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EFFECTS OF SOIL EROSION ON AGRICULTURAL PRODUCTIVITY IN SEMI-ARID REGIONS : THE CASE OF LOWER CHAMBAL VALLEY

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ABSTRACT

Soil erosion is a world-wide challenge for sustainability of agriculture especially in the tropical region. The rates of soil erosion that exceed the generation of new topsoil are a dynamic process which leads to decline in the soil productivity, low agricultural yield and income. The balance between soil-forming and depleting processes is of utmost importance for attaining long-term sustainability in any production system. Land degradation in the form of soil erosion is a major problem in the semi-arid region of Lower Chambal Valley. In the present study Landsat satellite images for the years of 1977, 1990 and 2000 have been used to identify the change in degraded land in the region. Evidences suggest that the rate of encroachment of arable land is high and is equal to spreading rate of degraded land. The data obtained by field survey reveal that productivity of crop land is negatively correlated with share of degraded land to gross cropped area. The productivity of agriculture, measured through gross value of output per area, is comparatively high in villages having fewer shares of degraded land and vice-versa. Simple linear regression model explains high variation of productivity by high share of degraded land (above 50 per cent of gross cropped area). This paper provides evidences of the severity of land degradation and its close association with agricultural production of the region.

Introduction

Soil erosion is a world-wide challenge for sustainability of agriculture especially in tropical region. It is the process of detachment and transport of soil particles. Erosion can decrease rooting depth, soil fertility, organic matter in the soil and plant-available water reserves (Lal, 1987). The rates of soil erosion that exceed the generation of new topsoil are a dynamic process which may lead to a decline of soil productivity, and result in lower agricultural yield and income, at least in the long run. The balance between soil-forming and depleting processes is of utmost importance for attaining long-term sustainability in any production system. Soil being a non-renewable resource and the basis for 97 per cent of all food production (Pimentel, 1993), strategies to prevent soil depletion are critical for sustainable development. For developing suitable soil conservation strategies, knowledge of the prevailing and permissible rates of soil erosion is an essential pre-requisite. In order to adequately understand the complex issues

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related to land degradation, it is necessary to identify the underlying causes and gain a comprehensive understanding of the physical, economic, political, institutional and social dimensions.

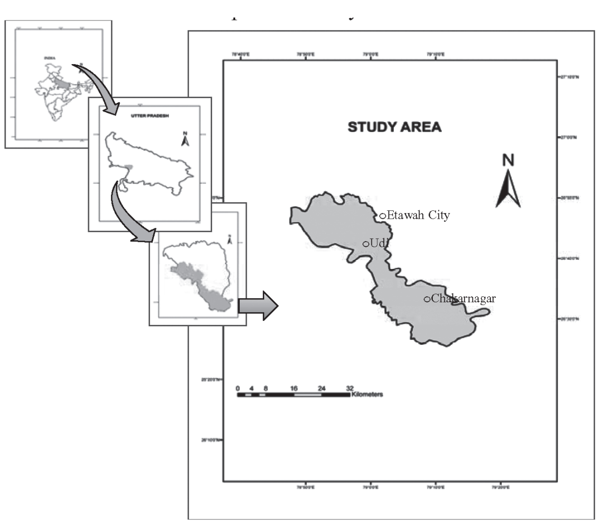
The question of sustainability of agriculture mainly focuses on production over an extended scale of time and space. This essentially would mean that crop production and economic gains would flourish over a long period of time, almost infinitely and globally (Van Loon, et al. 2004; Shah, 2006). It encompasses a range of strategies for addressing many of the problems such as loss of productivity from excessive erosion and associated plant nutrient losses; surface and groundwater pollution from pesticides, fertilisers, and sediment; impending shortage of non-renewable resources; and low farm income from depressed commodity prices and high production cost (Parr et al, 1990). Moreover, agricultural sustainability implies a time dimension and the capacity of a farming system to endure indefinitely (Lockeretz, 1988).

The problem of soil erosion is prevalent over 53 per cent of the total land area of India (Dhruvanarayana and Ram Babu, 1983). India loses about 16.4 t of soil ha^{-1} yr^{-1}, of which 29 per cent is lost permanently into the sea, 10 per cent gets deposited in the reservoirs reducing their capacity by 1–2 per cent every year and the remaining 61 per cent gets displaced from one place to another (Narayana, and Rambabu, 1983; Mandal and Sarda, 2011). The regions of high erosion include the severely eroded gullied land along the banks of the rivers Yamuna, Chambal. In these areas decline in the growth rates of agricultural production and productivity is a serious issue considering the questions of food security, livelihood, and environment.

Study Area

The study area is located in 25° 26' 30'' to 26° 50' 58''N latitude and between 78° 26'46" to 79° 18' 13''E longitude. It covers Badpura and Chakarnagar blocks of district Etawah, Uttar Pradesh. (Fig. 1). River Chambal forms

Figure 1 : Map of the Study Area



the southern boundary of Badpura block and further flow form Chakarnagar block. River Kunwari makes southern limit of this block. The region is characterised by sub-humid climate which experiences extreme temperature and rainfall conditions. The mean daily maximum temperature is about 42 °C and the mean daily minimum is about 26 °C. The summer is intensely hot, and dry. The average annual rainfall is 790 mm[2]. About 85 per cent of the annual normal rainfall is received during June to September. This entire area is known for its great expansion of gully and ravines, the region is inaccessible in character due to its irregular and undulating topography. These undulating and dissected alluvial terrains are known to provide safe hiding places for dacoits over the years.

Soil and Cropping Pattern : The soil of the region is sandy loam to loamy sand. Whole ravine area has poor soil with sticky and plastic in lower reaches. Kanker layer is generally found at the depth of 1 to 2 meters but in some places due to soil erosion it is exposed on surface. Because of long and continuous fluvial erosion a huge share of fertile land has gone out of plough. Moreover, due to this threat of land degradation, the water table has also gone down further retarding the development of irrigation facilities (Sharma, 1988). Within the ravine belt, there are some patches of land with accumulation of good soils that enabled the peasants to grow some crops.

The rabi (Syalu) and kharif (Unalu) are two main cropping seasons in the study area. The rabi season starts from the mid of October. Crop sowing of this season continues till mid-November and harvesting starts in late March and in April. Due to inadequate rainfall and absence of proper irrigation facility, low crop-productivity is a serious problem in the region. The kharif season starts with the onset of south-western monsoon from the end of June. Sowing is generally done in mid-July. In case of continuous rainfall the heavy textured soil that retains more moisture, brings some difficulties in tillage operation. It's harvesting starts in end of October and continues till December. The major portion of the total agricultural area in the surveyed villages is used for food crops. Commercial crops are occupying very little area. The main crops of rabi are wheat, mustard, gram, while the kharif crops are sinhua, bajra, pulses (pegion pea), jowar. As pointed out in Table 1, in Sahso and Rajpur, bajra followed by wheat and mustard are the major crops; in Bedhupur the major crops are mustard, wheat and bajra, respctively.

Objectives

The broad objective of this paper is to identify the impact of soil erosion of the study region. More specifically, the objectives are:

* To delineate the degraded land cover change in the study area
* To estimate the impact of soil erosion on agricultural productivity.

Database and Sampling Methods

Sampling Design : The study is based on both remote sensing as well as the household level primary data collected from three villages in the study area. The villages were selected on the basis of severity of land degradation which has been identified in the beginning through the Landsat data. Initially the Landsat MSS data of 1977 and Landsat ETM data of 2000 were used to prepare land cover maps of respective years by visual interpretation and on-screen digitisation method. The maps were later on superimposed by the village boundary for the selection of final villages according to the severity of the degradation for field survey. Although all these surveyed villages are part of ravine affected Chambal Basin area, the magnitude of degradation differs among these villages. As the first step, a degraded area was identified on the basis of satellite imagery and

Table 1: Percentage Share of Major Crops in Gross Cropped Area

Crops	Sahso		Rajpur		Bedhupur	
	Cultivators	Area	Cultivators	Area	Cultivators	Area
Wheat	38 (47.50)	221 (25.9)	67 (52.34)	301 (25.2)	60 (73.17)	362 (35.2)
Bajra	53 (66.25)	359 (42.3)	118 (92.19)	406 (33.9)	34 (41.46)	189 (18.4)
Mustard	47 (58.75)	195 (22.9)	68 (53.13)	270 (22.6)	51 (62.20)	]422 (41.0)
Peagon-pea	5 (6.25)	47 (5.5)	28 (21.88)	93 (7.7)	2 (2.44)	7 (0.7)
Gram	3 (3.75)	21 (2.4)	23 (17.97)	62 (5.2)	11 (13.41)	32 (3.1)

Note: (i) Area in bigha.; (ii) In share of cultivators, the total is more than 100 as farmers cultivate multiple crops. The share in GCA excludes the share of minor crops.

Source: Field Survey, 2009.

among the villages in the area, three villages were selected on the basis of information gathered from key informants and field observations. These villages represent different levels of land degradation in the study region. Out of the three selected villages, Sahso is considered as severely affected, Rajpur as moderately affected and Bedhupur as less affected village by land degradation.

In order to collect household-level data a questionnaire was prepared and was canvassed in the sample villages. Fieldwork was conducted during May, 2009. In total 295 households of three selected villages of the study area were surveyed. All households of each village were surveyed and information about farm holding size, cropping pattern, agents causing damage to crops and crop production, degraded land etc. were collected from households.

The village Sahso is situated on the right bank of river Yamuna. Population of this village is 677. Deep ravines and gullies affected land with babul trees extended in the east known as Hanumantpura Reserved Forest and Sahso Reserve Forest in west. Chambal river flows in north and Kunwari in south. A narrow Chambal-Kunwari plain is in its south. Chakarnagar-Sindos link is connecting it with rest of the world. Block headquarter is five kilometers far from here. Rajpur is settled on middle of Yamuna Chambal table-land. Both the north and south side of this table-land is moderately affected by land erosion. It is connected with Chakarnagar-Pachnada roadway. Chakarnagar, the block headquarters is on two and half kilometers distance. Bedhupur village is expended in finger shape in southern side of mid-Yamuna-Chambal plain of Badahpura block. Block headquarter is seven kilometers far from here. The southern part of this village is engulfed by gully and ravines of Chambal. The village is linked with Udi-Bah roadway that is the lifeline of this region.

The expansion of degraded land has been delineated with the help of Landsat images (1977, 1990 and 2000) and Survey of India topographic sheets of referenced area. Association of degraded land and productivity has been examined by correlating share of degraded land and productivity of land in rupees (Gross Value of Output per bigha of land). Prices of crops have been calculated according to local market price in 2009. To find out the relationship between crop productivity (dependent variable) and degraded land (independent variable), regression analysis has been attempted here. The form of any linear relationship between a dependent variable Y and an independent variable X is given as:

$$Y = \alpha+\beta x+U$$

Where the constants α and β are the intercept and slope of the straight line, respectively and u is the error term. Y is the variable whose values are being predicted from the independent variable x.

Results and Discussion

Agrarian Structure and Production Conditions : The agrarian structure is an important dimension of the agricultural economy of a region. Before proceeding to an analysis of land degradation and its impact on agriculture we have presented an overview of the agrarian structure of the villages through size-class wise distribution of operational holdings and area (Table 2). The agrarian structure in the study area is dominated by small and marginal holdings, accounting for about 97 per cent of holdings and 84 per cent of area. The share of marginal holdings is highest in Rajpur, but by and large, the same pattern is observed in all study villages.

Encroachments of Arable Land : Most part of this land is affected by erosion in the studied region. There are two large patches of plain. One of them is between Yamuna and Chambal,

Table 2 : Size-Class wise Distribution of Operational Holdings and Area

Villages	Marginal(<1.0 ha)		Small 1-2 ha)		Medium (2-5 ha)		Large (>5 ha)		Total	
	Area	Holdings	Area	Holdings	Area	Holdings	Area	Holdings	Area	Holdings
Sahso	17.36 (30)	54 (67.5)	34.71 (60)	25 (31.25)	5.79 (10)	1 (1.25)	0 (0)	0 (0)	57.86 (100)	80 (100)
Rajpur	37.49 (30)	92 (71.87)	53.73 (43)	32 (25)	17.49 (14)	3 (2.34)	16.24 (13)	1 (0.78)	124.95 (100)	128 (100)
Bedhupur	21.69 (29)	55 (67.07)	44.13 (59)	25 (30.49)	8.98 (12)	2 (2.44)	0 (0)	0 (0)	74.79 (100)	82 (100)
All	76.53 (29.7)	201 (69.31)	132.57 (54)	82 (28.28)	32.25 (12)	6 (2.07)	16.24 (4.3)	1 (0.34)	257.60 (100)	290 (100)

Note : Area in hectare. Figures in brackets refer to row totals.

Source : Field survey, 2009.

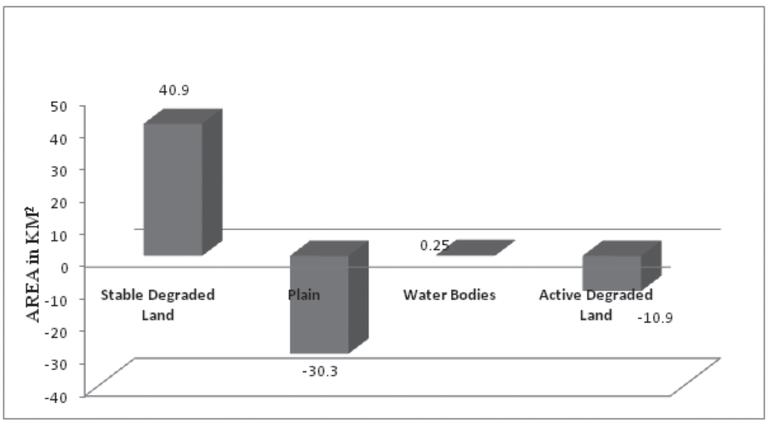
whose continuation is broken by headward erosion in the middle of the study area. The western Yamuna-Chambal table-land has its length around 23 kilometers that narrows at both ends. The eastern part of this plain that is separated from it have maximum length 13 kilometers with five kilometers maximum width also narrowing at both ends. Another big plain is in north of Yamuna and The plain between Chambal and Kunwari that is broken in many patches by headward erosion of ravines and gullies of both streams. Due to ravine expansion this land has been decreased by 44.6 to 40.7 per cent in period of 1977 to 2000. The distribution of land area among the various land cover classes, based on the land cover maps prepared from the Landsat images, has been given in Table 3[1].

It has been found that around half of the area of this region is under ravine activities. These are expanded along all four major streams. As a result of that a narrow belt of loamy plain left between Yamuna-Chambal and Chambal-Kunwari rivers. Almost all the plain between Chambal–Kunwari is eroded by streams. In middle of the region at many places the headward erosion in gullies and ravine of Chambal are combined themselves with degraded sites of Yamuna. Few plain areas are left in the form of patches there.

The village-wise share of degraded land in Net Cropped Area (NCA) has been presented in Table 4. It is found that among the study villages the highest incidence of land degradation in absolute amount is in Rajpur, but as a share of NCA is highest in Sasho, followed by Rajpur and Bedhupur.

Rate of Encroachment : As per our estimate of degraded area from satellite images, 46.6 per cent area of total region has been identified as degraded land in 1977 and it has increased to 50.4 per cent in 2000. The share of degraded land in total land has increased by 3.83 per cent; the area of stable degraded land has increased by 40.9 km^2 and active degraded land is decreased by 10.9 km^2 in referenced period (Figure 2). Hence total increase in degraded land is 30 km^2. On other hand, area under plain land is decreased by 30km^2 in the same time period. Thus, the expansion rate of degraded land is approximately same with the reduction rate of plain land. Therefore, it can be concluded that all the reduced plain land is converted into degraded land.

Figure 2 : Changes in Land Cover in the Study Area: 1977-2000



Source : Computed from Landsat images of 1977, 1990 and 2000.

Table 3: Distribution of Land Cover Classes

Land Cover Classes	1977		1990		2000	
	Km^2	%	Km^2	%	Km^2	%
Stable Degraded Land (Vegetation Cover)	49.9	6.4	46.9	6.0	90.8	11.6
Plain	349.8	44.6	333.1	42.5	319.5	40.7
Water bodies	69.1	8.8	69.5	8.9	69.3	8.8
Active Degraded Land	315.8	40.2	335.1	42.7	304.9	38.9
Total	784.5	100	784.5	100	784.5	100

Source : Computed from LANDSAT images of 1977, 1990 and 2000.

Impact of Soil Erosion on Productivity

The impact of degradation on socio-economic condition of a society comes through many ways. The direct impact of degradation can be identified in the variations of agricultural output. The magnitude of degradation decides its degree of impact, however, this impact is affected by a number of socio-economic and agro-ecological variables. Soil's physical degradation affects crop growth and yield by decreasing root depth, water availability and nutrient reserves. Thus, it leads to yield loss by affecting soil organic carbon, nitrogen, phosphorus, and potassium contents and soil pH. For example, as Scherr (1999: 8) points out, 'the effects of soil degradation vary with the types of soil, crops, extent of degradation and initial soil conditions and may not be linear. Lower

Table 4 : Share of Degraded Land and Cropping Intensity

Villages	Reported Net Cropped Area	Gross Cropped Land	Total Degraded Land to NCA	% of Degraded Intensity	Cropping
SAHSO	686.4	849	360	52.44	123.69
RAJPUR	1132.2	1194.32	478.72	42.28	105.49
BEDHUPUR	887.24	1028.5	188.6	21.26	115.92
ALL	2705.84	3071.82	1027.32	37.96	100.52

Note : Area in bigha.

Source : Field survey, 2009.

potential production due to degradation may not show up in intensive, high input system until yields are approaching their ceiling. Reduced efficiency of inputs (fertilisers, water, and biocides, labour) could show up in higher production costs rather than lower yields'.

Crop Productivity : In surveyed villages the lowest land productivity, as measured by Gross Value of output per bigha, is in Sahso, that is severally affected by land erosion. It is highest in Bedhupur. The area under degraded land has been presented in Table 4. About half of the households in Sahso village have reported to have degraded land with an average of 4.5 bigha per household. Thirty nine per cent of households in Rajpur and Bedhupur have been reported to have degraded land with an average of 3.74 and 2.30 bigha / household, respectively. On an average, degraded land per household is 2.4, 1.5 and 0.9 bigha in Sahso, Rajpur and Bedhupur, respectively. The estimates of village-wise cropped area, gross value of output and yield in agriculture are given in Table 5.

Regional variation in agricultural productivity is the result of various factors like the agro- ecological conditions of land, the variations of labour force employed in the agricultural practices and the other socio-economic factors related to land tenancy, size and parcels of land and so on. The population of Sahso village is high with large household size than in Rajpur and Bedhupur, respectively. However, only 20 per cent workforce of Sahso village has reported cultivation as their only occupation. The highest shares of these cultivators are reported in Rajpur (32 per cent of its total workforce). This result indicates that as agriculture comes under increasing environmental stress[2], mainly in the form of water shortage and land degradation, people tend to move out of agriculture. Although we have not quantified the linkage between land degradation and livelihoods diversification here, discussions with key informants and villagers suggest a strong linkage between declining agricultural productivity and shift of labour to non-agricultural occupations[3]. Normally shift to such occupations outside agriculture should increase the income of labour. But evidences from Chambal valley and other semi-arid regions suggest that at times labour shifting out of agriculture under environmental stress move to multiple, seasonal and low-earning occupations and activities (Pani et al, 2011; Chopra et al., 2001).

Table 5 : Cropped Area, Gross Value of Output and Yield in Agriculture

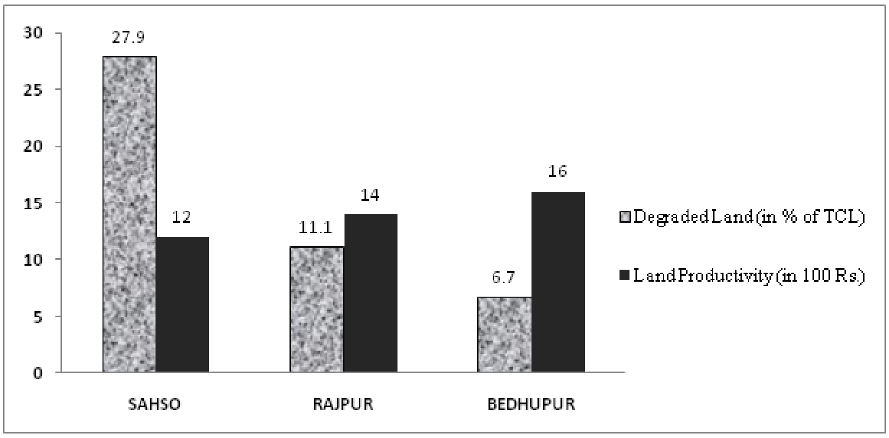
Name of the Village	Gross Value of Output (GVO) (in Rupees)	Gross Cropped Area (in bigha)	Yield (GVO) / Area (in Rs per ha)
SAHSO	1273.68	1273.68	1273.68
RAJPUR	1491.08	1491.08	1491.08
BEDHUPUR	1630.90	1630.90	1630.90

Note : GVO is sum of all crop produced by households valued at nearest market prices.

Source : Field Survey; 2009.

Association of Degraded Land and Total Crop Productivity : There is negative association between share of degradation and crop

Figure 3 : Share of Degraded Land and Agricultural Productivity



Source : Field Survey, 2009.

productivity. As the share of degraded land is increasing, the level of productivity decreases in the study area. Shaso village has the highest share of degraded land (52 per cent) to total cultivated land. The slope inclination is also sharp for this village. Analysis of primary data suggests that there is a strong negative correlation (-0.509) between share of

Figure 4 : Agricultural Productivity and Land Degradation : Sahso

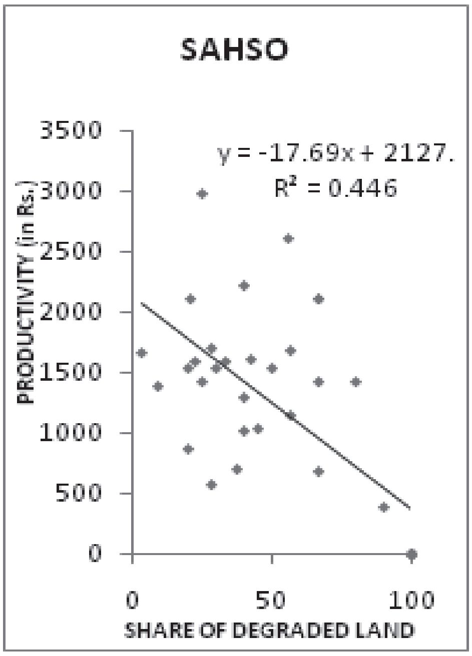


Figure 5 : Agricultural Productivity and Land Degradation : Rajpur

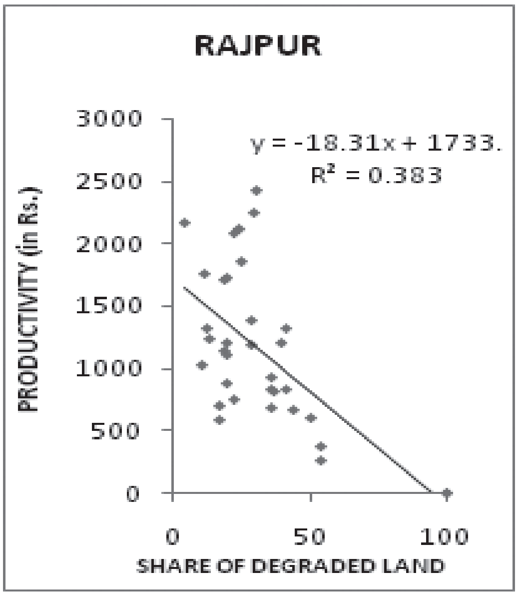
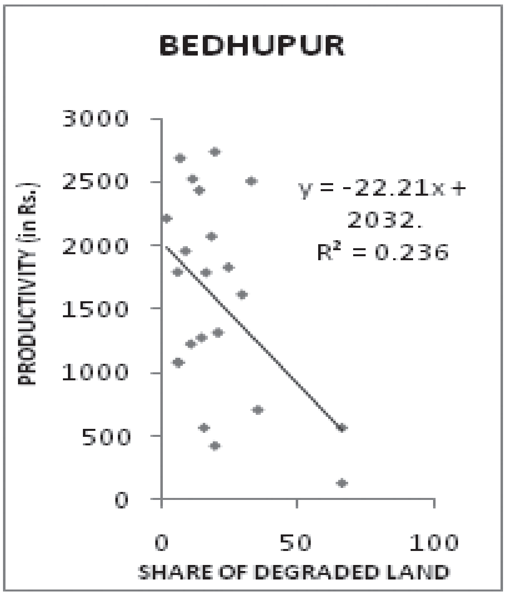


Figure 6 : Agricultural Productivity and Land Degradation : Bedhupur



Source : Computed from field survey data.

degraded land to total cultivated land and productivity of land per bigha. Figures 4 to 6 are showing regression results of land productivity and share of degraded land in surveyed villages.

Simple linear Regression has been run for measuring the impact of land degradation on total crop productivity. Here percentage of degraded land to total cultivated land is treated as independent variable and crops output (in rupees) per bigha as dependent variable. The market price of particular crop has been used for estimating the total output in rupees. This total output has been calculated per bigha of cultivable land.

It has been found that for village Sahso 44.6 per cent variation in productivity is explained by share of degraded land to total cultivated land. On other hand, Bedhupur is showing the least explanation (R^2 =0.236). Since Sahso has high share of degraded land (52 per cent), it explains the high share of variation of productivity. Bedhupur that has comparatively low share of degraded land (21 per cent) has no strong relationship between productivity of land and share of degraded land[4]. Therefore, it can be said that the dependency of productivity is high only in condition of big share of degraded land. Figures 7 to 9 are showing the association of land productivity and degradation levels in surveyed villages.

In a combined analysis of all three villages, it has been found that the dependency of crop productivity is explainable at a high level with high share of degraded land (more than 50 per cent of Gross Cropped Area). The impact of degraded land is very less (R^2=0.115) where the proportion of degraded

Figure 7 : Association of Productivity with Low Degradation

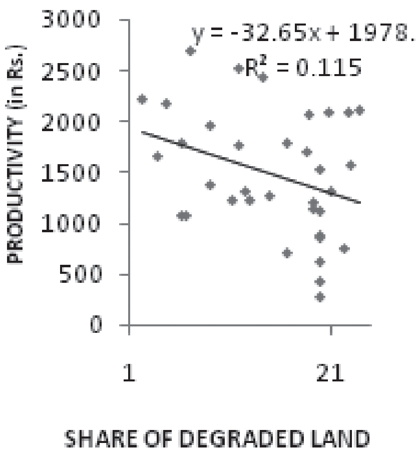


Figure 8 : Association of Productivity with Moderate Degradation

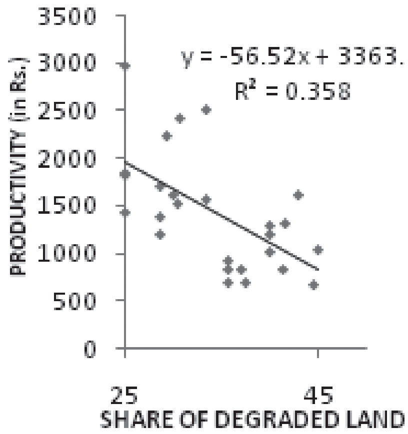
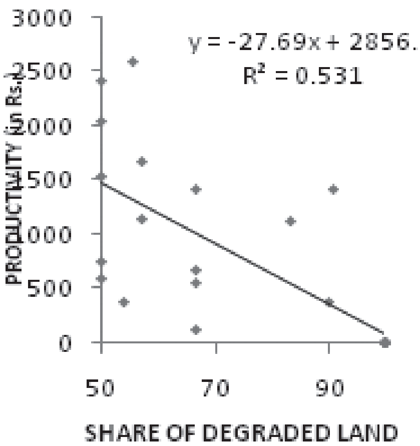


Figure 9 : Association of Productivity with High Degradation



Source : computed from field survey data.

land is less than 25[5] per cent. Thus, the evidence suggests that the impact of degradation on productivity increases with increase in its share. Beyond a threshold it becomes significant. Hence, expansion of area under degraded land is a major hindrance for sustainable agriculture in the region.

Conclusion

On the basis of the evidence presented here, it can be concluded that the region is severely affected by ravine and gully erosion and degraded land is expanding at an alarming rate. In the Chambal region, land degradation through ravine formation has been a major problem (Pani et al, 2009). The key impact of land degradation is through its impact on agricultural system (Pani et al, 2011). The encroachment of arable land by land degradation has adversely affected crop productivity of the region. Because of long and continuous fluvial erosion a huge share of fertile land has gone out of plough. As a result, crop productivity has declined in villages that are severely affected by land degradation. Moreover, due to this menace, the water table has also gone down further retarding the development of irrigation facilities.

The study brings out a clear relationship between land degradation and agricultural productivity, Gross Value of Output per land area has been found to be lower in villages severely affected by land degradation. The household data confirm this relationship. The strength of the impact of land degradation on agricultural productivity increases with severity of land degradation. This clearly points out that there may be a threshold level beyond which land degradation starts affecting agricultural productivity. Given the dependence of people on agriculture in this semi-arid region there is a need for proper agricultural strategy to halt the degradation of land. There is a need for micro-ecological management to stop the degradation before its impacts become catastrophic. Such effects need active coordination across multiple levels and among diverse players - such as government officials, village community, individual farmers and the wider scientific community.

Notes

1 In this study, open source satellite data have been used for the land use/ land cover analysis. The data for the year 2000 are post-monsoon data, where most of the shallow degraded area is covered by thorny bushes, and which was interpreted as a forest cover. This could be the reason behind the possibly inconsistent result of increase in the forest cover during 1990-2000.

2 In this area environmental stress includes declining forest cover, water shortage, soil erosion, declining land-man ratio and loss of agricultural and grazing land due to land degradation. However, a comprehensive analysis of these multiple linkages between land degradation and labour out-migration is beyond the scope of our paper.

3 In response to our queries on reasons for migration, most of the migrants or their family members cited declining or inadequate income from agriculture as the main reason for migration.

4 The F-values for these three regressions are 27.399859, 19.92783 and 6.196228, respectively.

5 The F-values for these three regressions are 4.28877, 13.4013, and 28.33763, respectively.

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