Article

From wooded savannah to farmland and settlement: population growth, drought, energy needs and cotton price incentives driving changes in Wacoro, Mali

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Abstract:

Land includes vegetation and water bodies and provides the basis for human livelihoods through primary production, the supply of food, freshwater, and multiple other ecosystem goods and services. The last three decades have recorded frequent drought events as well as rapid population growth, which has resulted in often negative land use and land cover change (LULCC) in the Sahel of Sub-Saharan Africa. In order to propose sustainable land management strategies, it is important to investigate the rate of LULCC and its driving factors in specific locations. This study investigated the case of Wocoro municipality in Mali using a combined approach of remote sensing, Geographical Information System, and focus group discussions. Satellite images and local people's perceptions on LULCC and drivers were collected and analyzed for the years 1990, 2000, 2010, and 2020. We found that the study area faced a severe decrease in wooded savannah with an increase in farmland and settlement directly or indirectly related to the rapid population growth, high cotton price (which encouraged cropland expansion), drought, firewood extraction, and charcoal production, which was exacerbated by poverty. There is a need to promote integrated land management strategies that consider current and future livelihoods needs and preserve the health of the environment for the benefits of future generations.

Keywords: Land use, land cover, drivers, change, Sahel

1 Introduction

It is well established that the last decade has witnessed a rise in consumer-driven demand for sustainable land use and land management, as well as commitments to restore degraded land that is unprecedented in human history due to the negative impacts it is making on the food system [1]. As the human population is projected to increase to nearly 9.8 (± 1) billion people by 2050 and 11.2 billion by 2100 ([2]; [3]) this may cause unpredictable consequences on land-based resources. This phenomenon in combination with inappropriate management of agricultural lands (including both grazing lands and croplands), especially in dryland areas, is the most extensive driver of environmental change [4]. Land use conversion also contributes to climate change through greenhouse gas (GHG) emissions from various deforestation and topsoil removal processes, which reduce carbon uptake rates from vegetation and soil organic matter [5]. As concluded by [6] in a study conducted in the Tougou watershed in Burkina Faso, the conversion of natural vegetation into cultivated areas led to a significant increase in the runoff potential. Land use corresponds to the socio-economic description (functional dimension) of areas: areas used for residential, industrial, or commercial purposes, for farming or forestry, recreational or conservation purposes, etc. Links with land cover are possible; it is under certain circumstances viable to infer land use from land cover and conversely [7]. According to [8], land cover data documents how much of a region is covered by forests, wetlands, impervious surfaces, agriculture, and other land and water types. Water types include wetlands or open water. Land use, on the other hand, describes how people use the landscape whether for development, conservation, or mixed uses. The different types of land cover can be managed or used quite differently. Land systems have been facing multiple changes during the last three decades all over the world. Their causes and driving factors are mainly related to human induced activities but are also related to natural factors [9]. Increasing farming activities, bush fires, and climate variability contribute to land use and land cover change (LULCC). Moreover, these can be linked to increasing human pressure on dry land resources, unsustainable agricultural practices, and the effect of physical factors on the environment, especially desertification and droughts, while human induced effects are related to increasing farming activities, overgrazing, agricultural intensification and deforestation [10].

In Sub-Saharan Africa, changes have been observed in the distribution and dynamics of distinct types of terrestrial ecosystems. Grasslands and shrublands, savannas and woodlands, and forests as sources of livelihoods are severely threatened terrestrial ecosystems, whose productivity has been diminishing throughout the years [11]. At the same time, Africa's population size is projected to double by 2036 and to represent about 20% of the world's population by 2050 [12]. [13] found that the loss of vegetation cover is likely to continue in the Sahel, and will be driven by a rapidly growing population, provided that no major change in land use policies and attitudes is taking place.

Focusing on Mali, it has been reported that the major causes of LULCC stem from a) climatic conditions, which include an arid environment and low and irregular rainfall patterns; b) climatic processes such as wind and water erosion; and c) human-induced land use changes [14] . The degradation of agricultural lands is one of the major threats to the future of humankind because of decreased food production and provision of other services including regional and global climate regulation and habitats for biodiversity [15]. Land-related issues are threatening the livelihoods of rural and peri urban communities, and especially the youth are seeking alternative income opportunities. As an issue of great concern, young people migrate abroad or to gold mining sites of Kayes in Mali [16]. Moreover, as a consequence of livelihood insecurity, high food prices and other land-related issues, community conflicts, jihadism and terrorism are spreading throughout Mali, especially the Sahel agroecological zone [17]. As land is becoming increasingly scarce and valuable, relations between groups of farmers and pastoralists have shifted from one of complementarity towards one of increasing tension and conflict because of land competition. At the same time, some regional studies have indicated

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that the Sahel is recovering or regreening [18]. Even though the West African Sahel was once synonymous with land degradation and desertification, it is now often celebrated as a region of environmental rehabilitation and recovery [19]. This contradictory information found in the literature needs to be investigated in a context-specific manner across Sahelian countries for the purpose of proposing sustainable land management options for resilient local livelihoods. This study aims to fill this gap for the case of Wacoro municipality in Mali.

2 Materials and Methods

2.1 Study area

Wacoro is located in the Sahel agroecological zone of Mali in West Africa (Figure 1). It is a home of primarily Bambara and Malinke farmers and used to form part of the pre-colonial Bambara Empire. Because of this and its rural character, Animism persisted in this area well into the 20th century. There are also populations of Muslim Maraka, Fula, and Bozo fishing communities. The municipality falls largely south of the dryer Sahel land, in the wetter Sudan, and is home to the headwaters of the Bani River. Major socioeconomic activities are crop farming and livestock keeping. The main cultivated crops in the area are cotton, followed by maize and groundnut. In terms of livestock, small ruminants (goat and sheep) predominate although there are also big ruminants such as cows and donkeys. The particularity of the study area is that it has common socio-economic and environmental characteristics to most of the municipalities within Mali's Sahel region, which attract most of the development interventions. Trees, shrubs, grass and animal species are representative for other areas within the Sahel region. The natural vegetation consists of trees and shrubs. In Wacoro, the dry season lasts from March to June, the rainy season from June to September and a cold season is from October to February with a drying Saharan wind called the harmattan. Over the course of the year 2021, the temperature varied from 17°C to 39°C and was rarely below 14°C or above 41°C with an annual average rainfall is 492.9 mm [20].

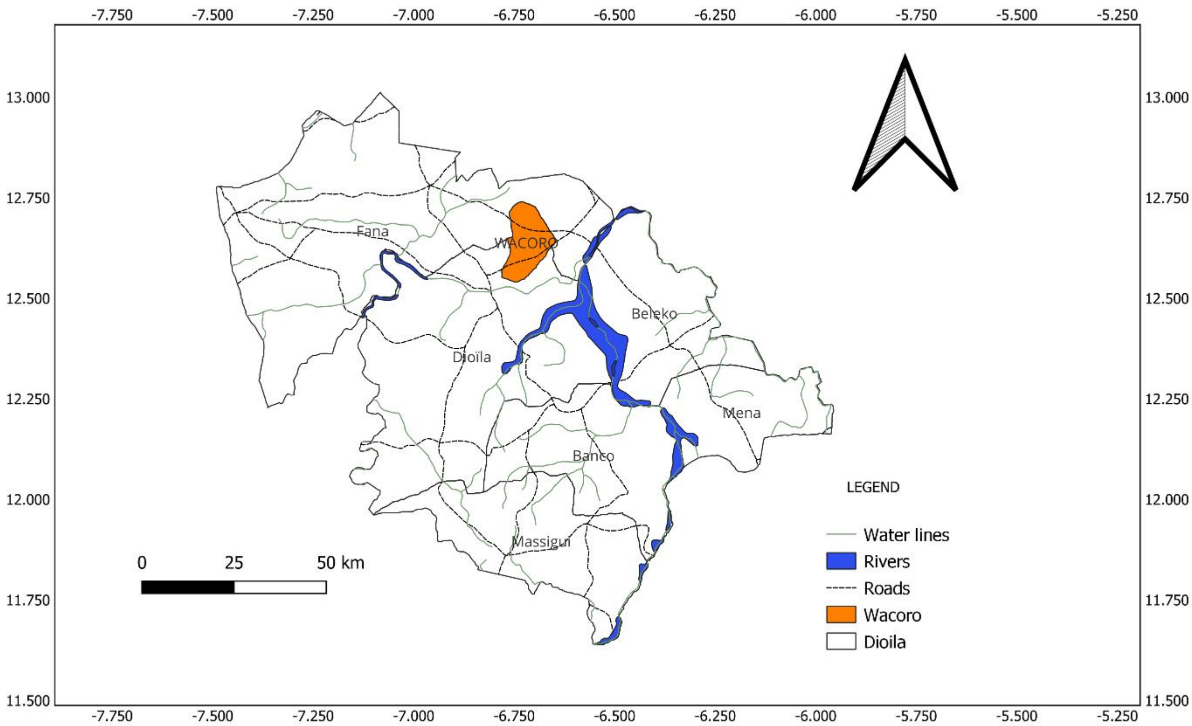

Figure 1 Map of the study area

2.2 Work flow for data collection and processing

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The different steps followed in this study for data collection and analysis are synthesized in Figure 2 below.

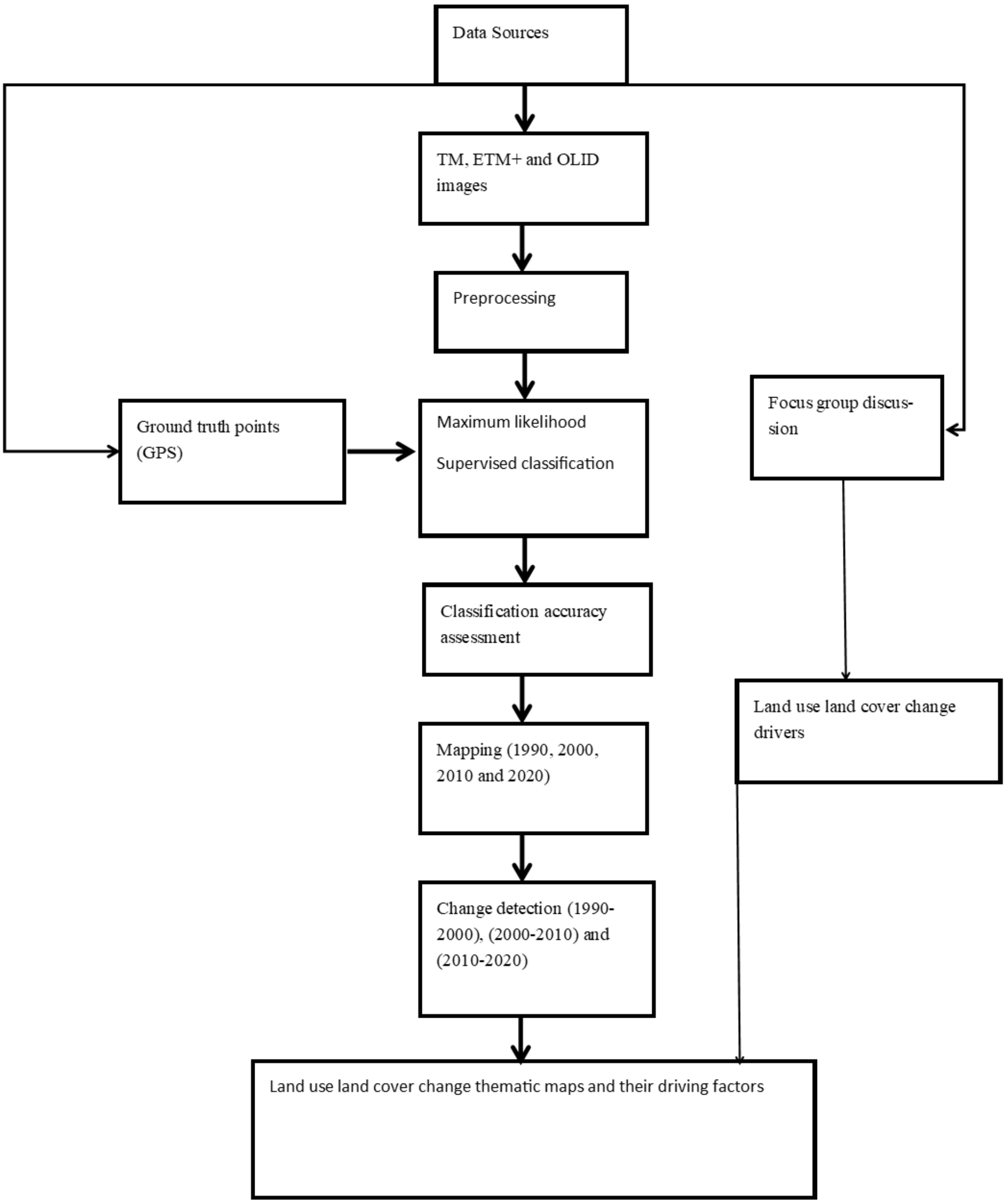

Figure 2 Schematic view of the working steps applied in this study (own illustration, adapted from [21])

Ground truthing has been conducted in October, 2022 to determine all land use land cover classes and GPS coordinates have been taken at each selected plot per class. The criteria considered during the class determination follow the definitions presented in Table 1.

2.3 Definition of the different land classes used in the paper

Table 1 Definitions of land use land cover classes (adapted from [22] and [23])

LULC Classes	Definition

Wooded savannah	Wooded savannah is a mix of woody and grass layers where the canopy of the woody component is not closed.
Shrub savannah	Shrub savannah is a mix of shrubs and grass layers.
Farmland	Farmland corresponds to cultivated land which can also show presence of woody components.
Water bodies	Water bodies represent standing water surfaces during most of the year.
Grassland	Grasslands are characterized as lands dominated by grasses and herbaceous annuals rather than trees or large shrubs.
Settlement	Settlements consist of residential areas, roads and other concrete infrastructure including areas for sheltering people, animals, and machinery.
Bare soil	Bare soil is barren land that has sand, rocks, and thin soil. It includes dry salt flats, sand dunes, deserts, beaches, gravel pits, quarries, exposed rock, strip mines, etc.
Rocky	Rocky areas are covered mainly by blocks of rock.

2.4 Sources of Land use/ cover data

Landsat images for the study site for the years 1990, 2000, 2010, and 2020 were downloaded from the USGS website (https://earthexplorer.usgs.gov/). Landsat 4 and 7 that we used in this work are the most accurately calibrated Earth-observing satellites and the latest in a long history of land remote sensing spacecraft, spanning 40 years of multispectral imaging of the Earth's surface.

2.5 Supervised classification

Remote sensing literature presents a number of supervised methods to tackle the multispectral data classification problem. The statistical method employed for the earlier studies of land cover classification is the maximum likelihood classifier. In recent times, various studies have applied artificial intelligence techniques as substitutes to remotely-sensed image classification applications [21]. In addition, the diverse ensemble classification method has been proposed to significantly improve classification accuracy[22], [23]. Scientists and practitioners have made great efforts in developing efficient classification approaches and techniques for improving classification accuracy. The quality of a supervised classification depends on the quality of the training sites. All the supervised classifications usually have a sequence of operations that must be followed: 1) Definition of the training sites, 2) extraction of signatures, 3) Image classification. The training sites are done with digitized features. Usually, two or three training sites are selected. With more training sites, better results can be gained [24]. We have decided to apply supervised classification, which has been used in previous studies [25]. It is a process of pattern recognition in remote sensing, which consists of carrying out the correspondence between the elements of an image scene, generally materialized by their radiometric values, and classes known a priori or not by a user. The correspondence is carried out by discriminant functions in the form of a decision rule such as the "maximum likelihood" of probabilities, or geometric distances. The chosen classification algorithm is the "Maximum likelihood". Indeed, this algorithm has the advantage of being a probabilistic method. It allows the classification of unknown pixels by calculating for each class the probability that the pixel falls in the class having the highest probability [26]. If the probability does not reach the expected threshold, the pixel is classified as unknown.

2.6 Estimation of the precision of image interpretation

To validate the results obtained from the classification, the error matrix or confusion matrix was generated in ENVI 5.5.2 in order to identify the proportion of well-classified topics. Thus, errors of omission and commission errors were calculated. For a land use study, the results can be considered validate if the Kappa coefficient is between 50% and 75%

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[27]. A method based on the evaluation of control points has been tried. This method consisted in verifying in the field, from the minute of interpretation, the points previously identified before the field mission for each of the land use classes, and determining the percentage of these verified points which correspond to those defined beforehand [28]. The ground truthing in this study was carried out as described below:

- stratified sampling was adopted so that the control points to be verified in the field are defined in proportion to the size of the stratum; 30 control points were determined for each of the classes
- a total of 210 points was defined for the entire study area (seven land-use units);
- at the level of each stratum, the control points were as dispersed as possible over the entire study area;
- a confusion matrix was constructed to report the results; the matrix revealed not only the general errors made at the level of each class during the interpretation but also the errors due to confusion between the classes of land use;
- errors of omission and confusion were calculated for each class of land use; the values obtained reflect the details of the interpretation of each class. Considering a class like woodland savannah, it was referred to as an error of omission when this woodland class had been omitted from the map. It was a confusion error when the wooded savannah area had been classified as another class on the map. Coordinates of each land use cover classes were collected from the field and incorporated into the maps for validating classified areas.

The Kappa coefficient was used to assess the precision of the classification adopted as described above. Its formula is as follows: P0 - Pc / Pp - Pc where P0 is equal to the actual percentage obtained from the classification of land use elements; it is equal to the quotient of the sum of the figures on the diagonal of the matrix with the total the number of observations;

Pc is the estimate of the probability of obtaining a correct classification; to calculate Pc, we proceed as follows: we realize the marginal products of the values of the columns and rows at the level of each cell of the matrix, then the sum of the values of the diagonal is divided by the total of the products of each cell of the matrix; for correct classification, the value of Pc is generally less than P0; and where Pp is the percentage obtained when the classification is perfect, i.e. 100% good.

From the above, the previous formula can be written: K = P0 - Pc / 1 – Pc

All maps were drawn with ArcGIS software version 10.8.

The primary application of the classification was to establish maps and statistics of land use. It also allowed, possibly associated with other characteristics, to follow the evolution of vegetation formations to induce work on forecasting production and preventive action against degradation and deforestation. An accuracy assessment was conducted using the confusion matrix to compare the classification results of 2020 with ground truth data collected on the field. As shown in Table 2, the Kappa coefficient on each image analyzed was above 75% which is considered as threshold [27].

Table 2 Analyzed image accuracy

Images	Global precision	Coefficient Kappa

TM 1990	88.70%	0.87
ETM+ (2000 and 2010)	87.41%	0.85
OLI 2020	93.51%	0.93

2.7 LULCC driving factors assessment

A number of focus group discussions (FGD) were organized in the study site to assess with communities the potential driving factors for the changes observed on the land use maps over time (1990-2000-2010 to 2020). LULCC data (maps and graphs) was presented in the form of posters to the local people during the FGDs.

FGDs were carried out in six villages in the study site. Overall, a total of 37 villagers participated in the FGDs. These included both male and female agro-pastoralists with a mean an age of 52 years. The rationale was to select people who experienced the time series selected (1990 to 2020) for coherency. All participants were thus selected by the local leaders based on the following criteria:

- Age (50 and above)
- their knowledge of the long term biophysical and socio-institutional context of the study sites
- their experience in local decision-making approaches
- their experience in working with extension workers

FGDs were moderated by the lead researcher together with a community facilitator and were guided by a list of questions related to LULCC and their driving factors. Each FGD consisted of 5–7 people and the discussion went on for two to three hours. Driving factors for LULCC were discussed by the participants for them to agree on a score in order of importance. The interval score was from 0 to 5 for each direct or indirect driving factor. Each focus group was expected to provide a common score. In case of disagreement among the participants in the scoring of a given driving factor, all members in the FGDs were asked to provide a score. Then the modal value (score that was most frequent) was retained. The scores for different criteria for each technology were then summed up and the results announced to the participants [29].

Data analysis was done using descriptive analysis. Collected data were analyzed in SPSS 24 to calculate the mean value for each factor. Then, the comparative frequency of each factor was drawn by using bare 2D. The score of each indicator is presented as the mean score given by the six groups, which determines the level of the effect on LULCC. The higher the score, the more likely was it classified as a main driving factor. The following scores were used: 0 = no effect, 1 = low effect, 2 = medium effect, 3 = relevant effect, 4 = very relevant effect, 5 = highly relevant effect.

Population data

Population data for our study years 1990, 2000, 2010 and 2020 were derived from the 2009 national census (INSTAT, 2009) obtained from the Malian National Institute of Statistics. These data do not take into account people who passed away or migrated out of the village during these periods. The following equation was used:

$$Pn = Po * (1 + r) \hat{} n$$

Where P (n) is the population projection for year x, Po is the population at the beginning, r is the growth rate, and n is the number of years [30]. Due to limited data availability related to internal population mobility, we could not include the out-migration in the final estimation of the population.

Pearson correlation analysis was computed between population data and land use/cover classes in the last 30 years (1990 to 2020). One assumption of the Pearson statistic is that the relationship to be tested is a linear one. In this case, the outcome is easy to derive.

$$r = \frac{C_{xy}}{\sqrt{C_{xx}C_{yy}}} = \frac{A}{|A|} = \pm 1$$

In other words, if y and x are exactly linearly related, r = _+/->1, depending on whether the slope is positive or negative (correlation or anti-correlation). More likely, with real data of any kind, there will be a spread in the values of x and y, in which case the correlation will be less than maximal, i.e. [r] < 1 [31]. Additionally, correlation was computed among LULCC classes in order to detect the possible conversion.

3 Results

3.1 Land use land cover change between 1990 - 2020 in Wacoro, Mali

These maps show. We observed remarkable changes in land use and land cover in Wacoro municipality over the past thirty years. Figure 3 shows the spatiotemporal dynamics between the years 1990, 2000, 2010 and 2020.

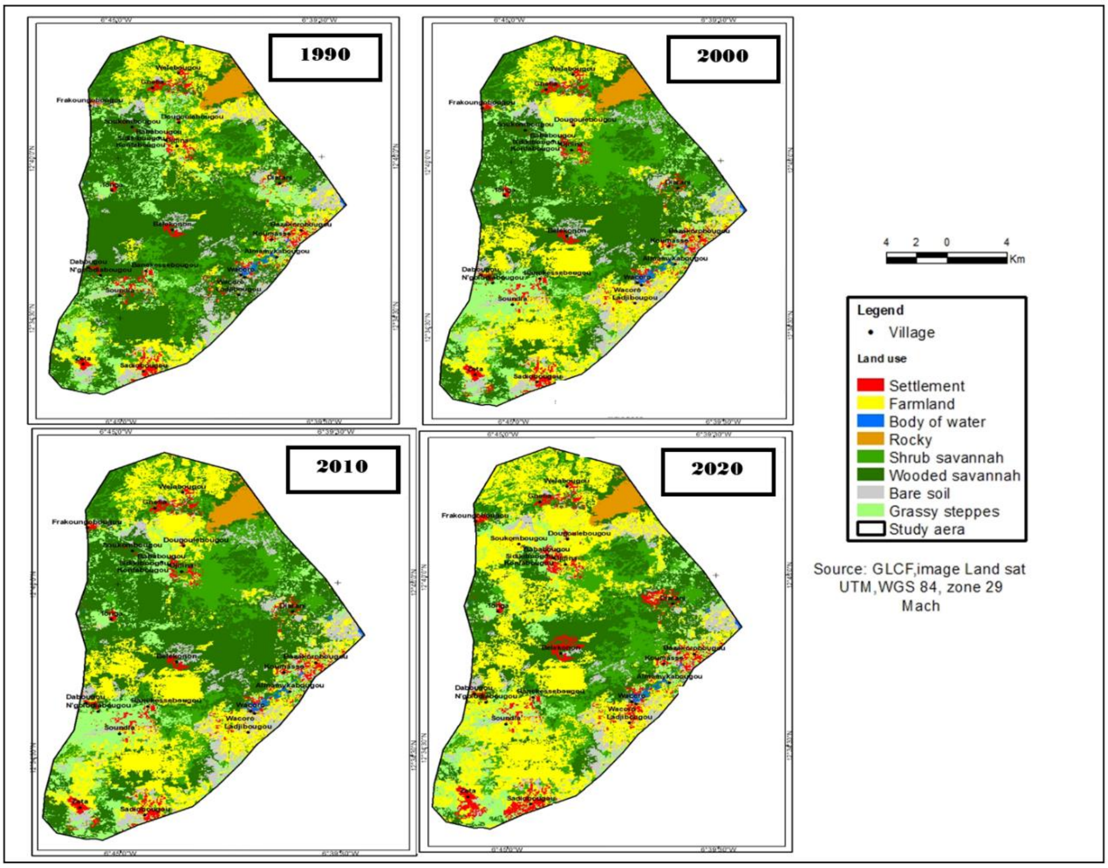

Figure 3 Maps in Wacoro Municipality in the Sahel Mali

From these results, all land use cover classes have recorded spatial and temporal changes. However, the degree of change varies from class to class. Wooded savannah recorded the most significant decrease while settlement, shrub

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savannah, grassy steppe, and farmland coverage increased consistently (Figure 4). The most important LULCC took place between 1990 and 2010.

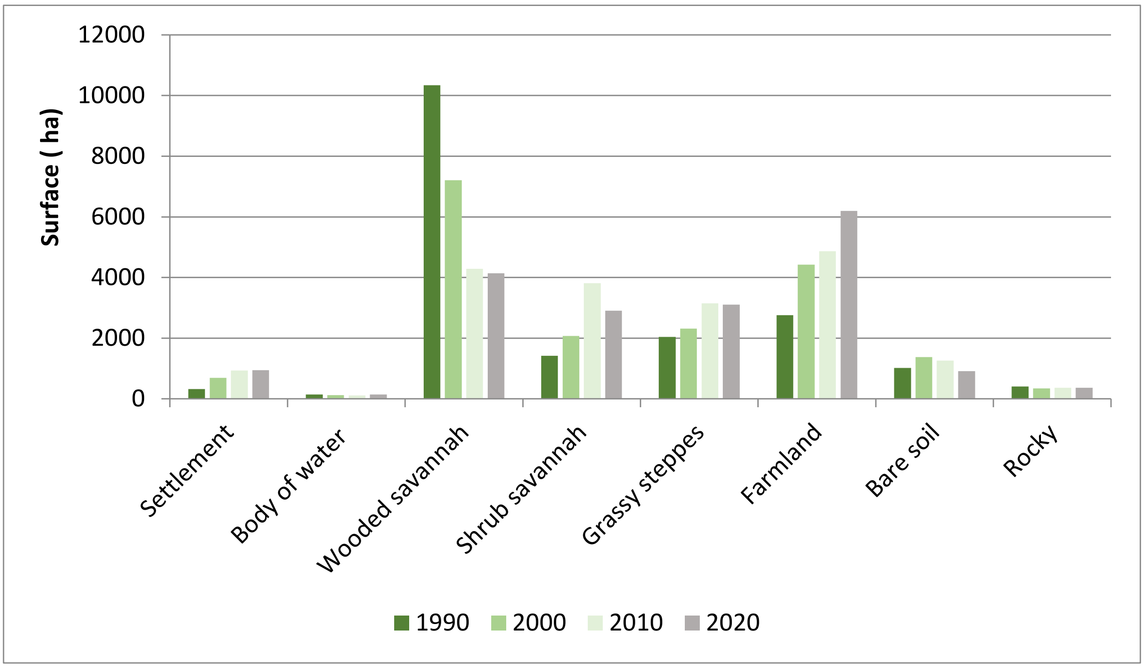

Figure 4 Land use land cover dynamics between 1990 and 2020

3.2 Correlation analysis

Bivariate correlation (Table 3) shows that within the time frame of 30 years (1990 to 2020), the increase in farmland significantly correlates with population growth (p-value = 0,04), whereas the decrease in wooded savannah correlates with the increase of settlements (p-value = 0,005) and the increase of grassland (p-value = 0,03). Moreover, a conversion of shrub savannah into grassland has also been recorded (p-value = 0.05). Degraded wooded savannah has been mainly converted into settlement and grassland savannah. Within the time frame, more villages were established and more pastoralist migrated to the area because of its natural vegetation and grassland cover.

Table 3 Correlation Matrix

Pearson's Correlations

Variable		Pop	Settlement	Bodyofwater	Woodedsavannah	Shrubsavannah	Grassysteppes	Farmland	Baresoil
1. Pop	Pearson's r	—							
	p-value	—							
2. Settlement	Pearson's r	0.865	—						
	p-value	0.135	—						
3. Bodyofwater	Pearson's r	−0.091	−0.402	—					
	p-value	0.909	0.598	—					
4. Woodedsavannah	Pearson's r	−0.893	−0.995**	0.365	—				
	p-value	0.107	0.005	0.635	—				
5. Shrubsavannah	Pearson's r	0.692	0.896	−0.619	−0.912	—			
	p-value	0.308	0.104	0.381	0.088	—			
6. Grassysteppes	Pearson's r	0.888	0.940	−0.333	−0.968*	0.944	—		
	p-value	0.112	0.060	0.667	0.032	0.056	—		
7. Farmland	Pearson's r	0.960*	0.927	−0.042	−0.927	0.695	0.857	—	
	p-value	0.040	0.073	0.958	0.073	0.305	0.143	—	
8. Baresoil	Pearson's r	−0.405	0.092	−0.808	−0.011	0.138	−0.135	−0.167	—
	p-value	0.595	0.908	0.192	0.989	0.862	0.865	0.833	—

* p < .05, ** p < .01, *** p < .001

3.3. Local people's perception of the main driving factors of LULCC

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According to the local communities, the main driving factors leading to decreasing wooded savannah are related to the increase in cotton price, which led to agricultural land expansion, as well as drought, population growth, and settlement expansion (Figure 5). Moreover, firewood and charcoal exploitation have also contributed significantly. All of these were exacerbated by recurrent poverty and low environmental law enforcement in the communities during the past 30 years. Most driving factors such as firewood and charcoal exploitation, timber extraction bushfire, wind erosion, poverty, recorded their peak from 2000 to 2010 due to the severe droughts that affected the communities. In order to withstand from the drought threats which, increase the level of poverty, people put pressure on natural resources as an alternative livelihood, thus contributing extensively to deforestation. The period between 2010 and 2020 is considered as a recovering period from drought due to the favorable environmental conditions. However, at the same time, these conditions and particularly the increase in cotton price contributed to agricultural land expansion. Local people stated that cotton farms increased and replaced much of the remaining wooded savannah cover during that period.

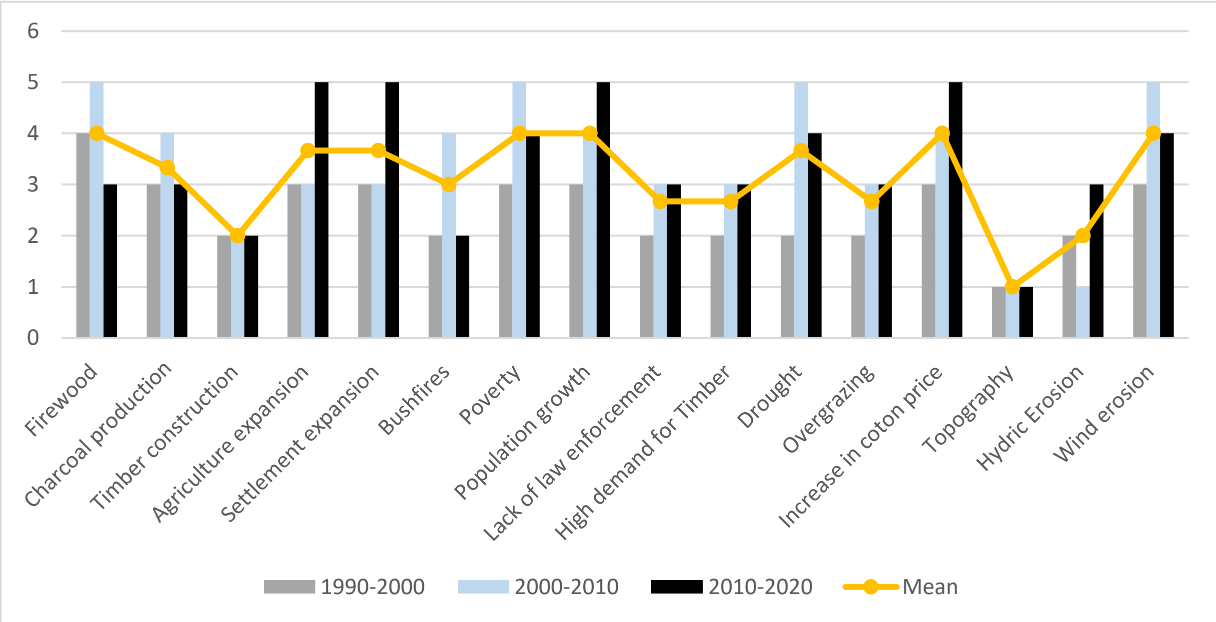

Figure 5 Driving factors of wooded savannah decrease in Wacoro municipality between 1990 - 2020

Regarding the observed increase in farmland, local communities reported that it is attributed mainly to the rapid population growth, increase in cotton price, low soil fertility, access to agricultural inputs for cotton farming with high relevance (Figure 6). Moreover, remittances, family labor force availability and low law enforcement contributed but with medium relevance. The results also show that, although agriculture land increase is related to the above driving factors, their effects differ from a period to another. Most of the driving factors recorded their peak between 2010 and 2020. This phenomenon is mainly due to the high demand of agricultural products for livelihood support (income and subsistence food) caused by high population growth. In addition, the cotton price got its highest peak from 2010 to 2020

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compared to the period 1990 to 2010. This finding justified the hypothesis of the socio-economical activities contribution to the land use changes.

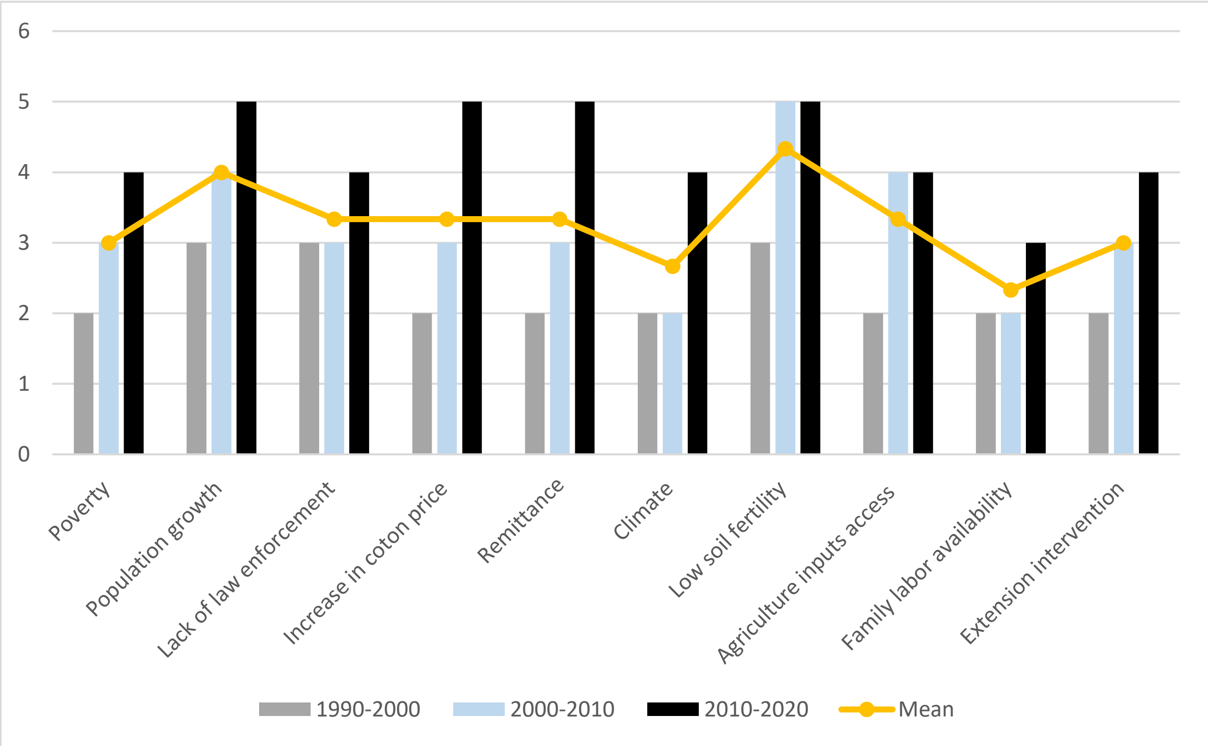

Figure 6 Driving factors of farmland increase in Wacoro municipality between 1990 - 2020

Increases in settlement area have been mainly attributed to the population growth, easy access to construction materials (tree-based products), remittances from internal and external migrants, and income from the cotton production (Figure 7). Labor force availability, construction technical know-how and low steppe topographical conditions are also contributing factors but with low relevant effects. Moreover, local people's technical capacities, labor availability and good topographical conditions have also contributed. However, all these factors are directly or indirectly related to the rapid population growth that the area has seen. Throughout the last 30 years, Wacoro's population recorded an exponential growth. In addition, external supports of migrants, income from cotton and access to the construction material contributed to increased settlements. These drivers recorded their peak between 2010 to 2020, which coincides with the period when cotton prices increased. More remittances were received as consequence, more pressure was put on the , shrub savannah and as well as on grasslands, and often even agricultural land was converted into settlements. This finding suggests a competing scenario between land use land cover classes without a proper management political plan in place.

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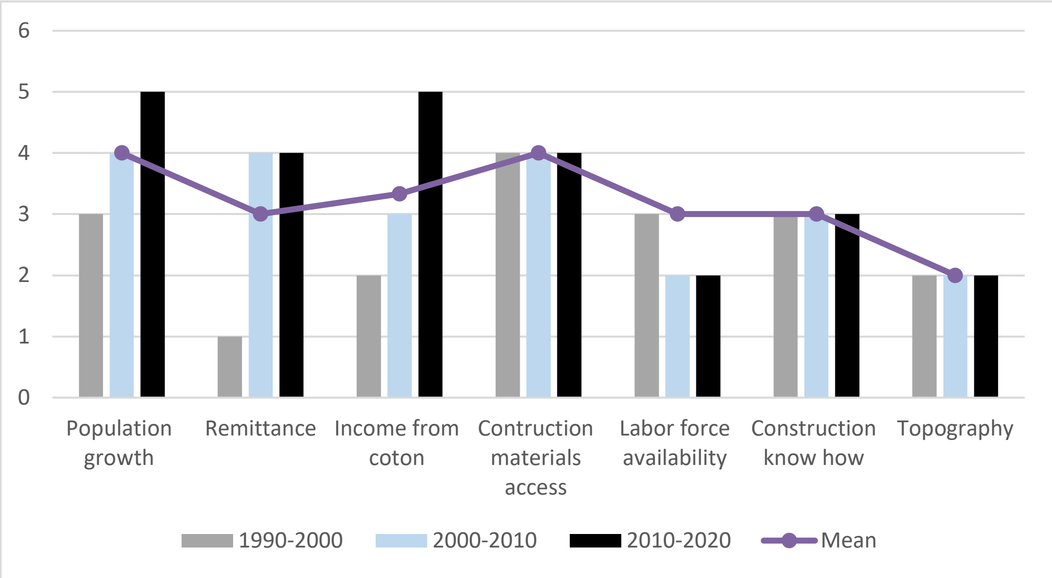

Figure 7 Driving factors of settlement increase in Wacoro between 1990 - 2020

The increase in grass and shrub land over the last 30 years has been mainly attributed to the decreases in wooded savannah. We found that an increase in grass and shrubland is negatively correlated with the wooded savannah decline but statistically significant with grass savannah increase (p-value = 0,03). This means that part of the already degraded wooded savannah became grass and shrub savannah in time. This finding is persistant with local people's perception of grass savannah cover increase due to the severe destruction of the wooded savannah for livelihood needs especially from 2000 to 2010, when drought caused damages on livelihood (Figure 8). Moreover, annual rainfall distribution positively or negatively contributes to the grassland and shrubland changes over the study period. As a way out, transhumance has been applied as a local adaptation strategy set in traditional rules to withstand the drought stress which affected agropastoralists between 2000 and 2010. The approach consisted of migrating most of the livestock (both big and small ruminants) to the humid areas as a group for a long period of time before the drought effects negatively affected the landscape. In the meantime, between 2007 and 2010, although climatic conditions were not as expected, livestock pressure has reduced the grassland and shrubs savannah. According to the local communities, from 2010 onwards, all livestock has been brought back without any further measure. From 2010 to 2020, the pressure on the regreened grassland and shrub land has increased again. This scenario was a lesson learned by the community in knowing that transhumance is not a long-term solution for grassland and shrub land restoration. Instead of being a solution, it may cause more unexpected damage. The perception on transhumance is consistent with [32], who found that in 2004, drought across Mali's north seriously affected transhumant populations, forcing pastoralists to remain near permanent water sources and leading to considerable overgrazing.

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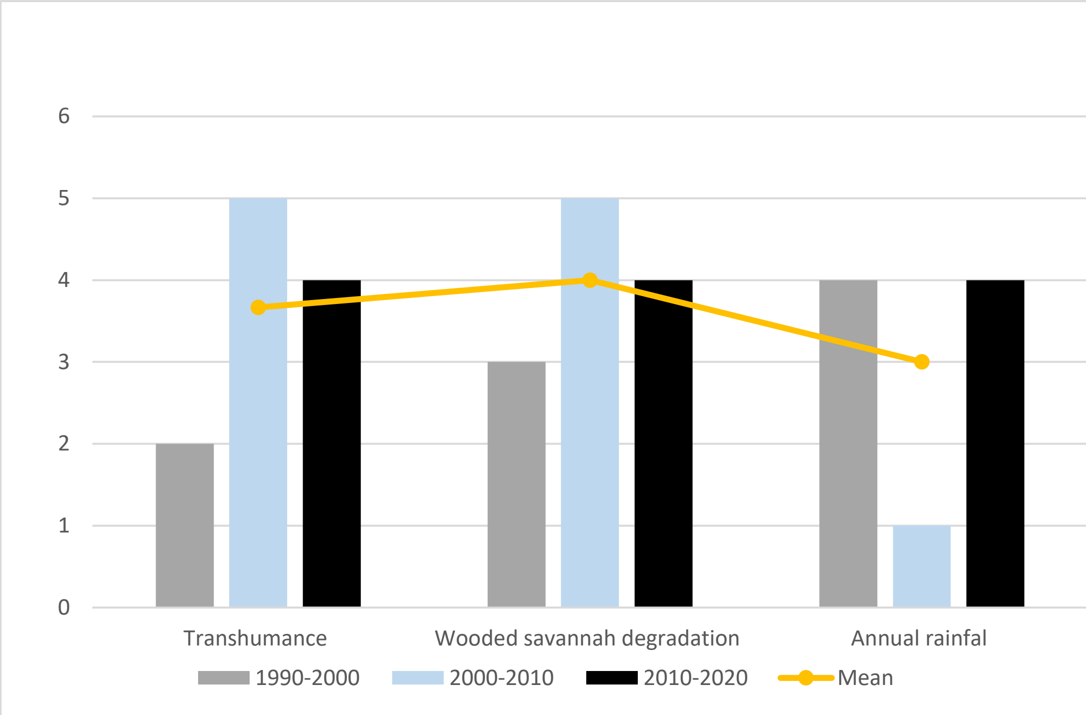

Figure 8 Driving factors of slight increases in shrub and grass savannah from 1990 - 2020

4 Discussion

The purpose of this study was to analyze land use cover changes and related driving factors. Our results support the hypothesis that land use land cover changed due to varying driving factors over the last 30 years (1990 to 2020). In general, a conversion and competition were noticed between land use land cover types (wooded savannah, grass and shrub savannah, settlement, and farmland) although the conversion rate differs from one land use land cover class to another. In general, we found a decline in wooded savannah with an increase of settlement, farmland, shrub and shrub savannah. That is mainly related to smallholder agricultural expansion, recurrent droughts, overgrazing, population growth, increases in cotton price and high needs of tree-based energy as driving factors. This corroborates with evidence stating that forestlands and woodlands have declined while agricultural lands, shrublands and grasslands have increased in a study of a landscape in Southwest Côte d'Ivoire, West Africa [33].

Similar to the results of our current study, other authors also reported that climate change in general and particularly through increased drought periods negatively affects the livelihoods of local communities' in Sahelian West Africa ([34]; [35]; [36] and that this pushes them towards expansion of cropland and search for alternative livelihoods (firewood, charcoal and timber), ultimately driving land cover change (ex. loss of wooded savannah) as observed in our study. Thereby, land cover management strategies need to consider climate friendly energy and timber sources for livelihood improvement in the Sahel[37].

Overgrazing has been considered by the majority of local people as contributing factor to the wooded, shrub and grass savannah decline due to the high demand of fodder from not only the community but also from the neighboring cities such as Dioila and Fana. Grazing of this huge number of livestock far beyond the carrying capacity in forest lands exerts tremendous pressure on forestland. Farmers often keep more livestock than the carrying capacity of the land they possess to meet the high meat and milk demand[38]–[40]. This, therefore, predisposes that the animals not only to feed on

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grass but also on perennial vegetation, thus leaving the ground bare and susceptible to soil erosion. Bare ground also exposes the soil to the hot sun during the dry period and dries the soil, hence causing the soil to suffer from wind erosion that takes away the fertile topsoil. Livestock densities are high, and overgrazing readily occurs. Removal of protective vegetation and trampling of exposed soils by livestock hooves lead to a decline in biological productivity of the land, reduced water infiltration and storage, and soil compaction and erosion [41]. Traditional grazing systems encounter difficulties due to an increasing number of animals and competition with farmers, affecting the availability of rangelands [42]. Therefore, degraded grazing lands needs to be restored through a combination of fodder trees, grass and shrubs planting or assisting combined with a control livestock population for sustainable livelihoods in the pastoral communities in the Sahel.

In line with our findings, evidence exists that population growth and density are some of the most important factors behind the declining use of fallows and increased land fragmentation in Burkina Faso [43]. This is also coherent with previous studies ([44];[45]; [46]) who observed that population growth leads to expanding human settlements and increasing demand for food (and related expansion of agricultural land), fuel, and building materials. In Mali's capital, Bamako, population growth rate accelerated from about 1.6 - 1.7 % between 1976 and 1987 to 3.1 - 3.6 % between 1998 and 2009 [47]. Such a rapid growth rate has consequences for jobs, unemployment, and the demand for social services. It increases pressure on arable (irrigated) land and access to water and has the potential to become a driver of social change and possibly even conflict in the future. Population pressure on resources could rise in the coming years and could threaten the survival of plant and animal areas and beyond the well-being of people in Mali and the poor especially in the current context of climate change [48]. Thereby, sustainable land management strategies should consider population projections in short, mid and long term for future stable and resilient natural resources and livelihood for local communities.

The the emergency of vegetation degradation due to the rapid expansion of local mining practices and deforestation for livelihood in the Sahel[49]. In our research, we found that in addition to the rapid population growth, recent increase in cotton price contributed significantly to agricultural land expansion which reduced wooded savannah cover. This phenomenon is due to the national policy oriented in facilitating agriculture inputs access for cotton farming. As a consequence, huge amounts of wooded savannah have been converted into agricultural land. Deforestation from both agricultural activity and settlement is therefore a driving factor in land cover changes [50]. Similar results were observed in neighboring countries, respectively Burkina Faso [35] and Senegal [51]. Incentives for cotton production need to be consider in land management practices for the Sahel.

Our research was limited to the actual LULCC and the driving factors behind these changes and did not investigate the economic loss attributed to driving factors per unit of land cover. Further research could dig into how an increase of each driving factor contributes to losses related to each change in land use in a timeframe.

5 Conclusions

This study highlighted that natural vegetation cover (wooded savannah) has been diminishing while anthropogenic land use (farmland and settlement) has increased from 1990 to 2020 in Mali's Wacoro municipality. LULCC in these areas has been driven by rapid population growth and related needs for food and energy (wood fuel) and conflicting agricultural policies such as attractive cotton prices (at sale), which encouraged farmer to expand cropland. All driving factors have been exacerbated by the recurrent poverty. Among all interval time frames considered in this study, 2000 to 2010 was the period when the highest LULCC happened due to continuous drought in the region that threatened the livelihoods of people through significant decreases in crop yield and livestock productivity, leading to expansion (land grabbing) to compensate for the loss in production. Also, the phenomenon pushed more people to seek for alternative livelihoods (fuel wood cutting, charcoal production, etc.), which caused huge damage to natural vegetation resources products and the biodiversity. This is already an adequate move towards reversing the degradation trend. However, there is still a need to sensitize and assist local communities in implementing sustainable land use and management practices that consider current and future livelihoods needs and also preserve the health of the environment for the benefits of future generations.

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