

SPATIAL STATISTICAL ANALYSIS OF THE RELATION IN BETWEEN POPULATION DENSITY AND HUMAN MODIFICATION OF TERRESTRIAL LANDS AT TABIA LEVEL IN THE TIGRAY REGION OF ETHIOPIA

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Received 2 April 2020, accepted in revised form 12 June 2020



Abstract

In this study first spatial pattern of the level of human modification of terrestrial lands and second its relation with population density was studied at Taiba level in the Tigray regional state of Ethiopia. For the level of human modification of terrestrial lands global Human Modification dataset (gHM) was used and for population density Gridded Population of the World, Version 4 (GPWv4.11) dataset was used. Both the data set were preprocessed before geostatistical analysis. To measure the distribution pattern Global Moran's I statistics, Cluster and Outlier Analysis (Anselin Local Morans I) statistics was used. To measure the relation between population density and human modification of terrestrial lands geographically weighted regression was used. In the case of first objective the resulting z-score of 50.50, confirm the tabias with high Human Modification of terrestrial lands are highly clustered. In case of second objective the results shows 214 Tabias containing high value and are surrounded by Tabias with high values (HH), 10 Tabias containing high value and is surrounded by Tabias with low values (HL). The relation between population density and human modification of terrestrial lands was found positive with $R^2 = 0.506$. This research will help the government and planners for proactive spatial planning to maintain biodiversity and ecosystem function before important environmental values are lost in tabias containing high value and is surrounded by Tabias with high values.

Keywords: Human Modification, spatial autocorrelation, Anselin Local Moran's I statistic, Tigray

1. Introduction

Ethiopia is a landlocked country in the Horn of Africa. It shares borders with Eritrea to the north, Djibouti to the northeast, Somalia to the east, Kenya to the south, South Sudan to the west and Sudan to the

northwest. With over 109 million inhabitants as of 2019 ("World Population Prospects - Population Division - United Nations," 2019).

With about 109 million people (2018), Ethiopia is the second most populous nation in Africa after Nigeria, and the fastest growing economy in the region. However, it is also one

of the poorest, with a per capita income of \$790. Ethiopia aims to reach lower-middle-income status by 2025 (World Bank, 2018).

Agriculture contributes almost half of Ethiopia's gross domestic product (GDP) ("Ethiopia - Economy | Britannica," 2020).

Land degradation is an important problem in Ethiopia, with more than 85 % of the land degraded to various degrees. Recent estimates using satellite imagery show that land degradation hotspots over the last three decades cover about 23 % of the land area in the country (Gebreselassie, Kirui, & Mirzabaev, 2015).

The country loses about \$106 million annually through soil and nutrient loss. Soil degradation is the one and the major form of land degradation that have been stayed for long period as the bottlenecks of the country's economy and human wellbeing. The economic loss soil degradation in the form of soil erosion and nutrient depletion only from the highlands of the country is about 10-11% of agricultural gross domestic products (Bekele Tsegaye & Bekele Tsegaye, 2018).

Tigray region is bordered by Eritrea to the north, Sudan to the west, the Amhara Region to the south and the Afar Region to the east and south east.

Tigray's agriculture is based on ox-plough cultivation of predominantly cereal crops. This technology has prevailed without modification for thousands of years, harvesting the same land over and over again. The level of subsistence, except for periods of good rains, has declined radically during the past decades, with almost everything produced being consumed at the farm household level. Quite apart from the erratic nature of rain water on which Tigray's agricultural production depends almost entirely, Tigray's agrarian system has, within it superimposed, a fast accelerating population growth, resulting in high density per arable land, causing, over time, the steady decline in soil and labour productivities. With such deterioration has come about

the deterioration of the terms of trade of agriculture affecting all areas of economic management. The Tigray's characteristics is general for all countries in the Horn of Africa and appropriately reflect the prevailing situation in the Sahel as well as in other African countries suffering from drought desertification land and environmental degradation, sometimes compounded by armed ethnic, tribal and civil conflicts ("Land and environmental degradation and desertification in Africa," 2020).

The government undertook two projects in Tigray. The first was the construction of terraces which, with the agreement and help of local communities, go up to the tops of the mountains at 2,500 meters. The goal was to prevent the rainfall flowing away immediately so that it could be conserved for the agricultural season. On the highest terraces were planted trees, mainly eucalyptus, the dominant tree in Ethiopia and native to Australia. These plants created a new microclimate (Wikipedia contributors. 2020, May 24).

Soil erosion, soil nutrient depletion, and soil moisture stress are the major land degradation problems facing the region. Though soil erosion is prevalent throughout Ethiopia, this problem is particularly severe in Tigray (Hagos, 1999).

The highlands of Tigray are well known for the devastating land degradation problem that has resulted in a decline in agricultural productivity in the region. Land degradation is manifested in the form of soil erosion, deforestation, declining biodiversity resources, and soil moisture stress. This severe land degradation is attributed to the heavy concentration of the population in the highlands, coupled with unchanged agricultural technology, thus putting tremendous stress on the natural resource base, particularly soil fertility. Average estimates of productivity loss due to soil degradation are estimated to be 2-3 percent annually. Currently about 1.4 million people in 31 woredas in Tigray are vulnerable

to chronic food insecurity due to natural and social-economic factors in the region (atigabu, 2012).

Meshesha et al (2012) studied the dynamics of land use and cover and land degradation by analyzing Landsat data from 1973, 1985, and 2006 using Geographic Information Systems and remote sensing techniques. The analysis revealed that in the last 30 years, water bodies, forest, and woodland decreased by 15.3, 66.3, and 69.2 per cent, respectively; intensive cultivation, mixed cultivation/woodland, and degraded land increased by 34.5, 79.7, and 200.7 per cent. The major causes of land use and cover change (LUCC) and land degradation in the area were population and livestock growth in regions of limited resources, unsustainable farming techniques, the Ethiopian land tenure system and poverty.

In this paper to study human modification of terrestrial lands in the Tigray regional state of Ethiopia the global Human Modification dataset (gHM) was used. The global Human Modification dataset (gHM) provides a cumulative measure of human modification of terrestrial lands globally at 1 square-kilometer resolution. The gHM values range from 0.0-1.0 and are calculated by estimating the proportion of a given location (pixel) that is modified, the estimated intensity of modification associated with a given type of human modification or "stressor". 5 major anthropogenic stressors circa 2016 were mapped using 13 individual datasets: (Kennedy, et al. 2019). 5 major anthropogenic stressors are listed below:

- a) Human settlement (population density, built-up areas)
- b) Agriculture (cropland, livestock)
- c) Transportation (major, minor, and two-track roads; railroads)
- d) Mining and energy production
- e) Electrical infrastructure (power lines, nighttime lights)

For population density the Gridded Population of World Version 4 (GPWv4) dataset was used. This dataset provides the

distribution of global human population for the years 2000, 2005, 2010, 2015, and 2020 on 30 arc-second (approximately 1km) grid cells. Population is distributed to cells using proportional allocation of population from census and administrative units. Population input data are collected at the most detailed spatial resolution available from the results of the 2010 round of censuses, which occurred between 2005 and 2014. The input data are extrapolated to produce population estimates for each modeled year (CIESIN, 2018).

To measure spatial pattern based on Tabia locations and its human modification values the Global Moran's I statistic was used. The Spatial Autocorrelation tool returns five values: the Moran's I Index, Expected Index, Variance, z-score, and p-value. These values are accessible from the Results window and are also passed as derived output values for potential use in models or scripts. Optionally, this tool will create an HTML file with a graphical summary of results (ESRI, 2020).

To identify statistically significant problem regions based on human modification, Cluster and Outlier Analysis (Anselin Local Morans I) statistics was used. The Cluster and Outlier Analysis statistics identifies spatial clusters of features with high or low values. The tool also identifies spatial outliers. To do this, the tool calculates a local Moran's I value, a z-score, a pseudo p-value, and a code representing the cluster type for each statistically significant feature. The z-scores and pseudo p-values represent the statistical significance of the computed index values (ESRI, 2020).

The specific objectives of the present research were framed as follows:

1. To measure the distribution pattern of human modification of terrestrial lands at tabias level.
2. To identify clusters and outliers contain high or low human modification of terrestrial lands at Tabias level.
3. To study relation in between population density and Human modification.

The Research Questions for the study

were framed as first what is the distribution pattern of human modification of terrestrial lands at Tabias level? Second where the clusters and outliers are contain high or low human modification of terrestrial lands at Tabias level? And the last what is the relation in between population density and Human modification?

The null and alternative hypothesis for spatial distribution was framed as follows:

H_0 = the spatial pattern of weighted human modification is not clustered Tigray Region.

H_a = the spatial pattern of weighted human modification is clustered Tigray Region.

2. Materials and methods

Study area

Tigray region was chosen as the study areas (Figure1). Tigray Region is the northernmost of the nine regions of Ethiopia (Wikipedia, 2018). which is geographically situated between $12^{\circ}14'10.795''N$ - $14^{\circ}54'47.612''N$ and $36^{\circ}25'48.181''E$ - $40^{\circ}0'18.685''E$.

Administratively, Tigray is bounded by Eritrea in the North, Afar in the East, Amahara in the South border, and Sudan lies in the West. Landforms in the research areas are dominated by mountainous terrain. The study is conducted at Tabia level and there are 767 Tabias in the regional of Tigray.

Research Methodology

Data types and Source

The global Human Modification dataset (gHM) was used in this study; it provides a cumulative measure of human modification of terrestrial lands globally at 1 square-kilometer resolution. The gHM values range from 0.0-1.0 and are calculated by estimating the proportion of a given location (pixel) that is modified, the estimated intensity of modification associated with a given type of human modification or "stressor" (Kennedy et al., 2019). The global Human Modification dataset was collected using (gHM) https://developers.google.com/earth-engine/datasets/catalog/CSP_HM_GlobalHumanModification#description web link.

For population density the Gridded Population of World Version 4 (GPWv4) dataset for the year 2020 was used. These population density grids contain estimates of the number of persons per 30 arc-second grid cell, consistent with national censuses and population registers with respect to relative spatial distribution but adjusted to match the 2015 Revision of UN World Population Prospects country totals (CIESIN, 2018).

Population density the Gridded Population of World Version 4 (GPWv4) dataset was collected using <https://developers.google.com/earth-engine/datasets/catalog/>

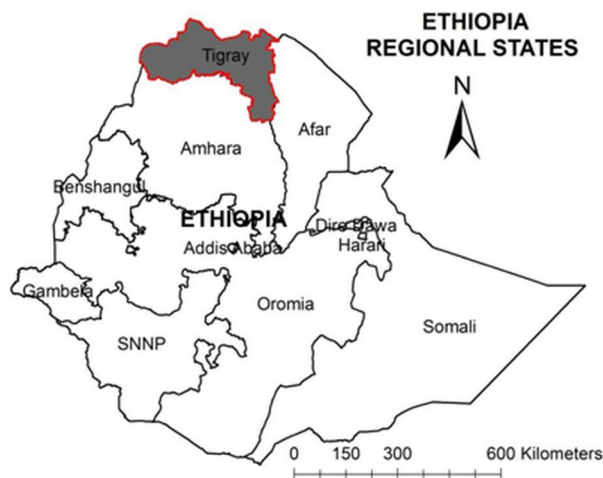


Fig. 1.

CIESIN_GPWv411_GPW_UNWPP-Adjusted_Population_Density link.

Methods of Data Analysis

To meet the first research objective the Spatial Autocorrelation (Global Moran's I) tool was used. The Spatial Autocorrelation (Global Moran's I) tool measures spatial autocorrelation based on both feature locations and feature values simultaneously. Given a set of features and an associated attribute, it evaluates whether the pattern expressed is clustered, dispersed, or random. The tool calculates the Moran's I Index value and both a z-score and p-value to evaluate the significance of that Index. P-values are numerical approximations of the area under the curve for a known distribution, limited by the test statistic.

The Moran's I statistic for spatial autocorrelation is given as eq.1:

$$I = \frac{n}{S_0} \frac{\sum_{i=1}^n \sum_{j=1}^n w_{i,j} z_i z_j}{\sum_{i=1}^n z_i^2} \tag{1}$$

Where z_i is the deviation of an attribute for feature from its mean ($x_i - X$), $w_{i,j}$ is the spatial weight between feature i and j , n is equal to the total number of features, and S_0 is the aggregate of all the spatial weights:

$$S_0 = \sum_{i=1}^n \sum_{j=1}^n w_{i,j} \tag{2}$$

The z_i -score for the statistic is computed as:

$$z_I = \frac{I - E[I]}{\sqrt{V[I]}} \tag{3}$$

where:

$$E[I] = -1/(n - 1) \tag{4}$$

$$V[I] = E[I^2] - E[I]^2 \tag{5}$$

To meet the second research objective Cluster and Outlier Analysis (Anselin Local Moran's I) statistics was used. The index of local Moran's I is a useful tool for identifying hotspots and for classifying them into spatial clusters and spatial outliers (Zhang et al).

Given a set of features (Input Feature Class) and an analysis field (Input Field), the Cluster and Outlier Analysis tool identifies spatial clusters of features with high or low values. The tool also identifies spatial outliers. To do this, the tool calculates a local Moran's I value, a z-score, a pseudo p-value, and a code representing the cluster type for each statistically significant feature. The z-scores and pseudo p-values represent the statistical significance of the computed index values.

The Local Moran's I statistic of spatial association is given as:

$$I_i = \frac{x_i - X}{S_i^2} \sum_{j=1, j \neq i}^n w_{i,j} (x_j - X) \tag{6}$$

Where x_i is an attribute for feature i , X is the mean of the corresponding attribute, $w_{i,j}$ is the spatial weight between feature i and j , and:

$$S_i^2 = \frac{\sum_{j=1, j \neq i}^n (x_j - X)^2}{n-1} \tag{7}$$

With n equating to the total number of features.

The z_{ii} -score for the statistics are computed as:

$$z_{I_i} = \frac{I_i - E[I_i]}{\sqrt{V[I_i]}} \tag{8}$$

Where:

$$E[I_i] = - \frac{\sum_{j=1, j \neq i}^n w_{ij}}{n-1} \tag{9}$$

$$V[I_i] = E[I_i^2] - E[I_i]^2 \tag{10}$$

Geographically Weighted Regression (GWR) was used to model spatially varying relationships in between population density and Human modification of terrestrial lands at Tabia level in the Tigray Region of Ethiopia. To calculate the Geographically Weighted Regression (GWR) Bandwidth was given as 25308 m.

The layer "Human modification of terrestrial lands at Tabia level" was given as dependent and the layer "Population density" was given as explanatory variable. The shape and size of the bandwidth is dependent on

Table 1. Global Moran's I Summary

Moran's Index:	0.502679
Expected Index:	-0.001321
Variance:	0.000100
z-score:	50.501943
p-value:	0.000000

Table 2. The cluster/outlier type, No. of Tabia and their Area

Cluster/Outlier type	Number of Tabia	Area km ²
HH	214	6911.19
HL	10	247.63
LH	77	4063.77
LL	207	26141.00
Other	179	17244.94
Grand Total	687	54608.56

user input for the Kernel type, Bandwidth method, Distance, and Number of neighbors parameters. Fixed Gaussian kernel was used to solve each local regression analysis. The extent of the kernel was determined using the Akaike Information Criterion (AICc).

3. Results & Interpretation

Table 1 shows Global Moran's I Summary, Given the z-score of 50.50 there is less than 1% likelihood that this clustered pattern could be the result of random chance. So, the null hypothesis spatial pattern of weighted human modification in Tigray Region is not clustered is rejected with more than 99%

of confidence level. As a result it can be accepted that the Tabias having high human modification are highly clustered.

Table 2 shows the cluster/outlier type, 214 Tabias containing high value and are surrounded by Tabias with high values (HH), 10 Tabias containing high value and is surrounded by Tabias with low values (HL).

Figure 2 clearly shows the location and concentration of different Tabias clusters and outliers. As tabias with HH cluster type are more clustered in the zones of Eastern, Southern and Central zone of Tigray.

These are because the Tabias located near the regional capital of Tigray region. So more

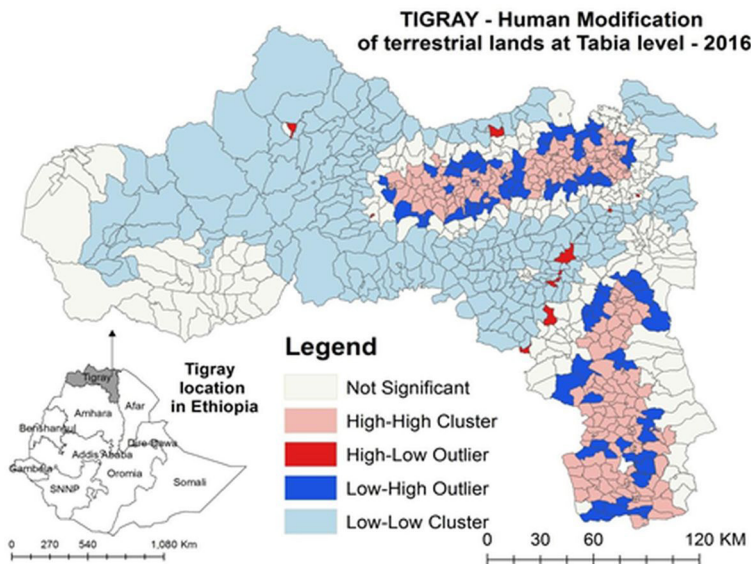


Fig. 2. Map of the Tigray region highlighting the Tabias cluster and outliers

Table 3. No. of Tabias with level of impact due to Pop Density

Level of Impact due to pop Density	Standard Error	No of Tabias
Very Low	-2.5	9
Low	-1.5 to 2.5	7
Insignificant	-1.5 to + 1.5	705
High	1.5 to 2.5	32
Very High	+2.5	14

Note: Sigma = 0.0712, R²= 0.506

development activities have taken place in this area. The activities like road construction, electricity development, industrial development. High population growth in this part of the region is another factor which accelerated the land modifications.

The results of geographically weighted regression are given in table 3 and Fig 3.

The major Tabias having very high impact of population density on the land are shown in red color in figure 3 as Bereket, Rawyan, Musie, Indasilassie Town Tabias 1, 2 &4, Kewanit, Enticho Town Tabias 02 &3, Hageselam, Adigrat Tabias 4, Kedamay, Weyane. These Tabias belongs to urban areas and indicate people are using modern machines and intensive techniques to modify

the natural environment. On the other hand Tabias shown in blue color belong more rural areas, human activities in these areas are more traditional and subsistence in nature.

4. Conclusion and discussion

Humans have intensely changed the terrestrial biosphere. The level of modification varies place to place. In this research an attempt was made to identify the distribution pattern of human modification at Tabia level, as a result it was found highly clustered. The tabias having high level of modification are more located in the urban areas where population density is higher and use of machinery is more. On the other hand rural areas shows human modification is not

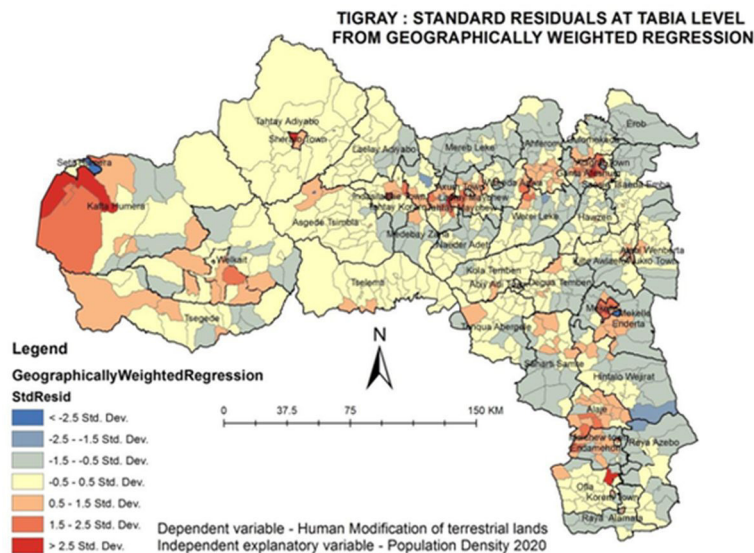


Fig. 3.

that much high due to their traditional way of agricultural practices. The relationship in between population density and the level human modification shows the positive trend. Interestingly, some of the Tabias shows there population density is more but human modification is not as much may due to less mechanization practices. These Tabias are located far from the major roads and access to the electricity is also less, this is the reason of low modification in these Tabias.

Human modification may be positive or negative; it can be studied in further investigation based on the present research findings.

Acknowledgements

We thank Center for International Earth Science Information Network, Columbia University for creating and providing Gridded Population of the World through NASA Socioeconomic Data and Applications Center (SEDAC). We are also thanks full to Kennedy, C.M., J.R. Oakleaf, D.M. Theobald, S. Baurch-Murdo, and J. Kiesecker for their research in the field of human modification on the land. Thanks to Google earth engine team their platform was used for data collection.

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