Population Increase and Deforestation: A Study in Kokrajhar District of Assam, India

Dilip C. Nath and Dimacha Dwibrang Mwchahary

Department of Statistics, Gauhati University, Guwahati-14, 781014, Assam, India

Abstract- Deforestation has emerged as one of the major concerns of the world community as significant environmental impacts are attributed to it. The plainly observed association between population increase and deforestation in most of the developing countries has deepened the concern on deforestation. An analysis on forest cover and population of Kokrajhar district of Assam in India over the period 1977-2007 revealed a strong inverse relationship between the two (correlation co-efficient = -0.99). Population growth rate was steadily decreasing in the district, while deforestation rate was found to fluctuate. During the period, the district lost 38% of its forest cover that existed in the beginning of the period. Despite of declining growth rate of population of the forest area, deforestation was taking place at an alarming rate. Estimation of forest cover of the district by the Forest Area Change Model of Food and Agricultural Organization indicated that if deforestation continues with the recent rate, and population growth rate remains more or less same, the district, in the next three decades, would loss 43.5% of its forest cover that was available in 2007. By the beginning of nineties of the current century, when the population density is expected to be about 492 per sq km, the vegetation of possible deforestable area of the district would be almost completely cleared. The results of the analysis were found to conform to FAO theories of deforestation. However, the association between population and deforestation was found to be weakened towards the last decade.

Index Terms- Deforestation, Deforestable, FAO, Forest area, Forest Area Change Model, Forest cover, Non-forest area, Population density.

I. INTRODUCTION

1.1 A varying relationship between population and deforestation

An assiduous debate on the role of population change in deforestation and forest degradation continues with one group considering population growth as the main cause of deforestation while the other group terming it as inconspicuous. Former group includes scholars like Mather, Needle, Robertson, Williams, Harrison, Palo, Litho and others; while in the later group Agrawal, Lohmann, Barraclough and Ghimire are prominent.

An inverse relationship between population and forest area had been recognized by the forest sector since two centuries or more [1]. From the studies on Scottish Highlands, Robertson opined that human population was adversary to the population of woods [2], an idea that was endorsed by Williams [3]. Allen and Barnes found from their studies that deforestation was significantly related to the rate of population growth in 39 countries in Africa, Latin America, and Asia over the period 1968-78, and opined that population may be ascribed as a primary driver of deforestation in the developing world [4]. Similar conclusion was drawn by Harrison that population growth was responsible for 79 percent of global deforestation between 1973 and 1988 [5], while Palo and Lehto described population pressure as one of the universal underlying causes of pan-tropical deforestation [6]. Alves and Hogan observed a positive association between population size and deforestation in Ribeira valley [7]; positive correlations between demographic and forest variables was found to exist in parts of East Africa too [8, 8a]. Studies conducted by Cropper and Griffiths [9], Geist and Lambin [10], Carr *et al.* [11] were also led to the same conclusion. Hartwick opined that deforestation was not a consequence of population growth in some cases, but rather it had been a principle ingredient of population growth [12].

On the other hand, the other group opined that though association between population growth and deforestation was credible, there remained many understated questions pertaining to the pace of deforestation relative to population growth. Lohmann contended that the amount of land cleared in Thailand increased by around threefold, but its population only doubled over the period 1960-1985, and as such, forest colonization could not be convincingly explained by population growth [13]. Agrawal opined that the conclusion that population increase results in forest degradation would be an over-simplified only [14]. Barraclough and Ghimire also reached at the similar conclusion for situation in Tanzania [15].

Despite the fact that there exists an inverse relationship between population growth and deforestation, review of the situations has revealed that this relationship had weakened in the recent decades. For deforestation in wider South East Asia during 1970-80, Kummer and Turner obtained a bi-faceted result for the correlation between population and deforestation [16]. They found that coefficient of total population and deforestation in the region was only 0.05, suggesting that population change could not be termed as a major driver of deforestation; while on the other hand, the rural population bore a correlation coefficient of 0.20 to the deforestation, which supported a role for rural population growth in the deforestation process. Mather and Needle had revealed that relationship between population and deforestation underwent reversal in some countries during the later part of nineteenth century and beginning part of twentieth century [1].

During the course of Forest Resource Assessment (FRA) in 1990, an analysis, conducted by Food and Agricultural Organization (FAO) for statistical relationships between observed forest area change and ancillary variables for tropical areas, demonstrated a significant relationship between forest cover and human population density. That result convinced the FAO to select population density as the independent variable of their algorithm developed to interpolate or project the change in forest cover [17].

Since more people results in more food and other agricultural products requirement, usually an inverse correlation may be expected between population density and forest cover. In order to meet their increased requirement for living, people have either to increase the output of lands currently under cultivation, or to expand the cultivated area. As the first one involves extra inputs such as fertilizer, pesticides etc., people are inclined to choose the second one, which is done at the cost of forests [17].

Still, a strong relationship between the processes of population growth and deforestation sometimes may not exist. Heilig emphasized that together with clearing land for basic food production, other human wants that may also affect upon the forest should also be taken into account [18]. Some of the human activities such as changing lifestyles, the use of the forest as a major revenue earner, etc. have a little or no concern with local population growth, while these may have significant contribution towards loss of forests. Based on this fact Marcoux (2000) opined that a given population density can cause different degrees of 'demographic pressure', and as such increases in population density and deforestation may not be proportional.

Thus, deforestation is a complex process, which is not governed by specific theory. Neither neo-Malthusian nor Boserupian theory has been able to explain it in a convincing way. It occurs on a local or regional level, but effects are global [18a]. Some studies at country or continent levels had established correlations between environment and demographic data, but their conclusions came with a recommendation that in order to explain such correlations it was important to work on a local level [19].

1.2 Quantification of deforestation

Deforestation has been defined in different senses by different organizations and researchers. According to Fearnside, it is the loss of original forest for temporary or permanent clearance of forest for other purposes [20], while Kaimowitz and Angelsen describe deforestation as a situation of complete long-term removal of tree cover [21]. For others, such as Collin, it entails permanent destruction of indigenous forests and woodlands [22]. Food and Agricultural Organization defines deforestation as the conversions of forest to another land use or the long-term reduction of the tree canopy cover below a minimum 10 percent threshold [23]. For the present study, by following the definition of FAO, deforestation has been defined as the quantity of degraded forest area possessing tree canopy density less than 10%.

1.3 Forest area, Forest cover and classes of forests in India

Forest Survey of India (FSI), an organization under the Ministry of Environment & Forests, Government of India, has been assessing forest cover of the country on a two-year cycle since 1987 and publishing the information through its "State of Forest Report" (SFR).

According to FSI, the term 'Forest Area' generally refers to all the geographic areas recorded as forest in government records and comprises Reserved Forests (RF) and Protected Forests (PF), which have been constituted under the provisions of Indian Forest Act, 1927. On the other hand, the term 'Forest Cover' refers to all lands more than one hectare in area, having a tree canopy density of more than 10%.

Thus, in the present study, population of forest area means population within the recorded forest area, irrespective of existence or non-existence of tree cover.

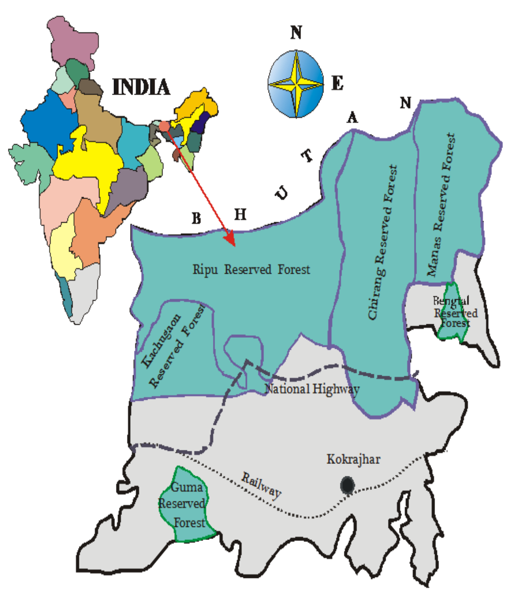
The Forest Survey of India (SFR 2009) has divided the forest cover of the country into following four classes –

Very dense forest- All lands with tree cover of canopy density of 70% and above
Moderately dense forest - All lands with tree cover of canopy density between 40% and 70%
Open forest - All lands with tree cover of canopy density between 10% and 40%
Scrub- Degraded forest lands with canopy density less than 10%

II. Study Area

2.1 Location

Assam is a state of India situated in the northeastern region and it lies in the tropical climate belt. Kokrajhar is one of the twenty-seven districts of Assam. The district occupies an area of 3169 sq. km. and it is bounded by $89^{\circ}46'$ to $90^{\circ}38'$ East Longitudes and $26^{\circ}19'$ to $26^{\circ}54'$ North Latitudes. The forest area constitutes a major part of the district, inhabitants of which are mainly tribal people- the ***Bodos*** and the ***Adivasis***, with some migratory population of Nepalese origin. They are underprivileged, solely dependent on paddy cultivation and collection of forest products [24]. They were forest friendly, who used forest resources in their daily life to a subsistence level [25]. Notified forest area of the district is comprised of six reserved forests- Guma, Ripu, Kachugaon, Chirang, Bengtal and Manas (**Figure 1**).



Source: Department of Forests, Bodoland Territorial Council

Figure 1: Reserved forests of Kokrajhar p.org

2.2 Topography of forest area of Kokrajhar district

The main forest area of the district is a contiguous area and it lies along the northern tract of the district in the foothills of Bhutan kingdom. The forest reserves along this northern tract occupy an ancient alluvial plateau jutting out south from the Himalayan foothills. This plateau varies in elevation from about 300 ft to 900 ft in the north, near the foothills, to as low as only a few feet above the low-level cultivation land in the south. The entire forest can be divided into two terrains- the **Bhabar** and the **Terai**. The Bhabar terrain extends for a breadth of 12 to 15 kilometers from the border of Bhutan kingdom and is waterless throughout the year except for the monsoon period. The water table in the Bhabar tract is very low due to deep layers of deposited boulders and this tract is extremely porous. Numerous rivers flow through the forest tract in a southerly direction. These rivers remain waterless in the 'Bhabar' tract and emerge as perennial streams in the southern 'Terai' tract. The 'Terai' tract of the Reserves extends over a maximum width of 8 to 10 kilometers south of the 'Bhabar' tract [25].

III. Aims and Objectives

The study aims at prognosticating the deforestation of Kokrajhar district based on the deforestation scenario over the last three decades from 1977 to 2007. The study intends at examining the relationship between population increase and deforestation in the district and then to apply Forest Area Change Model, developed by Forestry Information System (FORIS) of Food and Agricultural Organization (FAO), to project the future forest cover from the perspective of population growth. Furthermore, it is also intended to inspect if the results thus obtained were in conformity with theoretical concepts of FAO on deforestation.

IV. Materials and Methods

4.1 Population of the district

Populations of the district in different years were obtained from the General Population Census Report of Government of India, which is conducted every 10 years. Population figures for an intercensal year were estimated by the formula (Appendix A):

$$P_t = P_0 + \frac{n}{N}\left(P_1 - P_0\right) \tag{1}$$

Populations of notified forest area in different years were extracted from the same census reports. Table 1 shows the population of the entire district and its forest area since 1951.

Table 1: Population of Kokrajhar district and its forest area

Year	District Population	Forest Area Population
1951	202,516	31,673
1961	296,574	44,483
1971	457,554	75,333
1981	633,142	137,545
1991	808,730	199,754
2001	905,764	211,535

4.2 Forest cover of the district

Although the SFR started providing district wise forest cover from its 1991 assessment, independent figure for Kokrajhar district was not available until SFR 1999. The forest covers of the district in different assessments were as in **T*able 2*** [26].

The forest cover data of Kokrajhar district, provided by FSI, was not adequate to envisage the near future scenario of deforestation in the district as it covered only a small period of ten years. Therefore, four different satellite images- Landsat MSS Satellite Imagery of December 8, 1977, Landsat TM Satellite Imagery of December 14, 1987, Landsat MSS Satellite Imagery of December 14, 1997 and IRS P6 LISS III Satellite Imagery of November 17, 2007 were used to assess and analyze the deforestation situation of the district over the period 1977 - 2007. The assessments were carried out in the very dense forest, moderately dense forest, open forest, and scrub forest cover classes, which are the units for delineating forest cover followed by FSI (SFR 2009). ***Table 3*** shows the forest covers of the district obtained from these images for the last three decades from 1977 to 2007.

Table 2: Forest cover of Kokrajhar district as per SFR (in sq. km.)

Year	Forest cover	PC of Geog. area
1999	1630	51.44
2001	1364	43.04
2003	1183	37.33
2005	1183	37.33
2007	1163	36.70
2009	1144	36.10

4.3 Deforestation rate

Deforestation rate for a given period was evaluated using the following formula given by Armenteras *et al.* [27].

$$Deforestation\,rate = \frac{\left(\log \mathrm{F}_{t1} - \log \mathrm{F}_{t2}\right) \times 100}{\mathrm{t2} - \mathrm{t1}} \tag{2}$$

where 't1'and't2'indicate time-1 and time-2 respectively and F_{t1} and F_{t2} are the corresponding forest covers.

Table 3: Class wise forest cover of Kokrajhar district obtained from satellite images (in sq km)

Year	Very dense forest	Moderately dense forest	Open forest	Scrub forest	Non-forest
1977	872.00	539.70	410.87	485.39	860.77
1987	721.96	410.59	336.90	469.64	1229.91
1997	661.92	385.45	310.58	425.36	1385.69
2007	464.25	367.84	297.72	387.21	1651.98

4.4 Base work

The work by Walter Antonio Marzoli on application of Forest Area Change Model to Calakmul and Meseta Purépecha regions in Mexico had been used as a base for the current study [28].

4.5 The Forest Area Change Model

In this model, firstly, the forest cover is expressed as the percent of total land area of the geographic unit under consideration and is considered as dependent variable. Then taking the associated population density, stratified by ecological zones, as independent variable, a logistic model is used to relate these two variables. Lastly, the model simulates the loss in forest cover using projected human population for the area in question (Marzoli, 2003).

The equation of the general model is given by-

$$\frac{dy}{dp} = ay^{b} - cy \tag{3}$$

where $\frac{dy}{dp}$ and p are respectively dependent and independent variables and a, b, c are model parameters. The variable p used in the model was defined as-

$$p = \log(1 + population\,density)$$

which accommodated the idea of avoiding negative values that may result for geographic units having population density less than 1per square kilometer.

Besides the parameters mentioned above, the model involves two more implicit parameters, which are symbolized as dm and y_m.

These parameters are defined in the following way –

dm = maximum level of non-forest increase per unit population increase, it represents the derivative maximum of $\frac{dy}{dp}$, and

y_m = maximum possible deforestable area of the region, it represents the asymptotic value of y, where an increasing level of population has no effect on forest cover which remains stable in time.

With the help of these implicit parameters, physical interpretation of the model variables and parameters may be given as below-

$$y = \frac{Total\ area - Forest\ area}{Total\ area} \times 100$$

$\frac{dy}{dp}$: the ratio between population change and forest area change

a : a function of bioclimatic parameters that is determined by dm.

b : a function related to the non-forest percent value where the derivative reaches its maximum and the ratio $\frac{dy}{dp}$ starts to decrease.

c : a function related with accessibility, both physical and legal, of the forest resources; and to land suitability of forest areas for transfer to other land uses.

From stepwise statistical investigation, FAO found that a combination of ecological zones, expressed as percentage of total land area, was significantly correlated to dm. Hence the value of dm was evaluated by awarding weights to different ecological zones. The ecological components interpreted in the general model was meant to be valid at global level where local deviations are expected to be balanced at continental or global level. As such, while working at local level, the model predictions are required to be calibrated keeping the specific socio-economic conditions of the region in concern into account; and the model has provided a specific procedure, called 'local fit' for estimating dm .in this case. The guiding equation for estimating dm with this technique is:

$$dm = \frac{dy}{dp} \times \frac{y_m{}^{b} \times \left(b^{\frac{1}{1-b}}\right) \times \left(\frac{1}{b} - 1\right)}{y^{b} - y \times y_m{}^{b-1}} \tag{4}$$

by which, once the general model parameters for a small geographic unit are known, the value of dm may be calculated as a function of dy, dp, y, y_m and b.

On the other hand, from the statistical analysis, it was found that the parameter b was rather constant across different geographic regions and continents with a value of 0.98. So it was considered as a constant in the model formulation.

The value of y_m was kept at a constant of 100% level in the general model. However, it was opined that a value of less than 100% could also be estimated for it if local conditions suggested that for population growing to infinity deforestation would never reach 100% in the geographic unit in concern due to various factors such as physical constraints, legal constraints etc.

Following relationships may be established among various parameters involved in the model (Appendix B) -

$$y_m = \left|\frac{a}{c}\right|^{\frac{1}{1-b}}, \quad a = \frac{1}{1-b} \times \frac{dm}{y_m^{\,b}} \times \frac{1}{b^{\frac{b}{1-b}}},$$

$$c = \frac{1}{1-b} \times \frac{dm}{y_m} \times \frac{1}{b^{\frac{b}{1-b}}}$$

Kokrajhar district covers a small geographical area and lies within one ecological zone. Furthermore, when at least two reliable estimates of population and forest cover of a geographical unit in time are known, the quantities dp, dy and y may be calculated. For the present study, estimates of population and forest cover, both are available from population census and satellite imagery analysis. In addition, the value of y_m may be estimated for the district considering its physical conditions. Hence, the technique (4) can be applied to estimate the value of dm; and finally, the Forest Area Change Model can be applied for estimation of future forest covers of the district.

4.6 Population projection of the district

Based on the growth trends of the population of the district given in **Table 1**, the population of the district was projected by using the decreasing growth model (Appendix C):

$$P_f = S - (S - P_b)e^{-Kt}$$

4.7 Estimation of forest area change model parameters for the district

Value of y_m: The Bhabar tract of the forest of the district extends to a width of 15.54 km from the Bhutan boarder. This tract is suitable neither for human settlement nor agricultural purposes as water level is at a great depth from the surface. Some parts of this area remain inaccessible even these days. In this circumstance, a minimum of 5 km of forest area along Indo-Bhutan international boundary is expected to remain forested forever. Hence, maximum non-forestable area is less than 100% for the district. Considering all physical constraints the maximum non-forestable area was estimated at 92.881%, i.e., y_m = 92.88%.

Value of y:
Total geographical area of the district= 3169 sq km
Forest cover for the year 2007 = 1129.81sq km
Percentage of forest cover ***(fd)*** = 35.65%,
$y = 100 - fd = 64.35$

Values of dy and dp were obtained as 7.20 and 0.12 respectively.

Thus, $\frac{dy}{dp}$ = 61.76.

The parameter b is constant and $b = 0.98$

Consequently, with above relevant values it was found that

$dm = 89.93$, $a = 142.63$, $c = 130.27$ (Appendix D)

V. Results and Discussion

5.1 Correlation between population and forest cover

The forest covers and populations of the whole district and forest area since 1977 were as in **Table 4**.

The forest cover of the district bore negatively strong correlations with both the population of the district and the population of forest area (coefficients were -0.990

Table 4: Forest covers and populations of Kokrajhar districtand its forest area

Year	Forest Cover	Population (District)	Population (Forest Area)
1977	1822.57	562907	112659
1987	1469.45	738495	174870
1997	1357.95	866950	206823
2007	1129.81	976489	243142

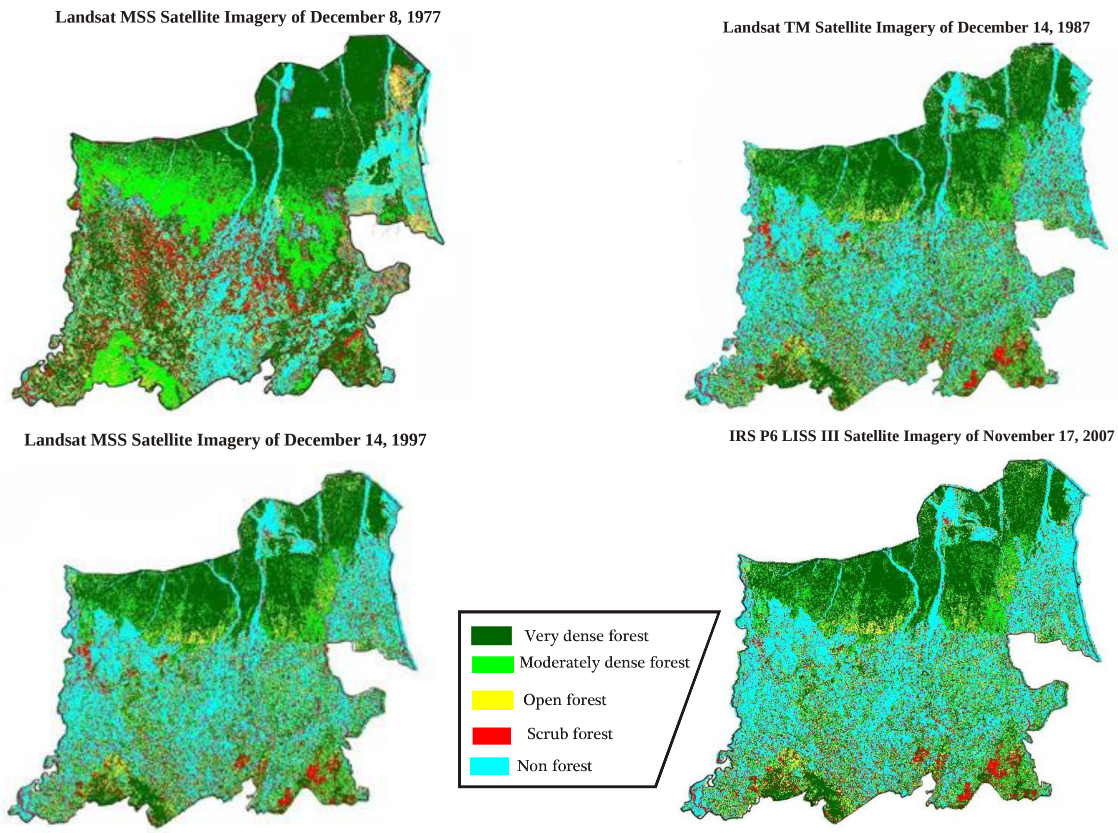


Figure 2: Satellite images indicating forest covers of Kokrajhar district

and -0.997 respectively). Thus, there existed an inverse relationship between the population and forest cover of the district.

5.2 Deforestation of the district

During the last three decades over 1977 to 2007, there was a reduction of 692.76 sq km of forest cover of the district, which was about 38% of the total forest area available in 1977. During the decade of 1977-1987, deforestation was the highest so as to loss a large forest cover of 353.41 sq km. However, during the middle decade of 1987-1997, there was a sudden decline in deforestation, losing an area of 111.5 sq km of forest. Then during the last decade of 1997-2007, the deforestation rose up again and deforestation of 228.16 sq km occured. ***Figure 2*** shows the satellite images of forest covers of the district in 1977, 1987, 1997 and 2007.

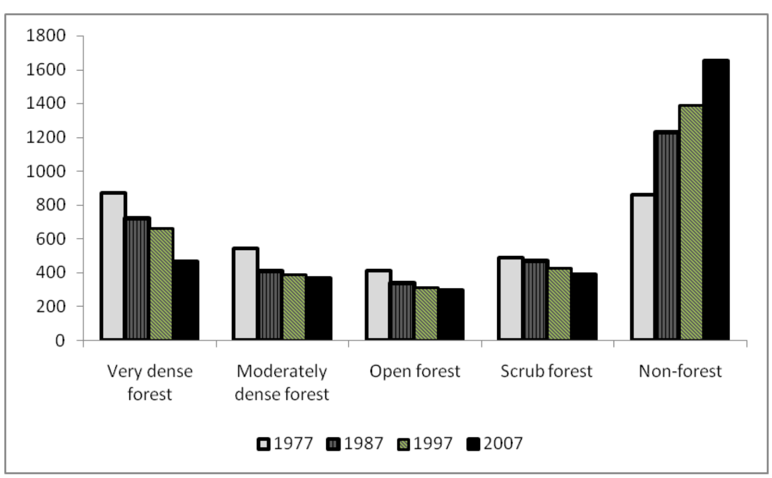


Figure 3: Class wise forest cover change of Kokrajhar district

During the study period, very dense class of forest suffered maximum loss (46.76%), followed by moderately dense forest (31.84%) and open forest (27.54%). There was a decrease of 20.28% in scrub forest. The absolute non-forested area was increased by 91.92% in the period. This suggested that deforested lands were being converted for use in other purposes. ***Figure 3*** shows the class wise changes in forest cover of the district during the period.

The rate of deforestation during the three decades 1977-1987, 1987-1997 and 1997-2007 were 2.15, 0.79 and 1.84 respectively. The mean rate of change in dense forest was 1.76 ± 0.85. Thus, deforestation situation in Kokrajhar district was less alarming than the deforestation in Nawarangpur district of Orissa in India, where change rates of dense forest were 3.62 and 3.97 during the periods 1973 – 1990 and 1990 – 2004 respectively [29]. However, the deforestation situation was worse than that of Western Ghats in India, where there was a loss of 25.6 % of total forest cover and 19.5% of dense forest over the twenty-four years from 1973 to 1995 [30]. The deforestation scenario was seemed almost similar to that of the nearby district Sonitpur of the same state [31].

5.3 Trend of population growth

Annual growth rate of population of forest area was initially lower than that of the whole district. However, during the intermediate period from 1971 to 1991, it rose up and remained higher than the district's population growth rate. Again, in 2001, population growth rate of forest area went below the annual growth rate of the district's population growth rate. Over the period 1951-2001, the mean annual growth rate population of the forest area was 3.89 ± 2.17, while that of the district's population was 3.05 ± 1.29. **Figure 4** shows the trend of growth rate of the populations of the district and its forest area. Correlation between population growth rate and deforestation rate was positive but weak (coefficient was 0.48).

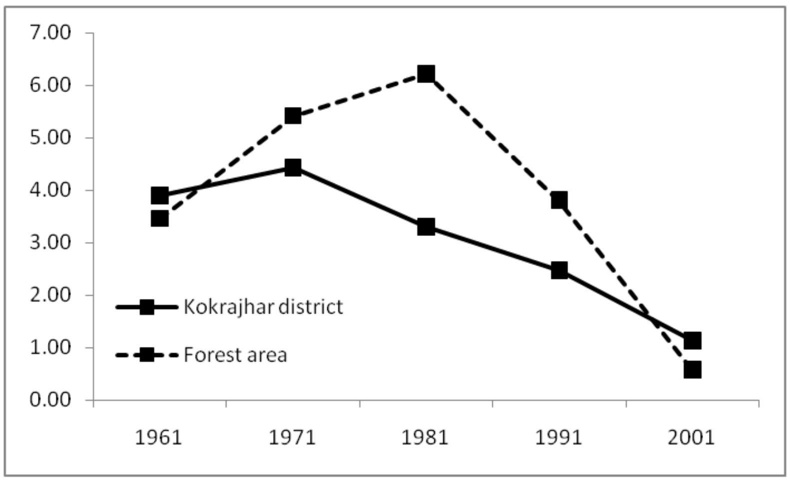


Figure 4: Annual growth rates of populations of Kokrajhar district and its forest area

5.4 Projected forest covers of the district

The future forest covers of the district projected by applying Forest Area Change Model were as in **Table 5**.

Table 5: Projected forest covers of Kokrajhar district

Year	Population	Population density	Non-forested area (%)	Forest Cover	Deforestation in successive periods	Deforestation rate in successive periods
2007	976,489	308	64.35	1129.81	-	-
2012	1,031,404	325	67.63	1025.83	103.98	1.93
2017	1,082,905	342	70.74	927.13	98.70	2.02
2022	1,131,204	357	73.37	844.03	83.10	1.88
2027	1,176,500	371	75.72	769.55	74.48	1.85

2032	1,218,979	385	77.98	697.82	71.73	1.96
2037	1,258,817	397	79.86	638.38	59.44	1.78
2042	1,296,178	409	81.68	580.70	57.67	1.89
2047	1,331,217	420	83.30	529.30	51.40	1.85
2052	1,364,076	430	84.74	483.72	45.58	1.80
2057	1,394,892	440	86.14	439.19	44.53	1.93
2090	1,555,423	491	92.85	226.71	212.47	2.00
2092	1,563,137	493	93.09	218.84	7.88	1.77

The projected figures indicated that after three decades from the base year 2007, in 2037, the forest cover of the district would reduce to 638.38, which amounts a loss of 43.5% of forest cover that was available in 2007. The deforestation was found gradually slowing down through time while population was steadily increasing. When the population density is expected to go up 491 per sq km in 2090, the non-forested area would be 92.85% of the total geographical area of the district, which is very close to the value of y_m .

5.5 FAO theories of deforestation

According to FAO (Marzoli, 2003) -

1) Deforestation increases relatively slow at initial stages, much faster at intermediate stages, and slow down at final stages.
2) Rate of deforestation starts to decline after non-forest area expands to 38% of maximum possible non-forest area.
3) Forest change approaches zero at various non-forest levels between 70 and 100%.
4) Forests of the maximum possible non-forest area would be cleared when the population density
approaches 500 per sq km.

5.6 Trend of deforestation

Deforestation started in Kokrajhar district during the second quarter of the twentieth century when villages were established by the government within and nearby the forests in order to ensure labors for commercial exploitation of forests. Deforestation of the district was not concerning one until 1972, but afterwards deforestation occurred at fast rate [32]. Deforestation of the decade 1997-2007 was considerably lower than that of the 1977-1987 decade. In addition, the projected forest covers indicate that deforestation would slow down in the next decades. Thus, deforestation was slower at initial stage, faster at intermediate stage and slowing down in later stages. The estimated and projected forest covers of the district since 1977 to 2057 was as in ***Figure 5***.

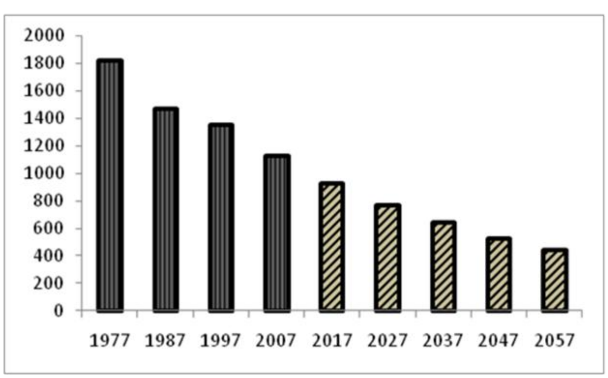


Figure 5: Estimated and projected forest covers of

For the district, if scrub forest is considered as non-forest due to adopted definition, the non-forested area crossed the value of 38% of maximum possible non-forest area (1107.88 sq km) earlier than 1977. However, if scrub forest is not considered as non-forest, this value was crossed during the period 1977-1987. Deforestations of the decades of 1987-1997 & 1997-2007, together with projected deforestations indicate that deforestation rate has acquired a declining trend.

The SFR of last two assessments of FSI (Table 2), reveal that areas of 20 and 19 sq km were deforested at an interval of two years. Projected deforestation shows that when non-forested area approaches its maximum expandable area, there would be a deforestation of 7 sq km of area in two years during 1990-1992, which is much lower than the current deforestation rate.

5.7 Forest cover - population density correspondence

There seems a consistent declining in the per capita availability of forest area in the district, the per capita availability of forest cover in the years 1977, 1987, 1997 and 2007 being 0.32, 0.20, 0.16 and 0.12 hectares respectively. Current per capita forest cover of the district remains higher than that of India’s 0.064 hectares. As per projection, in 2037, after three decades from the base year 2007, the per capita availability of forest cover would be minimized to 0.05 hectares; while in 2090, when maximum possible deforestable area would be almost completely deforested, it would remain at approximately 0.02 hectares.

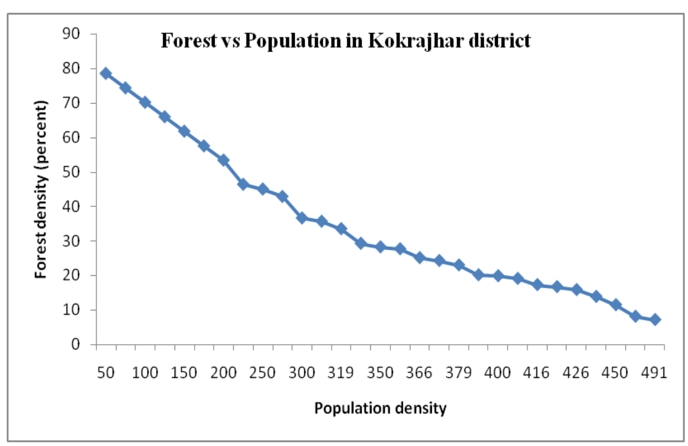


Figure 6: Forest cover - population density correspondence in Kokrajhar district

Projection of forest cover of Kokrajhar district by forest area change model indicates that by the time the maximum possible deforestable area of the district is converted into non-forest, the population density of the district would be approximately 492 per sq km. This is very close to population density of 500 per sq km. ***Figure 6*** shows the estimated and projected population density-forest cover correspondence in the district.

The discussions in 5.6 and 5.7 lead to a conclusion that the results of the analysis conform to all the FAO theories of deforestation almost in toto, except the third one. However, from the continuously declining deforestation rate point of view, the result of the analysis concerning the third theory also carries the same sense as the FAO theory.

VI. Conclusion

Through this work, deforestation of Kokrajhar district has been analyzed from the perspective of association between population increase and change in forest cover. The findings endorse that the recent trend of direct population-deforestation linkages in developing countries was prevailing in Kokrajhar district too, and that population increase remains to be a primary factor of deforestation. The results of the analysis comply with basic underlying FAO theories of deforestation. Thus, deforestation of a small geographic unit may be well explained by applying FAO Forest Area Change Model in the line of FAO theories of deforestation.

Despite declining trend of population growth rate, deforestation was occurring at high rate. This suggested that along with population increase there are some other significant factors, which are contributing towards deforestation of the district. Therefore, a study on other demographic and socio-economic factors that may contribute towards deforestation is deemed necessary for understanding causes of deforestation in a better way and then to adopt effective measures in order to control deforestation of the district.

VII. Appendices

A. Population of intercensal year

In the formula-

$$P_t = P_0 + \frac{n}{N}\left(P_1 - P_0\right)$$

P_t = Estimated population at time t, P_0 = Population in the previous census,
P_1 = Population in the succeeding census, N = Number of years between the censuses,
n = Number of years between the given year and the previous census year

B. Relationship between parameters

Integration of the differential equation (3) leads to the *Chapman-Richards function* of the form-

$$y = A_0\left(1 - B_0 e^{-C_0 p}\right)^d \tag{B.1}$$

The equation (B.1) is called the *State model* of the Forest Area Change model. This function gives the estimated forest area for a given population density level.

The parameters of the state model (B.1) are given by-

$$A_0 = \left|\frac{a}{c}\right|^{\frac{1}{1-b}}, \quad B_0 = \left[1 - \frac{y_0^{\,1-b}}{\frac{a}{c}}\right] = \frac{\frac{a}{c} - y_0^{\,1-b}}{\frac{a}{c}}, \quad C_0 = c(1-b), \quad d = \frac{1}{1-b} \tag{B.2}$$

$y_0 = y(p_0) =$ non-forested area when population density$(p) = 0$

a, b and c are parameters of the change model.

Since y_m is the maximum possible deforestation, and asymptotic size of *y* as $p \to \infty$, the state model (B.1) gives [33] -

$$y_m = A_0 = \left|\frac{a}{c}\right|^{\frac{1}{1-b}} \quad \text{(B.3); which in turn, gives} \quad c = \frac{a}{y_m^{\,1-b}} = a \times y_m^{\,b-1} \quad \text{(B.4)}$$

Now, according to the model structure, a is determined by *dm*. In addition-

$$dm = \left[\frac{dy}{dp}\right]_{\max}$$

If y_i be the value of *y* for which the derivative function (3) is maximum, then-

$$\frac{d^2y}{dp^2} = 0$$ (B.5), and the second order derivative of equation (3) is-

$$\frac{d^2y}{dp^2} = c\frac{dy}{dp}\left(b\frac{a}{c}y^{b-1} - 1\right) \qquad \text{(B.6)}$$

If there is a population p_i, such that equation (B.6) equals to zero, then -

$$y_i = \left[b\frac{a}{c}\right]^{\frac{1}{1-b}} \qquad \text{(B.7).}$$

Thus-

$$\left[\frac{dy}{dp}\right]_{\max} = ay_i^{\,b} - cy_i \quad \text{i.e.} \quad dm = ay_i^{\,b} - cy_i \qquad \text{(B.8)}$$

Using (B.7) and then (B.4) in (B.8), it may be obtained that-

$$dm = ab^{\frac{b}{1-b}} y_m^{\,b}(1-b)$$

Thus, $$a = \frac{1}{1-b} \times \frac{dm}{y_m^{\,b}} \times \frac{1}{b^{\frac{b}{1-b}}} \qquad \text{(B.9)}$$

Then (B.4) gives - $$c = \frac{1}{1-b} \times \frac{dm}{y_m} \times \frac{1}{b^{\frac{b}{1-b}}} \qquad \text{(B.10)}$$

C. Population projection of the district

Based on the growth trends of the population of the district given in T**able 1**, the population of the district has been projected by using the decreasing growth model –

$$P_f = S - (S - P_b)e^{-Kt},$$

where P_f =future population, S = saturation population,
P_b=base population (start of projection)
Po = initial population (in the applicable decelerating growth period)
$t_f = \text{ future year } (\text{end of projection})$, $t_b = \text{ base year } (\text{start of projection})$
t_o = initial year (earliest year in the applicable decelerating growth period)

$$K = \frac{-\ln\left(\dfrac{S - P_b}{S - P_0}\right)}{t_b - t_0},$$

$$t = t_f - t_b = no. \text{ of years from base year upto projected year}$$

Saturation population of the district was obtained by the formula-

$$S = \frac{\frac{1}{N_1} + \frac{1}{N_3} - \frac{2}{N_2}}{\frac{1}{N_1 N_3} - \frac{1}{N_2^{\ 2}}}$$

where N_1, N_2 and N_3 are populations of the district at times t_1 , t_2 and $2t_2 - t_1$ respectively [34], and was estimated at 1,859,708.

D. Estimation of forest area change model parameters

The maximum non-forestable area (y_m) has been estimated in the following way.

Total length of Bhabar tract = 45.12 km; Width of Bhabar tract =15.54 km; Width of area unsuitable for dwelling = 15.54 km; Width of Inaccessible forest area = 5 km (say), Total inaccessible forest area = 225.6 km, Total geographical area of the district = 3169 sq km. Maximum possible non-forested area= 2943.4 sq km, i.e. y_m = 92.88%

Value of dy :

Total Geographical Area (sq km)	Forest Area (sq km)		fd1	y1	fd2	y2	dy
	1997	2007	[% of 1997]	[100-fd1]	[% of 2007]	[100-fd2]	[y_2-y_1]
3169	1357.95	1129.81	42.85	57.15	35.65	64.35	7.20

Value of dp :

Total Geographical Area (sq km)	Population		pd1	pd2	log(pd1+1)	log(pd2+1)	dp [log(pd2+1)-log(pd1+1)]
	1997	2007					
3169	866950	976489	274	308	5.62	5.73	0.12

Value of $\frac{dy}{dp}$:

dy	dp	$\frac{dy}{dp}$
7.20	0.12	61.76

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AUTHORS

First Author – Dilip C. Nath, Department of Statistics, Gauhati University, Guwahati-14, 781014, Assam, India
Second Author – Dimacha Dwibrang Mwchahary, Department of Statistics, Gauhati University, Guwahati-14, 781014, Assam, India

Correspondence Author – Dimacha Dwibrang Mwchahary, Department of Statistics, Gauhati University, Guwahati-14, 781014, Assam, India, Email: ddmwchahary@gmail.com