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Sustainable Land-Use Recommendations in Light of Agroforestry Systems in Response to the Changing Scenario of Land-Cover

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Abstract

Change detection of land-cover to recommend the future directions of land-use is indispensable for sustainable development and the proper utilization of land resources. In this research, unsupervised classification maps produced using images of Landsat 8 OLI from 2013 until 2021 (with a 4-year interval) reveal important land-cover changes, along with their drivers, in Kapasia, Bangladesh. Overall, a substantial increase in paddy (24.7% to 27.2%) and urban (3.5% to 10.1%) and a decrease in homestead (67.5% to 59.3%) and forest (4.2% to 3.4%) were observed within the time interval. To direct the land-use towards long-term biodiversity and sustainability of the region, it is important to implement types of agroforestry systems as the observed decrease in homestead and forest areas are alarming. Agroforestry practices will not only have a positive environmental impact but can help diversify food systems, increase economic return and optimize natural resource use.

Keywords

Agroforestry Systems, Landsat 8 OLI, Land-Use and Land-Cover (LULC)

1. Introduction

Agroforestry is widely touted as a sustainable way to mitigate the impact of climate change and address the environmental, economic and social consequences of non-sustainable land-use practices. More than just "agriculture with trees", agroforestry is an agro-ecological technique involving farmers, livestock, trees and forests at various scales—along with trees on farms, farming in and at the margins of forests and tree-crop production [1]. Despite the widespread conversion of forested areas to human-dominated landscapes, there is a realization in modern society to go back to agroforestry, with the principle of growing trees in all possible places including homesteads and crop fields. In both cases, there is an association of trees with other food/feed producing plants and/or useful animals, which constitute the fundamental principle of agroforestry. Although the technology of agroforestry has been utilized in different ways in different countries, the principle of agroforestry is the same in all cases—a land-use system where the tree/perennial is the constant component along with several other variable components such as horticultural crops, field crops, domestic animals, fishes etc. [2]. In particular, the practices, deforestation and cultivation of crops in and around the forest zone, and afforestation in and around the crop field, both come under the concept of agroforestry in a broad sense [3]. Above all, agroforestry is aimed at the creation of a natural environment, close to that of a forest, and to increase diversified agricultural production through maximum usage of the land while retaining its productive qualities [4]. Benefits from the application of agroforestry technologies consist of food and nutritional security, economic stability, and ecological integrity [5]. As solutions to environmental services (e.g., biodiversity, carbon sequestration, watershed protection) as well as through financial viability and attractiveness, agroforestry systems are increasingly being recognized as an important land-use alternative in different settings throughout the world [6] [7].

It follows that the arrangements of different elements of agroforestry (e.g., perennial trees, agricultural crops, animals) and the level of interaction among different components are distinct for individual agroforestry systems. Depending upon the region, terrain, climate, soil and socio-economic conditions, agroforestry systems can vary considerably where one system differs from the other with respect to structure, composition, age, intensity, technology, inputs and outputs. It is difficult to single out any one system that can meet most of the requirements of agroforestry. However, these systems can be grouped based on any one factor/function of the farming system. Thus, the overall agroforestry system can be classified based on utility of the land, socio-economic criteria, physiognomy, ecology, structure and function. Based upon land utilization, agroforestry production systems can be classified into homestead agroforestry, forestland agroforestry, crop-farm-forestry, fish-farm-forestry and integrated-farm-forestry. Homestead agroforestry involves the production of fruit trees, certain multipurpose trees having less canopy, vegetables, spices and shade-loving crops; forestland agroforestry refers to the growing of crops in the available spaces within forests; crop-farm-forestry is the production of crops and trees within cropland; fish-farm-forestry is the production of trees and fishes in the fish farm; and integrated-farm-forestry is the production of crops, fishes and animals alongside trees [8]. Although both conservation and sustainability are considered significant aspects of agroforestry, socio-economic and bio-physical factors need to be considered if the potential of agroforestry is to be recognized [9].

As the land-cover changes and the global population grows over time, the demand for natural resources rises while effective land-use practices and sustainable agriculture and food systems become increasingly important. This study assesses four land-cover types using Landsat 8 OLI in the context of Kapasia, Bangladesh, to suggest how land-use can be sustainably adapted through the application of agroforestry systems. One of the categories studied within this research is paddy, a leveled flooded field that is used to grow water-dependent crops such as rice. Another category, forest, is land-covered with a large number of dense trees. Subsequently, the third category is classified as homestead. The agroforestry system, when practiced in forest lands and homesteads, is termed forest land agroforestry and homestead agroforestry, respectively. Apart from this, the homesteads, home yards, and marginal lands attached to or nearby homesteads are the main sources of most native fruits, country vegetables, fuelwood and timber in Bangladesh. In the homesteads of both rural and urban areas, fruit-, ornamental- and multipurpose trees can be produced for a better living environment [2]. Moreover, the urban category includes residential, industrial, different urban structures, etc. The abovementioned land-cover categories also align with the National Land Cover Dataset 1992 [10].

2. Methodology

2.1. Study Area

The selected study area, Kapasia, Bangladesh is located at a coordinate of 24.10˚N and 90.57˚E with a low to medium elevation (~10 to 30 m) [11]. Kapasia had a population of approximately 321,000 in 2001, whereas the population increased to 342,162 in 2011 [12]. The total area includes 231 villages and 11 unions: however, only 2 villages are fully urban, and the rest are rural. Agriculture is the main income source in Kapasia and crop productivity has been shown to be the highest in this area [12]. In addition to paddy cultivation, fish farming is common in Kapasia as well. The main water bodies/rivers that run through the landscape and the surrounding areas include the Shitalakshya, Old Brahmaputra, Banar, Buri Beel, Machha Beel, Nail Beel, Baniar Beel and Suti Canal [13]. In Kapasia, there are moist deciduous forests, which are identified as the Sal forest in Bangladesh. Furthermore, there are homestead forests throughout Kapasia.

2.2. Landsat 8 OLI

The present analysis implemented the Landsat 8 OLI (Operational Land Imager) satellite images for the years of 2013, 2017 and 2021 to observe the change in the land-cover types. The path and row were 137 and 43 respectively. To classify the land-cover into four categories (paddy, forest, homestead and urban), an unsupervised classification algorithm (ISODATA) was applied. In this study, six multispectral sensor bands of the Landsat 8 OLI with a 30 m resolution were utilized: band 1 (coastal aerosol, 430 - 450 nm), band 2 (blue, 450 - 510 nm), band 3 (green, 530 - 590 nm), band 4 (red, 640 - 670 nm), band 5 (near-infrared, 850 -

880 nm) and lastly band 7 (shortwave infrared-2, 2110 - 2290 nm). The enhanced radiometric resolution of the Landsat 8 improves the spectral record precision and avoids much of the spectral saturation. More importantly, the Landsat 8 has a different position of central wavelength with narrower bandwidths especially for bands 5 and 7 thus, it is worth mentioning that the narrower bandwidth can effectively discriminate specific objects [14]. Additionally, the OLI sensor collects data with improved radiometric precision over a dynamic range of 12-bits that improves the overall signal-to-noise ratio which in turn improves the characterization of the land-cover condition. Moreover, all data were collected in the same season (during March) to further simplify the interpretation, best extract meaningful changes and accurately track land-cover change. These Landsat 8 OLI scenes can be easily accessed through the US Geological Survey (USGS) archive.

2.3. Distribution of NDVI

Data that measure wavelengths of light both absorbed and reflected by green plants are studied by remote sensing phenology. The seasonal and annual variation in vegetation growth (phenology) can be actively monitored through vegetation indices, which describe the greenness, relative density and vegetation health for each pixel in a satellite image [15]. Intensifying the bio-physical characteristics of plants from remotely sensed imagery, NDVI (Normalized Difference Vegetation Index) describes the difference between the visible and near-infrared reflectance of vegetation cover, where the values range from +1.0 to −1.0. Using Equation (1)

$$\text{NDVI} = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}} \tag{1}$$

the NDVI map was generated where NIR (reflected by the vegetation) and RED (absorbed by the vegetation) stand for the pixel reflectance of bands 5 and 4 respectively. In the NIR and SWIR wavelengths, water tends to absorb more energy (low reflectance), whereas non-water reflects more energy (high reflectance). The Landsat 8's narrower NIR band, higher signal-to-noise ratio and improved radiometric resolution specify that it is less likely to be influenced by atmospheric conditions and has the potential to be more sensitive to surface reflectance variability [16]. Therefore, Landsat 8 can better represent the spectral properties of vegetation and can enhance the detection of temporal and spatial vegetation differences.

Meanwhile, the values of NDVI can be interpreted as follows: ≤0.1 as sand/water/areas of barren rock, ~0.2 to ~0.5 as sparse vegetation (*i.e.*, shrubs and grasslands) and ~0.6 to ~0.9 as dense vegetation [15]. As part of the previous research work, through the NDVI distribution derived from MODIS (250 m resolution) in January 2002, it was found that the values for Kapasia ranged mostly from ~0.3 to ~0.6 [17]. Nonetheless, in March 2017 using Landsat 8 OLI, the values were around ~0.2 to ~1.0 as seen in **Figure 1**. It is worth noting the changes in NDVI values that decrease during winter and increase during summer indicate phenological response to seasonal atmospheric forcing.

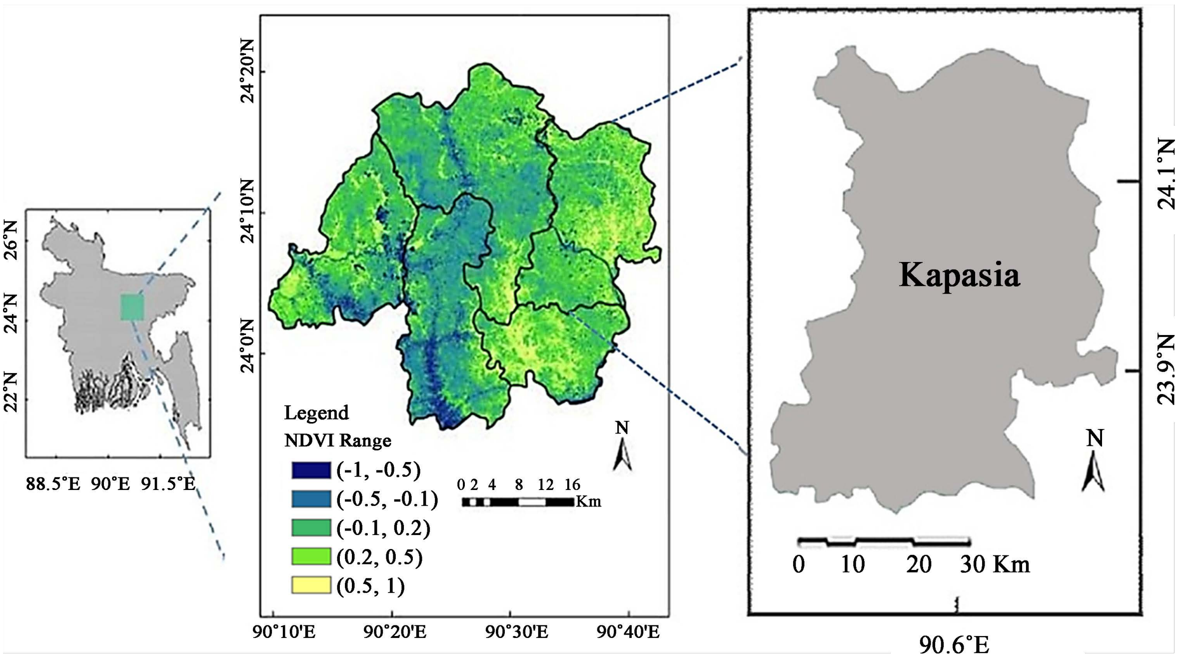

Figure 1. Kapasia, central-eastern part of Bangladesh, shown using NDVI in 2017.

Notably, aquasilviculture, which is a combination of aquaculture (the growing of aquatic animals) and silviculture (the growing of trees), can be applied as there are small water bodies around vegetation throughout Kapasia (**Figure 1**). When outdated fishponds get converted into aquasilviculture, this allows trees to be grown in order to provide shelter for some fish, shrimp, etc. [18]. As a modern farming system, aquasilviculture can be more beneficial for its integral production system where it can meet the daily needs for household consumption. The inclusion of trees and the aquaculture implemented (near irrigation channels, canals, etc.) can lead to increased diversification towards economic and ecological value. For this, the aquasilviculture practice can be put to use in small ponds near the diversified and integrated homestead areas as well as near the low-lying paddy areas. Nevertheless it is worth keeping in mind that the designing of agroforestry systems should be in harmony with available technology, the resource base and goals of the farmers' and the bio-physical settings of the farm holdings.

3. Results and Discussion

3.1. Land-Cover Change

The development of Earth observing satellites have made characterizing the state of the Earth's land-cover for large areas, an actual possibility. These LULC changes happen globally in a variety of scenarios from the human and ecological point of view. For instance, the intensification of agriculture, densification of urban structures or the exploitation of forests are all examples of continuous changes that do not modify the main land-cover and yet global change studies can have a major impact as some basic attributes get modified [19]. As a result, the timely information on the changes and dynamics of LULC is essential for understanding the interplay between natural phenomena and humans to optimally manage natural resources [20]. **Figure 2** depicts the classified images of Kapasia throughout the chosen time interval. The most discernible changes in land-cover types are observed for homestead and urban. In 2013, paddy areas are seen mostly concentrated in the central and south-western parts of Kapasia. However, across intervals, paddy areas are observed to be growing throughout, especially in the northern parts. The rapid urbanization was also clearly accentuated. While urban was barely visible in 2013, urban started to significantly increase in 2017 and 2021. Although majority of the land is seen to be homestead in 2013, with the increase in both paddy and urban, homestead is seen to have decreased dramatically in 2021.

Particularly, paddy was at 24.7% in 2013, 25.5% in 2017 and 27.2% in 2021 (**Figure 3**). Homestead started at 67.5% in 2013, decreased to 65.2% in 2017 and further dropped to 59.3% in 2021. The fraction of urban experienced rapid growth with it starting at 3.5% in 2013 and then scaling up to 7.0% and 10.1% in 2017 and 2021, respectively. Forest started at 4.2%, dropped to 2.4% in 2017 and increased to 3.4% in 2021.

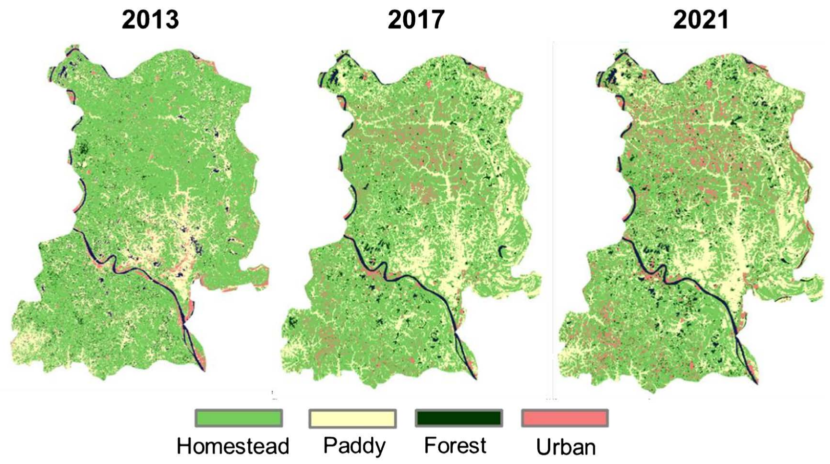

Figure 2. Classification maps of Kapasia for 2013, 2017 and 2021.

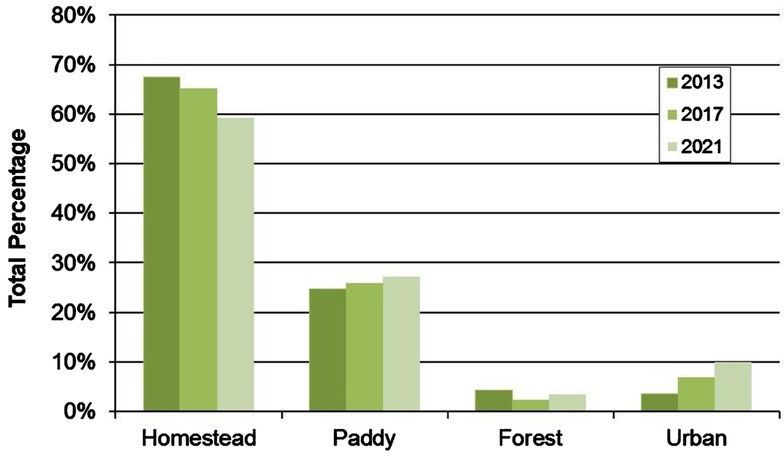

Figure 3. Category percentage of the four land-cover types throughout the time interval.

While it can be observed from space, land-cover changes occur at a local scale, which requires an ecological and socio-economic understanding to correctly interpret the reflectance registered by the satellite [19]. As paddy fields are susceptible to climate change, diversification through the integration of planted or naturally grown trees through agroforestry systems can help decrease the risk. To help farmers adapt to climate change, the Food and Agriculture Organization (FAO) of the United Nations authorized the World Agroforestry Centre to create a practical manual that would help farmers incorporate trees into paddy fields in Southeast Asia. Since trees are resilient to natural disasters, trees can keep on producing food even after the destruction of the rice crop. Therefore, farmers and other household members who are trying to optimize their resources will highly benefit from these techniques, achieve food and nutritional security and yield. Additionally, the rapid increase in population and the associated development activities could play a key role in the reduction of natural vegetation. Agroforestry combines production with protection, and targets on a comprehensive approach towards land management thus, it can effectively maximize overall production through a careful combination of trees, crops, and livestock. Not only that, agroforestry can also lead to sustainability by increasing diversity to tackle with economic and environmental variability, improve land resiliency and lastly, reduce negative environmental impacts by creating mutually beneficial land-uses [21]. Improved coordination between policies on forests, agriculture, land-use, rural development, and climate change could also reduce the complexities in the governance of land-use change [22]. Apart from this, the decrease in homestead (**Table 1**) can also lead to problems related to the energy crisis in Bangladesh since a large portion of biomass sources (trees, crops etc.) are provided by homestead agroforestry. Bio-energy is obtained from biomass and provides a clean and renewable alternative to diversify energy sources for the country. With the decreasing trend in homestead in Kapasia, proper development of agroforestry systems needs to be considered to avoid severe shortages in bio-energy. Despite the land constraint in Bangladesh, rural homesteads are generally underutilized; thus, rural homesteads can be made productive through the application of befitting production technology. Even through homestead agroforestry, the needs of the residents for vegetables, fruits, fuel wood, etc. could be fulfilled to a significant extent given that the principle of agroforestry is

Table 1. Land-cover change matrix from 2013 to 2021.

Land-Cover Type		2021 (Sq. km)				Total (2013)
		Forest	Homestead	Paddy	Urban	
2013 (Sq. km)	Forest	1.43	10.61	2.51	0.64	15.19
	Homestead	3.40	166.03	45.99	26.61	242.03
	Paddy	7.31	32.06	44.62	4.56	88.55
	Urban	0.20	3.66	4.50	4.23	12.59
	Total (2021)	12.34	212.36	97.62	36.04	358.36

well adopted [2]. With a rapid increase in the demand for organic, farm products and other environmentally certified products, farmers can also benefit from sustainable land management and agroforestry practices [23]. In regards to bio-energy production, agroforestry systems can provide different approaches for farmers to respond to the demand for more renewable sources of energy. Solely planting trees in fields or other areas does not necessarily mean agroforestry rather, agroforestry can provide farmers with a land management system that is effective and ensures production scales up within a balanced ecological environment [8]. However, land-use planning to identify specific locations based on the availability of resources and more technical expertise would be needed to promote agroforestry practices on farms. With the use of appropriate management technology, the maximum use of the land could be ensured.

3.2. Validation of the Classification Results

The precision by which image classification is processed with respect to ground truth data is defined by the accuracy assessment. In this study, a total of 30 random points were created to assess how successfully the pixels were sampled into the correct land-cover type. Here, the main focus was to create points on areas that could be recognized clearly on both the classified images and the high-resolution images from Google Earth. An illustration of this method is shown in **Figure 4** for two of the categories (homestead and urban) in 2021. The top image is located in the central part of Kapasia with a coordinate of 24˚10'N and 90˚37'E, and the bottom image is in the southern part at 24˚06'N and 90˚33'E. Using this method, it was verified that the points in the classified Landsat images are similar (the same category) to that of the real-world scenario. Furthermore, among accuracy assessment metrics, widely chosen methods include the user's accuracy, producer's accuracy, overall accuracy, and the kappa coefficient. In general, the overall accuracy is a measure of how each pixel is classified versus the definite land-cover condition obtained from their corresponding ground truth data. The producer's accuracy indicates how well a particular land-cover type was classified by the producer to assess how well the classifier performed while the user's accuracy indicates how often the areas assigned to a given land-cover type belonged to that land-cover type on the landscape. Moreover, an accurate and effective representation of the analysis is based on the kappa coefficient [24]. The values of kappa can be interpreted as ≤0 indicating no agreement, 0.01 - 0.20 as none to slight, 0.21 - 0.40 as fair, 0.41 - 0.60 as moderate, 0.61 - 0.80 as substantial and 0.81 - 1.00 as almost perfect agreement [25]. **Table 2** shows the user's accuracy (UA) and producer's accuracy (PA) for all four land-cover types along with the kappa coefficients and overall accuracy for the three years. As seen in **Table 2**, the derived classified maps in 2013, 2017 and 2021 revealed an overall accuracy of 93.0%, 90.0%, 86.7% and a kappa coefficient (κ) of 0.90, 0.87 and 0.82 respectively. It is recommended that for LULC classification, the level of accuracy be 85% [26], therefore, the obtained results could be considered reliable to a larger extent.

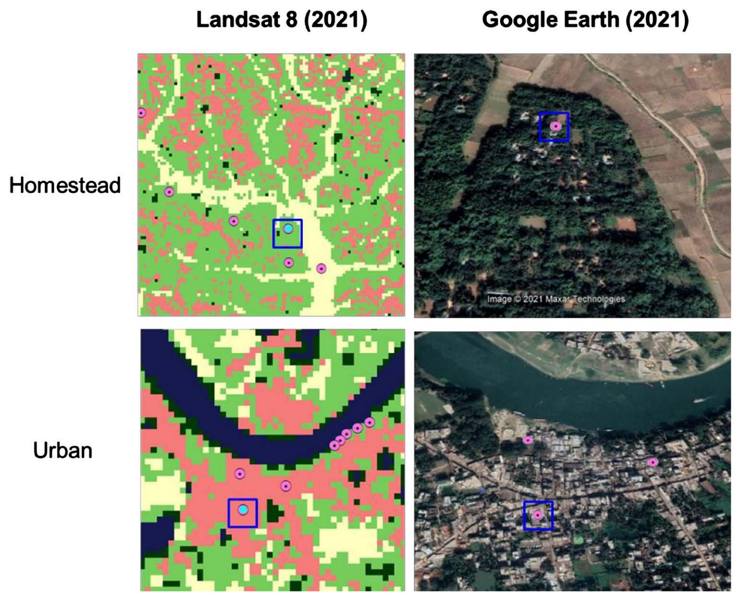

Figure 4. Two land-cover categories shown using Landsat 8 OLI and Google Earth both during 2021.

Table 2. Accuracy measures for each of the classified images in 2013, 2017 and 2021.

Year		Land-Cover Types					
		Paddy	Homestead	Forest	Urban	Overall Accuracy (%)	Kappa Coefficient (κ)
2013	PA	90.9	83.3	100	100	93	0.901
	UA	100	100	100	77.8		
2017	PA	90	100	60	100	90	0.873
	UA	100	80	75	100		
2021	PA	80	88	80	100	86.7	0.821
	UA	100	88	66.7	88		

PA = Producer's accuracy (%); UA = User's accuracy (%).

Misclassification and the spectral confusion of the different land covers are a result of spectral similarities of different land-cover types, which is why mixed pixels tend to be present within the classified images. Therefore, a mix of various components can cause difficulties within the land-cover classification. However, the kappa coefficient values indicate an almost perfect agreement ($\kappa > 0.81$) for the three classified images in this study.

4. Conclusion

Nothing beats a tree in making farming more diverse and landscapes more resilient. From 2013 to 2021, with a 4-year interval, a decrease in homestead and forest and an increase in paddy and urban were observed in Kapasia. With the ongoing development of imaging and processing technologies, the characterization of Earth's surface is constantly improving. Thus, addressing the land-cover change using satellite imagery and under the present context of the high population density in Kapasia, the land must be put to maximum usage by introducing suitable agroforestry systems. With the rising importance of climate change, agroforestry can act as a critical climate smart technology to tackle this extraordinary challenge since agroforestry is mostly dependent on natural conditions. However, public awareness and cooperation would be much needed to reach the goal of agroforestation. By monitoring the changing land-cover, this study highlighted the importance of maintaining heterogeneity in agricultural land-use decisions and the influence of modified landscapes on human food systems and biodiversity. This study will be helpful to climate adaptation action plans, policymakers and land-use planners to ensure that sustainability is maintained through the extensive application of agroforestry. Through this research, it is hoped that farmers and the residents of Kapasia would be able to not only have access to increased income sources but also receive diversified nutritional sources from a small piece of land and a better environment that can respond effectively to any stresses caused by a changing climate through agroforestry investment.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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