

# **Identifying the Economic Drivers of Land Use Change in Mangrove Ecosystems: A Case Study of the Indian Sunderbans<sup>1</sup>**

**Kanchan Chopra\*, Pushpam Kumar\*\* , Nisar A. Khan\*\*\***

\*Professor, Institute of Economic Growth, Delhi

\*\*Associate Professor and corresponding author, Institute of Economic Growth, Delhi

\*\*\*Senior Research Analyst, Institute of Economic Growth, Delhi

## **Abstract**

This paper attempts to explore the economic drivers of land use change in the fragile mangrove ecosystems of Sunderbans in Bengal, India. In last two decades, this region, which happens to be the UNESCO world heritage site of West Bengal, India, has witnessed significant amount of land conversion due to growing aquaculture leading to mangrove biodiversity loss, coastal water pollution impacting local population. The paper combines the high-resolution satellite data on land conversion for two major types of conversions-from paddy land to aquaculture and from dense mangrove forest to aquaculture. Combining the socio economic data with remote sensing data for the region during 1986-2004, in 8 blocks of the Indian, the drivers of land use have been identified. A multivariate panel regression has been used to look into the factors influencing the land use change. The analysis suggests that the net relative land productivity and population density drives both kinds of conversions. In addition, relative labour productivity is the other driving force behind the mangrove to aquaculture land conversion. The results from this paper would be useful to understand the forces causing the land use change impacting the ecosystem services of the mangrove forest, which has wider implications for the well being of the people. The paper provides helpful inputs for designing effective response strategy for management of this critical ecosystem.

**JEL Classification: Q01, Q15, Q24, Q56 and R14**

**Key Words: Land Use Change, Mangrove, Aquaculture, Aspatial Model, Panel Analysis, Fixed Effects, Random Effects, Sunderbans**

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# **Identifying the Economic Drivers of Land Use Change in Mangrove Ecosystems: A Case Study of the Indian Sunderbans**

## **1. Introduction**

Anthropogenic pressures on different ecosystems have caused a number of undesirable changes in the health and resilience of those ecosystems sustaining people's livelihoods. The problems like biodiversity loss, desertification, eutrophication, acidification, climate change, increase in sea level and countless other less exposed and less visible problems, are the results of land use change caused by human activities up to a greater or lesser extent. These environmental problems cause serious impacts like food security, human vulnerability, health and safety, and threaten the overall viability of earth. As Kates *et al.* (1990) put it "the lands of the earth bear the most visible if not necessarily the most profound imprints of humankind's actions".

These problems assume even more significant proportions in the developing countries like India, which exhibit lower levels of social, economic, and infrastructure amenities compounded with the state apathy. Moreover, the post-liberalisation India has seen more pressing demand for land under conversion on account of export-led and market-driven economic incentives. Among other commodities, marine product exports from India increased substantially after the new economic policies of 1990s, transforming vast areas of land under agriculture and mangrove into aquaculture farmlands. Also, the outbreak of viral disease in shrimp farms in Thailand and Vietnam reduced world supply of the product and provided a big opportunity to India to fill this supply demand gap.

For effective policy formulations, any analysis of land use change should answer the question "what drives/causes land use change". The drivers could be either bio-physical drivers or socio-economic or both. The bio-physical drivers comprise of weather and climate variations, landform, topography, volcanic eruptions, plant succession, soil types and processes, drainage patterns, availability of natural resources. The socio-economic drivers constitute demographic, social, economic, political and institutional factors and processes such as population and population change, industrial structure and change, technology and technological change, the family, the market, various public

sector bodies and the related policies and rules, values, community organization and norms, property regime.

Human driving forces, "or macro forces are those fundamental societal forces that in a causal sense link humans to nature and which bring about global environmental changes" (Moser 1996). The magnitude of land use change varies with the time period being examined as well as with the geographical area. Moreover, assessments of these changes depend on the source, the definitions of land use types, the spatial groupings, and the data sets used.

Keeping this in view, the paper tries to investigate the most important socio-economic factors behind the land use change pattern in the Indian Sundarbans, West Bengal. The analysis is carried out by combining the time series land use data, extracted from the high resolution satellite data, and the socio-economic data to estimate the underlying relationship econometrically for the period 1986-2004. The study becomes significant because Sundarbans exhibits a fragile and vulnerable natural system. Though, there are various forms of land use change in the region, but the purpose of the present study is to find out the factors behind the conversion of agricultural and mangrove land to aquaculture land.

The remaining paper is organised as follows. Section 2 reviews the relevant literature on the relationship between land use change and socio-economic factors. Section 3 explains the study area and sets the conceptual framework. Section 4 formulates the econometric model and explains the data used in the study. Section 5 reports the result of the econometric analysis and Section 6 concludes the paper.

## **2. Review of Some Relevant Studies**

There are studies where socio economic data has been combined with the spatial data obtained through remote sensing to understand the drivers of land use change. Most of the studies primarily attempt to explore the underlying factors of drivers of conversion land from one use to another. Turner and Meyer (1994) found that land use change that drives land cover change is shaped by human driving forces that determine the direction and intensity of land use. Pfaff (1999) attempted to understand the causes of deforestation in Amazon. He found that land characteristic such as soil

quality and vegetation type and factors that affect transport costs such as density of paved roads in a country as well as in the neighboring countries and distance to major markets are significant. In addition development project policies appear to have independent effects, although provision of credit infrastructure does not. The important aspect in this study is the finding that population density does not have a significant effect on deforestation when many potential determinants are included. A quadratic specification reveals that the first migrants to a country have greater impact than later immigrants. Thus the impact of a given population depends on its distribution.

Cropper, Griffiths and Mani (1999) focus on the drivers of deforestation and the country of study is Thailand using satellite imageries of land use. The independent variables are agricultural household density (total agricultural household divided by total area of the province), road density (road divided by total area of the province), slope of land (used as representative of soil quality) acrisol (used as representative of soil quality), distance to Bangkok, price of logs, price and four zonal dummies, viz. Northern Dummy, Northeastern Dummy, Southern Dummy and Central Dummy. A Linear probability model has been estimated with pooled data for the years 1976, 1978, 1982, 1985, and 1989. The coefficient of Distance to Bangkok has been found to be negative and statistically significant, signifying that higher distance from center place would lead to lower deforestation because nearer the center would mean more facilities at lower cost. Log or Timber prices and rice prices are statistically insignificant.

Nelson and Hellerstein (1997) use seven categories of land use as independent variables. These categories are chosen using satellite images of Central Mexico. The authors point out the high possibility of incorrect identification of the land uses other than forest and irrigated cropland. Therefore they have not taken into account the other land uses while estimating the regression equation. They have used nine explanatory variables. They are six geophysical variables and three socioeconomic variables. The authors find that for a region in central Mexico road access to land use does affect land use. Roads seem to influence location most near currently forested areas. The location identified as forest increase as roads access becomes more difficult. Removing effects of roads from regression allow forests to grow back down mountainsides. Roads also affect positively the irrigated crop areas. Negative effect of roads was found on irrigated cropland. An increase in the transportation cost to roads and villages reduces the probability that a location with irrigated crops

will remain cropped and increases the probability that a forested location will remain forested. The effect of transportation cost to large population center is also significant on both the categories. In other words this model also shows that roads are important factors for deforestation.

Seto, Karen. C and Kaufmann, Robert, K (2003) focus on the macro level socioeconomic factors and its effect on the rate at which agricultural land and natural ecosystems are converted to urban uses in Pearl Delta River of China. By using a panel data on land use from satellite imageries and other macro variable from conventional sources authors show that all the variables are found to have the desired sign and were all statistically significant. Hence the newest finding is the positive effect of FDI on land conversion to urban uses. The time period covered was 1988 to 1996. The land use data are satellite imagery. Other data were collected from various government statistical books.

### **3. Land Use Change in Indian Sundarbans**

#### **3.1. The Study Area**

The Sunderbans region in West Bengal covers the major portion of the districts of North and South 24 Parganas. Sunderbans area is located at the apex of the Bay of Bengal (21 degree 32' - 22 degree 40' N; 88 degree 03' - 89 degree 07' E). Important morphotypes of the area are sandy beaches, mud flats, coastal dunes estuaries, creeks inlets and mangrove swamps. Up to the year 1770, the total area of Sunderbans of India and Bangladesh was estimated to be around 36,000 sq. Km., which at present, stands to be 25,000 sq. km. The Indian part consists of 9,630 sq. km and the rest lies within Bangladesh. Out of the 9,630 sq. km., 4,264 sq. km of Wetland/ Mangrove constitutes reserve forests, which in turn comprises of 2,195 sq. km. of Wetland-Mangroves and 2,069 sq. km. of tidal river. This means that the reclaimed area around 5,366 sq. km. is used form human settlements. Surface water is generally saline giving the Sunderbans a high comparative advantage for various types of brackish water fish production systems including shrimp farming.

The Sunderbans is a region where the biodiversity is rich and valued. The tiger reserve comprising 2,585 square kilometers of the Sunderbans national park and its buffer zone is a part of this region. The national park was declared a UNESCO World Heritage Site in 1989. Two wildlife sanctuaries are also located within Sunderbans.

The Forest management divides the area into (a) core zones (b) buffer zones and (c) manipulation zones, which are made up of forestry and agriculture and aquaculture zones. The different areas support each other and in turn provide ecosystem services to the people of the region. Nutrient supply for instance comes from the mangrove forests. Salinity of water decreases landward within the rivers so that paddy and other agricultural cultivation is carried on there. The presence of mangroves near the coast provides important storm protecting and other regulating services. In other words, a variety of eco-system services falling within the groups of provisioning, regulating and cultural accrue simultaneously from this eco-system.

The region is also subject to a series of changes from natural causes including sea level rises due to temperature changes in the long run. The temperature is expected to rise at an average of 0.19 degrees C in this region. Sea ingress has been a feature of this area over the past three to four hundred years and the rate may rise in the future<sup>2</sup>. As a consequence land is an extremely scarce resource. A multiplicity of causes makes the region a fragile and vulnerable natural system. Assessing the biophysical impacts of an increase in aquaculture in the region is indeed a major challenge. To add to this, migration of people to areas of increased concentration of aquaculture has added to its vulnerability<sup>3</sup>.

### **3.2. Conceptual Framework**

There are two types of models, which discuss the drivers of land use change:

1. Spatial
2. Aspatial

In spatial model, location and landscape are in the mainstay. For the Aspatial model, the changes in land use, for example, deforestation, conversion of productive land to unproductive one, are explained in terms of behavior and response of land owners. There could be other types of conversion but their ecological impacts could be either insignificant or the magnitude of conversion itself is very small hence ignored in the study. For the conversion, socio-economic determinant are

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<sup>2</sup> According to a study of the School for Oceanographic Studies, Jadavpur University.

<sup>3</sup> According to the study of Jayshree Roy Chaudhary on migration patterns (personal communication).

induced which cause the conversion from - (1) paddy fields to aquaculture farm and (2) from mangrove to aquaculture farm.

In this work, we are trying to understand two types of land use change in the region of Indian *Sunderbans* (North and South 24, Paraganas). In case of first conversion  $Y_{it}$  is the annual cumulative paddy land in the region that is converted to aquaculture land in block  $i$  and year  $t$ . In the second case of conversion (Mangrove Forest to Aquaculture farm)  $Y_{it}$  would be the annual cumulative mangrove land converted to aquaculture farm in block  $i$  in year  $t$ ,

#### 4. Model Specification

A random effects model, which uses a procedure known as feasible generalized least squares and yields consistent estimates of the coefficients, has been used in the present study, with the following functional form:

$$\log Y_{it} = \alpha + \log \beta X_{it} + \mu_{it} + v_{it}$$

$X$  is the matrix of variables, which are supposed to influence the rate of land use change.  $\mu$  is an error term and

$\alpha$  and  $\beta$  are regression coefficients that are estimated from the panel data with an assumption that  $\beta$  for any block is equal to a mean value ( $\beta$ ) for all blocks plus some random error  $\varepsilon$

$$v_{it} = \alpha_i + \varepsilon_{it}$$

where  $\alpha$  represents omitted variables that vary across individuals, but not over time;  $\varepsilon$  denotes omitted variables which vary over time but are constant across individuals

The log-linear (double log) form of model has been used to make the data approximately normally distributed because of the skewed distribution of some of the variables as they are constructed as ratios. Moreover, the log-linear formulations can take care of the problems of unequal variation and outliers besides the easy interpretation of the regression results.

#### 4.1. Conversion of Paddy Land to Aquaculture Land

Model specification for conversion –1

$$\log(\text{PaddyField} \rightarrow \text{Aquaculture Land}) = \alpha + \beta_1 \log(\text{Value of gross paddy output/paddy workers}) + \beta_2 \log(\text{Population density}) + \beta_3 \log[(\text{Value of net paddy output/Paddy land}) / (\text{Value of net aqua output/AquaLand})]$$

Here, the conversion of paddy to aquaculture farm is correlated with the labour productivity in paddy field, population density and the return to paddy land relative to aqua land uses. Relative land productivity is used as a proxy for the opportunity costs of land conversion. It is quite possible that opportunity cost of conversion of aquaculture is higher than carrying out paddy cultivation. This higher opportunity cost of conversion would induce the greater conversion of paddy fields to aquaculture. Also, if paddy labour productivity is lower than the aqua labour productivity, there will be more incentives to convert paddy land to aquaculture uses. Population density also seems to be a guiding factor behind the conversion under this category.

#### 4.2. Conversion of Mangrove Land to Aquaculture Land

Model specification –2 (Log-Linear Formulation)

$$\log(\text{Mangrove} \rightarrow \text{AquaLand}) = \alpha + \beta_1 \log(\text{Population density}) + \beta_2 \log[(\text{Value of net paddy output/paddy land}) / (\text{value of net aqua output/aqua land})] + \beta_3 \log[(\text{Value of gross paddy output/paddy workers}) / (\text{value of gross aqua output/aqua workers})]$$

In this type of conversion, the relative factor productivity (labour) and sectoral productivity ratio would explain the conversion process. In case of both conversion, we would be assuming that the private opportunity cost of converting the paddy field and mangrove areas is far lower than maintaining them as they are (paddy land or mangrove forest). Also, in case of paddy to aquaculture conversion, the differential return of two land uses is of the critical factor.

For remote sensing data, we would identify the year in which the conversion occurred. This information would be used to generate annual data on land use change. This can be done with the help of two methods *Bayesian Maximum Likelihood* (Seto et al 2002) or *Econometric methods* to identify the year in which land use changes occurred in a time series of images. A detailed methodology on remote sensing based data analysis is given in Appendix 1.

### **4.3. Data and Variables**

This section deals with the sources and characteristics of data used in the study. The data on land use change has been procured from the National Remote Sensing Agency (NRSA) and the data on various socio-economic characteristics have been collected from many secondary sources like Census, Economic Surveys, and Statistical Handbooks etc.

For the panel or time series analysis, ideally, we should have data on most of the variables for all the periods in the study but, unfortunately, we do not have such data on many of the variables in this study for the period 1986-2004. Therefore, to make the series continuous between 1986-2004, data on land use has been generated on the basis of NRSA data for the years 1986-89, 1989-96, 1996-2001 and 2001-2004 while data on socio-economic variables has been generated on the basis of primary as well as secondary data for different years from different sources. The study area comprise of 2 blocks of North 24 Parganas (N24P) – viz. *Sandeshkhali I&II, Minakhan*, and 6 blocks of South 24 Parganas (S24P) – viz. *Namkhana, Basanti, Canning I&II, Kakdwip, Gosaba and Kultali* (Please refer to Map1).

#### **4.3.1. Land Use Data**

In the present study detailed land use mapping and change detection analysis of the Indian Sundarbans has been taken up to understand the land use/ land cover change dynamics of the area over the period 1986-2004 for the above mentioned blocks. These data are extracted from Landsat Thematic Mapper (TM) and Indian Remote Sensing (IRS) 1A LISS I, IRS 1D LISS III & IRS P6 LISS III images for the years 1986, 1989, 1996, 2001 and 2004. All the images were taken during the dry months of January and February. The procedure involved sorting of all the pixels of an image into a finite number of individual land cover classes or themes. Fundamentally spectral classification forms the bases to map objectively the areas of the image that have similar spectral reflectance/emissivity characteristics. The multispectral data is used to perform classification and, the spectral pattern present within the data for each pixel is used as the numerical basis for categorization while the temporal pattern recognition has used time as an aid in feature identification.

The digital satellite data procured from NRSA was first imported in Erdas Imagine 8.5 from Generic Binary to software compatible format. In present case of Landsat TM data was referenced with the option of Geometric Correction from the Raster of the viewer in which the data is opened. The referenced data was coordinated with ground coordinate system and the data got ready for digitization. The forest-covered part of the Indian Sundarbans was cut out from the full referenced data by the process called subsetting. At first the data was opened in any empty viewer and by selecting the polygon tool from the AOI tools of the viewer the area of interest was marked and thus all the different islands of Indian Sundarbans were separated into different files.

The ISODATA (Interactive Self Operational Data Analysis Technique) algorithm was adopted for doing the classification for generating the different land cover classes before field verification. The Change Detection Procedure was undertaken in ERDAS environment using a variety of mathematical, statistical, Boolean, neighborhood, and other functions, plus the input object that set up a function definition.

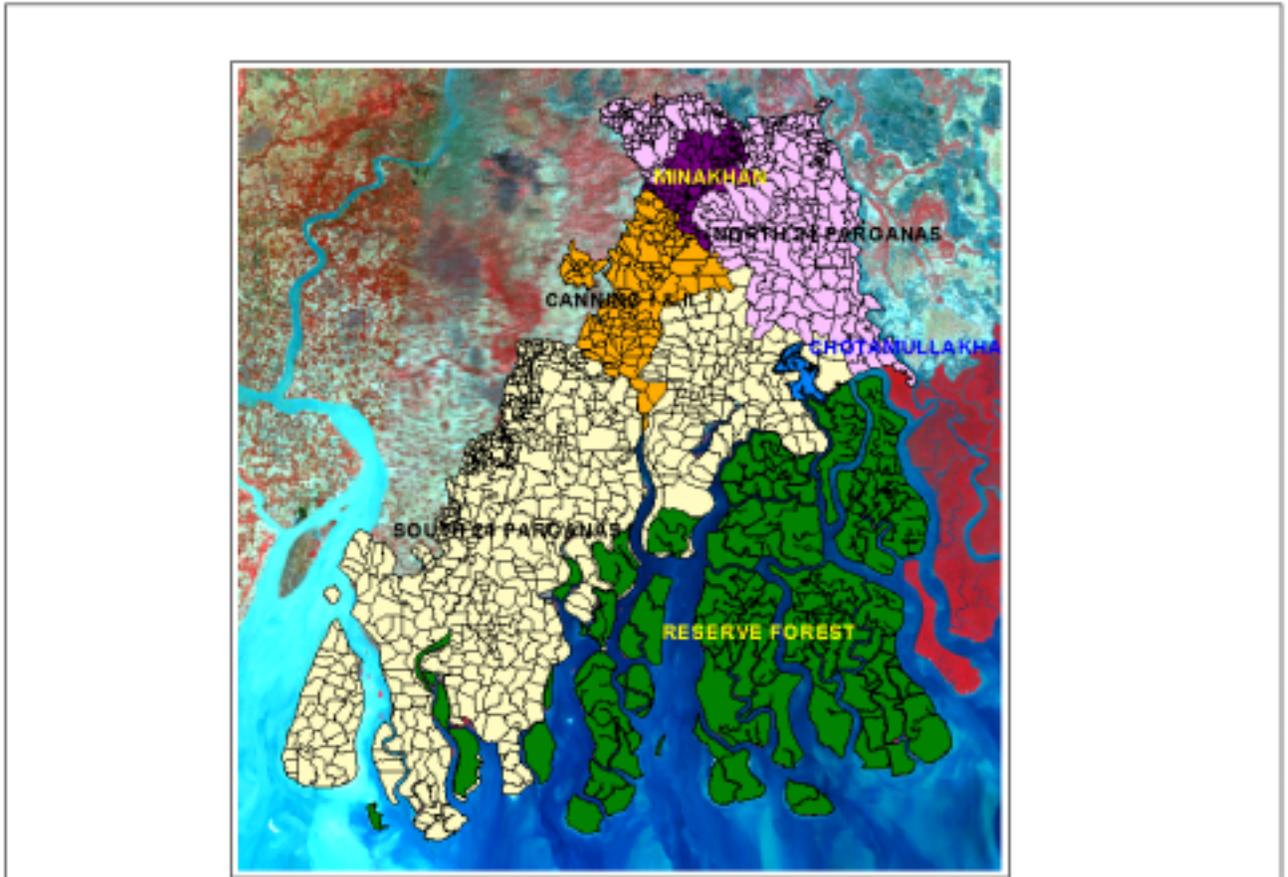
The Land use classes, adopted for Indian Sundarbans for the human habited parts are the following: Dense Forest, Settlement with Vegetation, Agriculture land, Aquaculture farm, Aquaculture farm (Dry), Water body/ Marsh Sand (Beaches/ Dunes), Mud Flats, Other vegetation, Swamp, Vacant Land, Reclaimed land from forest, and Mudflats with traces of mangroves. The Land use classes, adopted for Indian Sundarbans for the forest-covered parts are the following: Dense Forest, Degraded Forest, Saline Blanks, Water Body, Sand (Beaches/ Dunes), Mud flats, and Reclaimed land. Out of these classes, the present study focuses on the conversion of agricultural land to aquaculture land and the mangrove (Dense Forest only) to aquaculture land. The aquaculture land comprises both aquaculture farm and aquaculture farm (Dry)

#### **4.3.2. Socio-Economic Data**

Data on various socio-economic factors like average value of aquaculture, population density, paddy cultivation workers, average value of paddy production, etc. have been collected from primary field surveys of the aquaculture and agriculture farms as well as published secondary sources like District Census Handbooks and Village and Town Directories, Census of India 1991 and 2001, Evaluation Wing, Directorate of Agriculture, Govt. of West Bengal, 2001; Reports of the

Commission for Agricultural Costs and Prices, Dept. of Agriculture and Cooperation, Ministry of Agriculture, Govt. of India, 2001; Bureau of Applied Economics and Statistics 2001-02 & Past Issues.

**Map1: Reference map showing study blocks of the Indian Sundarbans**



A block wise trend in land use transformation from various land use classifications to aquaculture during 1986 to 2004 is shown in Table 1. The biggest chunk of land converted to aquaculture under each block has come from paddy. Namkhana and Kultali blocks exhibit conversion of dense forest to aquaculture to the tune of about 25 sq. km. and 11 sq. km. each during the study period whereas Minakhan block, with highest land being converted to aquaculture, does not have any conversions from dense forest.

**Table 1: Block-wise trend in Land Use Transformation from various classes to Aquaculture during 1986-2004:**

<i>Blocks</i>	<b>Transformation from class:</b>	<b>Transformation to Aquaculture (sq. km.)</b>	<b>Per cent to total transformation</b>
<i>Sandeshkhali</i>	Dense forest	0.384	0.37
	Paddy	56.24	53.82
	Other	41.573	39.83
	<b>Total transformation</b>	104.36	100.00
<i>Minakhan</i>	Dense forest	0	0
	Paddy	23.53	19.00
	Other	98.26	79.00
	<b>Total transformation</b>	124.41	100
<i>Namkhana</i>	Dense forest	6.12	25.78
	Paddy	9.82	41.45
	Other	6.70	28.22
	<b>Total transformation</b>	23.72	100.00
<i>Basanti</i>	Dense forest	1.184	3.17
	Paddy	25.79	69.00
	Other	7.53	20.16
	<b>Total transformation</b>	37.37	100.00
<i>Canning</i>	Dense forest	0.67	1.24
	Paddy	25.58	47.13
	Other	25.18	46.39
	<b>Total transformation</b>	54.28	100.00
<i>Kakdwip</i>	Dense forest	0.49	6.04
	Paddy	5.51	67.60
	Other	1.54	18.85
	<b>Total transformation</b>	8.159	100.00
<i>Gosaba</i>	Dense forest	0.71	2.21
	Paddy	21.14	66.23
	Other	7.72	24.19
	<b>Total transformation</b>	31.91	100.00
<i>Kultali</i>	Dense forest	3.50	10.84
	Paddy	15.40	47.82
	Other	11.60	36.02
	<b>Total transformation</b>	32.21	100.00

Source: NRSA (2004)

Note: Figures for land transformation from paddy to aquaculture have been arrived at by deducting 10 per cent from the total agricultural land transformed to aquaculture, assuming that out of total agricultural land in West Bengal 90 per cent land is used for paddy cultivation while 10 per cent is used for other crops.

Table 2 shows that blocks Sandeshkhali I&II and Minakhan each experienced conversion of more than 100 sq. km. of land for aquaculture during the study period while Canning observed about 54 sq. km. of land being converted to aquaculture.

The study period also witnesses conversion of aquaculture land mainly for settlement purposes. Almost all blocks except Basanti exhibit around 100 per cent land conversion from aquaculture to settlement.

**Table 2: Block-wise Total Land Transformed to and from Aquaculture and Total Land under Aquaculture during 1986-2004.**

<b>Blocks</b>	<b>Total Land<sup>1</sup> Transformed to Aquaculture (Sq. Km.)</b>	<b>Total Land<sup>2</sup> Transformed from Aquaculture (Sq. Km.)</b>
<b>Sandeshkhali I&amp;II</b>	104.36	17.122 (97.73)
<b>Minakhan</b>	124.41	35.267 (100)
<b>Namkhana</b>	23.72	6.995 (100)
<b>Basanti</b>	37.37	4.538 (77.61)
<b>Canning I&amp;II</b>	54.28	8.502 (100)
<b>Kakdwip</b>	8.16	3.361 (100)
<b>Gosaba</b>	31.91	8.240 (97.31)
<b>Kultali</b>	32.21	5.550 (100)

Source: NRSA (2004)

Note: 1 – This column shows total transformed land from various uses for the period.

2 – This column shows total transformed land from aquaculture to various uses.

Figures in brackets show percentage of total land converted from aquaculture to settlement.

#### **4.4. Description and Construction of Variables**

The analysis of land use change due to various socio-economic drivers involves the following variables.

##### *Dependent Variables*

PDGLD -Annual absolute (cumulative) paddy land converted to aquaculture

MNGLD -Annual absolute (cumulative) mangrove (dense forest only) land converted to aquaculture

Data on dependent variables is in absolute cumulative figures making it compatible with the independent variables since the independent variables do not show percentage change over the years but absolute cumulative changes. For example change in population density from one year to next is a cumulative figure having both the persons in the previous period as well as the new additions in the next period.

*Independent Variables*

POPDEN	-Population density
NETRELLDPROD	-(Value of net paddy output/paddy land)/(value of net aqua output/aqua land)
RELLBPROD	-(Value of gross paddy output/paddy workers/(value of gross aqua output/aqua workers))
PDLBPROD	-Value of gross paddy output/paddy workers

*MNGLD- (Annual absolute (cumulative) mangrove (dense forest only) land converted to aquaculture) (Ha):* - This variable has been constructed by using NRSA data on land conversion from dense forest to aquaculture in the periods 1986-89, 1989-96, 1996-2001 and 2001-2004 for all the blocks of the study. To make data continuous for the period 1986-2004, period-wise averages were calculated by dividing the data under each period by number of years in that period to arrive at the annual data. From the first period, i.e. 1986-89 onwards, for every next period, the previous land conversion has been added to the next period to make the data continuous and compatible with the independent variables.

*PDDL – (Annual absolute (cumulative) paddy land converted to aquaculture) (Ha):* - This variable has been constructed by using NRSA data on land transformation from paddy land (since data on paddy land is not given in the NRSA data, therefore, to arrive at paddy land converted to aquaculture, 90 per cent of land converted from agriculture to aquaculture has been used, assuming that 10 per cent of this land is used for other vegetation) to aquaculture in the periods 1986-89, 1989-96, 1996-2001 and 2001-2004 for all the blocks of the study. To make data continuous for the period 1986-2004, period-wise averages were calculated by dividing the data under each period by number of years in that period to arrive at the annual data. Here also, from the first period, i.e. 1986-89 onwards, for every next period, the previous land conversion has been added to the next period to make the data continuous and compatible with the independent variables.

*AQLD – (Aquaculture land) (Ha):*- This variable constitutes total aquaculture farm land (including dry aquaculture farms) for each block. Data has been generated for the period 1986-2004 on the basis of NRSA data for the years 1986, 1989, 1996, 2001 and 2004.

*Avg. Aqua – (Avg. value of aquaculture) (Rs./ha):* – This variable has been constructed from the primary survey data of aquaculture farms for the period 2000-2004. Average per hectare value for

*Minakhan, Canning and Gosaba* blocks were calculated from the survey data and then figures for the series 1986-2004 have been calculated from the linear interpolation of the available data. This generated data was filled for the remaining five blocks of the study according to the districts under which different blocks fall.

*VALAQ* – (*Value of aquaculture production (Rs.)*):- This variable has been arrived at by multiplying average aquaculture production (Avg. Aqua) by aquaculture land (AQLD) for each block and for each year of the study.

*POPDEN* – (*Population density (Persons/sq. km.)*):- This variable is based on the data from District Census Handbooks and Village and Town Directories, Census of India 1991 and 2001. First of all, on the basis of 1991 and 2001 figures, population for each block was generated for all the years of the study with the help of compound growth rate method and then population (all persons) for every block in the study was divided by area (sq. km.) under each block to arrive at the density at block level.

*PADPOP* – (*Paddy cultivation workers*):- This variable is based on the data from District Census Handbooks, Census of India 1991 and 2001. First, all the persons involved in agricultural activities (main and marginal cultivators and labourers) were taken together for each block to get the total number of persons involved in agriculture. Secondly, 10 per cent of this population was subtracted to arrive at total persons engaged in paddy cultivation. Finally, data was generated by linear interpolation for the study period 1986-2004 for each block separately.

*AQPOP* – (*Aquaculture workers*):- This variable has been arrived at from the PADPOP variable. Out of the total paddy workers, 10 per cent was assigned to aquaculture workers.

*Avg. Paddy* – (*Avg. value of paddy production (Rs./ha)*): – This variable has been constructed from the secondary data for N24P and S24P from various sources. Data is available for the period 1986-2001 for districts but we do not have this data at the block level, so, data for 2001-2004 has been extrapolated using compound growth formula. In order to fill the data under blocks, we have used

the data for N24P to blocks falling under this block whereas data for S24P has been used for the blocks under S24P.

*PDL D1 – (Paddy land) (Ha):-* Using the NRSA data, this variable has been constructed by deducting 10 per cent from the total agricultural land under each block to constitute total paddy land (assuming that out of total area under agriculture in these blocks 90 per cent is used for paddy cultivation). Data has been generated for the period 1986-2004 on the basis of NRSA data for the years 1986, 1989, 1996, 2001 and 2004.

*VALPD – (Value of paddy production) (Rs.):-* This variable has been arrived at by multiplying average paddy production (Avg. Paddy) by paddy land (PDL D1) for each block and for each year of the study.

## 5. Empirical Estimation of Land Use Change and Socio-economic Factors

### Model 1: Conversion of Paddy Land to Aquaculture (Log-Linear Specification)

$$\text{LogCUMPDLD} = f(\text{LogPOPDEN}, \text{LogNETRELDPROD}, \text{LogPDLBPROD}) \quad - \quad 1$$

CUMPDLD –Annual absolute (cumulative) paddy land converted to aquaculture

POPDEN –Population density

NETRELDPROD –(Value of net paddy output/paddy land)/(value of net aqua output/aqua land)

PDLBPROD –Value of gross paddy output/paddy labourers

**Table 3: Estimates of Log-Linear Model for Fixed and Random Effects**

S. No.	Variable	Fixed Effects	Random Effects
1	<b>Population density</b>	0.376 (1.54)	0.401*** (1.65)
2	<b>Net Relative Land Productivity</b>	-0.488* (-7.59)	-0.479* (-7.44)
3	<b>Constant</b>	1.492 (1.02)	1.357 (0.92)
4	<b>Breusch-Pagan Lagrangian Multiplier (LM) chi<sup>2</sup></b>		794.45
5	<b>Hausman Chi<sup>2</sup></b>		2.46
6	<b>Adjusted R<sup>2</sup></b>	0.16	0.16
7	<b>N (8*19) (i=1-8, t = 1986-2004)</b>	152	152

Note: Figures in parenthesis ( ) are t-ratios, [ ] are z-ratios, \*\*\*, \* imply significance at 10% & 1% respectively.

Table 3 reports the result for paddy to aquaculture conversion. Both the fixed as well as random effects models show overall good fit and highly significant relationships with correct signs of net relative land productivity and population density with the paddy land conversion to aquaculture. Initially, we started with three explanatory variables in the study but the variable paddy labour productivity came out to be insignificant in the regression and also had quite high negative correlation with another explanatory variable population density, therefore, it was dropped to avoid the multicollinearity problem.

Breusch-Pagan Lagrangian multiplier (LM) test of the significance of random effects confirms that the total variance is better treated as components of variation; both within and between individuals ( $\chi^2 = 794.45$ ,  $p = 0.000$ ). This result tells us that the fixed effects model with a single constant term is inappropriate for our data. The test rejects the null hypothesis in favour of the random effects model.

For testing the specification of the model for our study, another test, the Hausman test statistic  $\chi^2$  with  $k$  degrees of freedom (here  $k=2$ ) gives a value of 2.46. The critical value from the  $\chi^2$  table with two degrees of freedom is 5.99, which is quite larger than the test statistic. The hypothesis that the individual effects are uncorrelated with the other regressors in the model cannot be rejected. The test proposes that these effects are uncorrelated with the other variables in the model.

LM test proves that there are individual effects and the Hausman test suggests that these effects are uncorrelated with the other variables in the model; we prefer the random effects specification.

**Model 2: Conversion of Mangrove Land to Aquaculture (Log-Linear Specification)**

$$\text{LogCUMMNGLD} = f(\text{LogPOPDEN}, \text{LogNETRELLDPROD}, \text{RELLBPROD}) \quad - \quad 2$$

CUMMNGLD—Annual absolute (cumulative) mangrove (dense forest only) land converted to aquaculture

POPDEN -Population density

NETRELLDPROD-Value of net paddy output/paddy land)/(value of net aqua output/aqua land)

RELLBPROD -(Value of gross paddy output)/(paddy workers) / value of gross aqua output/aqua workers)

The results of the mangrove to aquaculture conversion are reported in Table 4. Here also, both the fixed as well as random effects models show highly significant relationship with correct signs between population

density, net relative land productivity and relative labour productivity with the mangrove conversion to aquaculture.

**Table 4: Estimates of Log-Linear Model for Fixed and Random Effects**

S. No.	Variable	Fixed Effects	Random Effects
1	<b>Population density</b>	0.0559* (2.60)	0.551* (2.57)
2	<b>Net Relative Land Productivity</b>	-0.117** (-2.30)	-0.119* (-2.34)
3	<b>Relative Labour Productivity</b>	-0.408* (-4.38)	-0.407* (-4.41)
4	<b>Constant</b>	-1.955 (-1.44)	-1.922 (-1.32)
5	<b>Breusch-Pagan Lagrangian Multiplier (LM) <math>\chi^2</math></b>		835.16
6	<b>Hausman <math>\chi^2</math></b>		5.75
7	<b>Adjusted R<sup>2</sup></b>	0.06	0.06
8	<b>N (7*19) (i=1-7, t = 1986-2004)\$</b>	133	133

Note: Figures in parenthesis () are t-ratios, [] are z-ratios, \*\*\*, \*\*, \* imply significance at 10%, 5% & 1% respectively.

\$ Minakhan block dropped from the study since there was no conversion of mangroves to aquaculture or to any other classification in this block).

In this type of conversion too, Breusch Pagan Lagrangian Multiplier (LM) as well as the Hausman specification tests validate the use of a random effects model rather than the fixed effects model. The LM test statistic of 835.16 is larger than the critical value of  $\chi^2$  at 1 per cent significance level, with one degree of freedom (k-1). The Hausman test statistic  $\chi^2$  with 2 degrees of freedom gives a value of 5.75. The critical value from the  $\chi^2$  table with two degrees of freedom is 5.99, which is higher than the test statistic. Based on the LM and Hausman tests, we use random effects as a superior option.

## 6. Discussion and Conclusions

We find that the paddy to aquaculture conversion shows statistically significant relationship of net relative land productivity and population density with the paddy land conversion to aquaculture. The sign of the coefficient of net relative land productivity (of paddy relative to aquaculture) is negative, which is a reliable estimate and it tells us that if the yield from the paddy goes down, there will be more incentive for that land to be converted to aquaculture otherwise not. Moreover the magnitude of - 0.47 on the variable tells us that, on an average, there will be conversion of 0.47 per cent of land annually from paddy to aquaculture as a result of 1 per cent decrease in the relative yield ratio.

The coefficient of the population density shows positive sign implying that as the over all population pressure (including natural growth net of migration) on the blocks increases, land under paddy goes for the conversion to aquaculture. This can be explained through the higher labour productivity and greater employment opportunities available in the aquaculture activity. Here, careful interpretation is required to understand the size of the coefficient of this (population density) variable since we are dealing with two different units of measurement here (one is in sq. km. and the other is in hectare). The coefficient shows a size of 0.40, which means that annually for every 1 per cent increase in population per sq. km., there will be a corresponding conversion of 0.40 per cent of land from paddy to aquaculture.

In case of mangrove to aquaculture conversion, population density, net relative land productivity, and relative labour productivity (productivity of paddy labour relative to aquaculture labour) variables illustrate statistically significant relationship with the land conversion. Here too, the sign of the coefficient of net relative land productivity is negative, which is a consistent estimate and it tells us that there will be conversion of mangrove land to aquaculture land given that the yield from the paddy relative to aquaculture decreases. This variable also highlights an interesting finding that the land under mangrove can be directly converted to aquaculture uses. The magnitude of this variable is -0.11, which says that, if the yield from paddy relative to aquaculture drops by 1 per cent, there will be conversion of 0.11 per cent of land annually from mangrove to aquaculture.

The variable relative labour productivity presents a negative relationship with land use change entailing that if paddy labour productivity is lower relative to aquaculture labour productivity, there is greater incentive to convert mangrove land to aquaculture activities. In case of higher relative paddy productivity, paddy land generates higher proceeds than aquaculture land leading to less motivation to convert mangrove land to aquaculture land. Otherwise, mangrove areas may be more pressed for conversion to reap higher profits on account of relative high labour productivity in paddy. The size of this variable is -0.40 meaning that annually for every 1 per cent fall in relative labor productivity ratio; there will be 0.40 per cent of land conversion from mangrove to aquaculture.

Population density comes out to be the major variable in this kind of land use change. The variable shows a positive relationship with mangrove land conversion. On an average, annually 0.55 per cent of mangrove land goes to aquaculture in response to 1 per cent increase in population density in the blocks.

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