamboo plantation in ravine lands. This is explained in terms of tradeoff between provisioning and regulating/ supporting services from forest and grass species including bamboo. Higher emphasis to former as compared to latter resulted in more production benefits realized as bamboo poles were harvested from 7th year onwards. The bamboo plantation in gully bed helped retain silt from loss through runoff (Table 7). The most effective intervention was check dam made of sand bags (*bori bund*) supported with bamboo. It reduced sediment loss by 10.35 t/ha followed by staggered contour trench which reduced sediment loss by 5.62 t/ha in comparison to control (no intervention). This sediment prevented nutrient loss from the field (Table 8). The annual indirect benefit of silt detention by conservation interventions was valued in terms of dredging cost prevented and replacement cost of nutrient supplement avoided. The per hectare annual benefit of silt retained was estimated as $ 236, $ 122.3 and $ 46.9 for 'trenching', 'bori-bund supported by bamboo' and 'bamboo as live check dam' interventions, respectively (Table 9).

Table 7. Sediment loss under different bamboo based interventions

Bamboo based interventions	Sediment loss (t/ha)
Bamboo plantation with Staggered Contour Trench	9.95
Bamboo plantation with check dam made of sand bags supported with bamboo	5.25
Bamboo plantation with Bamboo as Live Check dam	12.01
No intervention (Control)	15.57

Source: Experimental data collected from field

Table 8. Nutrient in soil profile under different bamboo based interventions

Bamboo based interventions	Avail K kg/ha	Avail P kg/ha	Avail N kg/ha	OC %
Bamboo plantation with Staggered Contour Trench	96.3	5.8	101.0	0.4
Bamboo plantation with check dam made of sand bags supported with bamboo	101.3	6.9	81.3	0.3
Bamboo plantation with Bamboo as Live Check dam	110.4	6.5	57.9	0.4
No intervention (Control)	105.4	7.2	83.2	0.5

Source: Experimental data collected from field

Table 9. Annual value of indirect benefits of silt and nutrient retained due to different bamboo based interventions

Bamboo based interventions	Indirect annual benefits of interventions over control			Present value of total indirect benefit of soil conservation over 20 year production period ($ ha^{-1})#
	Silt retained ($ ha^{-1}) *	Nutrient content in silt retained ($ ha^{-1})		
		Available K$	Available N@	
Bamboo plantation with Staggered Contour Trench	13.7	-	15.4	236
Bamboo plantation with check dam made of sand bags supported with bamboo	15.1	-	-	122.3
Bamboo plantation with Bamboo as Live Check dam	5.2	0.58	-	46.9

*Valued at average dredging cost (Rs 135/ cmt) of different channels and ports by Dredging Corporation of India, $ Valued at Rs 7.4/ kg, @ Valued at Rs 55.5/ kg, # Discount rate 5.9%, Rs 64 = $1, Source: Authors' estimation from experimental data collected from field

Beside resource conservation, bamboo has production value from the degraded ravines. The financial analysis of bamboo plantation in different treatments revealed that for a 20 years production period, the net present worth were 21162.7 \$ ha^{-1} in bamboo plantation supported with 'staggered contour trench', 5611.7 \$ ha^{-1} in 'bori bund supported by bamboo' and 4334.7 \$ ha^{-1} in bamboo plantation with bamboo as live check dam (Table 10). Similarly, the benefit cost ratio worked out to be 1.7, 1.4 and 1.6 in 'bori-bund supported by bamboo', 'trenching' and 'bamboo as live check dam' interventions, respectively. The internal rate of return (IRR) revealed that bamboo plantation performed better in 'bori bund supported by bamboo' intervention with a rate of return (19.7%) followed by 'bamboo as live checkdam' (17.59%) and 'trench' (14.1%) among the three bamboo plantation. The IRR in bamboo plantation elsewhere support our findings for ravine lands (Ying *et al*., 2010). This indicates a profitable option for local stake holders. This financial analysis suggests upfront financing of the bamboo based interventions by banking as well as no-banking financial institutions on large scale.

The annual equivalent value varied from 220.3 \$ ha^{-1} in bamboo plantation supported with staggered contour trench to 571.5 \$ ha^{-1} in bamboo plantation with bori bund supported by bamboo plantation (Table 11). The analysis suggests that bamboo plantation with conservation measures supported with bamboo is financially viable.

The economic analysis done considering indirect benefits and social discount rate of 5.9% revealed similar trend (Table 12). The net present worth were estimated as 3656.9 \$ ha^{-1} in bamboo plantation supported with 'staggered contour trench', 7976.1 \$ ha^{-1} in 'bori bund supported by bamboo' and 6304.4 \$ ha^{-1} in bamboo plantation with bamboo as live check dam.

Table 10. Financial analysis of bamboo plantations in different treatments, Period 20 years, Discount rate 0.08

S.No	Treatments	Net Present Worth (\$ ha^{-1})	Benefit-cost ratio	Internal rate of return (%)
1	Bamboo plantation with Staggered Contour Trench	2162.7	1.4	14.1
2	Bamboo plantation with check dam made of sand bags supported with bamboo	5611.7	1.7	19.7
3	Bamboo plantation with Bamboo as Live Check dam	4334.7	1.6	17.5

Rs 64 = \$1, Source: Authors' estimation from experimental data collected from field

Table 11. Yield and annual return of bamboo plantations in different treatments

S.No	Treatments	Yield (Bamboo poles ha^{-1})	Annual equivalent value (\$ ha^{-1} $year^{-1}$)
1	Bamboo plantation supported with staggered contour trench	3822	220.3
2	Bamboo plantation with check dam made of sand bags (*bori bund*) supported with bamboo	6225	571.5
3	Bamboo plantation with bamboo as Live Check dam	5412	441.5

Rs 64 = $1, Source: Authors' estimation from experimental data collected from field

Recommendation

Though comprehensive assessment of services from bamboo ecosystems is desired, the findings of this study strengthens the arguments for provisioning, regulating and supporting services flow from bamboo based interventions in degraded ravines. The economic viability of the plantation indicates scope for policy option in financing such projects through local community. This can be achieved by involving development agencies, Government and Non-Government organizations. Further, bamboo production with different bamboo based conservation measures also has good potential for silt retention and carbon sequestration. National and international efforts for adaptation to climate change can also be redirected towards this as the ravine lands are potential areas of carbon sink. The green climate fund (GCF) created by National Bank for Agriculture and Rural Development (NABARD) (https://www.nabard.org /content.aspx?id=690) can be one vehicle for such financing. India has laid down ambitious goals under the climate agreement and greening ravines with bamboo based interventions is one such potential area. Low-cost finance from sources like the GCF would go a long way in achieving the objective. At national level, Corporate Social Responsibility (CSR) fund can also be diverted towards this objective. Restructured National Bamboo Mission approved by the Cabinet Committee on Economic Affairs (CCEA) in April, 2018 is a well beginning in that direction. The operational guidelines (NBM, 2018) calls for increase the area under bamboo plantation in non forest Government and private lands to supplement farm income and contribute towards resilience to climate change. The findings of this study strengthen the objectives of the mission. The local and regional governments should be encouraged to be an integral part of this mission.

Table 12. Economics of bamboo plantations including soil conservation benefits under different bamboo based interventions, Period 20 years, Social discount rate 0.059

S.No	Treatments	Net Present Value ($ ha^{-1})	Benefit-cost ratio	Internal rate of return (%)
	Considering direct benefits of bamboo poles alone			
1	Bamboo plantation with Staggered Contour Trench	3420.9	1.5	14.1
2	Bamboo plantation with check dam made of sand bags supported with bamboo	7853.7	1.9	19.7
3	Bamboo plantation with bamboo as Live Check dam	6257.5	1.7	17.5
	Considering both direct and indirect benefits of sediment conserved and nutrient therein			
4	Bamboo plantation with Staggered Contour Trench	3656.9	1.5	14.6
5	Bamboo plantation with check dam made of sand bags supported with bamboo	7976.1	1.9	19.9
6	Bamboo plantation with bamboo as Live Check dam	6304.4	1.7	17.5

Rs 64 = $1, Source: Authors' estimation from experimental data collected from field

However, the economics of bamboo based interventions in ravines is subject to protection of the plantation from biotic interferences. Ravines are only partly under private ownership. A large part of the ravine ecosystem is still under government control in India and falls under the jurisdiction of locally elected governing body called Panchayat. This institution is least equipped to bring the ravine lands under plantation. Property rights with given tenure and usufruct sharing mechanism is one such potential approach worth trying in the ravine ecosystems of the major river systems in the country.

The productive and protective benefits notwithstanding, large scale adoption of the bamboo based conservation interventions in ravines is constrained for want of market availability. An assured price and outlet for disposal would encourage the local stakeholders to adopt the interventions.

CONCLUSION

Putting the degraded ravines under bamboo plantation with bamboo based conservation measures is a profitable option to retire these lands into productive and protective use. The net present worth of bamboo based bio-engineering measures in degraded gullied lands was estimated to be varying from 4335 \$ ha^{-1} to 21162.7 \$ ha^{-1} making it worthwhile proposition for local dwellers with government support. Further, the environmental benefit of silt retention from loss into downstream rivers and reservoirs warrants strong policy intervention by local governments. The silt retention varying from 3.5 t ha^{-1} to 10.3 t ha^{-1} under different bamboo based bio engineering interventions strengthen this argument. Though present study estimated soil carbon alone, studies done elsewhere estimated a carbon stock of 381.5 t ha^{-1} in *Dendrocalamus strictus* (Tariyal *et al*., 2013). The financial and economic analysis done, even without considering the carbon in bamboo above ground biomass, were estimated to vary between 1.4-1.7 and 1.5-1.9, respectively. Among the bamboo based interventions, bamboo plantation with check dam made of sand bags supported with bamboo performed best in terms of bamboo poles and silt retention. The economic analysis also confirmed the highest annual equivalent value of returns (571.5 \$ ha^{-1} $annuam^{-1}$) from this measure. This suggests economic viability of bamboo based soil conservation measures in degraded ravine land and leaves scope for bank financing with technical backup to local dwellers. However, bamboo establishment in degraded gullies is capital intensive in initial couple of years and putting these lands into bamboo based productive protective use could be a constraint for group of small and medium stakeholders and Panchayati Raj Institutions (politically elected governing body at the local level) entrusted with the management of these lands in India. Bamboo survival in gully warrants protection from wild life in the first couple of years and the protection cost is high. Once a clump is established, the menace from wild life reduces and so is the cost of protection. Initial provision of fund for this would ensure a profitable cycle of bamboo in ravines.

Relevant government schemes encompassing subsidies and financial assistance can be of help. To address the issue, Government's Waste Land Development Programme, Mahtma Gandhi National Rural Employment Guarantee Act (MGNREGA) can be amended to link with greening of degraded lands in the country. Appropriate budgetary provisions can also be made for the public funding of these in the development plans of state, regional and corporate entities involved in the rural development in the country.

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