Chapter

Impact of Climate Variability on Forest Vegetation Zones in Malawi

Edward Missanjo and Maggie Munthali

Abstract

A study was conducted to evaluate the influence of climate variability on forest type and forest living biomass. Three scenarios were used in the assessment. Namely: Near century (2011–2040), mid-century (2041–2070), and end-century (2071–2100). Holdridge Life Zone model and GAP Formind modified were used for the assessment. The results show that three forest vegetation zones will be observed from near century to end century. Namely: dry forest, very dry forest and thorn woodland forest. Under near century climate conditions, there are two forest vegetation zones occurring: dry forest and very dry forest. Under mid-century climate conditions, thorn woodland forest will emerge, and dry forest will disappear in the end-century. There will be a significant decrease in forest living biomass (1000 kg ha^{-1} yr^{-1}) 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. 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, climate condition

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 23,677 km^2. This represents 25% of the total land area. The forest is mainly categorized into two: Miombo woodlands and plantation forests. Miombo woodlands covers 96% (22,857 km^2) of the forest, while the plantation forests cover the remaining 4% (820 km^2) of the forest. Brachystegia is the most predominant tree genus in miombo woodlands while pine and eucalyptus are the most mutual trees in the plantations [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 variability and change as evidenced by recent floods and drought [10].

Therefore, it is important for Malawi to identify measures and strategies for adapting the climate variability and 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, and forest living biomass. 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.

2. Material and methods

2.1 Study area

Malawi is placed in Southeast Africa. It is bordered by Zambia on the west and northwest, by Tanzania on the north and northeast, and by Mozambique on the east and southwest (**Figure 1**). Malawi's sub-tropical climate is characterized into three seasons: Cool-dry, warm-wet, and hot-dry seasons. Cool-dry season is evident from May to August with a mean temperature variety of 4–10°C. In cool-dry season, specifically in June and July frost may fall in some areas. Warm-wet season stretches from November to April with an annual mean rainfall series of 725 mm to 2500 mm.

Figure 1.
Location of Malawi in Africa.

This is the season through which 95% of the annual rainfall falls. Hot-dry season lasts from September to October with a mean temperature range of 25–37°C [11].

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**). Seasonal climatic characteristics and other information about the five climatological zones in Malawi are presented in **Table 1**. The assessment used three scenarios: Near-century; mid-century; and end-century with the following time frames: 2011–2040; 2041–2070; and 2071–2100, respectively. The projected precipitations and temperatures for the three scenarios were obtained from the Ministry of Forestry and Natural Resources in the Department of Climatic Change and Meteorological Services

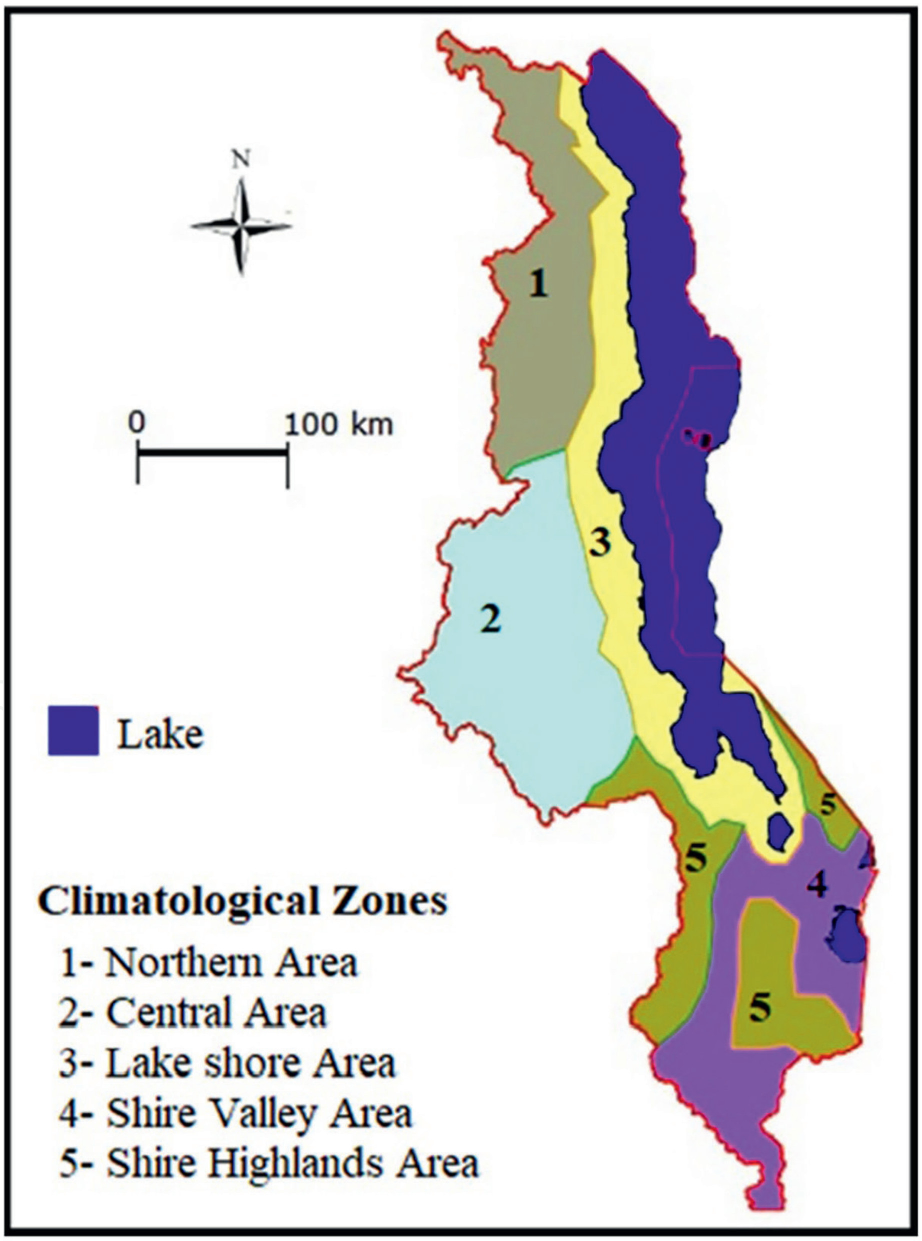

Figure 2.
Malawi's five climatological zones.

Climatological zone	Climate area (km^2)	Seasonal climatic characteristics
Shire valley area	18,305.01	These are Malawi's lowest areas with altitudes below 50 metres above the sea level. Covers areas along the shire river, Lake Chirwa and Lake Chiuta Valleys. The area has a semi-arid climate prevailing. The wet season is oppressive and mostly cloudy, the dry season is clear, and it is hot year-round. Over the course of the year, the temperature typically varies from 19°C to 36°C and is rarely below 17°C or above 40°C. The rain period of the year lasts for 7 months from October to May with an average rainfall per month of 12 mm. The month with the most rains is January with an average rainfall of 200 mm.
Shire highlands area	15,268.33	These are the plateau areas in the southern part of Malawi and Kirk Range up to Dedza. The plateau varies in elevation from 600 to 1100 mm above the sea level. The highest peak is Sapitwa in Mulanje Massif at 3002 m followed by Zomba Mountain at 2087 m. The area experiences extreme seasonal variation. The wet season is muggy and mostly cloudy, the dry season is clear, and it is warm year-round. Over the course of the year, the temperature typically varies from 13°C to 28°C and is rarely below 12°C or above 32°C. The rain period of the year lasts for 7 months from October to May and the month with the most rains is January with an average rainfall of 260 mm.
Lake shore area	20,074.26	These are areas along Lake Malawi. The wet season is hot, oppressive, and overcast and the dry season is warm, windy, and mostly clear. Over the course of the year, the temperature typically varies from 16°C to 32°C and is rarely below 13°C or above 35°C. The rain period of the year lasts for 6 months from October to April and the month with the most rains is January with an average rainfall of 250 mm.
Central area	25,916.06	It covers the following areas Lilongwe, Mchinji, Dowa, Ntchisi, Kasungu, and part of Mzimba district. The climate is warm and temperate. The summers are much rainier than the winters. The average annual temperature is 20.4°C. In a year, the rainfall is 739 mm. The driest month is June, with 1 mm of rain. The greatest amount of precipitation occurs in January, with an average of 211 mm.
Northern area	18,143.93	It covers all areas north of Mzimba district expect the Lake shore area. The climate is classified as warm and temperate. When compared with winter, the summers have much more rainfall. The average annual temperature is 19.2°C. Precipitation is about 1487 mm per year. The least amount of rainfall occurs in September. The average in this month is 15 mm. In January, the precipitation reaches its peak, with an average of 303 mm. The temperatures are highest on average in November, at around 21.9°C. At 15.3°C on average, July is the coldest month of the year

Table 1.
The area and seasonal climatic characteristics of climatological zones in Malawi.

(DCCMS), Blantyre, Malawi. Briefly, projections for future precipitation and temperature were developed using the 20 global scale general circulation models (GCMs). These are downscaled outputs used in the Intergovernmental Panel on Climate Change Fifth Assessment report. The GCMs were used in concurrence with two representative concentration pathways (RCPs; RCP4.5 and RCP8.5) [12]. Observed

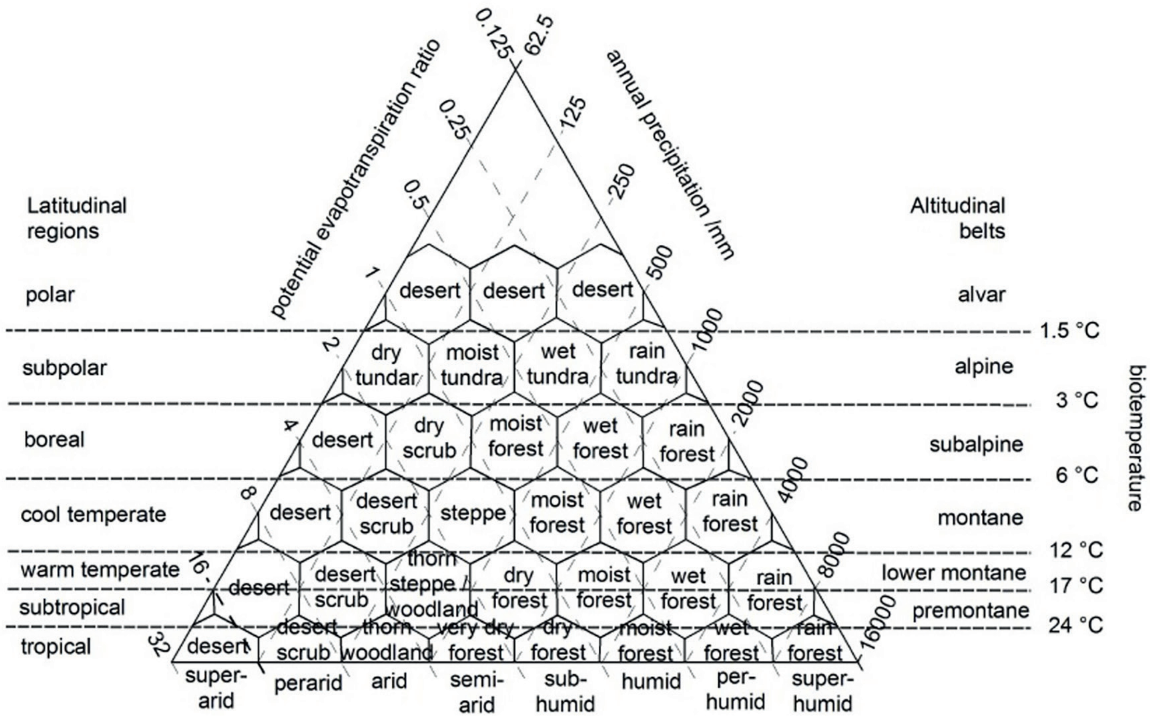

Figure 3.
The Holdridge Life Zone model concept framework that divides the world territorial ecosystems into 39 vegetation zones.

data temperatures and precipitation data used was for the period 1961–2010 while daily temperatures and precipitation data used was for 1971–2000.

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 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]:

$$ABT = \frac{1}{12}\sum_{i=1}^{12} T_i \tag{1}$$

$$AP = \sum_{i=1}^{12} P_i \tag{2}$$

$$PER = 59.93 \text{ x} \frac{ABT}{AP} \tag{3}$$

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

2.2.3 GAP formind modified model and biomass estimation

The impact of climate variability on forest living biomass was assessed using the GAP-Formind modified model, while the above and below ground biomass were estimated using the following site-specific models [14].

$$AGB = 0.21691 \text{ x } DBH^{2.318391} \tag{4}$$

$$BGB = 0.284615 \text{ x } DBH^{1.992658} \tag{5}$$

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:

- Liwonde National Park, Lengwe National Park and Mwabvi Wildlife Reserve (Shire valley area)

- Chongoni and Dzonzi-Mvai Forest Reserves (Shire highlands area)

- Dzalanyama and Ntchisi Forest Reserves (Central area)

- Chinyakula Village Forest Area in Nkhatabay (Lake shore area)

- Misuku and Perekezi Forest Reserves, Chileta and Chowe Village Forest Areas in Rumphi and Chitipa, respectively (Northern area)

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 instance, the central area and northern area forests would be converted from dry forest in near century to very dry forest in mid-century. The central area forests would further be converted from very dry forest in mid-century to thorn woodland forest in end-century. The lake shore area forests would be converted from very dry forest in near century to thorn woodland forest in mid-century. On the other hand, the shire highlands forest would be converted from dry forest in mid-century to very dry forest in end-century. Interestingly, the shire valley forests would not be affected by climate change.

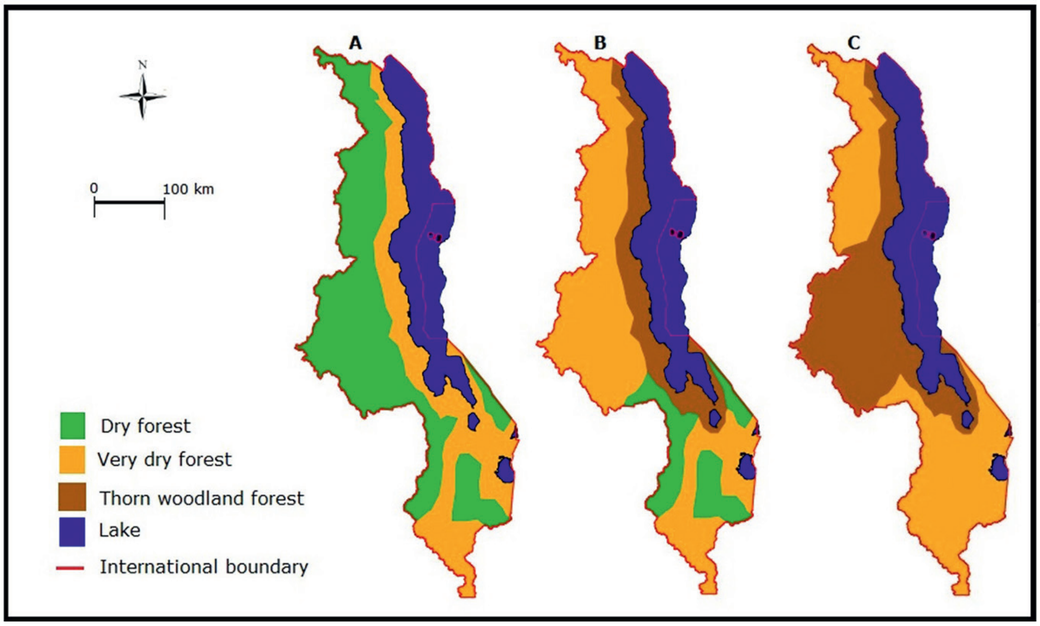

Figure 4.
Impact of climate change on forest type using Holdridge Life Zone (HLZ) model under three scenarios, A: Near century (2011–2040); B: Mid-century (2041–2070); and C: End-century (2071–2100).

3.2 Spatial distribution patterns of vegetations 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.

3.3 Area distribution change of forest vegetations zones

Summary of the results on the area distribution change of forest vegetation zones in Malawi are presented in **Table 2**. The results show that dry forest vegetation zone shall decrease its area proportion from 60.7% to 15.6% from near century to mid-century. On the other hand, very dry forest vegetation will expand its area proportion from 39.3% to 63.8% under the same climate condition scenario. Most notably is that, thorn woodland forest would shall emerge under the same climate condition scenario. Furthermore, the results indicate that thorn woodland forest would increase its area proportion from 20.5% to 47.1% from the mid-century to the end-century. Consequently, very dry forest would decrease its area proportion from 63.8% to 52.9%, while dry forest will disappear.

3.4 Effect of climate variability on forest living biomass

Summary of the results on the effect of climate variability on forest living biomass, are presented in **Figure 6**. The results show a significant decrease in forest

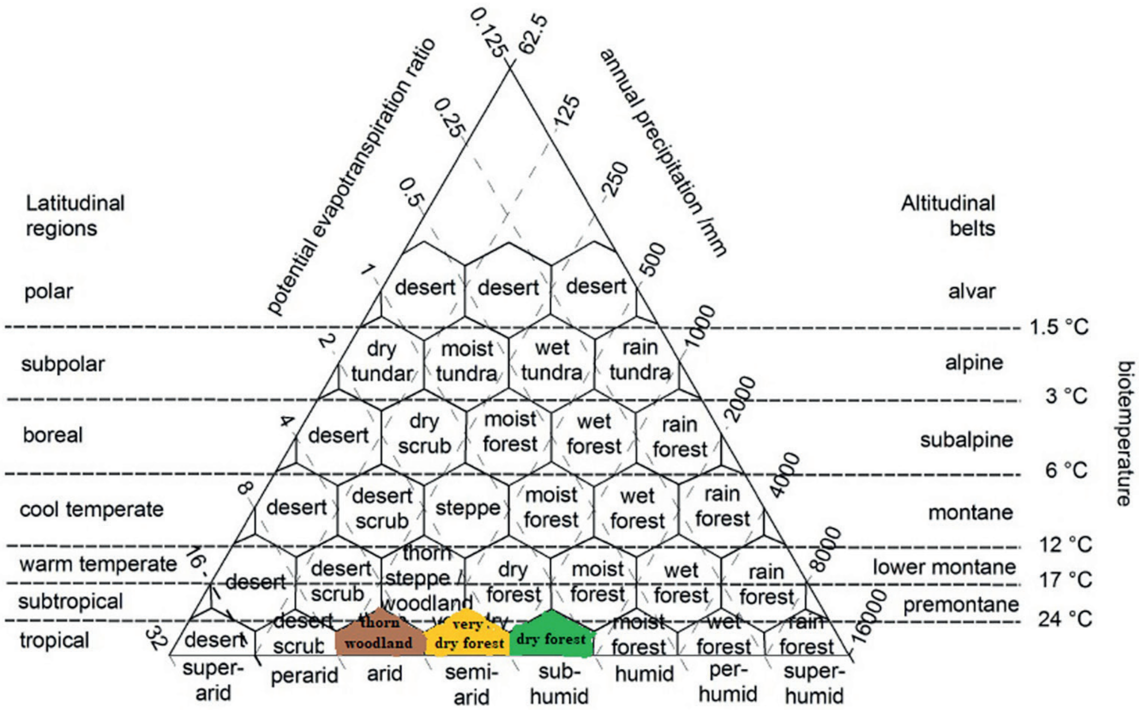

Figure 5.
Three forest vegetation zones that occurs and that will be observed in Malawi under Holdridge Life Zone model system.

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

Table 2.
The area of forest vegetation zones under near-century, mid-century and end-century climate change scenario.

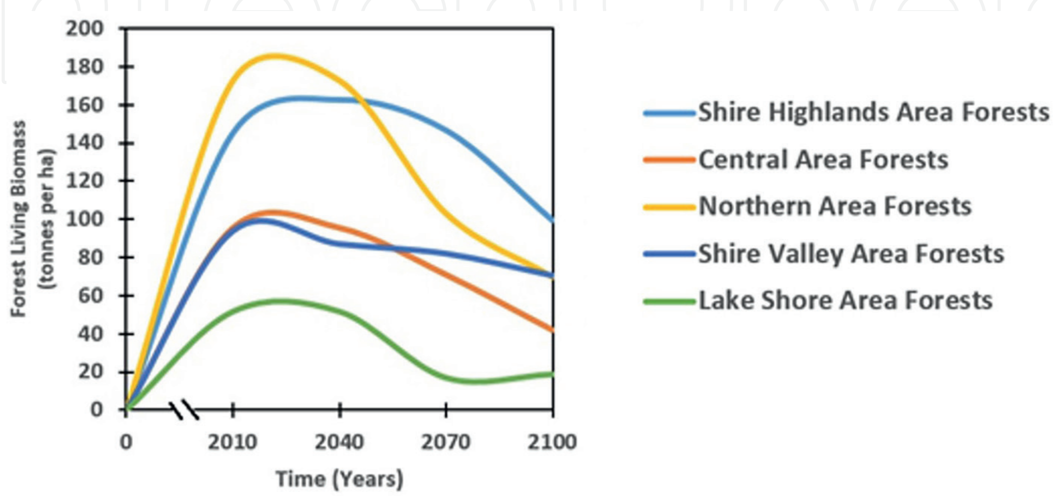

Figure 6.
Prediction on the impact of climatic change on forest living biomass for different climatological zone forests in Malawi.

living biomass from near-century to mid-century for both lake shore area forests (1200 kg ha^{-1} yr^{-1}) and northern area forests (2300 kg ha^{-1} yr^{-1}). Likewise, projections show a significant decrease in forest living biomass from mid-century to end-century for both shire highlands forests (1600 kg ha^{-1} yr^{-1}) and central area forests (1000 kg ha^{-1} yr^{-1}). Conversely, the projections show that forest living biomass for shire valley area forests would not be highly affected by climate variability.

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 due to climate change in 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.

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Conflict of interest

The authors declare no conflict of interest.

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