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(RESEARCH ARTICLE)

# Modelling of climate conditions in forest vegetation zones in Malawi

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## Abstract

Adverse impact of climate change on the environment has been widely reported. Malawi has not been spared from the adverse impacts of climate change as evidenced by recent floods and drought. This study was conducted to assess the impact of climate change on forest type, forest living biomass, basal area and number of stems. Holdridge Life Zone model and GAP Formind modified were used for the assessment. The results show that there are currently two forest vegetation zones occurring in Malawi (2011-2040). These include: tropical dry forest and tropical very dry forest. In mid-century (2041-2070) thorn woodland forest will emerge, while tropical dry forest will disappear in end-century (2071-2100). There will be a significant decrease in forest living biomass (1,000 kg $ha^{-1}yr^{-1}$) and basal area (43.5%) from near century to end-century. On the other hand, there will be a significant increase (5 stems $ha^{-1}yr^{-1}$) in number stems from near century to end-century. The study has demonstrated that future climate change will be conducive to growth and expansion of very dry forest vegetation zone, which causes positive effects on reforestation planning and adaptive strategies in this region. Therefore, the study suggests the following as some possible strategies to adapt climate change: promotion of natural regeneration of tree species, promotion of tree site matching, production and promotion of new tree seed varieties; and seed banking for drought resistant tree species.

**Keywords:** Adaptation; Climate change; Vegetation zone; Forest biomass; Tree basal area

## 1. Introduction

Forests contribute directly to Malawi's GDP through domestic and export product sales, employment and tourism. Forest supply more than 96% of the country's energy need. Apart from energy, trees provide timber and non-timber forest products [1-2]. Malawi's forest cover 25% (23,677 $km^2$) of the total land area. Miombo woodlands cover 22,857 $km^2$ while plantation forests cover 820 $km^2$. Pine and eucalyptus are the most common trees in the plantations while Brachystegia is the most prevalent tree genus in miombo woodlands [2]. Despite the important role forests play in Malawi, the forests are being cut and degraded much faster than they are regenerating. It is estimated that the rate of deforestation is 2.8% per annum [3-5]. Furthermore, recent study has shown that between 2019 and 2025, Malawi's demand for wood fuel will exceed sustainable supply [1]. In addition, the adverse impact of climate change on the environment has been widely reported [6-9]. Malawi has not been spared from the adverse impacts of climate change as evidenced by recent floods and drought [10]. Therefore, it is important for Malawi to identify measures and strategies for adapting the climate change. The purpose of this study was: (1) to determine how many forest vegetation zones exist in Malawi, (2) to determine how the structure of forest vegetation zones respond to future climate change in the aspects of boundaries, areas, forest living biomass, basal area, and number of stems. This study is of importance for improving our understanding of the effect of climate change on vegetation zones and for planning the adaptation strategies of future ecological restoration programmes in Malawi and the surrounding region.

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## 2. Material and methods

### 2.1. Study area

Malawi is located in Southeast Africa (Figure 1). It is bordered by Mozambique on the east and southwest, by Tanzania on the north and northeast, and by Zambia on the west and northwest.

Malawi has a sub-tropical climate and it is categorized into three seasons. Namely: Hot-dry, warm-wet, and cool-dry seasons. Hot-dry season is evident from September to October with an average temperature range of 25 °C to 37 °C. Warm-wet season lasts from November to April with an annual average rainfall range of 725 mm to 2,500mm. This is the season during which 95% of the annual rainfall takes place. Finally, the cool-dry season stretches from May to August with an average temperature range of 4 °C to 10 °C. In cool-dry season, especially in June and July frost may occur in isolated areas [11].


**Figure 1** Location of Malawi in Africa

### 2.2. Simulation process

#### *2.2.1. Climate layers and future scenarios*

The assessment was conducted based on five climatological zones of Malawi (Figure 2.). Three scenarios were used in the assessment. These include: Near century (2011-2040), mid-century (2041-2070), and end-century (2071-2100). The projected temperatures and precipitations for the three scenarios were obtained from Department of Climatic Change and Meteorological Services, Malawi. Briefly, projections for future temperature and precipitation were developed using downscaled outputs from 20 global scale general circulation models (GCMs) used in the Intergovernmental Panel on Climate Change Fifth Assessment report, in conjunction with two representative concentration pathways (RCPs; RCP4.5 and RCP8.5) [12]. Observed data temperatures and precipitation data used was for the period 1961-2010 while daily temperatures and precipitation data used was for 1971-2000.

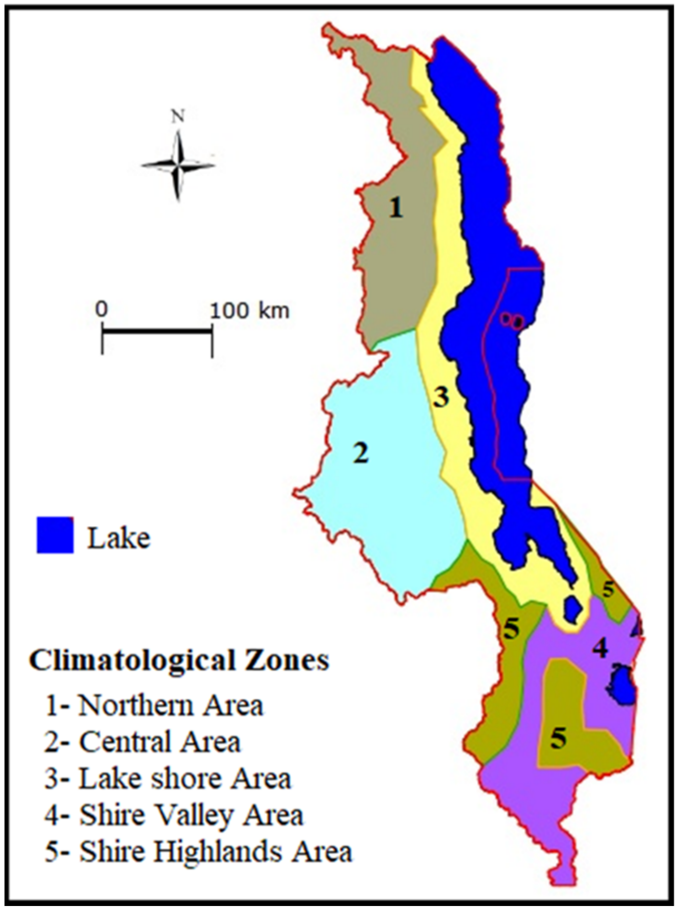


**Figure 2** Malawi's five climatological zones

*2.2.2. Holdridge life zone model*

Holdridge life zone (HLZ) model was used to assess climate change impact on forest type while QGIS3.2 was used to produce the forest type maps. HLZ model is well explained by Li et al. [6]. Briefly, The HLZ model is a classic climate-vegetation model designed by L.R. Holdridge [13]. It divides world territorial ecosystems into 39 vegetation zones (Figure 3). The 39 vegetation zones are mapped in a triangular coordinate system with three key climatic variables [6,13]. The three key climatic variables are: annual bio temperature (ABT), annual precipitation (AP), and potential evapotranspiration ratio (PER) [6]. In this study ABT, AP and PER were estimated using the following equations [6]:

$$ABT = \frac{1}{12}\sum_{i=1}^{12} T_i \quad (1)$$

$$AP = \sum_{i=1}^{12} P_i \quad (2)$$

$$PER = 59.93 \text{ x} \frac{ABT}{AP} \quad (3)$$

Where Ti is monthly mean temperature and Pi is monthly precipitation. In addition, QGIS 3.2 was also used to analyze the change area of the vegetation zone.

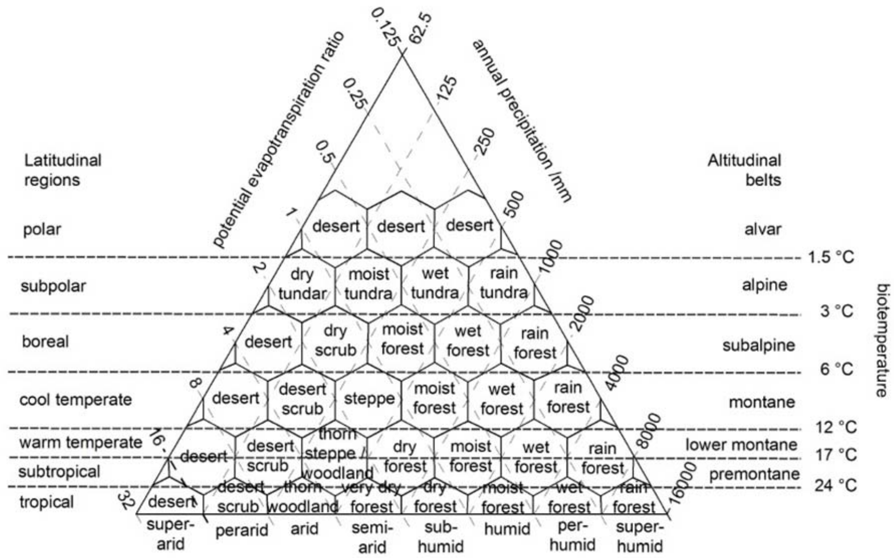


**Figure 3** The Holdridge Life Zone model concept framework that divides the world territorial ecosystems into 39 vegetation zones

*2.2.3. GAP Formind modified model and biomass estimation*

GAP-Formind modified model was used to assess the impact of climate change on forest living biomass, tree basal area and tree numbers. The current forest living biomass (above and below ground biomass) was estimated using the following site specific models developed by Kachamba et al. [14]:

$$AGB = 0.21691 \text{ x } DBH^{2.318391} \quad (4)$$

$$BGB = 0.284615 \text{ x } DBH^{1.992658} \quad (5)$$

Where*AGB* and *BGB* are above and below ground biomass (kg dry matter per tree), respectively and *DBH* is the diameter at breast height (cm). The total living biomass per tree was estimated by adding up *AGB* to *BGB*. In Addition, the following National Forest Inventory (NFI) data for different climatological zones were used for the estimation of biomass, stems per hectare and tree basal area per hectare:

- Northern area – Misuku and Perekezi forest reserves, Chileta and Chowe village forest areas in Rumphi and Chitipa, respectively.
- Lake shore area - Chinyakula village forest area in Nkhatabay
- Central area – Dzalanyama and Ntchisi forest reserves
- Shire highlands area – Chongoni and Dzozi-vai forest reserves
- Shire valley – Liwonde national park, Lengwe national park and Mwabvi wildlife reserve.

## 3. Results

### 3.1. Impact of climate change on forest type

Climate change projections indicate that some forests would significantly change while others would not change (Figure 4). For example, the northern area and central area forests would change from dry forest in near century to very dry forest in mid-century. The central area forests would further change from very dry forest in mid-century to thorn woodland forest in end-century. The lake shore area forests would change from very dry forest in near century to thorn woodland forest in mid-century. The shire highlands forest would change from dry forest in mid-century to very dry forest in end-century. However, the shire valley forests would not be affected by climate change.

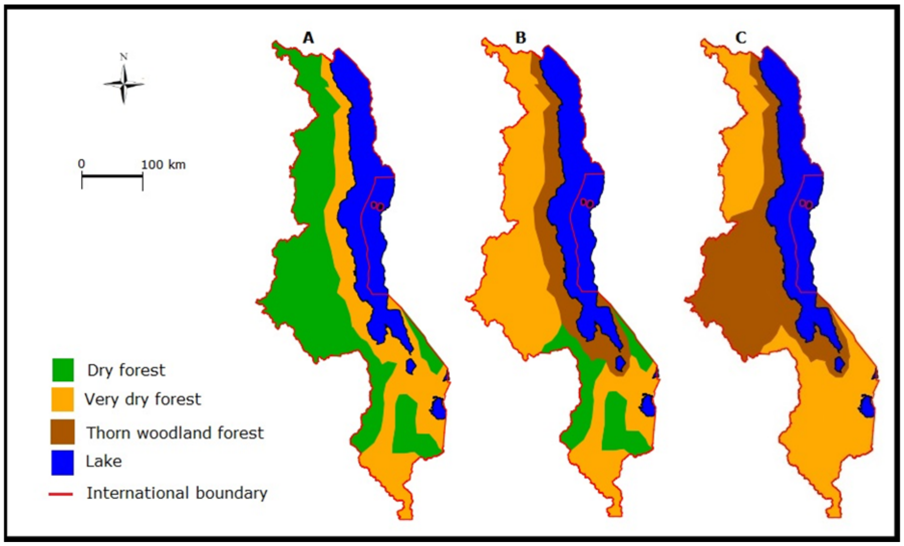


**Figure 4** Impact of climate change on forest types using Holdridge life zone (HLZ) model under three scenarios, A: Near century (2011-2040); B: Mid-century (2041-2070); and C: End-century (2071-2100)

### 3.2. Spatial distribution patterns of vegetation zones

The results on the spatial distribution pattern of forest zones in Malawi are presented in Figure 5. Three forest vegetation zones will be observed in the near century, mid-century and end-century climate change scenarios from the concept framework of Holdridge Life Zone model system. They are dry forest, very dry forest and thorn woodland forest. Under near century (2011-2040) climate conditions, there are two forest vegetation zones occurring in Malawi: dry forest and very dry forest. Under mid-century (2041-2070) climate conditions, one new forest vegetation zone will emerge in Malawi (thorn woodland forest), and dry forest will disappear in under end-century (2071-2100) climate conditions.

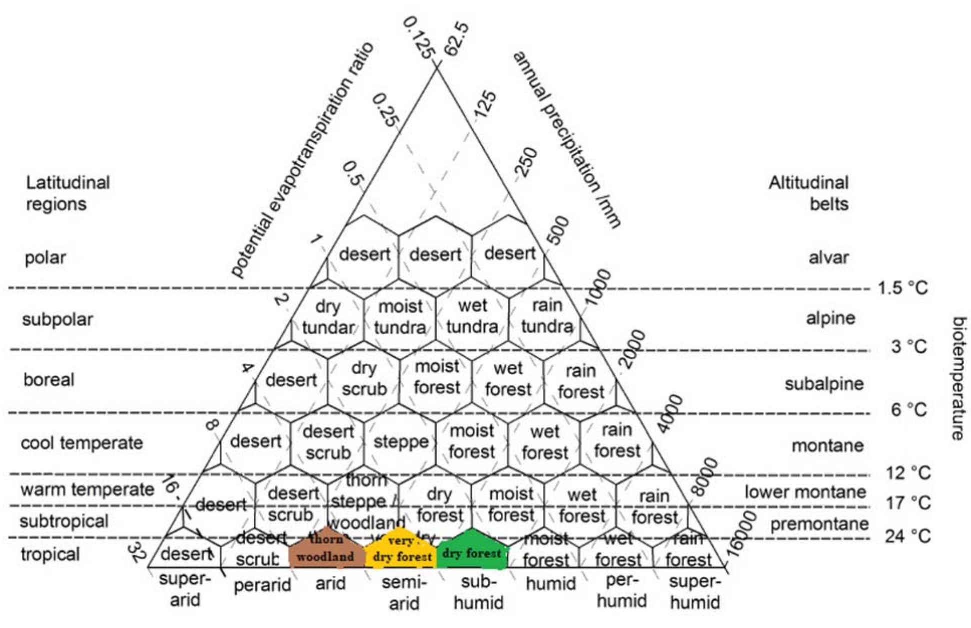


**Figure 5** Three forest vegetation zones that occurs and that will be observed in Malawi under Holdridge life zone model system

### 3.3. Change distribution area of forest vegetation zones

Summary of the results on the change distribution area of forest vegetation zones are presented in Table 1. The results show that from near century to mid-century very dry forest vegetation will expand its area proportion from 39.3% to 63.8%, while dry forest vegetation will decrease its area proportion from 60.7% to 15.6%. Under the same climate condition scenario thorn woodland forest would emerge. From the mid-century to end-century the thorn woodland forest would increase its area proportion from 20.5% to 47.1%, while very dry forest would decrease its area proportion from 63.8% to 52.9%. On the other hand, dry forest will disappear.

**Table 1** The area of forest vegetation zones under near-century, mid-century and end-century climate change scenarios

| Vegetation zone | Climate area (km$^2$) | | |
|---|---|---|---|
| | **Near-century (2011-2041)** | **Mid-century (2041-2070)** | **End-century (2071-2100)** |
| Dry forest | 59,328.32 | 15,268.33 | - |
| Very dry forest | 38,379.27 | 62,365.00 | 51,717.27 |
| Thorn woodland forest | - | 20,074.26 | 45,990.32 |

### 3.4. Impact of climate change on forest living biomass, tree basal area and tree number

Summary of the results on the impact of climate change on forest living biomass, tree basal area and tree number are presented in Figure 6. The results show a significant decrease in forest living biomass for northern area forests (2,300 kgha$^{-1}$yr$^{-1}$) and lake shore area forests (1,200 kg ha$^{-1}$yr$^{-1}$) from near-century to mid-century. Similarly, projections show a significant decrease in forest living biomass for central area forests (1,000 kg ha$^{-1}$yr$^{-1}$) and shire highlands forests (1,600 kg ha$^{-1}$yr$^{-1}$) from mid-century to end-century. On the other hand, the projections show that forest living biomass for shire valley area forests would not be highly affected by climate change.

The projections further show a significant decrease (40%) in tree basal area for northern area forests from near-century to mid-century. Similarly, the results indicate a significant decrease (32%) in tree basal area for shire highlands area forests from mid-century to end-century. Conversely, tree basal areas for shire valley, lake shore and central area forests would not be highly affected by climate change.

In addition, the projections show a significant increase in number of stems for northern area forests (13 stems ha$^{-1}$yr$^{-1}$) from near-century to end century and a significant increase in number of stems for lake shore area forests (8 stems ha$^{-1}$yr$^{-1}$) from near-century to mid-century. Equally, the projections show a significant increase in number of stems for shire highlands area forests (8 stems ha$^{-1}$yr$^{-1}$) from mid-century to end-century. On the other hand, number of stems for shire valley and central area forests would not be highly affected by the climate change.

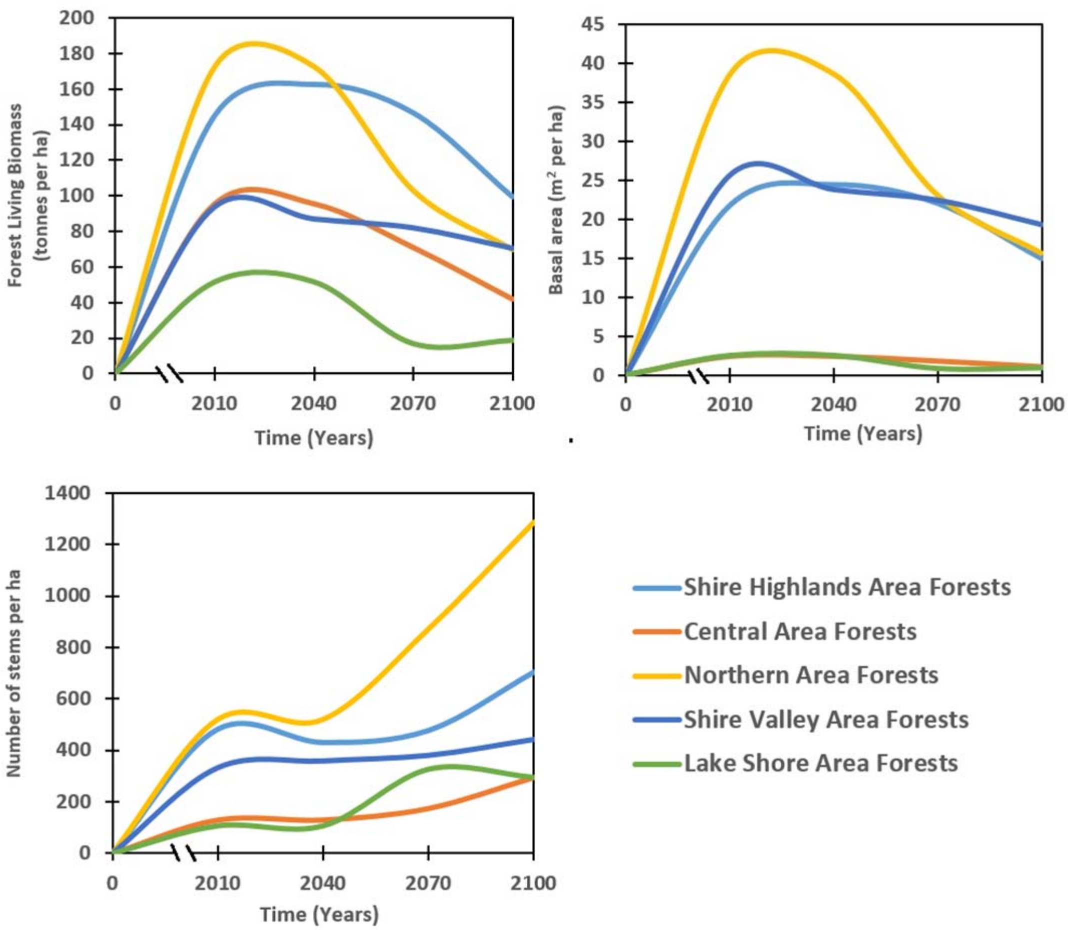


**Figure 6** Prediction on the impact of climate change on forest living biomass, tree basal area and tree number for different climatological zone forests in Malawi

## 4. Discussion

Numerous research studies have been conducted to examine the potential effects of climate change on the distribution of terrestrial vegetation at regional, national and district scales [6, 15-17].The present study shows that forest vegetation zone responses to climate change are significantly different under the three climate conditions scenarios. It has been demonstrated that dry forest vegetation zone will likely disappear in the end-century. In addition, one new vegetation zones (thorn woodland forest) will appear in the mid-century scenario.

In mid-century and end-century more than 50% of the forest vegetation would be very dry forest. This indicates that mid-century and end-century climate changes will be beneficial for the growth and expansion of the very dry forest. The results reported by Li et al. [6] also support the present findings.

Various climate-vegetation models are used for determining the impact of climate change on forest vegetation type [16]. The present study used HLZ model because of its simplicity, it only needs three parameters to be used, hence more advantageous than other models [6, 18, 19]. Even though the parameters used in HLZ model may sufficiently simulate vegetation patterns, the actual patterns can be described by a function of additional factors that are not clearly considered in the model, which are caused by human [6]. Li et al. [6] and Josa et al. [20] argued that human activities may change the response of vegetation to climate change through transformation of land use types. Therefore, it is said that HLZ model simulates ecosystem potential functions rather than the actual ecosystem structure [6, 20]. Equally, the present study is in agreement to that argument.

The forest vegetation zones simulated under the three climate conditions scenarios in the present study can provide important reference information for policy makers in planning regional vegetation restoration. Some of the strategies that can be used to adapt to the climate change would be promotion of natural regeneration of tree species, promotion of tree site matching, production and promotion of new tree seed varieties; and seed banking for drought resistant tree species.

## 5. Conclusion

The present study assessed the impact of climate change on forest type, forest living biomass, basal area, and number of stems. HLZ model and GAP Formind modified were used under three climate condition scenarios; near century (2011-2041); mid-century (2041-2070); and end-century (2071-2100). The results show that two forest vegetation occurs in Malawi (dry forest and very dry forest) in near century. Thorn woodland forest will emerge in the mid-century, while dry forest will disappear in the end-century. Furthermore, the results indicate an overall significant decrease in forest living biomass and basal area due to climate change in the end-century. On the other hand, there would be a significant increase in number of tree stems per hectare the end-century. Therefore, future climate change will be conducive to growth and expansion of very dry forest vegetation zone, which causes positive effects on reforestation projects in the region.

## Compliance with ethical standards

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### *Disclosure of conflict of interest*

Authors declare no conflict of interest.

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