Land Change in Ethiopian Basins

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Land Use Land Cover (LULC) changes analysis is one of the most useful methodologies to understand how the land was used in the past years, what types of detections are to be expected in the future, as well as the driving forces and processes behind these changes. In Ethiopia, Africa, the rapid variations of LULC observed in the last decades are mainly due to population pressure, resettlement programs, climate change, and other human- and nature-induced driving forces. Anthropogenic activities are the most significant factors adversely changing the natural status of the landscape and resources, which exerts unfavourable and adverse impacts on the environment and livelihood. The main goal of the present work is to review previous studies, discussing the spatiotemporal LULC changes in Ethiopian basins, to find out common points and gaps that exist in the current literature, to be eventually addressed in the future. A total of 25 articles, published from 2011 to 2020, were selected and reviewed, focusing on LULC classification using ArcGIS and ERDAS imagine software by unsupervised and maximum likelihood supervised classification methods. Key informant interview, focal group discussions, and collection of ground truth information using ground positioning systems for data validation were the major approaches applied in most of the studies. All the analysed research showed that, during the last decades, Ethiopian lands changed from natural to agricultural land use, waterbody, commercial farmland, and built-up/settlement. Some parts of forest land, grazing land, swamp/wetland, shrubland, rangeland, and bare/ rock out cropland cover class changed to other LULC class types, mainly as a consequence of the increasing anthropogenic pressure.

Africa | Ethiopia | geographic information systems | land use land cover change | remote sensing

1. Introduction

Land use is defined as how the land is utilised by people and their habitats, usually with an accent on a functional role of land for economic activities, whereas land cover is a physical characteristic of the Earth's surface [1][2]. Land use land cover (LULC) dynamics are a well-known, accelerating, and substantial process, mostly driven by human activities, that is contributing significantly to forest fragmentation, land degradation, and biodiversity loss [3][4]. Land use land cover changes (LULCCs) analysis is one of the most used techniques to understand how the land was used in the past years, what types of detections are to be expected in the future, as well as the driving forces and processes behind these changes [3][4]. Besides natural variations, the increasing human population is driving modifications of the Earth's land surface that are unprecedented, and evidence is present on a global scale [5]. Therefore, there is the need for better evaluation of changes in the land cover (namely, the biophysical attributes of the Earth's surface) and land use for human purposes to understand the past variations and depict future trends for the coming decades.

LULCCs are so persistent that, when aggregated globally, they expressively affect strategic aspects of Earth's system functioning. They directly impact biotic diversity worldwide, contribute to local and regional climate change as well as global climate warming, and are one of the primary sources of soil degradation. By altering ecosystem services at the local and regional scales, LULCCs affect the ability of biological systems to support and adapt to human needs [6][7][8]. Indeed, the major modifications of LULC worldwide could be related to the intense agricultural development and the growing population [9].

Similar to the rest of the world, East Africa (Horn of Africa) is not an exception to these land use land cover changes (e.g., [10][11][12][13]). In particular, very rapid changes are clearly recognisable in Ethiopia, due to the population pressure, resettlement programs, climate change, and other human and nature-induced driving forces. Similar to other countries, anthropogenic activities are the most significant factors adversely changing the natural status of the Ethiopian landscape [12], involving detrimental and adverse impacts on the natural environment and livelihood [14][15][16]. The land is a critical resource for the livelihood of East Africans, and there has been a steady decline in the size of land holdings per household. Following the demand for land, LULCCs in this region have resulted in a decline of natural forests to human settlements, urban centres, farmlands, and grazing lands [17]. Between 1990 and 2015, the East African forest cover decreased annually by about 1%, while the human population increased at an average annual rate of around 2% [10]. As pointed out by Dibaba et al. [18], factors such as biophysical, socioeconomic, institutional, technological, and demographic, contributed to LULCCs, which leads to a decline in the agricultural yield and a loss of biodiversity in the entire upper Blue Nile Basin, but significantly in the Finchaa sub-basin in the Oromia Regional State, Ethiopia. The authors also pointed out that extended aridity and persistent drought, land and soil degradation, as well as the decline of water resources in general, are the major consequences of LULCCs at the regional scale.

Forest disturbance and the subsequent conversion to other LULC classes (such as grazing land, agricultural land, bare land, pasture, or settlement areas) could modify the hydrologic cycle at the local scale, involving significant effects on water yields, water quality, and streamflow dynamics [19][20]. The rapid rate of deforestation is mainly occurring because of several reasons such as unsustainable large and small scale agriculture, forest fire, migration and population growth, illegal logging for construction purposes, charcoal and fuelwood production for cooking, and poor resource management [21], namely, deforestation, which is connected to the increased occurrence of shifting cultivators, triggering mechanisms that invariably involve changes in land development and new policies by the national governments that push migrants into sparsely occupied areas [8]. Focusing on the Horn of Africa, the main forest types that have undergone this decrease are tropical rain and dry forests, tropical shrubs, tropical maintain the forest, and mangrove forests, while there have been intensive efforts to establish plantation forests [10]. Land policy in developing countries such as Ethiopia is considered a crucial part of the overall development policy that the national governments need for assuring rapid economic growth and poverty mitigation, regardless of the natural resources management [22].

Ethiopia is historically passed significant dynamics in LULC for many decades. However, nowadays, LULCCs and degradation are increasing at an alarming rate, playing a significant role in the increasing rate of soil erosion. The need for more cultivated lands has negatively affected the presence of forest and grasslands, eventually fostering soil erosion [23]. Environmental conversions and changes can be mainly attributed to various adverse human actions such as the expansion of farm plots at the expense of agricultural lands, massive fuelwood and charcoal production, overgrazing, and encroachment of farmsteads into vegetated lands. According to Tefera [12], ecologically, Ethiopia is characterised by a rich but shrinking diversity in biological resources such as forest, woody and grassy lands, shrubs, varied wildlife, and fertile soil. It is also renowned for its massive mountain ranges, high flat plateaus, deep gorges, river valleys, lowland plains, extensive wetlands, and deserts. Landscape degradation by soil erosion has increased considerably in the Ethiopian highlands since the deforestation of the natural mountain forests and the cultivation of large areas, resulting in serious danger to the Ethiopian population [24][25]. This also affects the water balance of an area by changing the balance between rainfall, evaporation, infiltration, and runoff. Based on the observed trends, it is clear that a systematic analysis of LULCC is crucial to exactly comprehend the extent of the changes and take necessary measures to scale down the soil erosion [16], rate of changes, and protect the land cover resources sustainably.

The main objective of this article is to review the actual literature on LULC in Ethiopian basins, to point out what are the existing situations and the research gap that should be addressed in the future.

2. Case Study: Ethiopia

Ethiopia is located in the north-eastern part of the African continent, in the so-called Horn of Africa, which lies between 3° and 18° north latitude, 33° and 48° east longitude, within the tropics (Figure 1). The total area of the country is 1,119,683 km^2, while the area occupied by waterbodies is 7,444 km^2 [26]. Ethiopia is a country where about more than 80 million people, containing 50.46% male; the country is grappling with all sorts of natural and manmade problems such as famine, environmental degradation, erratic rainfalls, the prevalence of malaria and HIV/AIDS, poor but improving governance, and widespread poverty. About 84% of the people live in rural areas, assuring their livelihoods with subsistence agriculture, which is a sector nowadays suffering from the lack of essential inputs and a very variable rainfall pattern. Poverty is more than common in Ethiopia, though slightly declining over time [12].

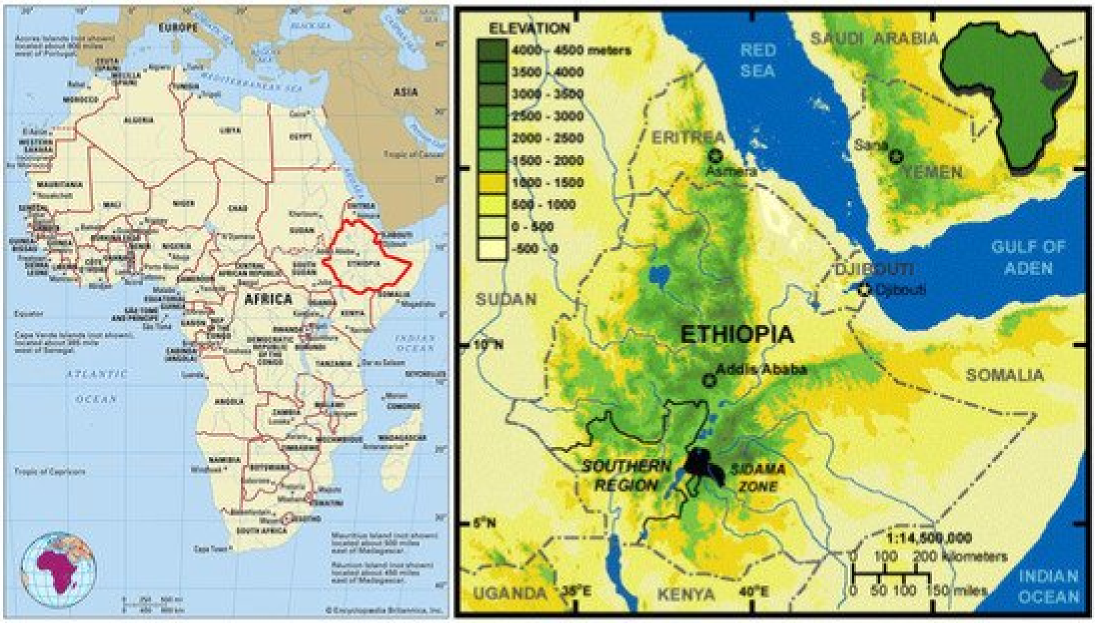

Figure 1. Maps of Africa (on the left) and Ethiopia (on the right).

In terms of geography, the prominent features of Ethiopia are the extensive high lands, surging plateaus, and deep river canyons, and the Great East African Rift System, dividing the country into the central/western part, mostly mountainous, and the southern highlands, which are surrounded by lowlands [27]. As indicated by Tefera [12], about 45% of the country is highland, with an average altitude greater than 1500 m and peaks of around 4000 m, in which about 88% of the country's population is located. Overpopulation, extensive croplands, and frequent incision by ravines and gullies characterise the highlands. On the basis of altitude, its influence on temperature, and rainfall, Ethiopia is traditionally classified into four broad agro-climatic zones. These are termed wurch (cold moist), dega (cool humid), woina dega (semi humid), and qolla (arid and semiarid). The wurch region encompasses all areas located around 3200 m above the mean sea level, with an average annual rainfall of over 22 mm. The dega zone consists of areas with altitudes and an average annual rainfall ranging from 2400 to 3200 m, and 1200 to 2200 mm, respectively. The woina dega zone covers areas within the altitudinal range of 1500 to 2400 m, having an average annual rainfall of 800 to 1200 mm. The qolla zone refers to areas lying below the altitude of 1500 m, where the average annual rainfall is around 800 mm [12]. In addition to these four regions, the Ethiopian physical environment can further be classified into eleven more detailed groups, still depending on average altitude and annual rainfall: bereha (namely, desert), dry qolla, moist qolla, wet qolla, moist woina dega, wet-woina dega, moist dega, wet dega, moist wurch, wet wurch, and high wurch.

The Ethiopian economy is among the most vulnerable in sub-Saharan Africa, and it is heavily dependent on the agricultural sector, which has suffered from the recurrent droughts that are reflected in extreme fluctuations of outputs. For example, agricultural production has been growing by about 2.3% during the period 1980–2000, while the population was growing at an average rate of 2.9% per year, leading to a decline in per capita agricultural production by about 0.6% per year [15]. According to this report, the percentage of people in Ethiopia who were absolutely poor in the year 2001 was around 44%, but the level of poverty shows significant variation among rural, urban areas and across regional states. In this country, the income distribution seems to be more unequally distributed in rural and urban areas, compared to other sub-Saharan African regions. To tackle this situation, in recent times, the Ethiopian Ministry of Agriculture and Rural Development (MoARD) announced one of the most detailed agro-ecological arrangements of the country by taking also soil moisture regimes into account, in addition to altitude and temperature.

3. Discussion

The results of the reviewed articles indicated that LULCCs for the past decades, as derived from the analysis of satellite imagery, were in accordance with field evidence (e.g., ground truth data and focus group discussion). In fact, most of the authors used techniques such as key informant interviews, focal group discussions, and field data collection to study the socio-economy and to validate the results obtained from Landsat data. In the majority of the analysed works, the key informant interviews were conducted involving the elder peoples, aged greater than 60 years old, to derive more consistent information on the history of the study area. Focal group discussions were performed with household farmers and local peoples, regardless of their age and social position. During the field data collection, the authors used GPS information to validate the results.

The outcomes presented in this review article agree with the analysis performed by Lambin et al. [8], who reviewed different studies covering a wider spatial scale. They argued that the pathways of LULCCs are a result of globalisation processes, intended as the [cide with the incorporation of a region into an expanding world economy, as is visible also for the Ethiopian case study. In this case, the expansion of internal and transnational markets influenced the LULC, involving deforestation, rangeland modifications, agricultural intensification, and urbanisation, since economic growth and persistent urbanisation are unavoidable global phenomena that initiate urban encroachment into agricultural lands [28][29].

Theoretical and numerical modelling can represent a very helpful tool for meeting land management needs, and for better assessing and projecting the future role of LULCCs in the functioning of the Earth's system [30]. To be effective, such models should be able to reproduce the main drivers of land use change, accounting for their scale dependency, predicting both the location and the quantity of LULCC, incorporating all possible biophysical feedbacks [29][30][31][32][33]. Numerical modelling approaches can benefit from the recent development in computational resources and the availability of remotely sensed data. Cloud computing services such as Google Earth Engine can provide information on the long-term LULCCs over a wide area [34], creating an extensive dataset to calibrate and validate numerical models.

The reviewed articles addressed LULCCs with high detail, providing significant evidence at the watershed scale. In fact, all the studied basins experienced a general trend towards 'more people more erosion', with implications in terms of land degradation and hydrological response. However, there is a lack of (i) detailed investigations of the implications of LULCCs on land erosion and basin-wide hydrology and (ii) studies focused on forecasting future trends of LULCCs. Therefore, there is the need to tackle both these aspects in detail to develop adequate strategies for land management and monitoring systems needed for assuring a sustainable Ethiopia for the next decades.

In this sense, a few studies tried to simulate the future evolution of LULCCs across Ethiopian basins, mainly using cellular automata and Markov chain models, which permit to account for both physical and socioeconomic drivers of LULC dynamics [13][35][36][37]. Despite the challenges associated with data and model validation, these authors have shown that such kind of studies is needed to support governmental strategies, both in rural and urban areas. They pointed out that the increase in built-up areas is an indication of the rapid population growth, and this may remain a challenge unless environmentally friendly policies on land use will be implemented to harmonise the demand and diminish the impacts that arise from it.

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