



Climate Change Vulnerability Indices for Kakamega - Nandi Forest Complex in Kenya

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Abstract: Climate change has been defined as ‘a change in the average conditions – such as temperature and rainfall – in a region over a long period of time’. Vulnerability can be defined as the extent to which a socio-economic and environmental system is exposed to climate change. Determination of vulnerability can enable mitigation measures to be taken against climate change induced effects. In particular, the use of Climate Change Vulnerability Indices (CCVI) ensures that correct and timely actions to mitigate impacts can be taken. In a study to evaluate climate change vulnerability (CCV) in the Kakamega-Nandi forest complex, annual rainfall and temperatures, vegetation cover, land use and soil organic carbon were measured and used to construct Climate Change Vulnerability Index (CCVI). CCV was formulated as a function of soil organic carbon (SOC), vegetation cover (LAC), land-use/land-use change (LUC), temperature changes (TEMPs) and rainfall amount (RAIN). Thus: $CCV = f(SOC, LAC, LUC, TEMPs, RAIN)$ Initial analyses revealed that some variables were significantly co-related to others and these were removed to avoid auto-correlation. Climate change well being indices were developed using a weighting factor (Wt_i) for vegetation cover and land use / land cover (LULAC), with Natural forests given the highest weight (well-being) and bare land the lowest. The weighting factor was guided by ANOVA results of SOC and separation of means which gave groups that significantly differed statistically at $\alpha=0.05$. The final CCVI was calculated as:

$$CCVI = 1 - \left\{ \left(\sum_i^N (Wt_i * \%COVER)^{\frac{1}{Wt_i}} \right) * \left(\frac{1 - \%COVER}{TOTAL AREA} \right) \right\}$$

The results showed that land use and land cover substantially influenced climate change vulnerability with bare land showing the highest vulnerability index and intact Natural forests and plantations showing the lowest CCVI. Effects of rainfall and temperatures, variables which have been associated with climate change most often, were correlated with land use and land cover in this study. The developed index can serve as a useful tool to assist in decision-making regarding the vulnerability of communities in areas with extreme land-use land cover changes. We recommend that further in-depth studies be carried out to improve the sensitivity of the CCVI developed in this study.

Keywords: Climate Change Vulnerability Index, land-use.

INTRODUCTION

Climate change manifests itself in various forms including change in weather patterns e.g. increase in mean temperatures and reduced amounts of mean annual rainfall and/or

increased out-of-season and sporadic heavy down pour (Mwangi *et al.* 2020), reduced land cover in particular reduction in forest area and or increased forest degradation, change in land use especially a shift from more perennial uses e.g. forestry to seasonal uses e.g. subsistence agriculture. Climate change caused by intense and longer droughts, heavy precipitations and extreme temperatures is becoming a common phenomenon in the tropical and subtropical countries. In fact, according to a report on Climate change vulnerability, 23 of the 33 high risk countries are in Africa (NatureServe 2017). Climate change effects are now seen to be responsible for severe food shortages, declining living standards and loss of biodiversity. Agriculture and livestock farming are the main livelihoods in many developing countries. A changing climate will negatively affect agriculture, livestock rearing, water resources, insects and soils (Climatechangeconnection.org 2013). The result will be increased negative anthropogenic impact on natural forests. The need, therefore to quantify climate change effects is important. But quantifying the effects of climate change is challenging given that some of the important driver variables are difficult to measure and/or data may not be readily available.

Vulnerability can be defined as “the sensitivity or coping ability” to effects of exposure to climate change. It is the defencelessness or helplessness to climate change effects. It is a function of exposure, sensitivity and adaptive capacity (Glick *et al.* 2010, Roy and Blaschke 2015, Weis *et al.* 2016). Ludena and Yoon, (2015) argue that the extent to which a socio-economic and environmental system is affected by climate change, and the ability of a system to withstand and recover from climate change caused disturbances is its adaptive capacity. How readily a system is impacted by climate change defines its sensitivity while the ability to cope and/or stabilise following climate change effects shows adaptive ability (Ludena and Yoon, 2015). Assessment of vulnerability can enable mitigation measures to be taken against climate change induced damage. Vulnerability to climate change can be estimated using measures of economic loss on community production systems and/or on bio-physical conditions of the environment e.g. land use and land use/cover change or level of forest degradation or complete loss of forest cover.

An index is a composite number or ratio which is calculated from response variables and used as a gauge of the wellbeing and/or performance of a system (Commeau *et al.*, 1993) and/or how the system is impinged by certain measured variables or their intensity. Thus, in this study we investigated the impact of different land uses on climate change impact reduction and developed an index to show vulnerability. Climate Change Vulnerability Index (CCVI) is therefore a measure of the extent to which there is exposure to climate change effects. CCVI can be useful in predicting not only the level of susceptibility and seriousness of potential climate change effects suffered but also the need for action to reduce climate change impacts. The use of Indices to gauge the impact of climate change is therefore one approach that can be used to assess climate change vulnerability (CCV). However, in Kenya few studies have developed and applied CCV indices (CCVI). This study focused on developing CCVI using soil organic carbon, land use practices and land cover to assess vulnerability to climate change in Kakamega - Nandi forest complex.

Problem Statement and Justification

High temperatures, little or more than normal rainfall and especially ‘out of season’ rainfall have all led to loss of agricultural production and loss of livestock which are the main

livelihood provisions for local communities in developing countries (Climate Change Connection, 2013, Farming in a changing climate 2013). With burgeoning populations, subsistence agriculture is the main livelihood engagement for most rural communities. Conversion of forested and wooded areas into agriculture is on the increase thus exacerbating climate change effects (The International Institute for Environment and Development (IIED), 2009). But this could easily lead to a '*rat race*' effect as extreme weather patterns are forecast to increase which may lead to decreased subsistence agricultural productivity especially where fallow periods are reduced due to land pressure. One of the challenges facing most governments in addressing climate change impacts is the lack of locally developed tools to estimate the effects of climate change and/or the potential damage which will be suffered if no action is taken. Tools to estimate the impact of climate change and vulnerability of communities to climate change effects will assist policy makers to prioritise areas most vulnerable to climate change and roll-back the negative impacts of climate change. This paper, therefore reports on development of climate change vulnerability indices (CCVI) for Kakamega-Nandi forest complex in Kenya to evaluate climate change vulnerability and assist in making informed management decisions.

STUDY APPROACHES

Study Site

The study was done in the Kakamega - Nandi forest complex in Kenya. A detailed description of the study site characteristics can be sourced from Wabusya *et al.* (2020).

Building the Vulnerability Indices: Theoretical Base and Assumptions

1. The Indices were constructed such that a low value implied that people were at low risk of climate change related impacts. Meanwhile, people living near the forest, for example, while they experience low impacts of climate change related occurrences, they may suffer most in future if the forests are dilapidated. Hence, they have to protect the forest because if they destroy it, they will suffer most devastating effects of climate change.
2. Any land cover is better than none. Thus, land cover will attract high protection/mitigation effects. Places with no land cover suffer high impacts of climate change and hence highest vulnerability.
3. Soil organic carbon implies that there is some biomass. In this study, preliminary analyses showed that soil organic carbon could be used to group land-use/land cover into similar groups. These groups were thereafter used to do weighting of possible climate change effects for different land use categories.
4. Land use has a significant effect on climate change related impacts. However, some land uses have a dilution effect on the overall impact of climate change related impacts. For example, intact natural/plantation forests will lower climate change effects to small scale farmers residing near the forest. Hence, such farmers will end up with lower vulnerability values due to their proximity to the forest.

5. Some land uses have additive effects while others may have multiplicative effects. For example, grazing will have an additive effect to small scale agriculture as both land uses encourage low vegetation cover, hence aggravating the impacts of climate change leading to higher vulnerability index value. Meanwhile, intact natural forest and forest plantations will have a multiplicative effect given that both land use types lead to low climate change related impacts hence low vulnerability.
6. Weighting of the variables which had been assessed was done based on ANOVA results of soil organic carbon and means separation (as explained later). Thus, intact natural forest was given a higher weight (less climate change impacts and lowest vulnerability) than for example, small scale agriculture (more climate change impacts and high exposure to vulnerability due to soil exposure and increased greenhouse gases as a result of excessive fertilizer use, burning of farm debris, among other effects. Similarly, sugar cane growing was given a higher weight than grassland and bare land due to its stature and greenery most of the year compared to small scale agriculture where the land could be left bare especially following harvesting of the crops.

Formulating Vulnerability Indices

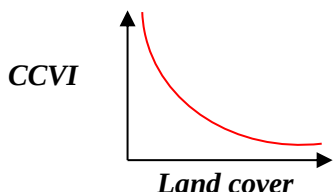
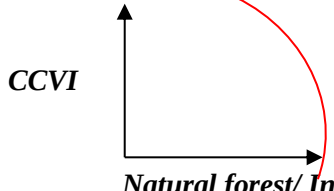
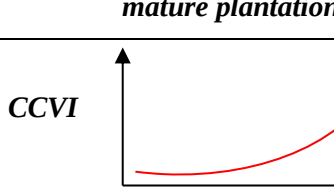
An index can be defined as a number which shows the measure of changes in some given variables related in a certain defined way; normally by an equation (Kironko 1996). Various indices exist in various fields of study e.g. Economics (the Dow, NASDAQ, household poverty index) and in forestry (e.g. weed competition index). In formulating the vulnerability indices, the following procedures were followed:

1. Land cover: forest cover > agriculture > grassland > bareland (as explained later based on Anova groupings using soil organic carbon);
2. Landuse: Natural forest = plantations > tea estates=cane growing> grazing=maize growing > bareland.
3. Soil organic carbon (SOC): ANOVA results (given later), showed that forested areas had higher SOC than tea and sugarcane which were also higher than grazing and maize growing, with bare land having the least.

Hypothetical Scenarios of Possible Vulnerability Forms in Different Land Cover/ Land Use Categories

These assumptions are based on the expected nature and shape of the vulnerability index under low and high values of the variables used (table 1). A study carried out in the Mau, Cherangany and Mt. Elgon water tower ecosystems on climate change vulnerability assessment showed that vulnerability is a factor of exposure, sensitivity and adaptive capacity (USAID 2018). Kironko (1996) states that indices can be formulated by including the main factors influencing the magnitude of the effects of the index in terms of their intensity, dominance and interaction effects when in combination with other influencing factors together. Following this line of argument therefore, the CCV was formulated as a function of soil organic carbon (SOC), vegetation cover (LAC), land-use/land-use change (LUC), temperature changes (TEMPs) and rainfall amount (RAIN). Thus:

Table 1: Hypothetical scenarios of CCVI in different vegetation cover.

Variable Explanation		Assumed CCVI Impacts
Vegetation Land cover - high vegetation land cover implies a lower index and vice versa.		
Land Use	Natural forest / forest plantation	
	Changing landuse from forestry to Tea plantations / Bushland / Maize / Grassland / Bare land	

$$CCVI = f(SOC, LAC, LUC, TEMP_s, RAIN)$$

These variables inherently include effects of exposure (magnitude of climate change to biotic and abiotic systems), sensitivity (degree of effect on the system) and Adaptive capacity (coping ability of an affected system), (USAID 2018). But from preliminary analysis comparing LULAC and SOC it was evident that SOC results can act reliably as surrogates for LULAC. Thus, the results of analysis of SOC gave the following main groupings based on land use - land cover and soil organic carbon (SOC) table 2. Moreover, some variables have interaction and/or synergistic effects on others. In such situations the main variable (one that expresses the consolidated effects of the minor variables) is used. This approach of analysing and building models / indices is prudent to avoid unnecessary auto-correlation effects (Kironko 2000). For example, a healthy forest inherently implies good rainfall, high levels of soil organic carbon and moderated temperatures, hence lower climate change effects and lower CCVI value.

Preliminary analysis (ANOVA and Separation of Means - results shown later) showed that SOC could be used to group major landuses together; viz. Following the ANOVA results of the SOC in different land uses, the following weighting was used;

Table 2: Climate change impact weighting (higher values show low impact)

Group		Weighting
Group 1	Intact Natural Forest and intact forest plantations	5
Group 2	Tea and Sugar cane plantations	3
Group 5	Forest regeneration, Grazing, Maize, Grass land, Bush land	2
Group 6	Bare ground/Bare land	1

1. The approach used was to calculate the percent cover for any given land cover (PCT = LULAC/TOTAL AREA).
2. Climate Change Weighting Index (CCWI) i.e. LULAC that has significant positive impact was given a higher weighting than one that has low mitigation potential. A weighting index was then developed to capture land use which has higher mitigation impact e.g. Natural forest compared to maize growing.
3. A simple index (CI) was initially developed based on the land use and land cover (LULAC) classes found in the study area.

$$CI = \sum_i^N (Wt_i * \%COVER)^{\frac{1}{Wt_i}} \dots\dots\dots \text{Equation 1}$$

Where;

- a) **CI** = Simple Change Vulnerability Index
 - b) **Wt_i** = the given weighting value for land use/cover i,
 - c) **% cover** = percent land use / land cover.
4. A dilution effect (**DE**) factor for areas nearest forests was used to make the simple index sensitive. This is because areas nearest the forest suffer less negative climate change effects than areas further from forests. The dilution effect considers the area of the forest as well. Small and Fragmented forests will have reduced climate change moderation than large forest blocks. The dilution effect factor was calculated thus:

$$DE = \frac{1 - \%COVER}{TOTAL AREA} \dots\dots\dots \text{Equation 2}$$

Where;

- a) **DE** = dilution effect
- b) **Total Area** = Total area of the forest/land cover,
- c) **% cover** = percent land use / land cover.

The Impact Change Index then becomes (**CI*DE**):

$$ICI = \left(\sum_i^N (Wt_i * \%COVER)^{\frac{1}{Wt_i}} \right) * \left(\frac{1 - \%COVER}{TOTAL AREA} \right) \dots\dots\dots \text{Equation 3}$$

5. The simple index (ICI) based on LULAC was then combined with SOC, rainfall and temperatures to give a more inclusive CCVI based on current understanding of the effects of climate change.

The final CCVI was calculated by combining equations 1, 2 and 3:

$$CCVI = 1 - \left\{ \left(\sum_i^N (Wt_i * \%COVER)^{\frac{1}{Wt_i}} \right) * \left(\frac{1 - \%COVER}{TOTAL AREA} \right) \right\} \dots\dots\dots \text{Equation 4}$$

Intact Natural forests and intact mature plantations were given higher weighting of 5 and not 4 because of their tremendous and significant mitigation effect compared for example to Tea plantations or agriculture which due to their seasonality have intermittent impact.

RESULTS AND DISCUSSION

Landuse/Landcover Change Groupings

Results of ANOVA and means separation showed that 4 main groups could be used.

Table 3: Anova results for landuse categories

Source	Df	Sum of Squares	Mean Square	F value	P > F
Site	7	22.42802458	3.20400351	5.38	< 0.0001
Landcover	5	27.73802096	5.54760419	9.32	< 0.0001
Error	89	53.0021740	0.5955300		
Total	101	117.0135343			

Further, means separation was carried out using Tukey test and the results are in table BBB.

Table 4: Means separation and landuse groupings

	Natural forest	Plantation	Tea	Maize	Grazing	Sugar cane	Bare land
Natural forest		<i>ns</i>	***	***	***	***	***
Plantation	<i>ns</i>		***	***	***	***	***
Tea	***	***		<i>ns</i>	<i>ns</i>	***	***
Maize	***	***	<i>ns</i>		<i>ns</i>	***	***
Grazing	***	***	<i>ns</i>	<i>ns</i>		***	***
Sugar cane	***	***	***	***	***		***
Bare land	***	***	***	***	***	***	

*** shows statistical significance between groups at 95% confidence level

Climate Change Wellbeing Index (CCWI)

Our results show that there are 3 main groupings of landuses in terms of climate change wellbeing/mitigation effects: group 1 = Bushland, Grassland and small scale agriculture; group 2 = Tea plantations and forest regeneration and group 3 = intact forest plantations and Natural forests (figure 1). Intact forests are most important in climate change impact mitigation than other land uses. Our results show that grassland, small scale agriculture (maize growing) and bushland have some potential to mitigate climate change but their impact is not only low but also on a trajectory that flattens at about 20% impact (Figure 1). Meanwhile forest regeneration and Tea plantations (and sugar cane) have a higher-level trajectory flattening at about 45%. Thus, part of the benefits of forests is due to their higher impact potential compared to other land uses. Meanwhile, intact forests flatten at above 60% (Figure 1).

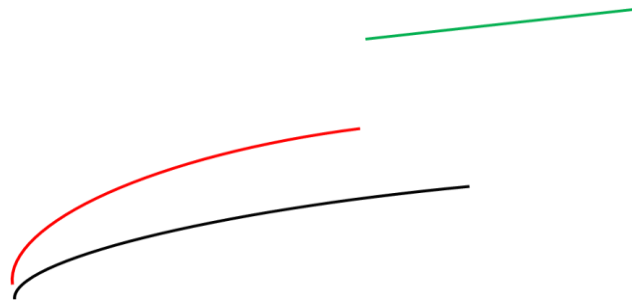


Figure 1: Climate change Wellbeing trajectories of different land uses

(CCWI = Climate Change Well being Index; i.e. the mitigation potential of a certain land use adopted in the area. WEITPCT = a percent weighting method adopted in the study to ensure that different land uses were given the due impact envisaged in practice; LULAC = ; ABare = ; Bush-Lan = ; CTea-Pla = DGrass-L = ; Esmall-S = ; Forest-R = ; Natural = Natural forest and mature plantation forests together).

From these results therefore, Natural forests and intact plantations are the first line of defence in mitigating Climate change effects. Forest regeneration is important but below intact forests. This could be due to the fact that forest regeneration may still have low leaf area (LA) compared to mature forests and thus low C-fixation potential as well as low canopy cover. While Tea is on the same trendline as forest regeneration, it is at the lower tailend. This may imply that if left untouched Tea may give similar effects to those of forest regeneration after some time, but this does not happen. Bushland, Grassland and small scale agriculture have similar trends but in increasing order of importance. This may be due to the fact that all the three types of landuses have closely related crops/plants hence similar influence in terms of climate change mitigation.

Climate Change Wellbeing Index by Landuse/landcover by year

The results from this study show that land use and land cover were associated extensively with climate change vulnerability with bare land showing lowest well-being values and Natural forests showing the highest well-being index irrespective of the year (figure 2). This may imply that for the study period 1985 - 2015 annual variations were all the while clustered together and that landuse over-rode yearly effects (figure 2).

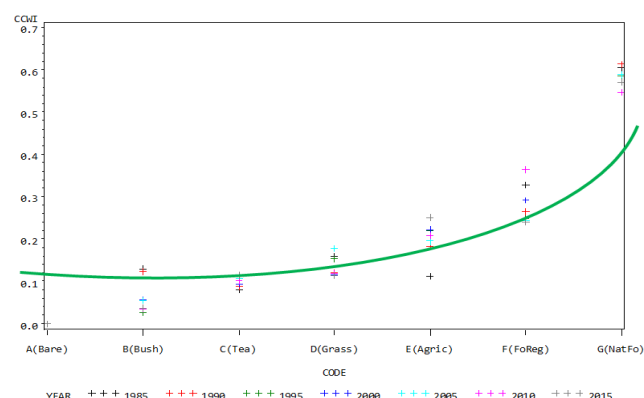


Figure 2: Climate Change Wellbeing Index (CCWI) for various land use / land cover types in the study area between 1985 - 2015.

Climate Change Vulnerability Index (CCVI)

Climate Change Vulnerability Index (CCVI) which is a measure of the extent to which there is exposure to climate change effects, can be useful in predicting the level of seriousness of potential climate change effects suffered and also the need for action to reduce climate change impacts. In figure 3 the CCVI is highest for bare land reducing gradually until it hits the lowest value for intact forest. It is important to note that this concave trend implies that while change in vegetation type may be immediate (e.g. a community converting land from forest to agriculture), the actual climate change impacts of this action may be very gradual. Increased exposure of the soil to the sun may lead to drying, increased erosion, loss of biodiversity and low productivity. Thus, with time the effects will increase in magnitude and intensity. CCVI therefore can assist us in making the right decisions regarding land uses e.g. not to convert forests into agriculture. The Climate change wellbeing Index increases steadily with increasing vegetation cover but more so with the kind of land cover (figure 1). This may be due to SOC amount and general climate amelioration effects that various land cover / land use types have.

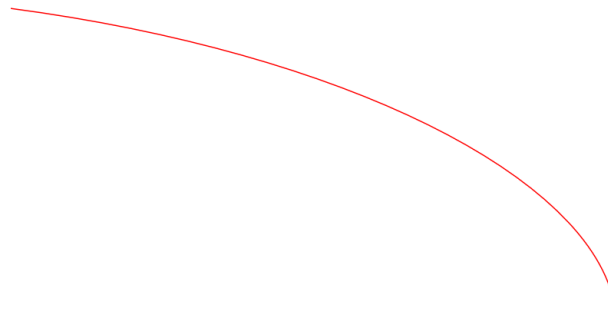


Figure 3: Climate Change Vulnerability Index (CCVI) for various Land use / land cover used in the study.

The concave shape of the CCVI graph further highlights the fact that areas without meaningful forest cover (e.g. bareland, subsistence agriculture, bushland, grassland) are highly vulnerable but the vulnerability may be gradual as land use cover changes from one with high mitigation potential (e.g. forest) to that with lower potential (e.g. forest to agriculture). Meanwhile, forested areas have lower CCVI but still not a perfect score (0) due to potential anthropogenic effects. Further, the difference in CCVI values between intact forest cover and other land uses is quite significant, evidence of the exposure potential.

Results of CCVI for the years investigated show that forested areas had the lowest while bareland the highest. Bushland, Grassland, small scale agriculture and forest regeneration recorded some fluctuations. There is no significant evidence of major fluctuations for forested areas (Figure 4). However, these may be masked by the timeframe as well as the fact that there were no directed studies to investigate climate change effects in any particular land use during this time.

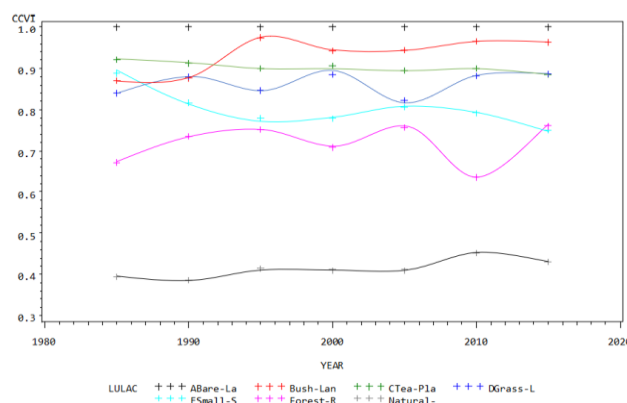


Figure 4: Climate Change Vulnerability Index for various land use / land cover types in the past 30 years.

It can be seen from figure 4 that over the past 30 years, natural forests had the lowest vulnerability while bare land had the highest and other land uses are in between. This reinforces the observations that; 1) converting forests to agriculture or pasture leads to high exposure and susceptibility to climate change effects and increases vulnerability and 2) Natural forest and/or plantation forests have low vulnerability. Therefore, conservation efforts should be geared towards increasing forest cover and reforesting bareland and/or reclaiming degraded forests. Moreover, while annual fluctuations are observable, the overall position of different vegetations is maintained (figure 4). Therefore, more sensitive studies may be needed to verify annual changes in vulnerability. But it could also imply that the data we have did not capture changes in vulnerability well or these changes were masked by seasonal local events e.g. sudden heavy rainfalls as observed under climate change effects (e.g. IIED, 2009).

Communities living in high vulnerability locations traditionally have learnt to live with climate variability and have been argued to cope and adapt (e.g. IIED, 2009). But are their reactions to climate change effects reactive or based on scientific data? Are these 'coping mechanisms' displayed by communities in high vulnerability areas transferable to similar sites? We are of the opinion that tools like CCVI can be very useful in not only guiding policy decisions but also ensuring efficient use of little available resources to give most benefits to highly vulnerable locations.

CONCLUSIONS

We conclude that similar studies should be carried out especially in areas where Natural forests have shown signs of degradation to elucidate change impacts. As these changes are gradual, quantitative tools like the development and refining of CCVI will be very useful in informing and guiding policy and landuse changes to ensure that communities adjacent to these forests are supported to maintain and protect them, while those in highly vulnerable areas are not unduly exposed to climate change impacts because of poor decisions.

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