Short Communication

A Robust Method of Computing the Annual Rate of Land Use/Land Covers Change in Landscapes

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Abstract

Background: Several earlier studies have used different formulae to compute the annual rates of land use/land covers changes in landscapes. Moreover, the magnitudes of the land use changes from two time points (i.e., initial and recent) only have been used to compute the annual rates. However, the use of different formula by itself is confusing and the failure to take into account the instantaneous changes in magnitude of the land use changes from the intermediate time points along the time period may lead to either overestimation or underestimation of the annual rates.

Objective: A formula to compute the annual rate of change in land use/land cover in a robust method was suggested based on the property of the function of instantaneous change in slope and law of compound interest in economics.

Materials and methods: The property of instantaneous changes in slope was integrated with the formula of compound interest in economics to derive the formula of calculating the interest rate of change in land use. With the application of this approach, the differential effects of the drivers of land use change along long temporal scale can be taken into account by converting the magnitude of the changes into change factors. Here, data are "scaled" to change factors from the ratios of the mid points (tangent lines) to the consecutive intermediate initial time points along the time period and these change factors are again averaged over number of time intervals of change detection to enhance the precision of calculating annual rates.

Result: The annual rate of change in land use should be computed as,

$$\mathrm{L_r} = \frac{1}{\mathrm{T}}\left(ln\left(\frac{l_{ti} + 2\sum_{i=1}^{m}(l_{ti+1})_m + (l_{ti+1})_j}{2n(l_{ti})}\right)\right) \times 100.$$

Conclusion: For both short and long time periods, the present formula can be applied as standard and such computation is an ideal input for planning biodiversity conservation and development strategies.

Keywords: Change factors; Compound interest; Instantaneous changes; Time period

1. Introduction

Land or natural landscapes have been altered throughout human history due to the conversions for agricultural production, industrialization and settlements among others (Prasad *et al.,* 2010; Ganasri *et al.*, 2013). Land use/land cover refers to the ecosystem functions and services, while land cover is described based on vegetation cover, wetlands and grass covers-the observed biophysical features in human-modified landscapes (Lillesand *et al.*, 2004; Feranec *et al.*, 2007).

The drivers of the land use/land cover changes are most often categorized as proximate causes including extensive agriculture and over exploitation of forest resources (i.e., wood extraction for timber production, fire wood and charcoal and construction) and underlying causes such as population growth, inappropriate institutional arrangements, weak law enforcements and political instability (Geist and Lambin, 2002). As a result, the current scenario shows that the human-modified landscapes are heterogeneous, fragmented and comprised of different land use /land cover types and hence we need to understand the rates of changes and the consequences on biodiversity.

The changes in land use have both positive and negative impacts on biodiversity conservation and sustainable utilization of the resources and hence, management thereof needs effective land use planning and policies. To this end, understanding of the processes of the land use changes and at what rates these changes are taking place in explicit and implicit ways could be one of the key inputs for policy makers in designing conservation and development strategies (Chauhan and Shailesh, 2005; Papastergiadou *et al.*, 2007; Lin *et al.,* 2009). However, different authors have been using different formulae to calculate the annual rate of changes of land use/land covers (See Abate Shiferaw and Singh, 2011; Tesfa Worku Meshesha *et al.*, 2016; Krios Tsegay Deribew and Desalegn Wana Dalacho, 2019). Similarly, students who have been studying for their masters and PhD in thematic areas of the dynamics of landscapes are

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also using various formulae and report in their theses in either within the same or in different universities (personal observation).

Besides the confusions emanating from using different formulae, these formulae also yield different values of rates. The nature of the land use change dynamics often take continuous exponential pattern with instantaneous trend and comprise outliers. Nevertheless, the previous formulae do not take into account these factors and such failure may cause either overestimations or underestimations and this can lead to wrong conclusions either in area of academia or in planning development and conservation activities. In relation to this, Puyravaud (2003) from India has standardized the calculation of the annual rate of deforestation from the formula adapted by FAO (1995) which is based on the Compound Interest Law in economics (the formulae were shown in results section for comparison purposes). These two formulae have been widely used, but have shortcomings for substantial reasons: (1) were limited only to two time points (the initial and recent) from the time period and cannot be applied to calculate the annual rate of change from instantaneous changes along time period, (2) the farmers decisions and the associated magnitude of land conversion is continuing process and vary from time to time and as a result the changes are instantaneous in nature along time periods, and (3) computing the annual rate from only two points of land use changes undermines the effects of the outliers and intermediate changes and may not indicate the actual rate of change on the ground due to either overestimation or underestimation of the annual rates.

The land use changes are exponential in nature and exhibit a continue change and hence the magnitude of the change factors need to be averaged from various time points and from the midpoints (tangent lines) of the instantaneous changes of slopes (land use/land cover). Therefore, the aim of this short communication is to suggest a formula on how to compute the annual rate of land use change in a robust way by take into account the nature of the instantaneous changes in land use and based on the basics of the compound interest rate and average rate of change in slope in geometry.

2. Materials and Methods

In geometry, the slope or rate of change between two points is calculated as $r = \frac{\Delta y}{\Delta x} = \frac{y_i - y_o}{x_i - x_o}$, however, when there are several changes in slopes over long time, the formula will be extended to $r = \frac{f(x + \Delta x) - f(x)}{\Delta x}$. In this case, the rate of slope change is calculated from one point with the assumption that Δx approaches zero when scant lines become closer to tangent lines in the curve, i.e., $r' = \lim_{\Delta x \to 0} \frac{\Delta y}{\Delta x} = \frac{f(x + \Delta x) - f(x)}{\Delta x}$. Here, the slopes from various tangent lines (mid points) are averaged before converted to change factors or change of slopes. Let us assume that we have analyzed change detection for certain land use/land cover types over certain time periods and changes are quantified as (a, b, c, d, e). Then, the average of changes will be calculated from the intermediate points as $\frac{(a+b)}{2}, \frac{(b+c)}{2}, \frac{(c+d)}{2}$ and $\frac{(d+e)}{2}$. We can easily understand from this method that the annual rate of land use/land covers changes need to be calculated integrating the logic of instantaneous changes with the formula of compound interest in economics ($C = P\left(1 + \frac{r}{m}\right)^{mt}$), where, C is the recent capital, P, the initial principal capital, r, interest rate, m, the time periods or how many times within a year when interest rates are calculated. Unlike the calculation of interest rate (r) in financial system, the rate of land use change is rather computed per year than per periods within a year and, hence, contextually, this formula can be adjusted to$C = P(1 + r)^{T}$, where, r is a fixed annual interest rate or "annual rate of change" in land use/land cover context and T is the total time period of the change detection.

Thus, $r = \left(\frac{C-P}{P}\right)^{\frac{1}{T}}$ and with integration, this becomes, $r = \frac{1}{T}\ln\left(\frac{C-P}{P}\right)$. When the concept of instantaneous rate of changes (i.e., calculating the average rate of slopes) is applied into this formula, the change factor is computed from mid points (the tangent lines) (Figure 1) rather than subtracting the initial value from the recent value of change. Based on the above example, r is computed as $r = \frac{1}{T}\ln\left(\frac{C}{P}\right) \times 100$ $= \frac{1}{T}\ln\left(\frac{\frac{(a+b)+(b+c)+(c+d)+(d+e)}{2n}}{a}\right) \times 100$ $= \frac{1}{T}\ln\left(\frac{a+2(b+c+d)+e}{2na}\right) \times 100$, where, n is the number of time points of the time period and the division by n is to take the average of the mid points.

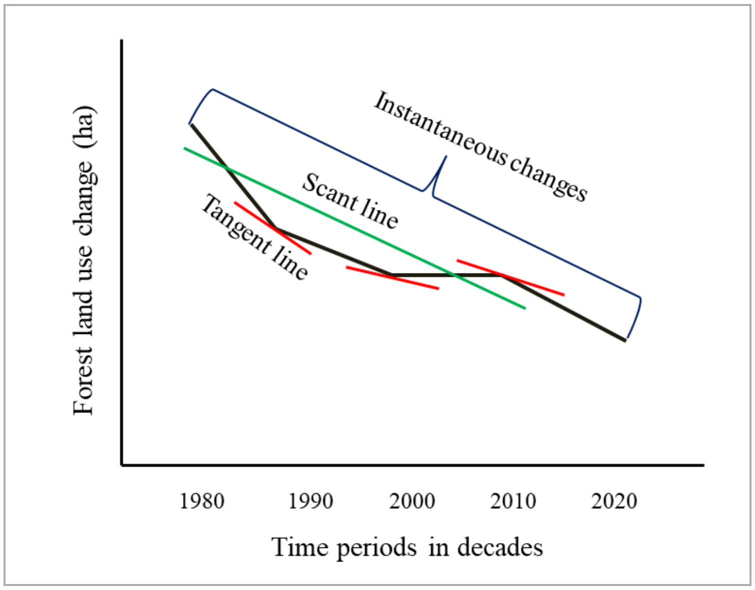

Figure 1. The hypothetical line graph illustrating how the change of the land use (e.g. Forest) vary and the importance of taking into account the instantaneous changes or change factors of the intermediate time intervals over time period (i.e., five decades).

3. Results

The following formula (Eq. 1) is, therefore, suggested to robustly compute the annual rate of land use/land cover change as,

$$\mathrm{L_r} = \frac{1}{\mathrm{T}}\left(\ln\left(\frac{\mathrm{l_{ti}} + 2\sum_{\mathrm{i=1}}^{\mathrm{m}}(\mathrm{l_{ti+1}})_{\mathrm{m}} + (\mathrm{l_{ti+1}})_{\mathrm{j}}}{2\mathrm{n}(\mathrm{l_{ti}})}\right)\right) \times 100 \quad \text{(Eq. 1)}$$

where, l_{ti} =the initial amount of land use change, $(l_{ti+1})_m$ = the mid points of the amount of land use changes (m=number of mid points), $(l_{ti+1})_j$ = the recent amount of land use change, $n =$ the number of time points from the time period for which the change detection is computed, and T =Total time period of the change detection. The L_r can be computed in R statistical program using the script shown in Box A.

Box A. The script to compute the annual rate of land use/land cover changes in landscapes in R statistical program.

Computing the Annual Rate (%) in change of Land use in R-statistical program

$$\mathrm{L_r} = \frac{1}{\mathrm{T}} * \left(\ln\left(\frac{\mathrm{l_{ti}} + 2*\mathrm{sum}((\mathrm{l_{ti+1}})_{\mathrm{m}} + (\mathrm{l_{ti+1}})_{\mathrm{j}}}{2*\mathrm{n}*(\mathrm{l_{ti}})}\right)\right) * 100 \quad \text{Eq. (A)}$$

Where, l_{ti} = the initial amount of land use change, $(l_{ti+1})_m$ = the mid points of the amount of land use changes (m = number of mid points), $(l_{ti+1})_j$ = the recent amount of land use change, $n =$ the number of time points from the time period for which the change detection is computed, and T = Total time period of the change detection.

4. Discussion

The present formula can be applied as standard to compute rates of land use/land covers changes over both short and long time periods, and such computation is an ideal input for planning biodiversity conservation and development strategies. The robustness such computations was illustrated using both hypothetical graphs and by taking examples of the actual data. Moreover, the rates computed with this present formula are compared for its intuitiveness with the formulae used by Puyravaud (2003) and FAO (1995). Let us assume that we wanted to understand the annual rate of forest land use change over the last five decades from 1980 to 2020 in a certain area. Then, to apply the formulae adapted by

FAO (1995), $q = ((\frac{A2}{A1})^{\frac{1}{(t2-t1)}} - 1) \times 100$ (Eq. 2)

and Puyravaud (2003),

$\frac{1}{T2-T1} \ln\left(\frac{A2}{A1}\right) \times 100,$ (Eq. 3)

we have to take the value of the forest land use from the initial time point of 1980 and from the recent time point of 2020. Such kinds of calculations assume that the drivers and the associated magnitude of change in forest land use are "constant" in the intermediate time points or over the time period of 40 years, which in reality are not the case. On the contrary, the variation in the changes of the forest land use during these five decades can be supposedly illustrated as shown in Figure 1. Moreover, these facts can be further elaborated by comparing the rates applying these two formulae and the current formula (L_r). As we can see from the hypothetical data in Table 1, the rates calculated using $q\ and\ r$ higher when compared with rate from L_r. Most likely, the rates for $q\ and\ r$ are overestimated since both do not take the average of the changes from the initial and recent time points before converting to change factors. Moreover, as can be clearly observed from Figure 2 in which the annual rates were computed for five land use types (see Table 2), the annual rates calculated using $q\ and\ r$ are less strongly correlated (ρ = 0.87) with coefficient of variation when compared with that of L_r $(\rho = 0.99)$. As a result, at lower coefficient of variation, the annual rates computed are similar for $q, r\ and L_r$. However, when coefficient of variation get higher, significant variations are observed between L_r and (q, r) (see Table 2). Here, applying the later formulae, for the effect of the outliers are not minimized and the change factors from the intermediate land use changes are not optimized either underestimations or overestimations may occur in the annual rate of changes in land use. On the contrary, L_r assumes that the landscape variables- whether biological or biophysical, are in dynamic process in mosaic landscapes in spatial and temporal context (Sokal and Rohlf, 1969; Gotelli and Ellison, 2004) and does not reach exponential decay as previous formulae assume.

5. Conclusion and Recommendation

Altogether, with the application of L_r besides its advantage for computing the annual rate of change in a robust way and avoids wrong conclusions (Sambou *et al.*, 2015). Moreover, the present formula can be used as a standard and avoids the confusions that arise from using different formulae to compute the annual rates of land use/land cover changes in human modified landscapes.

Table 1. Comparing the rate of forest land use changes using only the two time periods from the initial (1980) and the recent time period (2020), unit is in percentage per year.

Land use	1980	1990	2000	2010	2020	$q = \left(\left(\frac{A2}{A1}\right)^{1/(t_2-t_1)} - 1\right)\times 100$	$r = \frac{1}{T2-T1}\ln\left(\frac{A2}{A1}\right) \times 100$	$L_r = \frac{1}{T}\left(\ln\left(\frac{l_{ti} + 2\sum_{i=1}^{m}(l_{ti+1})_m + (l_{ti+1})_j}{2n(l_{ti})}\right)\right)\times 100$
	Area (ha)	Area (ha)	Area (ha)	Area (ha)	Area (ha)			
Forest	8040	5060	3070	4436	1806	-3.66	-3.73	-2.96

Table 2. The annual rate of land use changes are calculated for L_r q and r. The land use data analyzed is from the satellite images of 1973, 1986, 2000 and 2018 in southwest Ethiopia (resolution = 30×30m).

No	Land use	1973	1986	2000	2018	Data dispersion (CV) in (%)	L_r	q	r	$\left(\frac{L_r - q}{L_r}\right)\times 100$	$\left(\frac{L_r - r}{L_r}\right)\times 100$
		Area (ha)	Area (ha)	Area (ha)	Area (ha)						
1	Forest	82054	70123	63369	44588	24.09	-1.14	-1.35	-1.36	18.4	19.3
2	Shrub land	8785	9581	8364	5955	19.11	-0.73	-0.86	-0.86	17.8	17.8
3	Wetland	6316	7224	6929	4886	16.40	-0.55	-0.57	-0.57	3.64	3.64
4	Crop land	8170	18542	28567	46440	64.08	1.83	3.94	3.86	115.3	110.93
5	Bare land	7	1044	46	65	173.12	8.21	5.08	4.95	313	326

Data organized from Fikiru Belete (2020).

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7. References

Abate Shiferaw, Singh, K.L. 2011. Evaluating the land use and land cover dynamics in Borena Woreda of South Wollo Highlands, Ethiopia. *East African Journal of Sciences,* 2(1): 69–104.

Chauhan, H.B., Shailesh, N. 2005. Landuse/land cover changes near Hazira Region, Gujarat using Remote Sensing Satellite data. *Journal of Indian Society of Remote Sensing*, 33: 220–227.

FAO (Food and Agriculture Organization). 1995. *Forest resources assessment 1990*. Global Synthesis, FAO, Rome.

Feranec, J., Hazeu, G., Christensen, S. *et al*. 2007. Corine land cover change detection in Europe (case studies of the Netherlands and Slovakia). *Landuse Policy,* 24: 234–247.

Fikiru Belete. 2020. Land use/land cover dynamics and perception of the local communities in Bita district, southwest Ethiopia. M.Sc. Thesis, Kotebe Metropolitan University, Addis Ababa, Ethiopia.

Ganasri, B.P., Raju, A., Dwarakish, G.S. 2013. Different approaches for landuse/land cover change detection: A Review. *Research Reviews: Journal of Engineering and Technology,* 2: 44-48.

Geist, H,J., Lambin, E.F. 2002. Proximate causes and underlying driving forces of tropical deforestation. *Biosciences,* 52: 143–150.

Gotelli, N.J., Ellison, A.M. 2004. *Primer of Ecological statistics*, Sinauer Associates, Inc. Publishers, Sunderland, Massachusetts, U.S.A.

Krios Tsegay Deribew, Desalegn Wana Dalacho. 2019. Land use and forest cover dynamics in the North-eastern Addis Ababa, central highlands of Ethiopia. *Environmental Systems Research*, 8:8 https://doi.org/10.1186/s40068-019-0137-1

Lillesand, M.T., Kiefer, W.R., Chipman, W.J. 2004. *Remote sensing and image interpretation*. Wiley, India.

Lin, Y.P., Verburg, H.P., Chang, C.R., Chen, H.Y., Chen, M.H. 2009. Developing and comparing optimal and empirical land-use models for the development of an urbanized watershed forest in Taiwan. *Landscape and Urban Planning*, 92: 242–254.

Papastergiadou, E.S., Retalis, A., Kalliris, P., Georgiadis, T.H. 2007. Land use changes and associated environmental impacts on the Meditteranean shallow Lake Stymfalia, Greece. *Hydrobiologia*, 584: 361–372.

Prasad, R.C.P., Rajan, K.S., Dutt, C.B.S., Roy, P.S. 2010. A conceptual framework to analyze the Landuse/Land cover changes and its impact on phytodiversity – a case study of North Andaman Islands India. *Biodiversity and Conservation*, 19: 3073–3087.

Puyravaud, J.P. 2003. Standardizing the calculation of the annual rate of deforestation. *Forest Ecology and Management*, 177: 593-596.

Sambou, S., Lykke, A.M., Sambou, H., Guiro, I., Sambou, B., Mbow, Ch. 2015. Land Use-Land Cover Change and Drivers of Deforestation in the Patako Protected Area of Center-West of Senegal. *American Journal of Environmental Protection*, 4: 306–317.https://doi.org/10.11648/j.ajep.20150406.17.

Sokal, R.R., Rohlf, F.J. 1969. *Biometry, the principles and practice of statistics in biological research*, 2nd edition, W.H. Freeman and Company, San Francisco.

Tesfa Worku Meshesha, Tripathi, S.K., Khare, D. 2016. Analyses of land use and land cover change dynamics using GIS and remote sensing during 1984 and 2015 in the Beressa Watershed Northern Central Highland of Ethiopia. *Modeling Earth Systems and Environment* 2:1−12, https://doi.org/10.1007/s40808-016-0233-4.