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Effects of Land-Related Policies on Deforestation in a Protected Area: The Case Study of Rema-Kalenga Wildlife Sanctuary, Bangladesh

Mohammad Ismail Hossain * and Shinya Numata

Graduate School of Urban Environmental Sciences, Tokyo Metropolitan University, Tokyo 192-0397, Japan; nmt@tmu.ac.jp
* Correspondence: ihossain1634@gmail.com

Abstract: In protected areas (PAs) in Bangladesh, as policies shift from net deforestation, conservation initiatives and various management plans have been implemented to reduce deforestation and include public participation at multiple levels. However, the interactive effect of land-related policies on deforestation in PAs is poorly understood. In this study, land-use change analysis using geographic information system data was performed to investigate how policies affected land use and land cover change in Rema-Kalenga Wildlife Sanctuary (RKWS), particularly the National Forest Policy (1979~), National Land Policy (2001~), and Agricultural Land Policy (1999~), using a series of Landsat images captured at different times. Our analyses showed that the total forest area increased in the 1994–2005 period when a plantation program was implemented, and also that many forest areas were replaced with noncommercial agricultural land areas in the 2005–2013 and 2013–2018 periods, when land zoning and co-management programs were implemented under different land-related policies. Commercial and non-commercial agricultural land expansions were the main drivers of deforestation, suggesting that several programs under the different land-related policies could have had synergetic effects on deforestation even in PAs. Our findings emphasize the importance of considering the undesirable effects of land-related policies in PAs, and the need to support the community for forest conservation.

Keywords: decision making; implementation; Landsat images; land use and land cover change; forest policy impacts

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1. Introduction

The establishment of a protected area (PA) is one of the most effective methods of protecting natural resources, including biodiversity [1]. However, land use and land cover (LULC) changes in forest areas of PAs, particularly those resulting from activities in their surroundings, are still recognized as one of the most significant issues affecting deforestation in PAs [2]. Some PAs in India and Nepal permit local residents to use small areas for natural resource extraction (such as pasture, non-timber forest product (NTFP) exploitation, wood extraction, etc.), and many residents graze their livestock inside PAs [3]. Therefore, land-related policy could be an important determinant of deforestation even in PAs [4–6]. Regarding forest policy in Bhutan, PAs have been established over more than 27% of the country's area and tree planting is encouraged on private land to increase forestland [7].

In Bangladesh, national parks and wildlife sanctuaries have served as PAs for a long time [8]. Since national parks and wildlife sanctuaries were introduced in Bangladesh in 1960, their numbers have increased slowly [9]. In the 1960s, the establishment of the PA system in Bangladesh was launched through the designation of national parks and wildlife sanctuaries under the Forest Act (1927) and the Wildlife Preservation Act (1974) [10,11]. Terrestrial and marine PAs cover approximately 636,390.46 ha and represent 4.31% of the country's area, comprising 18 national parks and 20 wildlife sanctuaries in 2016 [12]. In Bangladesh, these PAs are valued for supporting the livelihoods of the dependent local communities [13,14]. The forests in PAs have been managed by official forest service bodies by way of planning, management, and monitoring tools (e.g., training in goal-oriented management and guidelines) [15,16]. Several forest policies (Forest Policy 1894, Forest Act 1927, Forest Policy 1955, Forest Policy 1962, Wildlife Preservation Act 1974, and Forest Policy 1979) have been enacted to guide the management of the forests [17,18]. After gaining independence in 1971, the Bangladeshi government formulated the first forest policy in 1979, the second in 1994, and the third in 2016 [8,19].

The Bangladesh Forest Policy (1994, 2016) has recognized land leasing rights to local residents, including tribal and Bangalee majority groups, to live inside PAs [20,21]. The national land policy introduced a land zoning system in PAs [22,23], and the national agricultural policy (1999, 2013) focused on improvement of local livelihoods in PAs in 1999 [23,24]. Such different programs under different policies could interactively cause unintended interactions in PAs [25,26]. In particular, forest conservation in PAs may be influenced by land zoning programs aimed at the improvement of local livelihoods, but little is known about how these policies and programs interactively influence changes in land use and land cover changes in PAs. To understand how land-related policies could influence deforestation in PAs, a LULC change analysis was performed in this study using satellite imagery to evaluate the influence of policies on forest land use changes in Rema-Kalenga Wildlife Sanctuary (RKWS). We assumed that the different programs under different policies would cause different LULC change in PAs [27]. Understanding the effects of land-related policies on deforestation in PAs could be an important step toward management strategies and policies for better forest conservation in PAs.

1.1. Land Use Trajectory Due to Forest Policy and Management in Bangladesh over Time

During the time of British colonial rule (1760–1947), efforts were focused on four national forests. Since then, forest-related, as well as all land-related policies in Bangladesh began to provide basic guidelines for the formulation of Acts and Rules for forest management in 1973 [23]. In 1979, forest policy and PA conservation shifted from the traditional natural production and conservation approach to increasing the revenue collection of local people in PAs and forest areas [10,28]. The exploitation of forests occurred at an ever-accelerating rate under British rule, with little consideration for the preservation or conservation of resources [29]. Different sectoral policies were conjointly issued, together with the Agricultural Policy, Water Policy, Industrial Policy, and the Land Use Policy after 1971 [30]. After 1971, the Bangladesh government made attempts to increase revenue from forests. During 1974–1975, the annual average revenue from the sales of timber and other forest products increased [23].

1.1.1. Bangladesh National Forest Policy (1994~)

In 1994, land leasing rights were granted to local residents living inside PAs under the land leasing program. In the statement of the 1994 national forest policy, the traditional rights (inheritable right) of people living within and adjacent to PAs were designated, and their forest-related cultural values and religious beliefs were highlighted to be respected [31]. In the Forest (Amendment) Act of 2000 and 2004, a social forestry program was introduced to plant fast growing tree species in order to mitigate the demands of timber and fuel wood [32]. In 2013, the co-management program was introduced to engage local stakeholders' management and offer livelihood (intensive use of land) supports under a donor-assisted project [9,11] which may have encouraged people to change their agricultural practices (noncommercial to commercial) and encourage deforestation (Figure 1).

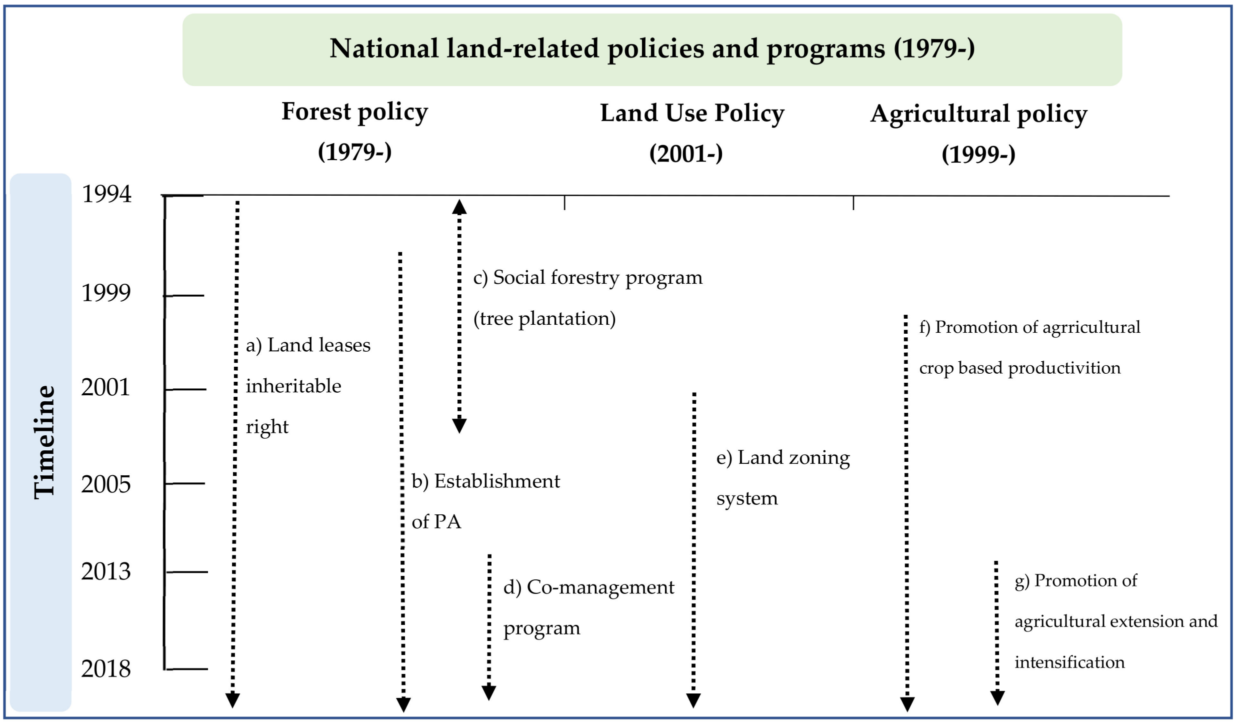

Figure 1. National land-related policies and programs in Bangladesh since 1979. (**a**) Muhammed et al. 2008; Rahman et al. 2018; (**b**) Muhammed et al. 2008; (**c**) Hossain., 2016; (**d**) Chowdhury and Koike., 2010; Mukul et al. 2008; (**e**) Millat-e-Mustafa., 2001; MLNR., 2019; (**f**) Tapa and Rasul., 2006; Hasan et al., 2013; (**g**) Ministry of Agriculture Report., 2019.

1.1.2. National Land Policy (2001~)

The encroachment of land by the local people was accelerated by the absence of zoning in PAs [33]. The National Land Use Policy of 2001 was addressed to identify components for ensuring sustainable land use activities. To ensure the best practice of the classified lands in PAs, general guidance was provided for management and administration [34].

1.1.3. National Agricultural Policy (1999~)

The National Agricultural Policy in 1999 was promoted to increase land productivity and crop land expansion by supporting small scale farmers [23,35]. In 2013, the National Agricultural Policy launched a new program to encourage national agricultural extension, intensification and agricultural investment initiatives to promote agricultural expansion [24].

2. Materials and Methods

2.1. Study Site

RKWS (24°05′–24°13′ N, 91°34′–91°40′ E), including forest reserve areas and wildlife sanctuary areas, is in the Chunarughat Upazila Subdistrict of Habiganj District, Bangladesh (Figure 2). The area falls under the Sylhet Hills Zone, and the administrative area is known as the Rema-Kalenga Forest Range [36,37]. The reserve contains one of the remnant patches of tropical natural hill forests under extreme threat due to climate change-driven natural calamities and anthropogenic pressures in Bangladesh [38]. The sanctuary is home to diverse flora and fauna and is of high conservation value, as ~80% of the forest is still in the natural condition; plantations cover only ~9% of the forest area [39]. The sanctuary consists of three beats (a beat is the smallest administrative unit of a large forest area), namely, the Rema beat, Kalenga beat, and the Chanbari beat. It is one of the most important PAs as it is the habitat of the globally threatened white-rumped vulture (*Gyps bengalensis*) [40].

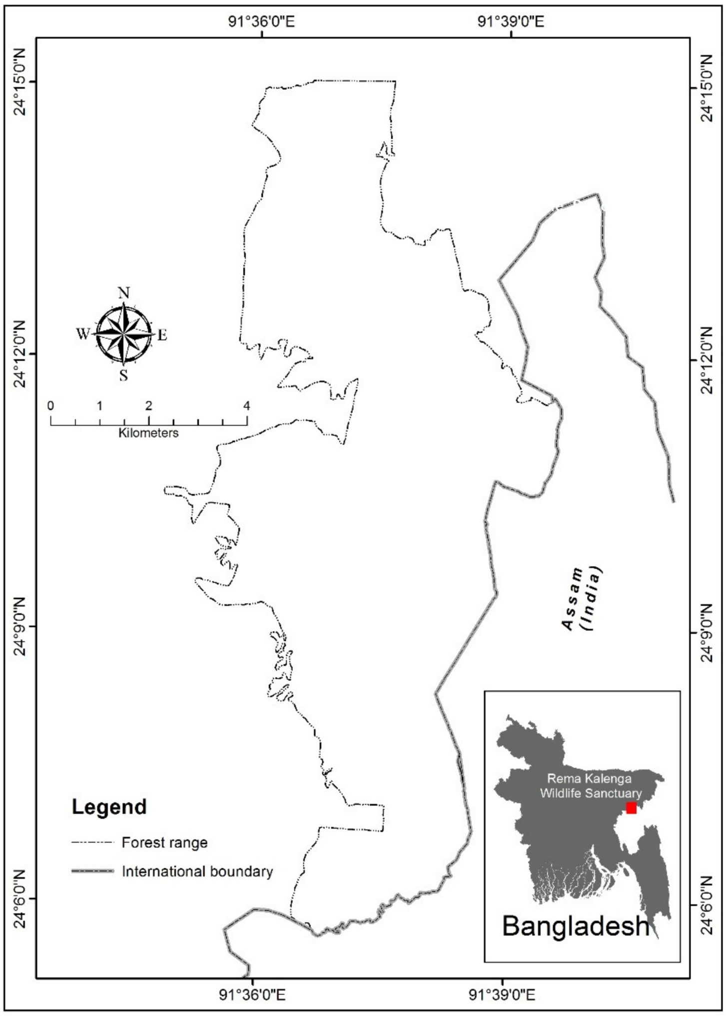

Figure 2. Location of the Rema-Kalenga Wildlife Sanctuary (RKWS), as a protected area in Bangladesh. RKWS consists of forest reserve areas and wildlife sanctuary areas.

The sanctuary has rich flora and fauna but there are concerns regarding the over-exploitation of natural resources [24]. To conserve the white-rumped vulture, the fishing cat (*Prionailurus viverrinus*), and the large Indian civet (*Viverra zibetha*) [40], an area of 1795.54 ha was designated as a wildlife sanctuary in 1996 (total area of RKWS is 6232 ha), following the International Union for Conservation of Nature guidelines [37]. Eight ethnic communities reside in and around RKWS: the Tripura, Santal, Urang, Kharia, Kurmi, Goala, Bunargi, and Telegu, among whom the Tripura comprise approximately 90% of the total ethnic population [30]. Approximately 46,228 people live in 63 villages both in and around the PA [40].

2.2. Data Sources

The main types of spatial data used to study the LULC dynamics of the study area were Landsat 5 Thematic Mapper (TM) and Landsat 8 Operational Land Imager/Thermal Infrared Sensor (OLI/TIRS) images from 1994, 2005, 2013, and 2018 (Table S1). All images were geometrically and radiometrically corrected and acquired at level 1T and were obtained free of charge from the United States Geological Survey Earth Resources Observation Systems data center under the Landsat Archive. Geometric correction was carried out using ERDAS IMAGINE software by referencing the aerial photos to 1:25,000 topographical maps using well-defined ground control points. The years were selected by considering the quality and availability of Landsat images with less than 10% cloud coverage, the PA declaration years, and the implementation of land redistribution.

To remove the effect of seasonal variations, the Landsat images were acquired for the same season. Ground truthing based on field and satellite imagery was processed using ArcGIS 10.2.2 and ERDAS IMAGE 14. Before the initiation of the actual classification, pre-processing of the images, including sub-setting and layer stacking tasks, was completed. Moreover, to improve image quality, all acquired satellite images were enhanced using histogram equalization. Other supporting data were also collected for the analyses, including Global Positioning System (GPS) points of major LULC classes, historical maps, topographic maps, the RKWS boundary, and the location of the forest. LULC change was analyzed for three different periods, and Google Earth was used to validate the LULC classes in the area before field observation (Figure 3). Landsat images were classified using supervised classification; initially, more than 117 signature extractions with a maximum sample size of 28 samples per class were used to classify images according to the investigated land cover classes.

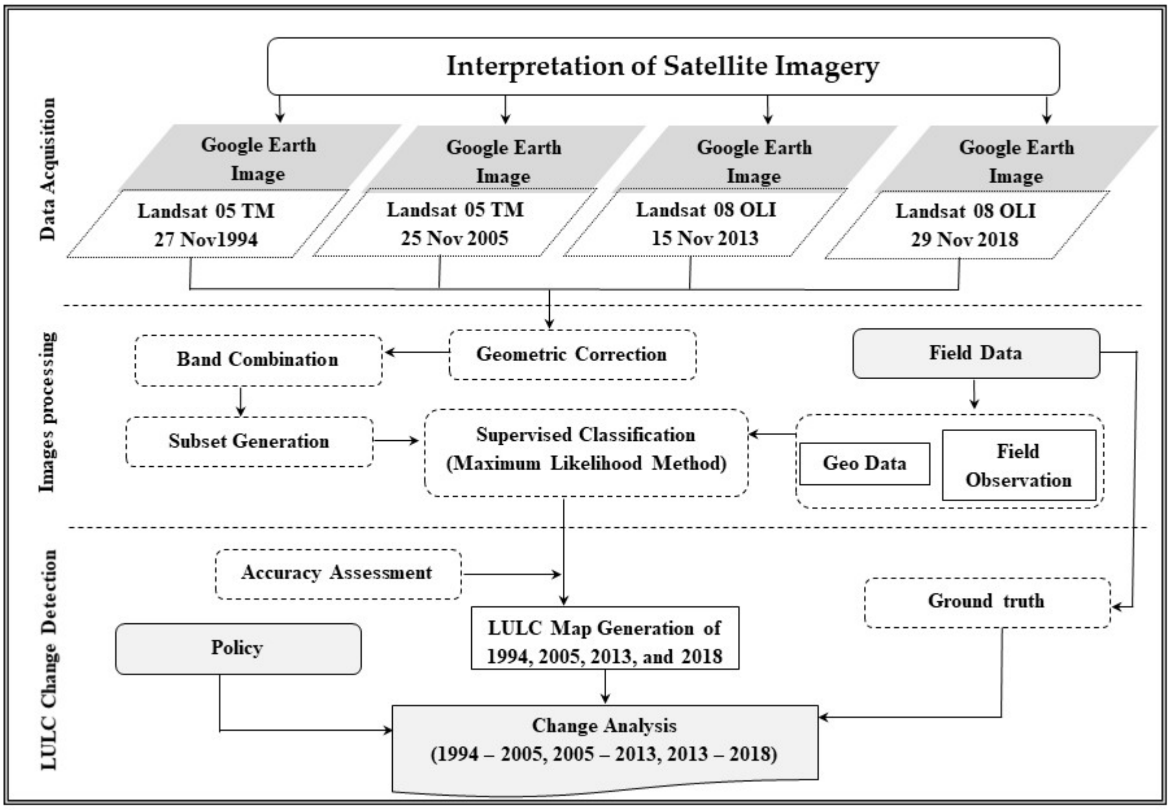

Figure 3. General methodological flowcharts: data acquisition, land use and land cover (LULC) analysis, and trends in forest land use changes in RKWS, Bangladesh.

Ground truth data and GPS point data were collected within the study area to examine the major types of LULC, identify LULC categories in the study area, and perform accuracy assessments of the LULC classes developed [41]. A field survey was conducted from February to April 2019 (Figure S1a–c) to collect field information for identifying the effects and drivers of each land cover class in the study area. Detailed information was collected by interviewing local people, including community leaders, community elders, and professionals with first-hand knowledge of changes. Field observations and ground truthing were used to identify the primary causes of deforestation both in and around the study area. Observations of various LULC classes were conducted using a digital camera; each sampling location (Figure S1d–f) was recorded using a GPS unit and referenced with Google Earth and historical topographical maps from 2009.

2.3. Land Use Mapping and Land Cover Mapping

Landsat TM (1994, 2005) and OLI/TIRS (2013, 2018) data were used to classify LULC categories into different informational classes for three periods (1994–2005, 2005–2013, and 2013–2018). The major informational classes were derived from the different satellite images using a supervised classification maximum likelihood algorithm [42,43] targeting five classes: (1) forest: land covered with trees reaching 5 m in height, 0.5 ha in area, and a canopy cover of >10% without other land use; (2) non-commercial agricultural lands: areas of land prepared for crop production such as paddy, homestead vegetable; (3) commercial agricultural land: lemon gardens, tea orchards, groves, vineyards, nurseries, and ornamental horticultural areas; (4) waterbodies: rivers, ponds, ditches, and streams; (5) built-up areas: urban, temporary, or permanent settlements (Table S2). The major classification hierarchy was derived from field observations, topographic maps, historical changes, current documents from the forest department office, and LULC classifications from previous studies. Land cover refers to the physical and biological cover of the Earth's surface, including artificial surfaces, agricultural areas, forests, wetlands, [44,45] and waterbodies, and is defined by the attributes of the Earth's land surface and immediate subsurface [46]. Land use refers to the intended use or management of the land cover type by human beings [47] and is defined as the purpose for which humans exploit [46,48] the land cover or the manner in which humans utilize the land and its resources [49], with more complex terms for patterns of human activities such as agriculture, forestry, and building construction that alter land surface processes including hydrology and biodiversity [46]. The classification of each LULC category was based on information from ground surveys and remote sensing.

2.4. Land Use Transition Matrix

The maximum likelihood classification approach is widely used for land use change assessment [43,50]. The forest land use changes were calculated using a land use transition matrix. This method is used to describe the conversion size of land use types across different periods [51]. Matrices of forest land use transition were established for three periods in this study: 1994–2005, 2005–2013, and 2013–2018. The transition matrix indicates the amount of different land use types that changed or remained unchanged during the study period. A further calculation based on the matrix table was made to calculate gains and losses. A gain in one land use type is equivalent to the increase in the land use type between the study periods, whereas a loss is the measured size of the decrease in that land use type between periods. In the present study, the magnitude of change for each land use class was calculated by subtracting the area coverage in the initial year from that in the second year, as shown Equation (1).

Equation (1): Land use transition matrix

$$\text{Magnitude of change} = \text{Magnitude in the new year} - \text{Magnitude in the previous year} \tag{1}$$

The percentage change (trend) for each land use type was then calculated by dividing the magnitude of change by the base year (the initial year) and multiplying by 100, as shown in Equation (2).

Equation (2): Land use transition percentage

$$\text{Percentage change (PC)} = \frac{\text{Magnatitude (recent year)}}{\text{Magnatitude (base year)}} \times 100 \tag{2}$$

To obtain the annual rate of change for each land use type, the difference between the final year and the initial year, which represents the magnitude of change between the corresponding years, was divided by the number of study years, namely, 11 years for 1994–2005, 8 years for 2005–2013, or 5 years for 2013–2018, respectively, and as appropriately, using Equation (3).

Equation (3): Annual rate of change

$$\text{Annual Rate of Change} = \frac{\text{Final year - Initial Year}}{\text{No. of Years}} \tag{3}$$

2.5. Deforestation Analysis

Land use change is not a one-way process, and a specific land use type is theoretically changed into or from other land use types [52]. The land use transition possibilities between different classes are recorded in a transition matrix that originates from the land use transition matrix [44]. To highlight forest area changes over time, we analyzed the deforestation rates by calculating the forest change rate (F) and mapping the spatial patterns of forest land losses and gains. The deforestation and gain rates were calculated as follows in Equation (4):

Equation (4): Deforestation and gain rates

$$\text{F = Sb - Sa} \tag{4}$$

where:

F = Forest change rate;
Sa = Area of the land use type at the beginning of a period;
Sb = Area of the land use type at the end of a period.

2.6. Accuracy Assessment

The accuracy of the classification was evaluated using an error matrix. The overall accuracy, Kappa coefficient, producer accuracy, and user accuracy were calculated from the error matrix. A total of 69 test sample plots were surveyed in 2018, and half of them were used for the accuracy assessment; no accuracy assessment was conducted for the other classification dates due to the lack of historical or reference data. Images from different reference years were first independently classified, then change detection processes were implemented. A Kappa statistic ≥0.80 denotes strong agreement [53,54]. For the accuracy assessment, a total of 197 ground truthing points were selected based on Survey of Bangladesh topographical maps (scale 1:50,000) from 1994, 2005, 2013, and 2018. The Kappa co-efficient of agreement was also calculated by using the following equations [55] (Table S3).

$$\text{Kappa coefficient } (\hat{K}) = \frac{P_o - P_c}{1 - P_c} \tag{5}$$

where:

$P_o = \sum_{i=1}^{r} P_{ii}$, $P_c = \sum_{i=1}^{r} (P_{i+} \cdot P_{+i})$;
r = The number of rows in the error matrix;
P_{ii}= The proportion of pixels in row "i" and column "i";
P_{i+}= The proportion of the marginal total of row "i";
P_{+1}= The proportion of the marginal total of column "i".

3. Results

3.1. Trends in LULC Changes from 1994 to 2018 in RKWS

The major land cover in RKWS was forestland. Based on total area percentages of each class in 1994, 2005, 2013, and 2018, RKWS had the most forestland in 2005, representing 94.42% (5885.13 ha) of the total LULC categories assigned (Figure 4, Table S4) and an increase from 89.65% (5587.90 ha) in 1994. Then, forest cover underwent a major shift and decreased to 86.68% (5402.64 ha), and 80.15% (4995.78 ha) in 2013 and 2018, respectively. The area of non-commercial agricultural land decreased in 2005 to approximately 3.79% (235.98 ha) from 8.16% (508.81 ha) in 1994, then increased in 2013 and 2018 to 9.94% (619.27 ha) and 14.68% (915.21 ha), respectively. LULC change was also observed in commercial areas, which increased from 1.22% (75.80 ha) in 1994 to 1.88% (117.28 ha) and 3.05% (189.86 ha) in 2013 and 2018, respectively, although it decreased to 0.91% (56.98 ha) in 2005 (Figure 4, Table S4). Built-up areas have been expanding over the last 24 years. Especially, cover in this class increased considerably from 1.18% (73.40 ha) to 1.66% (103.29 ha) in 2013–2018. Similarly, total water area increased from 0.21% (12.98 ha) in 1994–2005 to 0.34% (20.90 ha) and 0.46% (0.46 ha) in 2013 and 2018. Proportions of land use class significantly differed among the years (1994, 2005, 2018 and 2013) (df = 16 χ^2 = 632.3, and $p < 0.0001$).

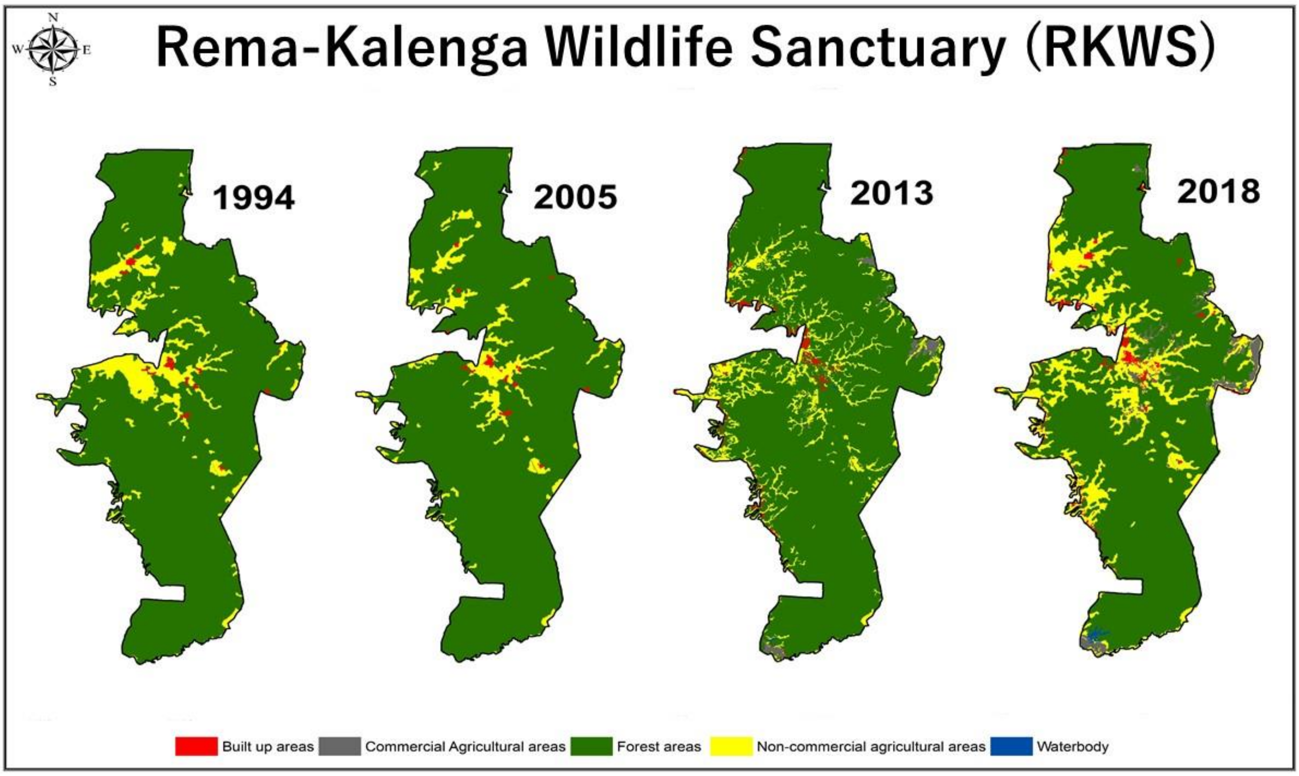

Figure 4. Temporal and spatial land use land cover changes in 1994, 2005, 2013, and 2018.

3.2. Forest Cover Change Trajectories from 1994 to 2018

Forestland increased by 297.23 ha of land area, whereas non-commercial, commercial, built-up, and water areas decreased by 272.83, 18.82, 5.66, and 0.10 ha, respectively. After 2005, the forestland area in RKWS was continuously converted to non-commercial and commercial agricultural areas. During the 2005–2013 (eight years) period, 619.27 ha of forestland was converted to non-commercial land, and 117.28 ha was converted to commercial land. During the 2013–2018 (five years) period, forestland decreased from 5402.64 to 4995.78 ha, meaning that it was continuously being converted for other types of land use. Transitions occurred both ways and the level of forest turnover was high, indicating that the forest lands were not stable but changed back from other land uses (Figures 4 and 5).

The annual rate of deforestation differed among the periods (1994–2005, 2005–2013 and 2013–2018) (df = 9, χ^2 = 38.9 and $p < 0.0001$). The annual change rate of forest cover was 0.43%, and the other land areas decreased in the 1994–2005 period (11 years). In the 2005–2013 (eight years) and 2013–2018 (five years) periods, the annual rates of forest cover were −0.97% and −1.31%, respectively. During the third periods, forest areas were replaced to noncommercial agricultural (0.77–0.97%) and commercial agricultural areas (0.12–0.23%), built-up areas (0.06–0.16%) and water areas (0.02–0.03%), respectively (Table S5).

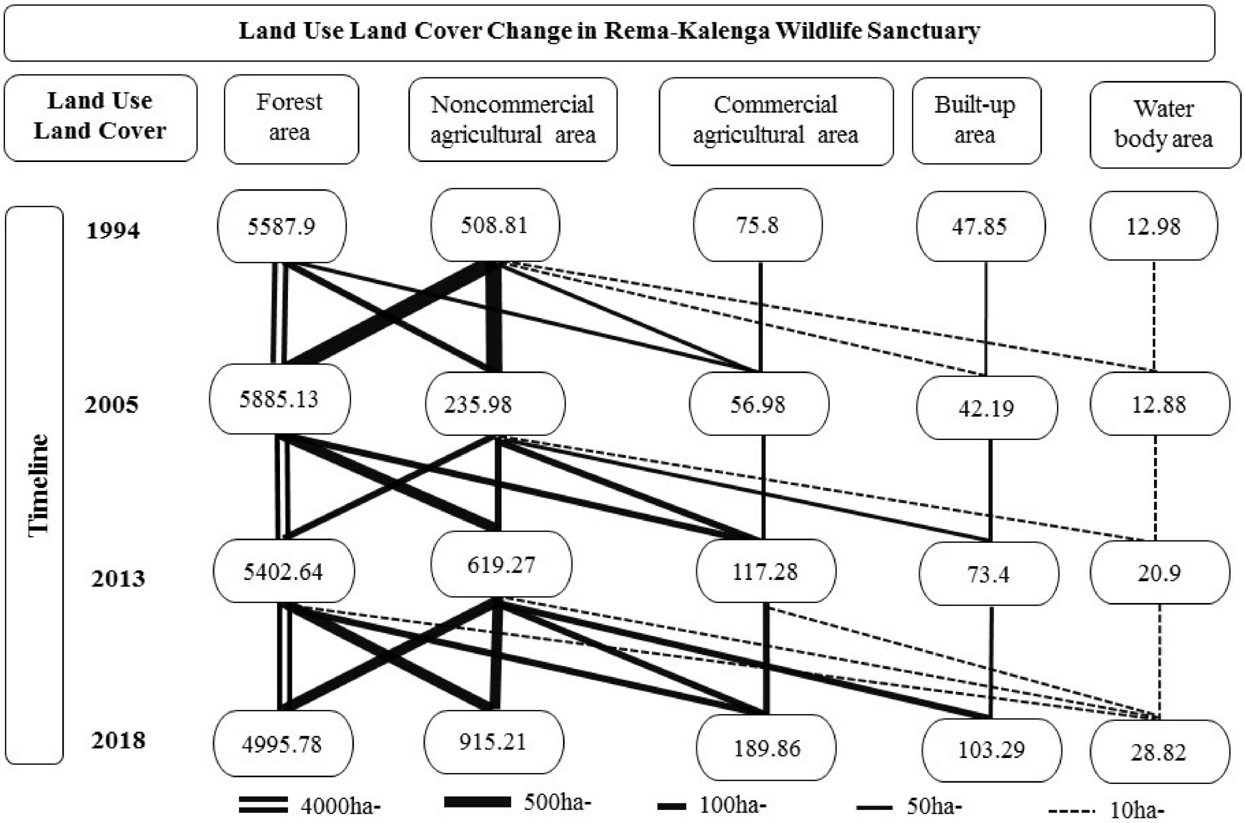

Figure 5. Transitions among forest land use types and the extent of each land use type from 1994 to 2018. Changes larger than 10 ha are described. The size of the circle corresponds to the area for each land use type, and the width of the lines between circles represents the area of conversion. Large areas of forest and agricultural lands were converted to each other between 1994 and 2005, 2005 and 2013, and 2013 and 2018 in the study area. After 2013, there was an increase in conversion from forest land to land for commercial uses, such as crop fields.

4. Discussion

4.1. Overall Deforestation in the RKWS PA

We identified the key drivers influencing forest area change in RKWS: non-commercial and commercial agriculture land expansions. In the second (2005–2013) and third (2013–2018) periods, deforestation occurred in the study area, and the expansion of non-commercial agricultural areas greatly contributed to deforestation in the second and third periods. Commercial agricultural, built-up, and waterbody areas increased in the second and third periods but increases in these areas did not contribute greatly to deforestation (Figure 5).

Our observation is consistent with the report that stated the decline in forest cover in PAs in Bangladesh began after 2005, including in RKWS (Figure S2) [39]. Rahman et al. (2017) [56] reported that the collection of fuelwoods, bamboo, house building materials, and other NTFPs was the top driver of deforestation and forest degradation in RKWS. However, this collection may not have been a main driver of deforestation in the 2005–2018 period, because forest areas were continuously transforming from forestland into non-commercial agricultural areas, and from non-commercial agricultural areas into commercial agricultural, built-up, and waterbody areas (Figure 5). Therefore, we conclude that most of the forest changes in RKWS were caused by agricultural land use practices. A wide variety of non-commercial agricultural crops (paddy and homestead vegetable) and commercial agricultural activities (lemon orchard and tea garden expansions) were likely to have been direct drivers of deforestation in RKWS [57].

4.2. How Policies Affected Deforestation in RKWS

In the first period (1994–2005), no significant difference was found in deforestation, even though the land leasing and crop production support programs were introduced. This is probably due to the fact that the forest plantation program of fast-growing tree species was taken up, to mitigate the demand for timber and fuel wood [32]. The government's twenty-year Forestry Sector Master Plan (FSMP 1993–2013) was approved in the 1990s, whose main objective was to bring 20% of the country's land under tree cover [8]. Extensive plantation trials of commercial timber species, the *Pinus*, *Eucalyptus* and *Acacia* tree species, were undertaken in Bangladesh PAs [32]. In RKWS, *Acacia* and *Eucalyptus* trees were planted through large scale afforestation/reforestation programs, especially in the barren hills and low lands [58,59]. The forest plantation program could have increased forest plantation areas in the first period but might not have contributed to the increase in natural forests in RKWS.

In the second and third periods (2005–2013 and 2013–2018), deforestation and gradual increases in non-commercial and commercial agricultural land were found (Figures 3 and 5). These may have been because effects of the land leasing program were modified by the land zoning program of the National Land Policy introduced in 2001. The land zoning program did not aim to replace forestland with agricultural land [60], but local people might not have followed the rules, including community ownership in the land tenure system [61]. Furthermore, some lease owners who leased land sold their allotted land leasing rights to local affluent elites [62–64]. It was observed that land lease owners constructed small huts or houses (made of wood and soil) in the forest's vacant places, and also that they started to clear forest lands by cutting trees and converting these areas into noncommercial agricultural land [62,63]. If so, we assume that changes in compliance with the land leasing program by the land zoning program could have triggered deforestation in the RWKS.

Furthermore, after 2013, the land leasing program could have been more strongly influenced by the co-management program, which permits the intensification of agriculture in PAs. The co-management program aims to involve local elites, political leaders, and local religious and cultural organizations in forest land management in PAs [65], but some of them did not follow the land zoning program [66]. This is consistent with a report showing that 0.56% of conserved (core area) forestlands were averagely annually replaced with non-commercial and commercial agricultural lands [67]. Rahman [65] also reported similar observations in the Chunati Wildlife Sanctuary, the Dhopachari Wildlife Sanctuary, and the Baroyadhala National Park in Bangladesh. Therefore, we assume that changes (forest transition) to the observance of the land leasing program in zoning areas by the co-management program could have caused deforestation in the RWKS. The transformation of agricultural land use depends on topographical characteristics such as elevation [68]. If our assumption is correct, the transformation of noncommercial agricultural areas to commercial agricultural areas could have been found in lowland and hilly areas. Future studies should clarify the spatial pattern of LULC change and its topographic effects to discuss how the interactive effects could escalate deforestation.

The recovery of the natural forest ecosystem in terrestrial PAs is a key for biodiversity conservation. For better biodiversity conservation in a PA, the decisions that lead to land use change and the socio-economic conditions of that specific area must be understood. The increases in forest area in RKWS in the first period, however, might not have significantly contributed to biodiversity conservation in RKWS, because those forests were plantation forests of commercial timber trees. This study cannot discuss forest quality in terms of biodiversity, because forest areas were evaluated using remote sensing. Further research is required to discuss the changes or modifications of policies required to reach desired reductions in forest loss and to promote the conservation of biodiversity in RKWS.

5. Conclusions

Our analysis revealed that the general pattern of deforestation in RKWS included an expansion of agricultural areas. Forest areas increased in the 1994–2005 period when the plantation program was implemented; however, many forest areas were replaced with noncommercial agricultural land areas in the 2005–2013 and 2013–2018 periods when the land zoning and co-management programs were implemented under different land-related policies. Therefore, agricultural land use and the forest land leasing policy could have synergetic effects on deforestation even in PAs. Our findings suggest the importance of considering the undesirable interactive effects of land-related policies in PAs. To reduce deforestation and biodiversity loss in the PA, the reconsideration of forest land leasing should be discussed by forest and agricultural management authorities and policy makers.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/conservation1030014/s1, Table S1: Summary of spatial Landsat datasets used in this study, Table S2: Classification of land use and land cover (LULC), Table S3: Accuracy assessment, Table S4: Transition matrix of LULC in Rema-Kalenga Wildlife Sanctuary (RKWS) between 1994 and 2018 (unit: hectare), Table S5: Annual rates of change, Figure S1: Examples of primary data sources in RKWS. Clockwise: (a participatory mapping, (b) GPS data, (c) informal discussion with local residents, (d) settlement in the protected area (PA), (e) commercial land use, and (f) non-commercial agricultural land use, Figure S2: Major LULC conversions from 1994 to 2018.

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Conflicts of Interest: The authors declare no conflict of interest.

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