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Mathematical Modeling on Assessing Rate of deforestation in The Sheka Forest South West Ethiopia

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ABSTRACT

Deforestation leads to increasing temperature and depletion of soil nutrients, to soil erosion, and to changes in local and, some evidence indicates, global climate. These environmental disruptions increase the risk to human populations from both natural and man-made disasters and the immediate risk-takers are the local population. Tropical deforestation has become a global concern, with an annual total forest loss of 9.4 million hectares. The total forested area of Ethiopia has decreased substantially during the past half-century and the recent figures show that the country's forest cover has shrunk to less than 3–3.6%. Primary data was collected from the local community in addition to the secondary data about the forest. The growth rates of forestry resources and population density are assumed to be following the logistic growth model. The growth of forest resources is in the direct proportion of population density and population pressure. The mathematical model of a system of differential equations was solved using backward Euler's method; the deforestation rate was decreased because of the NGOs and the government worked together to increase awareness to the community about the importance of the forest. The rate of deforestation is per population change, this indicates the rate of deforestation is decreased. Recommendations were given to the concerned body.

Key words: Population Density, Rate of Deforestation, Mathematical Model.

1. INTRODUCTION

Three well-known global changes are increasing carbon dioxide in the atmosphere, alterations in the biochemistry of the global nitrogen cycle and continuing land-use/land cover change(LU/LC), which generates many environmental consequences globally and locally, such as the release of greenhouse gases, the loss of biodiversity and the sedimentation of lakes and . In particular, it is recognized as the major driver of the loss of biodiversity and ecosystem service. The effects of land-use changes on biodiversity may be greater than climate change, biotic exchange, and elevated carbon dioxide concentration at the global scale. Deforestation is known as one of the most important elements in LU/LC. Globally, deforestation has been occurring at an alarming rate of 13 million hectares per year (FAO, 2000).

The continuing loss of the world's tropical forests is leading to massive environmental disruptions, including historically unprecedented rate of species extinction. Loss of protective forest cover reduces the sustainable yield of watersheds which can lead to alternating floods and water shortages. Deforestation also leads to depletion of soil nutrients, to soil erosion, and to changes in local and, some evidence indicates, global climate. These environmental disruptions increase the risk to human populations from both natural and man-made disasters and the immediate risk takers are local population.

Several studies have attempted the difficult task of inventorying the extent of tropical forests and their rate of destruction (*J Lanley, J.P 1983, Allen, J.Cet al.,1985*) conclude that, in short term, deforestation is the result of population growth and agricultural expansion. Many studies stated that deforestation in developing countries is mainly the result of poverty and under development. Increase of cultivated land for cash crops, grazing of cattle, shifting cultivation, logging, and fuel-wood requirements in developing countries as well as airborne pollutants and acid rain in developing nations should be major driving forces for deforestation. That means almost all the causes are strongly related to human activities.

In 1992 the FAO stated that Africa could lose all existing forest in just 60 years if things go allow. Ethiopia is one of the countries in Africa in which the environmental problems are of severe aptitude. Similarly Tropical deforestation has become a global concern, with an annual total forest loss of 9.4 million hector. The total forested area of Ethiopia has decreased substantially during the past half-century and the recent figures show that the country's forest cover has shrunk to less than 3–3.6% [16]. Forest loss in northern Ethiopia probably goes back many hundreds of years (*Melaku B)*, with the main remaining forest now confined almost entirely to the southern part of the country (*Friis I, 1992)*

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According to climatic climax vegetation cover of Ethiopia, the whole plateau of the SW part could have been covered by forest vegetation (*Anonymous,1988).* Forest cover of the region has been declining from time to time over the last two to three centuries mainly due to increased human settlement. The forest cover of the highland plateau in the SW Ethiopia was quiet high until recent years, when compared to other parts of the country. The change in forest cover during the last 30 years is the most severe anthropogenic catastrophe that the country has seen. Anonymous estimated that the closed high forest of SW Ethiopia dropped from a 40% cover between 1971 and 1975 to only 18% by 1997, which is a loss of 60% . Conversion of forestland to other land use types is the major cause of deforestation. Around 235,400 ha of closed and slightly disturbed forest areas were deforested between 1971 and 1997, a loss of about 10,000 ha forest every year.

This study was conducted in the Sheka zone of the SNNP Regional State. Sheka Zone has very high forest area and it is the center of origin for many spices and tuber food crops. The area is exposed to all causes of forest cover change, ranging from conversion to agriculture by smallholder farmers to large-scale coffee and tea plantations of their first kind in the country. Hence the area is selected for this study to assess the deforestation rate of the forest.

2. STATEMENT OF THE PROBLEM

Ethiopian government follows the path to sustainable development to build Climate-Resilient Green Economy. However Ethiopia has facing a high deforestation rates and loss of its rich natural resources. Antonio W. (2004) stated that about 60% of the forest cover of the highland plateau of SW Ethiopia was lost due to manmade destruction during the last thirty years. It has also been stated that 9000 km2 of closed high forests were destroyed between 1973 and 1990. Similarly about 50% of natural high forests were found to have been degraded to slightly or heavily disturbed forestlands in the period from1971 to 1997 (*DabaWirtu, 2000). Teklu Tesfaye* (2002) et al., reported rapid loss of forest in the sheka zone in the south west Ethiopia mainly due to deforestation according to these, deforestation is the series problem.

3. SIGNIFICANCE OF THE STUDY

With the background described above and collected literature related to the study, it was observed that no in – depth study has been attempted to evaluate the risk factors of deforestation in the Sheka Zone, South West Ethiopia. On the other hand, information on demographic, economic, and cultural characteristics is crucial in planning and evaluation of deforestation. So, the purpose of this study is to identify the major risk factor of deforestation in the Sheka zone, south west Ethiopia. Besides, it will help as an input for researchers for further study, analysis and developing appropriate intervention methods of deforestation. Therefore, it will hope that, results from this study will serve as a base for any further studies mainly to the study area and similar other areas, and as well can be used as a basis for effective policy formulation and implementation.

4. OBJECTIVE OF THE STUDY

4.1 General objective

The general objective of the study is to assess rate of deforestation using Mathematical modeling, in Sheka zon south west Ethiopia.

4.2 Specific objectives

- To identify the main responsible factors of deforestation.
- To determine the rate of deforestation across time.
- To provide information to tackle the risk factor of deforestation for the concerned body.

5. METHODOLOGY

5.1 Study Area

The Sheka Forest in southwest Ethiopia, known as the last indigenous forest in Ethiopia, has long been a source of livelihoods and spiritual practices for local communities. In the southwest, the Shekacho people have developed traditional management practices based on religious taboos (Ethiopian Orthodox church) and customary tenure rights that have sustained the Sheka Forest for centuries. However, the future of the forest is threatened by the growth illegal logging and population pressure that has led to new settlements and urban development. Land is also being rapidly cleared for coffee and tea plantations, including those that sell products to Starbucks, limiting access for local communities.

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5.2 Model Formulation

In this study the density of forest resource is basically considered as the variable of study which is affected by population density and population pressure. Therefore, the variables of studies included in the model are
the cumulative density of forest resources, the human population density, the Population pressure
To model the dynamics of forest density dependent on population density and population pressure, the following assumptions have been made:
i. The growth rates of forestry resource and population density are assumed to be following logistic growth model.
ii. The growth of forest resources is in the direct proportion of population density and population pressure.
The Mathematical model of deforestation due to human population is given below [1,8, 16]

$$\begin{aligned} \frac{dH}{dt} &= r\left(1-\frac{H}{L}\right)H + r_0HF + r_1HB - r_2H \\ \frac{dB}{dt} &= s\left(1-\frac{B}{K}\right)B - r_1HB - s_1B + \theta BH \\ \frac{dF}{dt} &= (s_2 + s_3B)F - r_0HF \\ \frac{dT}{dt} &= \mu(K-B) - \mu_0T \end{aligned} \qquad (1)$$

where
H Density of the Human population.
B Density of the Trees.
F Density of the crops in Farm fields.
T The degree of endeavour of technology used for conservation of Trees.
r Intrinsic growth rate the human Population.
r_0 Rate of increase in Human population due to the crops.
r_1 Rate of increase in Human population due to Trees.
r_2 Natural death rate of Human population.
S Intrinsic growth rate of the trees.
S_1 Natural death rate of the trees.
S_2 Intrinsic growth rate of the crops.
S_3 Growth rate of crops due to the irrigation formed by Trees.
μ Growth rate of technological endeavour.
μ_0 Depletion rate of technological endeavour.
θ Growth rate of trees due to technological endeavour.
L Carrying Capacity of the human population.
K Carrying Capacity of the trees.
We discretize the above system of differential equations using backward Euler's method and we obtain the following system of difference equations.

$$\begin{aligned} H_{n+1} &= H_n + rH_{n+1}\left(1-\frac{H_{n+1}}{L}\right) + r_0H_{n+1}F_{n+1} + r_1H_{n+1}B_{n+1} - r_2H_{n+1} \\ B_{n+1} &= B_n + sB_{n+1}\left(1-\frac{B_{n+1}}{K}\right) - r_1H_{n+1}B_{n+1} - s_1B_{n+1} + \theta B_{n+1}T_{n+1} \\ F_{n+1} &= F_n + (S_2 + S_3B_{n+1})F_{n+1} - r_0H_{n+1}F_{n+1} \\ T_{n+1} &= T_n + \mu(K - B_{n+1}) - \mu_0T_{n+1} \end{aligned} \qquad (2)$$

Solving the system of equation (2) gives the Jacobi Matrix

$$J = \begin{pmatrix} 1 + r - \frac{2rH}{K} + r_0F + r_1B - r_2 & r_1H & r_0H & 0 \\ -r_1B & 1 + s - \frac{2sB}{L} - r_1H - S_2 & 0 & \theta \\ -r_0F & S_3F & 1 + (S_2 + S_3B) - r_0H & 0 \\ 0 & -\mu & 0 & 1 - \mu_0 \end{pmatrix} \qquad (3)$$

Stability of the model
Theorem: the fixed point is stable if

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$r < 2 + r_2, s_2 < 2 + s - r_1\left(\frac{K(r-r_2)}{r}\right),\ r_0 < \frac{(2+s_2)r}{K(r-r_2)}, \mu_0 < 2$, Otherwise unstable [11]

The independent variables listed above are directly or in directly depends on human activity, population growth and population density. Hence, for any given geographic unite with the range of years when population is monotonically increasing, time is a single valued function of population. By combining together forest cover time series, demographic time series and ecological setting Chapman-Richards deforestation change model is best suited to deforestation rate [3]

$$\frac{dy}{dp} = b_1 * y^{b_2} - b_3 * y \qquad (4)$$

Where y is defined as the percentage of non-forested area,

$\frac{dy}{dp}$ is the rate of none forested area with respect to the population density, b_1, b_2 *and* b_3 are parameters.

The value of b_1 is determined by the parameter DM that represents the maximum level of non-forest area increase per unit population increase. In other words, the same population growth rate has different effect in different ecological conditions. The parameter b_2 represents the inflection point of the curve, where deforestation rate culminates and start to decrease. From the statistical analysis b_2 is found constant for different geographic regions and continents with the value of $b_2 = 0.98$ and b_3 is the maximum possible deforestation (*Antonio W 2003)*

Solving equation (4) gives $y = a_0 * (1 - a_{1*}e^{(-a_2*p)})^{a_3}$ (5)

The function gives the estimated no forested area for a given population density level and y_m represents the maximum possible non forested area. However, the sheka zone has forest protection mechanism. The parameters a_0, a_1 , a_2 and a_3 expresses with respect to b_1, b_2 *and* b_3 gives the following system of equation

$$\begin{cases} a_0 = y_m \\ a_{1=1-(y_0*y_m)^{(1-b_2)}} \\ a_2 = (1-b_2) * b_1 * {y_m}^{(b_2-1)} \\ a_3 = \frac{1}{1-b_2} \end{cases} \qquad (6)$$

Where y_0 represents the initial condition of the site interims of forest cover change (non forest area) for population density is zero. As the result of the questionnaire indicates the area of the zone is fertile, there is no rocks, lakes and unfertile area hence the value of y_0 (non forested area for population density =0) is also zero.

From equation (6) $a_0 = y_m$ and $a_1 = 1 - (y_0 * y_m)^{(1-b_2)} = 1 - \left(\frac{0}{y_m}\right)^{0.02} = 1$

The value of b_1 is the productivity index, or site quality to follow the analogy with yield modeling and it was determined by the parameter DM that represents the derivative maximum.

$$a_2 = (1-b_2) * b_1 * {y_m}^{(b_2-1)}$$

$$= 0.02 a_2 b_1 (2387.25)^{0.02}$$

$$a_2 = 0.023 b_1$$

$$a_3 = \frac{1}{1-b_2} = \frac{1}{1-0.98} = 50$$

Substituting the above parameter values in equation (5)

$$y = a_0 * (1 - a_{1*}e^{(-a_2*p)})^{a_3}$$

$$y = 2387.5 * \left(1 - e^{(-0.023p)}\right)^{50}$$

The statistical report of Ethiopia Population and Housing Census was conducted in 2007 and the population growth of SNNP was 2.9% per year.

$$53 = 2387.5 * \left(1 - e^{(-0.023(2.9)b_1)}\right)^{50}$$

$$\frac{53}{2387.5} = \left(1 - e^{(-0.023(2.9)b_1)}\right)^{50}$$

$$\sqrt[50]{\frac{53}{2387.5}} = 1 - e^{(-0.023(2.9)b_1)}$$

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$$0.9265 = 1 - e^{(-0.023(2.9)b_1)}$$

$$-0.0735 = -e^{(-0.023(2.9)b_1)}$$

$$\ln(0.0735) = -0.0667b_1$$

$$b_1 = 39.1375$$

The parameter b_3 is related to the maximum possible deforestation (y_m) representing the asymptotic value of y where an increasing level of population has no effect on forest cover which remains sable in time. hence there is asymptotic value of forest protection. Combining the above parameters results Chapman – Richards growth estimation model which is used to find the derivative maximum for the rate of deforestation area increase per unit population increases (DM that represents the maximum level of non-forest area increase per unit population increase). In other words, the same population growth rate has different effect in different ecological conditions but this condition happens if the area was parked or by changing communities altitude to stop any deforestation activity.

$$d_m = \frac{dy}{dp} * \frac{{y_m}^{b_2} * {b_2}^{\frac{1}{(1-b_2)}} * \left(\frac{1}{b_2} - 1\right)}{y^{b_2} - y * {y_m}^{(b_2-1)}} = \frac{dy}{dp} * \frac{100^{0.98} * 0.98^{\frac{1}{(1-0.98)}} * \left(\frac{1}{0.98} - 1\right)}{53^{0.98} - 53 * 100^{(0.98-1)}}$$

$$d_m = 0.7532 \frac{km^2}{population\ change} * 0.0006$$

$$d_m = 0.00045 \frac{km^2}{population\ change}$$

0.0.00045 km^2 of the forested area will deforested per year for a unite change of population. This deforestation rate was caused by population growth and human activity like agricultural expansion, charcoal, fuel wood, grazing of cattle, temper product etc but it does not include deforestation caused by investment.

Hence, $0.00045 km^2$ is the rate of non forested area per a unit change of population yearly but this deforestation rate does not include deforestation by investment because this activity was not conduct by the local community or human activity.

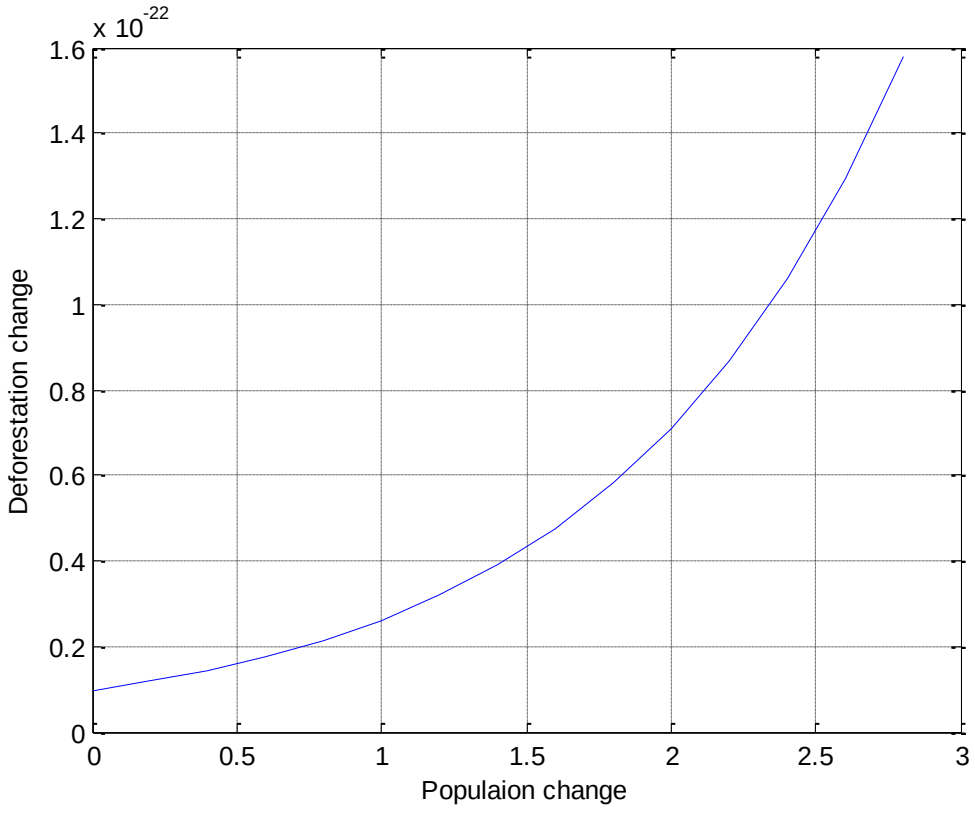

Figure 1: Rate of deforestation Pere population change

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Local NGOs and the federal government of Ethiopia ware paving the way to ensuring better environmental protection of forest areas and building community capacity to value traditional practices. Founded in 2004, MELCA, which means "river ford" in Amharic and Oromo, is dedicated to strengthening advocacy skills among locals. The organization has made great progress in facilitating workshops with multiple stakeholders regarding environmental and community rights.

NGOs also has trained clan leaders to develop their negotiation skills and focus on the importance of environmental impact assessments, which can serve as indicators of limitations in existing policies as well as potential ways to accommodate the interests of the community. In addition, it has held training specifically for woreda office representatives to raise their awareness of the environmental and cultural rights of the community

NGOs initiated and facilitated the formation of the Sheka Forest Alliance, which advocates legal protection of the Sheka Forest by encouraging the Sheka regional government to work out the legal discrepancies over land and territory in current legislation and the Ethiopian constitution. In August 2006, an awareness-raising workshop on the political, legal and institutional systems in sustainable forest conservation was held for cabinet members of Sheka Zone and Masha and Anderacha *woredas*. As a result of this event, the zonal and woreda officials announced they would ask the government for more funding, which should deter the regional government from leasing the forest area for development in order to generate income.
One major focus of NGOs working to protect the Sheka Forest is to build capacity among communities to reduce poverty by sustainably harvesting non-timber forest products such as honey, forest coffee, bamboo and spices. The Non-Timber Forest Products and Participatory Forest Management Research and Development Project is a joint effort among several European universities, Sustainable Livelihood Action and Ethio-Wetlands and Natural Resources Association, an Ethiopian NGO. This project works to support the use and production of these products by coordinating the efforts of the regional state agencies, community institutions and local traders.

Generally sheka forest deforestation rate was decrease because of the NGOs and the government works together to increase awareness to the community about the importance of the forest.

6. CONCLUSION

The government of Ethiopia and local NGOs ware created awareness about how to keep the forest and the outcome of the awareness creation is fruit full. The rate of deforestation is $0.00045km^2$ per population change, this indicates the rate of deforestation is decreased. The deforestation rate of sheka forest is very low, hence due to population change there is no significance impact in deforestation. This indicates that, if the local community and the local government works together to keep the forest whatever population density increases there is no change on deforestation rate.

RECOMMENDATION

Deforestation rate does not highly influenced with population density; to keep this rate of deforestation the researcher recommended the following.

- The local community should adapt as a culture of keeping the forest like that of their home animals.
- Republic of Ethiopian government should continue creating aware ness for the community to keep the forest.
- NGOs should do more than this for awareness creation to the community.
- The local government should create job opportunities for the community who depends to the forest resources.

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