Chapter

Remote Sensing Based Quantification of Forest Cover Change in Somalia for the Period 2000 to 2019

Sylus Kipngeno Musei, Justine Muhoro Nyaga and Abdi Zeila Dubow

Abstract

Deforestation is a driver of land degradation and a major environmental problem in Somalia, and has been linked to frequent incidences of drought over the years. Monitoring of changes in forest cover is therefore critical for the country's environment. The problem of land degradation has been worsened by the large scale charcoal production that is witnessed in the country. This study aimed at estimating forest cover change between 2000 and 2019 in Somalia using Landsat-based forest cover datasets. Google Earth Engine (GEE), a cloud based computing system was used to provide a platform for this analysis. Based on the 30% threshold recommended by International Geosphere Biosphere Program for differentiating forest from non-forest trees, approximately 23% forest cover loss was found, from 87, 294 hectares in 2000 to 67, 199 hectares in 2019. Most of the country's forest is within the southern and central parts of the country, and significant forest cover losses occurred mainly around Mogadishu and Kismayo port throughout the study period. There is therefore a need for the Federal Ministry of Environment and environment ministries in the federal member states to design mechanisms and strategies for restoration of the degraded forests and to curb deforestation.

Keywords: remote sensing, land degradation, Somalia, Google earth engine, charcoal production

1. Introduction

Forests form a critical component of global carbon cycle [1] in form of woody above ground biomass. Their destruction through deforestation disrupts this cycle leading to serious negative consequences on ecosystem functioning. Deforestation may be caused by both natural and anthropogenic factors. Anthropogenic factors included population growth, technological advancements and cultural norms, and these may accelerate deforestation at both local and regional levels [2, 3]. This in turn threatens carbon storage, watershed protection and biodiversity particularly in developing countries [4, 5] where they have been rampant. Forest cover is the most important indicator of forest degradation. The 2015 forest resource assessment

(FRA) report of the Food and Agricultural Organization (FAO) indicated that the global forest cover was about 4 billion hectares [6] (about 30.6% of world's land area). Tropical forests covered about 20% of the global land area which dropped to less than 7% at the end of the 20th century [1]. The tropical region experienced the greatest loss and acquisition of forests among the four climate domains of the world, and the highest loss ratio (3.6 to >50% tree cover), indicating the prevalence of the dynamics of deforestation [4].

Conservation of forests improves livelihoods of communities dependent on them for various goods and services. Globally, over 1.6 billion people rely on forests as a source of food, fuel, medicines, water and for cultural use either directly or indirectly [7]. All over the world, forests play an important role in minimizing greenhouse gas emissions [8] and removing excess carbon dioxide from the atmosphere through carbon sequestration. In sub-Saharan Africa, at least 80% of the urban population and 90% rural population depend on charcoal as a source of energy for cooking and warming houses [9, 10]. The main source of energy for cooking in Somalia is charcoal [11–13] which is obtained from forests through deforestation. Furthermore, Somalia being a pastoralist country depends on trees and shrubs for livestock feeds during dry seasons [14, 15]. The resultant forest destruction could lead to devastating impacts on the natural resources which are highly depended on by the pastoral communities [16]. Foreign demand for charcoal has also escalated deforestation rates in Somalia with 4.4 million trees cut down annually for making of export charcoal [13]. As a major export product, charcoal is the major source of income for 70% of the poor and middle-income pastoralists since it requires small capital for production [17–19]. This has significantly contributed to destruction of the country's natural forest resources [20].

In addition to the basic conservation concern about deforestation in Somalia, the international "Reducing Emissions from Deforestation and forest Degradation" (REDD+) initiative has recently become a major component of forest conservation in the country. This is a global effort aimed at conserving, sustainably managing, enhancing, and monitoring forests [21] and thus requires the government through the forestry department to account for the current forest extents for sustainable forest management. This may further require quantification of greenhouse gas emissions and reductions from forests. These therefore necessities quantification of forest cover changes across the country. However, quantifying forest cover changes through field surveys is limited by time and resource availability.

Remotely sensed data however provides alternative means for monitoring forest cover changes [22, 23]. Temporal and spatial components of observational remotely sensed data have improved the quality and the quantity of satellite data by enhancing their applicability in monitoring environmental changes. A number of satellite-derived products have been developed with a focus on global forest cover. MODIS images that have been captured by Terra and Aqua satellites since 2000 have enabled formation of the first annual forest cover product, MODIS Vegetation Continuous Field (VCF) [24, 25]. This product is limited by the patchiness of tree cover changes which have smaller spatial sizes compared to the MODIS VCF [26]. This deficiency led to the production of Landsat based global continuous field cover product (30 m) [27]. The Landsat based product has finer spatial resolution compared to the MODIS based VCF and thus facilitates a more accurate forest cover change assessment. Besides the finer spatial resolution, Landsat data also have high amounts of cloud cover contamination as well as infrequent revisit coverage [28]. Due to this limitation global mosaics were produced for the years 1975, 1990, 2000, 2005 and 2010 [29]. However, more recently a global 30 m forest cover change product was published during 2000–2012 [4]. A latest version of this product is available for the period between 2000 and 2019.

Even with the increased availability of high-resolution satellite data, it has always been difficult analyzing high spatial resolution satellite data, for example, at a country level. This is because at such a large scale, huge volumes of data are required to cover the entire country [24]. Google Earth Engine (GEE), a cloud-based platform however overcomes this challenge since it allows for processing of huge geospatial datasets [29]. Satellite resources have been used to monitor forest cover changes in various countries across the globe [4]. In the case of Somalia, there have been a few applications but none have quantified forest cover change across the entire country. In this study we utilize the historical earth observation datasets to map and quantify forest cover over time in Somalia by utilizing the capabilities of Google Earth Engine (GEE). The main objective was to evaluate the spatial and temporal patterns of forest cover from 2000 to 2019 across Somalia.

2. Materials and methods

2.1 Study area

This assessment covered the whole of Somalia (**Figure 1**). The country extends from the equator to the north of Gulf of Aden. It is one of the Horn of African countries and borders Kenya and Ethiopia to the west, Indian Ocean to the east and Djibouti to the northwest. The country's population was estimated at 14.74 million in 2017 by the World Bank. The population increased from 8,872,254 in 2000 to 15,442,905 in 2019 (**Figure 2**). This is equivalent to an increase of 6,570,651 (74.06%).

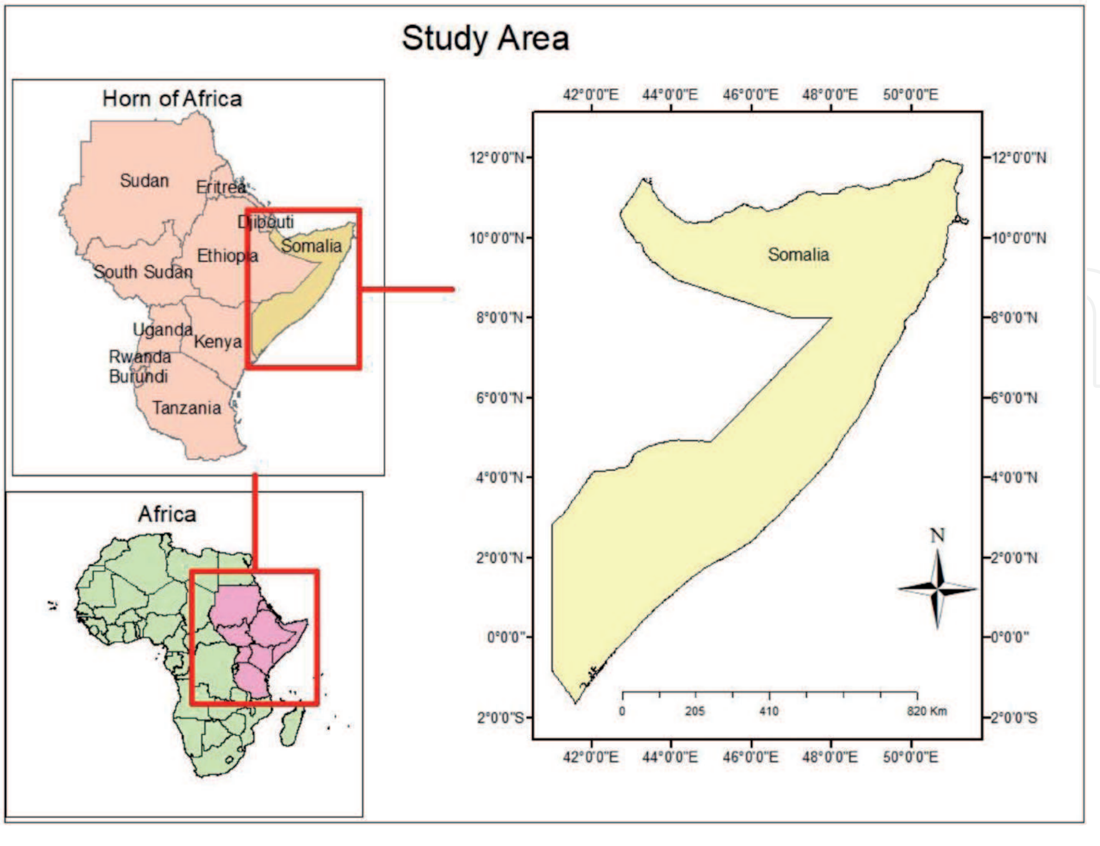

Figure 1.
Map of the study area. Somalia is part of the horn of Africa and the eastern-most country in the African continent.

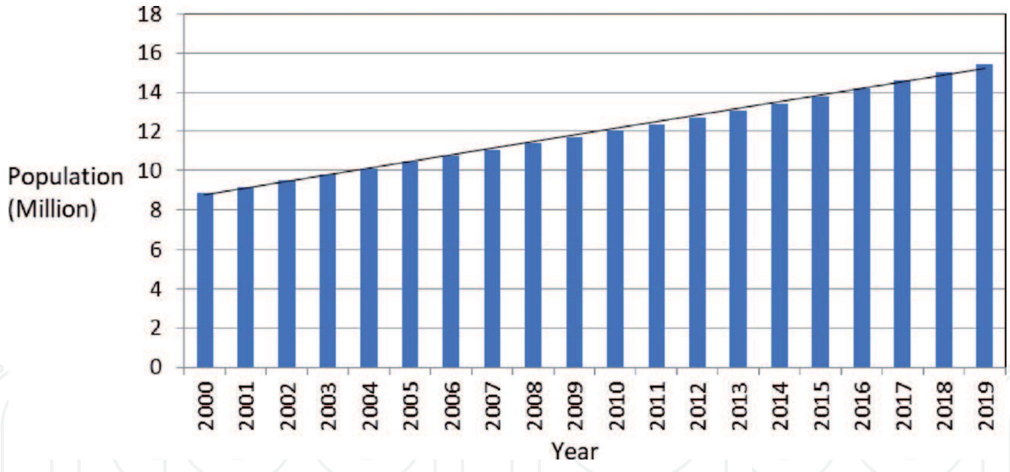

Figure 2.
Population variations between 2000 and 2019 (source: The World Bank database).

Somalia covers a total land area of 637,660 km^2 most of which may be classified as either arid or semi arid. Its administrative and commercial capital is Mogadishu. According to [30], at least 50% of the country's economy is dependent on pastoralism.

Topographically, the country is divided into several physiographic zones. The northern part of the country receives high annual temperatures and forms the driest zone. Plateaus cover the central and southern parts bordering the coastline. The two main perennial rivers (Webe Shebele and Jubba), whose source is Ethiopian plateau, are found in southern Somalia. Between these two rivers is a highly productive plain which is occasionally affected by floods. Somalia's coastline covers 3,025 kilometers and is the longest in Africa.

Generally, the country is hot throughout the year with an annual average day temperature of 27°C. This is attributed to country's close proximity to the equator and the low rainfall amounts received. The northern parts experience highest temperatures of 45°C around Karkaar Mountain in summer while the lowest temperatures are experienced to the south of Somalia along the coastline largely due to the effect of the sea breeze. Somalia received little amount of rainfall throughout the study period with an average of 20.96 mm per year. The lowest (18.5 mm) and highest (25.6 mm) amount of rainfall was received in 2010 and 2019 respectively. Although there is a generally upward trend in the amounts of rainfall received over the years from 2000 to 2019, the total annual amount of rainfall is still small as shown in **Figure 3**.

Somalia has two climate zones, arid and semiarid zone. The semiarid zone covers the northern and southwest parts of the country and the arid zone covers the central and the northernmost parts [31]. The semiarid zone receives medium rainfall and is suitable for rain fed agriculture whereas the arid zones receiving low rainfall are preferably used for pastoralism. The most common tree species is *Acacia commiphora* [32] which covers about 50% of southern Somalia. Others include: Apple ring acacia (*Acacia albida*), Egyptian thorn (*Acacia nilotica*), Gum arabic (*Acacia senegal*), Umbrella thorn (*Acacia tortilis*), soapberry tree (*Balanites aegyptiaca*), Myrrh tree (*Commiphora myrrah*), common tug tree (*Conocarpus lancifolius*), Yihib nut tree (*Cordeauxia edulis*), Spiny desert tree (*Terminalia spinosa*), Pencil cedar (*Juniperus excels*), Tamarisk (*Tamaria aphylla*) and Tamarind (*Tamarindus indica*).

2.2 Dataset and the analysis platform

This study adopted the word wide forest data that was developed by Hansen [4]. The dataset was created from the annual 30 m resolution Landsat data. The

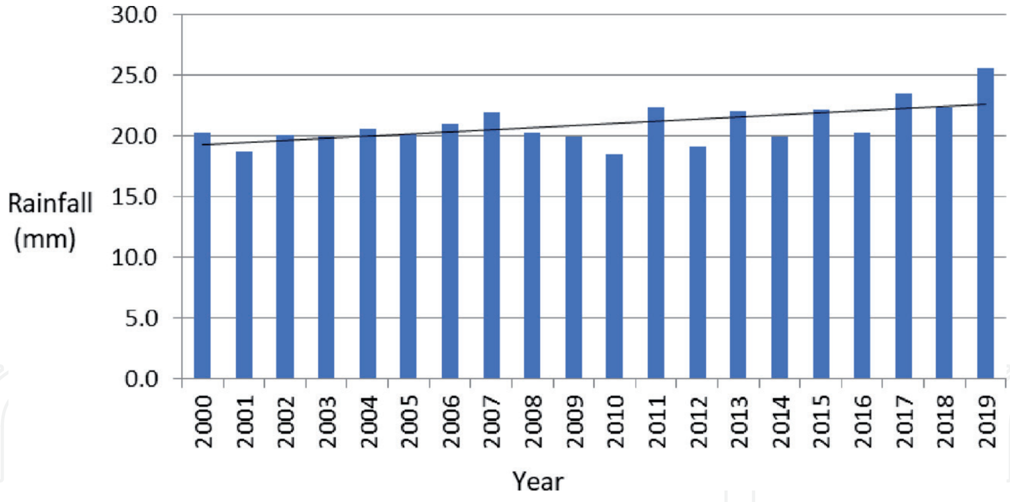

Figure 3.
Annual rainfall trends from 2000 to 2019 (source: The World Bank database).

products being global forest cover at year 2000 and annual forest cover loss and gain. In this dataset, vegetation above 5 m in height is defined as trees. Trees are expressed as '2000 Percent Tree Cover' percentage per output plot cell. Forest Cover Loss is defined as a change from forest to non-forest status in the period 2000–2019. Forest gain is defined as the opposite of loss, that is, the change in non-forest to forest in the period 2000–2019.

Google Earth Engine (GEE) enables cloud computing processing of Landsat images through its online system. This helps to navigate the challenge of processing Landsat images at global scale which is normally expensive in terms of time and resources [4]. Landsat images are ideal for monitoring environmental changes at local scale because of the 30 m spatial resolution [33]. Since 1972, Landsat have been used for land cover change analysis [34–37]. Due to its ability to analyze large volumes of remotely sensed datasets, GEE was preferably selected for Landsat data analysis in this study. For ease and fast workflow, a web-based JavaScript API was developed in the GEE Code Editor Feature.

2.3 Data analysis

First, forest cover in the starting year, 2000, was analyzed using Google Earth Engine. This was then followed by evaluation of temporal patterns of forest cover losses from the year 2001 to 2019. GEE enabled selection of the whole Somalia from the global Hansen [4] forest dataset using Google Earth Engine code editor with JAVA script API.

3. Results

3.1 Spatial trends of forest cover in Somalia

This internet link (https://code.earthengine.google.com/6d67bcdf27fd3139f89c0a1af94a3c9d) leads to the script developed for this analysis. The area covered by forest in Somalia in the year 2000 was 8,729,400 ha. This is approximately 13% of the total land area in the country. **Figure 4** shows the extent of forest cover in the year 2000. Forest mainly covers the southern part of the country with small patches to the north. The largest part of the country is dry as shown in the **Figure 4** with the green patches showing the forested areas and the non-green parts shows non-forested areas.

3.2 Forest cover loss

The spatial distributions of forest cover loss throughout the country are shown in **Figure 5**. The red spots show areas where forest cover has been lost. From this figure, it's clear that areas around the country's capital (Mogadishu) such as Jowhaar, Mahaday, Wyne and Merca have suffered the highest forest cover loss over the years. Apart from the capital, Kismayo and the surrounding areas of Dujuma, Haramka, Jamaame, Jilib and Yoontoy also experienced high forest cover loss throughout the study period.

3.3 Temporal variations of forest cover loss

The patterns of forest loss were computed based on Hansen's [4] forest cover change dataset. Temporal changes in forest loss areas were calculated from 2000 to 2019 also based on Hansen's [4] forest cover change data. **Figure 6** shows the

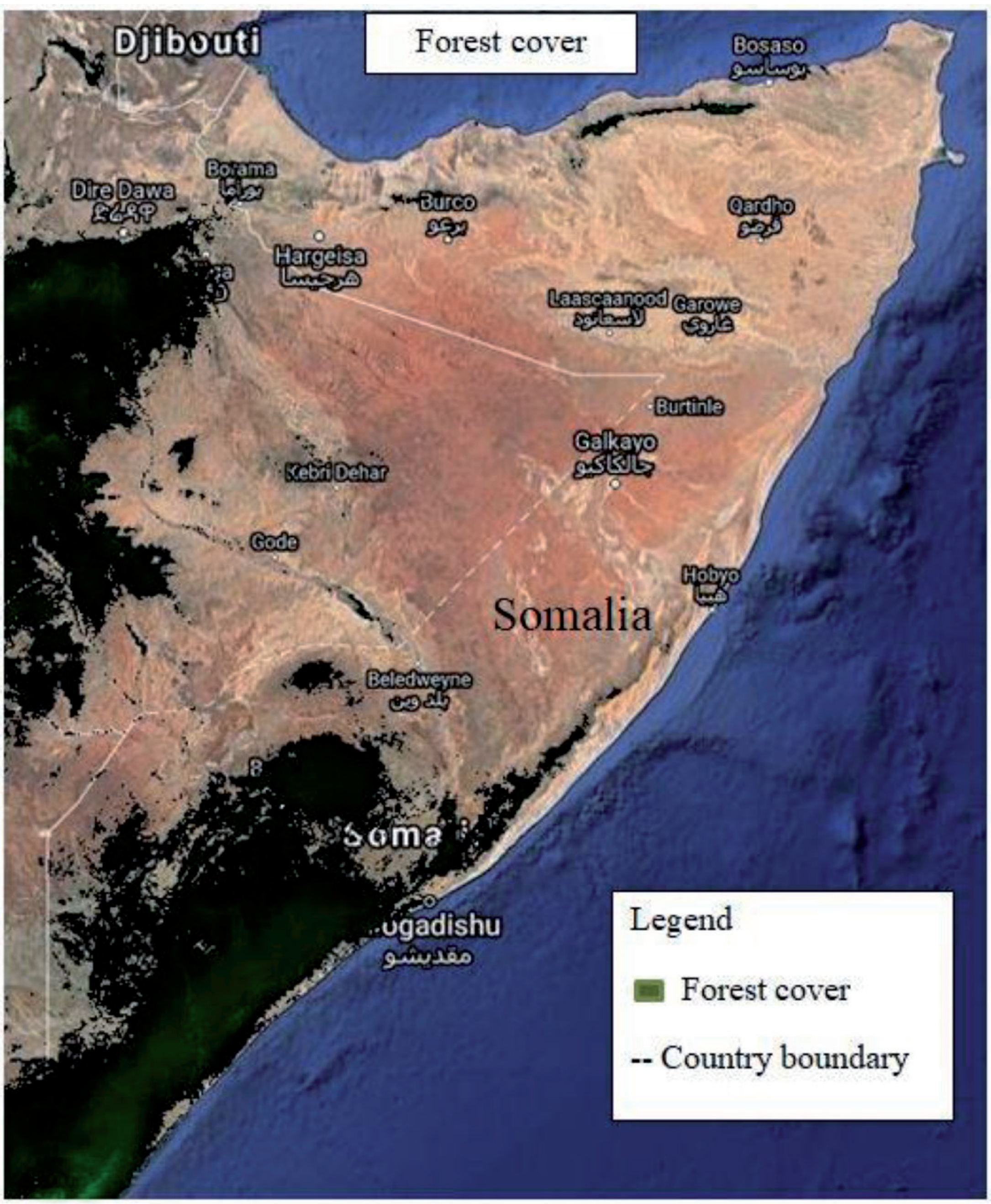

Figure 4.
Forest cover in 2000.

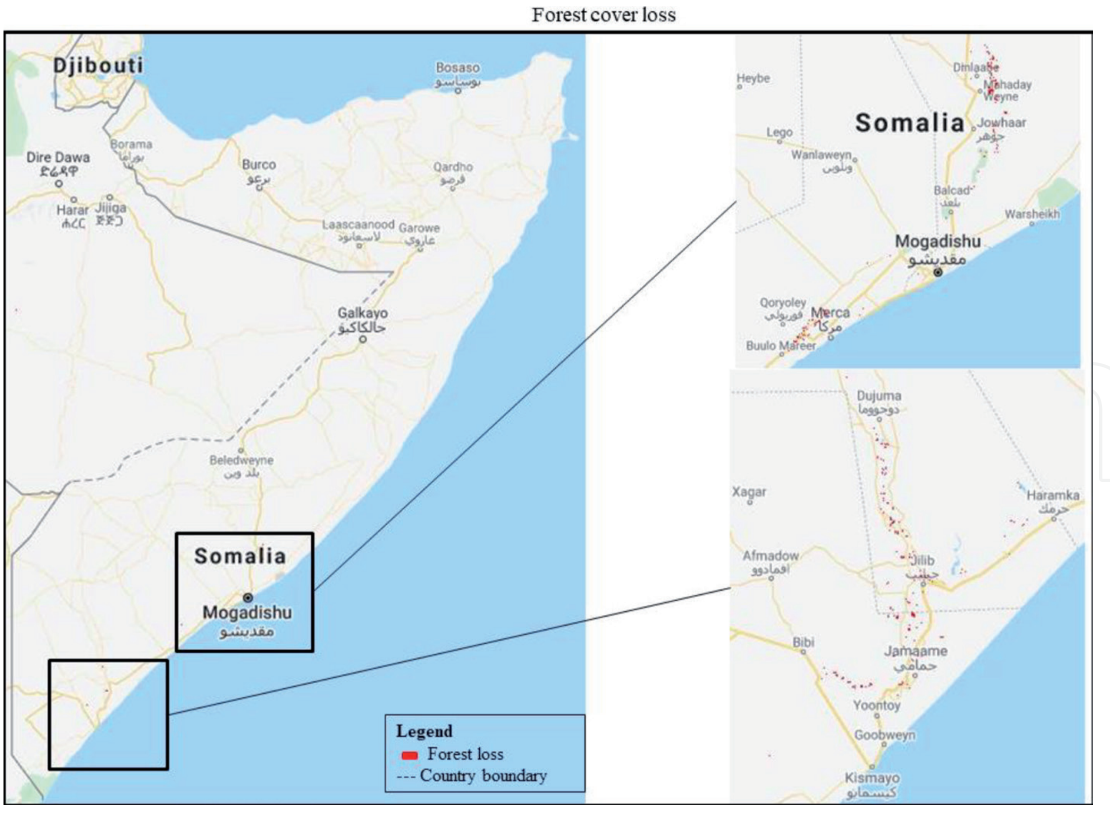

Figure 5.
Forest cover loss between 2000 and 2019. The red spots show areas of forest loss throughout the study period.

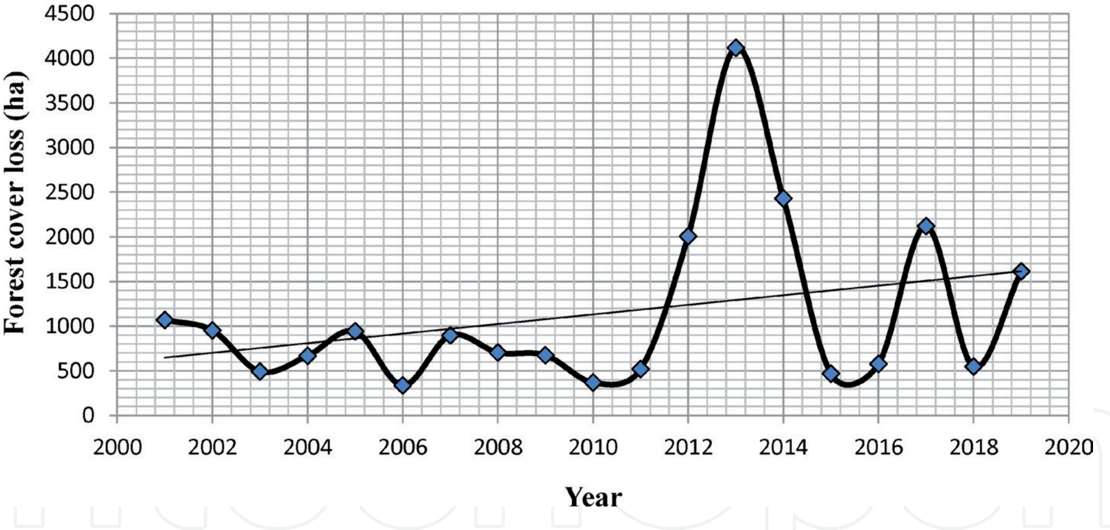

Figure 6.
Annual trends of forest area loss from 2000 to 2019.

yearly trend of forest cover loss in Somalia throughout the study period. There is generally upward trend of forest loss with the peak occurring in the year 2013 when 4116.76 ha of forest cover were lost. The least forest cover loss happened in the year 2006 when 336.72 ha of forest was lost.

4. Discussions

In this study, the year 2000 was used as the baseline, and during that year, most of the forest in Somalia was in the southern parts with only small patches of forests in the northern parts of the country (**Figure 4**). This pattern of forest cover may be explained by the significant variations in climatic conditions between the northern and southern parts of the country. Relatively high temperatures are experienced throughout the year in the northern parts of the country compared to the southern parts that have relatively lower temperatures. The southern parts also receive moderate amounts of rainfall on occasional basis and these have been shown to support vegetation growth [38], thus the higher forest cover relative to the north.

Forest cover loss was unevenly distributed throughout the country as shown in **Figure 5**. It is evident that most of the forest loss occurred to the southern parts of the country, mainly around Mogadishu and Kismayo, probably due to the higher forest cover there. Besides, it is in these parts of the country where charcoal production and use is very high. Research on household sources of energy in Somalia has established that the main source of energy for Mogadishu is charcoal [11]. In 2011, the United Nations Monitoring Group for Somalia and Eritrea reported that charcoal was also an important source of income for Al Shabaab [39]. The proliferation of this armed militia group in the country has been a source of insecurity and underdevelopment from 2008 to date. Their growth and expansion may be partly attributed to the incomes generated from the illegal sale of charcoal produced in the southern parts of Somalia. Besides Al Shabaab being forced out of the country's capital in 2011, they continued to control vast southern and central parts of Somalia including the port of Kismayo. Most of illegal charcoal export by Al Shabaab from Somalia has been through this port [40, 41]. These among other unexplored reasons explain the high levels of forest destruction in the southern and central parts of Somalia throughout the study period. Some of these reasons may include inappropriate land use and extraction of other natural resources besides the forests. These practices have been so rampant in Somalia that forest cover loss in this country has also significantly contributed to forest cover loss across the African continent. It has been shown that Somalia is responsible for 6% of all trees lost in the continent with an estimated annual forest cover loss of 76,757 hectares [6].

Results from this study show a general upward increasing trend of forest cover loss throughout the study period (**Figure 6**). The peak of forest cover loss was in 2013 when over 41,00 ha of forest area was lost. This can be attributed to the high charcoal production (approximately 24, 000 metric tons of charcoal produced between 2011 and 2013 in southern parts of Somalia) and sale that was experienced during this period in Somalia [42]. During this time, the charcoal industry was dominated by the Al Shabaab militant group which controlled the region at the time, and had no regard for environmental conservation. Their main goal was to raise money to finance their terrorist activities, and charcoal production and sale was a one of their major sources of income.

Apart from charcoal production, the high losses in forest cover can also be attributed to the high rates of population increase in the Somalia (**Figure 2**). Population increased exponentially throughout the study period, with a total percentage increase of 75% between the year 2000 and 2019. Increase in population exerts more pressure on economic land resources consequently resulting in their degradation and eventual destruction. The gradual increase in population in Somalia over the study period exerted considerable pressure on the forest resources which are major land economic resources in the country. More trees were cut down to provide energy for cooking as firewood or charcoal, and also for construction timber among other forest products. Another thing that may explain the high forest cover losses in Somalia is the low annual precipitation the country received over the study period. Although the annual rainfall had a generally increasing trend between 2000 and 2019, the average annual rainfall for the entire period remained low at approximately 21 mm. Low rainfall slows down regeneration of degraded forests and may lead to drying out of the young seedlings planted to replace the cut down trees.

5. Conclusions

From this study, the following conclusions can be made;

1. There is an increasing upward trend of forest cover loss throughout the study period in Somalia with the peak loss recorded in 2013.

2. Most forests cover the central southern parts of Somalia. Forest cover loss mainly occurred in areas around Mogadishu and Kismayo port.

3. Google Earth Engine combined with satellite data provides a quick means to assessing forest cover changes at regional and global scale thus saving on time and money resources. It also makes it easy to study environmental resources in Somalia besides the high insecurity in the country.

These results informs the need for the department of Forestry under the Federal ministry of Environment to design policies and targeted actions towards restoration of degraded forests and protection of the non-degraded forests in Somalia. Further research can be done to ascertain the causes of the upward trend of forest cover loss, especially after Al shabaab militants were driven out of their bases in Southern Somalia. This information would inform government actions geared towards management of forest resources in the country.

6. Recommendations

To increase forest cover and enhance management of forest resources, the national government and the federal member states of Somalia, through the respective ministries of environment and forestry need to consider the following recommendations.

1. Develop a long lasting forest cover change monitoring platform to monitor dynamics of forest cover for informed and timely protection efforts based on the magnitude of destruction.

2. Develop a national afforestation and reforestation program and framework to guide country's efforts towards restoration of degraded forests. For example, fast growing trees can be planted in areas that have experienced vast forest destruction such as Kismayo and the country's capital, Mogadishu. Some of the fast growing desert trees that can be planted as a way of mitigating deforestation impacts include: Chitalpa tree (*Chitalpa x tashkentensis*), Chinese elm (*Ulmus parvifolia*), California pepper tree (*Schinus molle*) and *Melia volkensii* [43].

3. Create public awareness on the risks and implications of forest destruction so that the community sees the need to protect forests and move away from activities such as charcoal production which is the leading driver of deforestation in the country.

4. Create and strengthen existing avenues for community involvement in forest management. Such may include establishment of Community Forest Associations which could co-manage the forest resources with government agencies. This will enhance cooperation among various stakeholders in the forestry sector. Community Forest Association are important since they create a sense of possession among community members and this can go a long way in protection of the forests.

5. The government through the ministry of education should include forest protection and management topics in the schools curricula so that a culture of protection of forest resources is inculcated to learners at an early age. They could also develop and include risk and vulnerability management programs that are related to forestry at all levels in educational sector.

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